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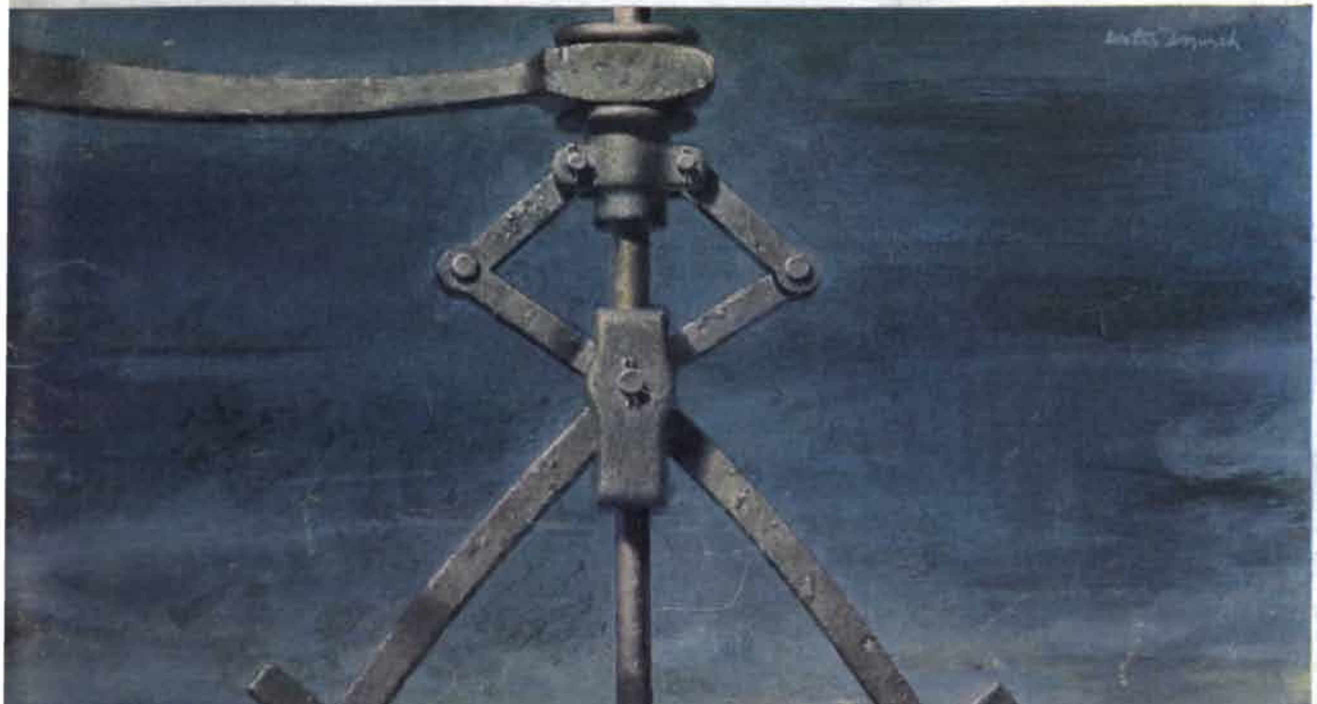

AUTOMATIC CONTROL

FIFTY CENTS

September 1952

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Why man-made textiles?

Today's man-made textile fibers bring you thrilling new qualities for clothing and home furnishings

All of the fabrics that go into your clothing, blankets, and home furnishings are made of fibers. Whether plant, animal, or man-made, these fibers are chemical structures.

Through the years scientists have developed processes that increase the strength, beauty and durability of many of nature's fibers. They also have done much to overcome the effects of weather, insects, and disease that often make these materials scarce when they are most needed.

SCIENCE TO THE RESCUE—But scientists are restless—never satisfied. From new sources of supply, they sought to create fibers with special qualities. The result has been an exciting variety of textiles that meet our various needs better than they were ever met before. And the chemicals that go into the new ones come from such plentiful materials as coal, salt, gas—and even air.

DYNEL IS AN EXAMPLE—Nowhere have these achievements been better shown than in *dynel*—Union Carbide's new fiber that's made of acrylonitrile and vinyl chloride, chemicals produced from natural gas.

Sturdy, yet soft and friendly to the touch, dynel is now available to you in the form of blankets, underwear, socks and many other products that are mothproof and fire resistant. Also, they have shape retention, are easily washed, and are resistant to shrinkage.

UCC AND TEXTILE PROGRESS—Dynel is the latest contribution to textile progress by the people of Union Carbide. More than 20 years ago their mass production of raw materials for acetate and rayon helped bring early man-made fabrics within the reach of all. And today a variety of UCC chemicals serve industry in the production and finishing of all forms of textile materials.

FREE: *If you would like to know more about dynel, write for a copy of "Meet Dynel." Please ask for booklet H.*

UNION CARBIDE
AND CARBON CORPORATION
30 EAST 42ND STREET UCC NEW YORK 17, N. Y.

UCC's Trade-marked Products of Alloys, Carbons, Chemicals, Gases, and Plastics include

DYNEL Textile Fibers • BAKELITE, KRENE, and VINYLITE Plastics • LINDE Oxygen • SYNTHETIC ORGANIC CHEMICALS
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EVEREADY Flashlights and Batteries • NATIONAL Carbons • ACHESON Electrodes • PRESTONE and TREK Anti-Freezes

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FASTER ANALYSIS WITH X-RAYS

Chemical analysis by x-ray absorption is now successful on a commercial scale with the G-E X-Ray Photometer, saving hours of valuable laboratory time, and freeing the analytical chemist from tedious routine work. Petroleum refiners slash time and cost determining tetraethyl lead in gasoline, and sulphur in oils.
See bulletin GEC-412A*.

NEW MERCURY VAPOR DETECTORS

Users of mercury compounds can now determine harmful concentrations of mercury vapor with the new, completely redesigned G-E Mercury Vapor Detectors. Electronic and chemical detectors provide either instantaneous or continuous indication. Electronic detector pictured being used to check curing oven in laboratory of silicone rubber plant.
See bulletin GEC-312*.

MEASURES MOISTURE IN GASES

G-E Dewpoint Recorder gives continuous indication and record of dewpoint temperature in gas streams from ambient to minus 90 deg. F. Manufacturers and distributors of gases measure moisture content at different stages of manufacture and various transmission points.
See bulletin GEC-588*.

***To obtain these publications, contact your nearest G-E Apparatus Sales Office, or write General Electric Co., Section 687-101, Schenectady, N. Y.**

Operator observes cracking pattern of natural gas sample with G-E Mass Spectrometer.

NEW ELECTRONIC INSTRUMENTS SPEED CHEMICAL ANALYSIS

Research and production chemists benefit by better results—faster

Rapid chemical analysis, by electronic means, makes the G-E Mass Spectrometer an important tool for the modern chemist. Because it measures a basic fundamental unit—mass—it does not suffer from many of the limitations of physical methods. For basic research and routine process control of most gaseous and liquid mixtures the G-E Mass Spectrometer is ideally suited.

It automatically records peaks at mass numbers ranging from 1 to 600, and separation of a dozen or more compounds is common practice. Immediate results save time in the identification of common impurities and traces of rare isotopes. High resolution permits complete separation of high-mass elements.

Here is another example of G-E research and development—linked to produce more and better instruments for modern industry. See bulletin GEC-587*.

Convenient sample system facilitates introduction of unknown gas mixture.

GENERAL ELECTRIC

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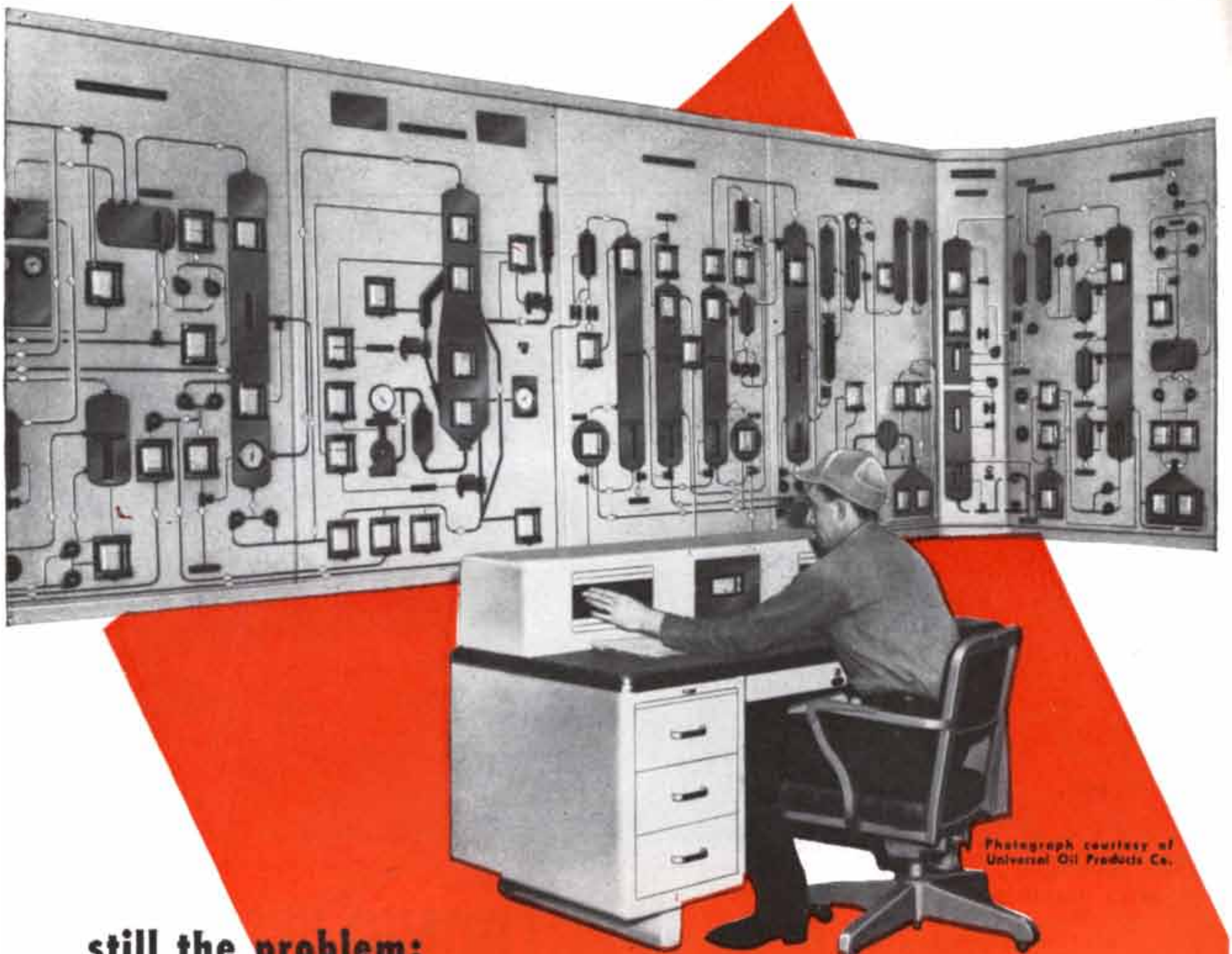

still the problem:

MAKING IT CONCEIVABLE FOR ONE MAN

For continuous quality output, supervision of plant operations by less men, or ideally one man, is a definite advantage. One man can usually accomplish more by inherently better co-ordination and singleness of purpose than two or many men.

The problem lies in bringing the entire plant in to the immediate conception, and every variable of the process to the simultaneous attention of that one man. The activities of these three associated corporations are directed toward this purpose.

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PANALARM

PANELLIT engineers and is the largest builder of coordinated and graphic control panels. They give the operator not just an indication of process variables, but the overall picture necessary to take positive corrective action.

PANASCAN produces multiple-point scanning systems: Effectively, automatic supervision of any number of process variables measurable by transducers.

PANALARM PRODUCTS manufactures packaged annunciator systems . . . the guardian of process variables. When conditions go "off-normal", the PANALARM system directs the attention of the operator.

. . . These companies are building the push-button plant of today . . . and planning the push-button plant of tomorrow.

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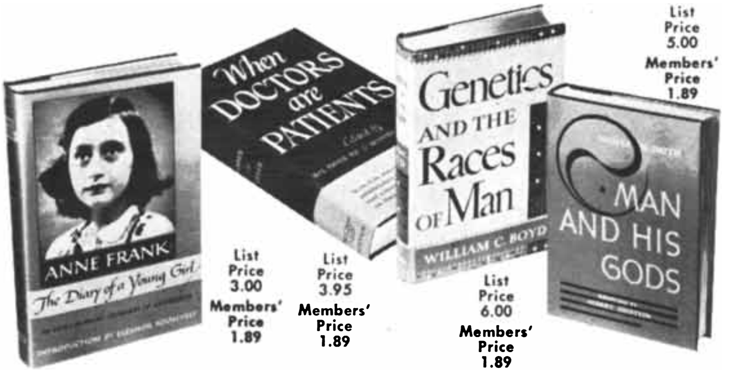
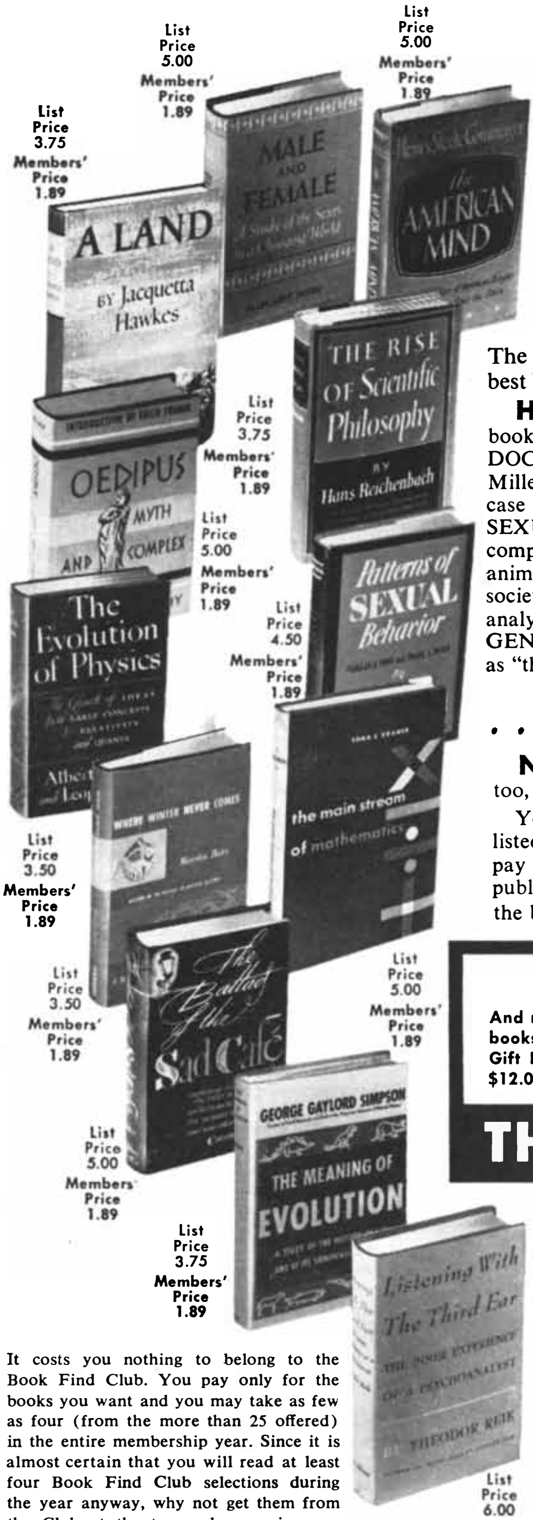
in the Sciences . . .





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SCIENTIFIC AMERICAN
September, 1952

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Vol. 187
No. 3

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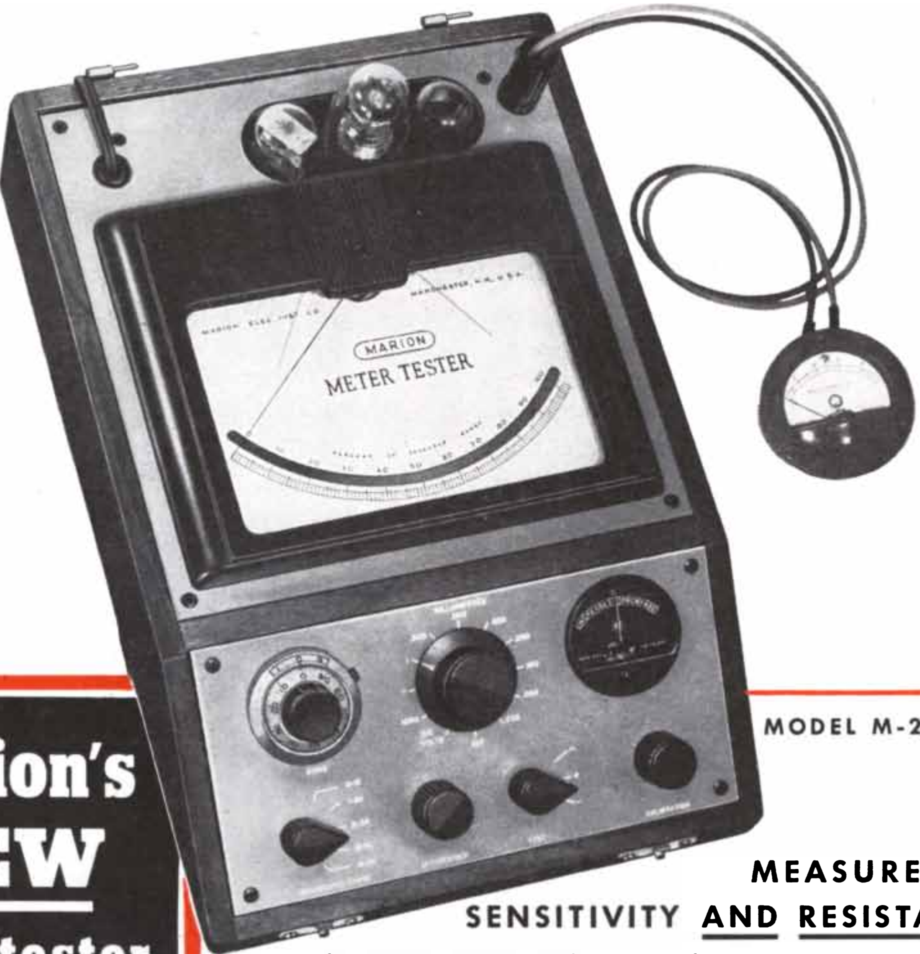
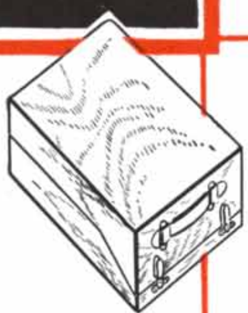


marion's NEW metertester

MODEL M-2

MEASURES SENSITIVITY AND RESISTANCE

for testing and calibration of D. C. instruments in the laboratory and on production lines



Marion's New Metertester (Model M-2) retains proven Marion features but increases application flexibility. In addition to improved circuitry for sensitivity measurement it also measures internal resistance of sensitive instruments without exceeding full scale rating of the instrument under test.

FEATURES

- Regulated Power Supply
- Stepless Vacuum Tube Voltage Control
- Illuminated 8½" Mirror-Scale Standard Instrument, Hand Calibrated
- Marion Ruggedized Null Indicator movement for bridge balance indication
- Decade of .1% accurate Manganin Wire Wound Resistors
- Direct Reading Bridge Circuit using Helipot
- Complete. No accessories required

SPECIFICATIONS

ACCURACY: Overall better than ¼ of 1%
RESISTANCE RANGE: 0-5000 ohms
POWER SOURCE: 115V A C 60 cycles
CASE SIZE: 15⅛" x 10⅛" x 5⅜"
WEIGHT: 15 lbs.

SENSITIVITY RANGES

0-25UA	0-200UA	0-800UA	0-10 MA
0-50UA	0-400UA	0-1 MA	0-100 Volts
0-100UA	0-500UA	0-5 MA	

The New M-2 Model can also be used for additional purposes, such as a precise source of DC current and voltage and as a precision Wheatstone bridge in the 0-5000 ohm range.

For further information write Marion Electrical Instrument Co., 416 Canal Street, Manchester, N. H., U. S. A.

marion meters

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MANUFACTURERS OF RUGGEDIZED, HERMETICALLY SEALED AND STANDARD PANEL INSTRUMENTS

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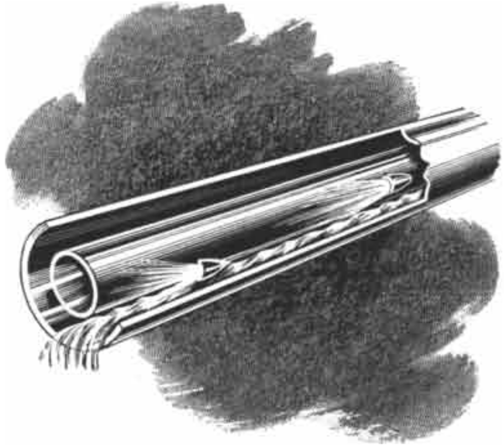
BUSINESS IN MOTION

To our Colleagues in American Business . . .

There is a kind of steam unit heater known as the tube-within-a-tube type. In this, the inner tube is perforated, and uncondensed steam passes through the holes to join the condensate. Such a design is largely used in industrial heating systems. Some time ago a manufacturer made studies to determine if the efficiency could be increased, in order to get more heat out of the steam at the point where heat is needed. His engineers came up with the idea that an appreciable improvement would result if the steam could be ejected from the inner tube in a jet having the same direction as the flow of the condensate. It was found that this rather simple idea was effective; it improved heat transfer materially.



However, when it came time to reduce the new design to practical production methods, a severe problem arose. The tubes were made of copper, which has highest heat conductivity of any commercial metal. To use any other metal would sacrifice most or even all the advantages of the development. But, the orifices had to be shaped carefully in order to assure the desired directional jet, and to produce them a combination of shearing and flaring was necessary. It was felt that rather soft copper would be required for these operations, perhaps so soft as to make it difficult to maintain the necessary straightness to keep the inner tube concentric with the outer one.

We at Revere were asked if we would like to sit in on this problem. Indeed we would, and did. Representatives of the Technical Advisory Service met with the manufacturer's engineers and production men, for a thorough mutual study of the last link in the chain leading to an improved device. It was developed that the engineers were right when they said some copper was too soft to maintain straightness after shearing and flaring. However, we pointed out that copper tube is available in various tempers, and that surely among them there must be one or two that would meet the needs of production processes, and at the same time remain straight. The physical characteristics of the various tempers were examined, tests were run, and finally a temper was selected that was both workable and strong. This has now been proved by several years of use.

The Technical Advisory Service is part of Revere's contribution to the efficiency of American industry. If you have a problem concerning the specification or fabrication of copper and copper alloys, or aluminum alloys, Revere will be glad to collaborate, confidentially, of course. Just get in touch with the nearest Revere Sales Office.

And by the way, do not forget that no matter what you buy, there are suppliers who, like Revere, can give you helpful assistance and literature.

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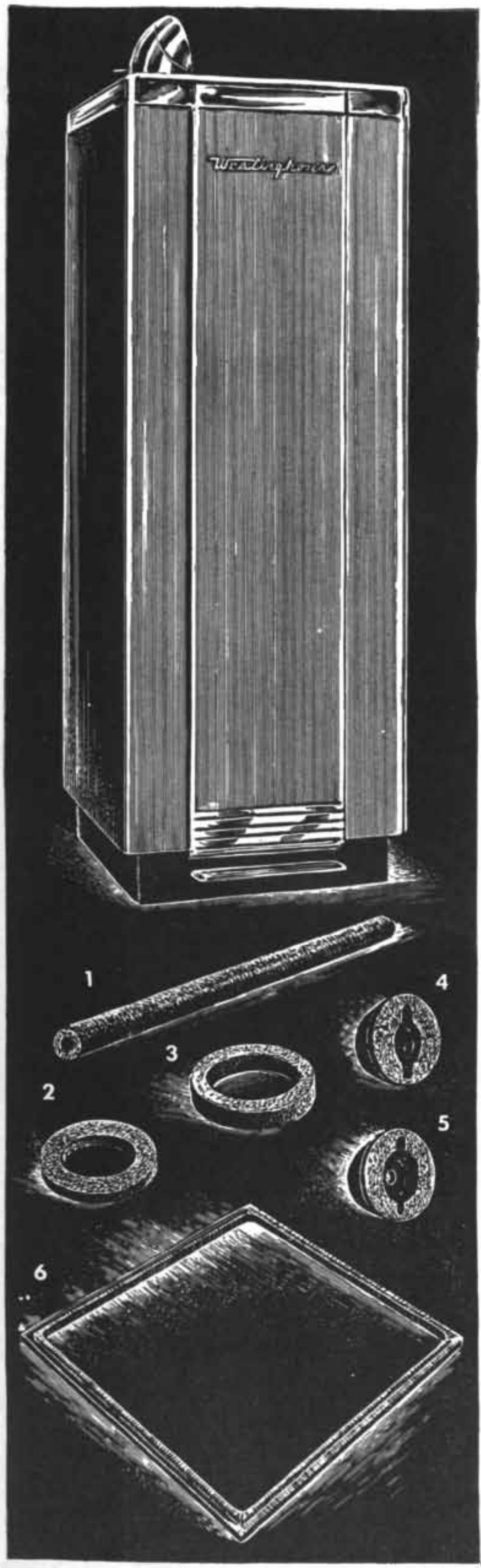

Westinghouse Water Cooler

gives longer, better service with

SPONGEX Cellular Rubber

Corrosion . . . deterioration . . . mechanical failure . . . repairs and parts replacement—an inevitable sequence wherever moisture condensation collects. It's a problem particularly troublesome in refrigerating equipment—but not in this Westinghouse water cooler!

Westinghouse has given its cooler a wardrobe of Spongex cellular rubber. Exposed cold surfaces—tubing, valves, even the waste water drain—are covered by custom molded Spongex parts. These Spongex parts not only prevent condensation but their insulating qualities increase refrigerating efficiency. For this cooler, Spongex means a longer, better, more efficient life.

The Westinghouse Wardrobe of SPONGEX

1. Tube insulator—
covers cold water tubing that supplies the drinking bubbler.

2. Basin drain seal—
forms a water tight seal between bottom of the water cooler basin and top of the drain. The compressibility of Spongex compensates for variations in the clearance between basin and drain.

3. Basin drain insulator—
covers exposed end of the waste water drain.

4. Regulator valve cap—
covers the cold surfaces of valve. Elasticity and flexibility of cap makes it easily removed for valve adjustment.

5. Water valve cap—
covers shut off valve controlling water flow to bubbler.

6. Door gasket—
forms an air tight seal for the door opening into the cold storage compartment. The gasket also seals off the insulating air space between the inner and outer panels of the door.

Perhaps Spongex can help better your product, too. We would be happy to hear from you.

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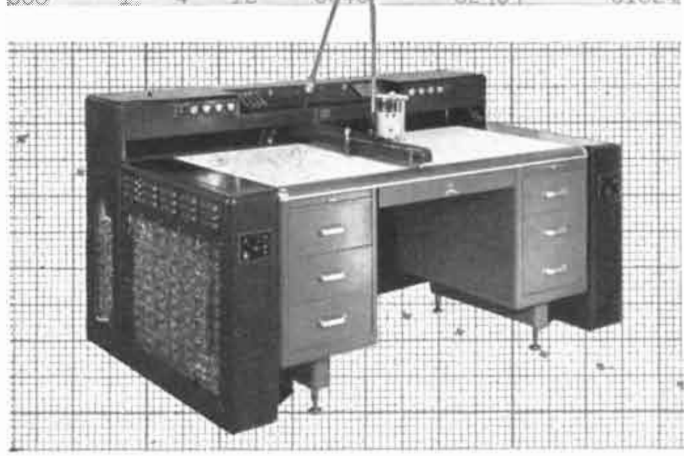

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your data analysis

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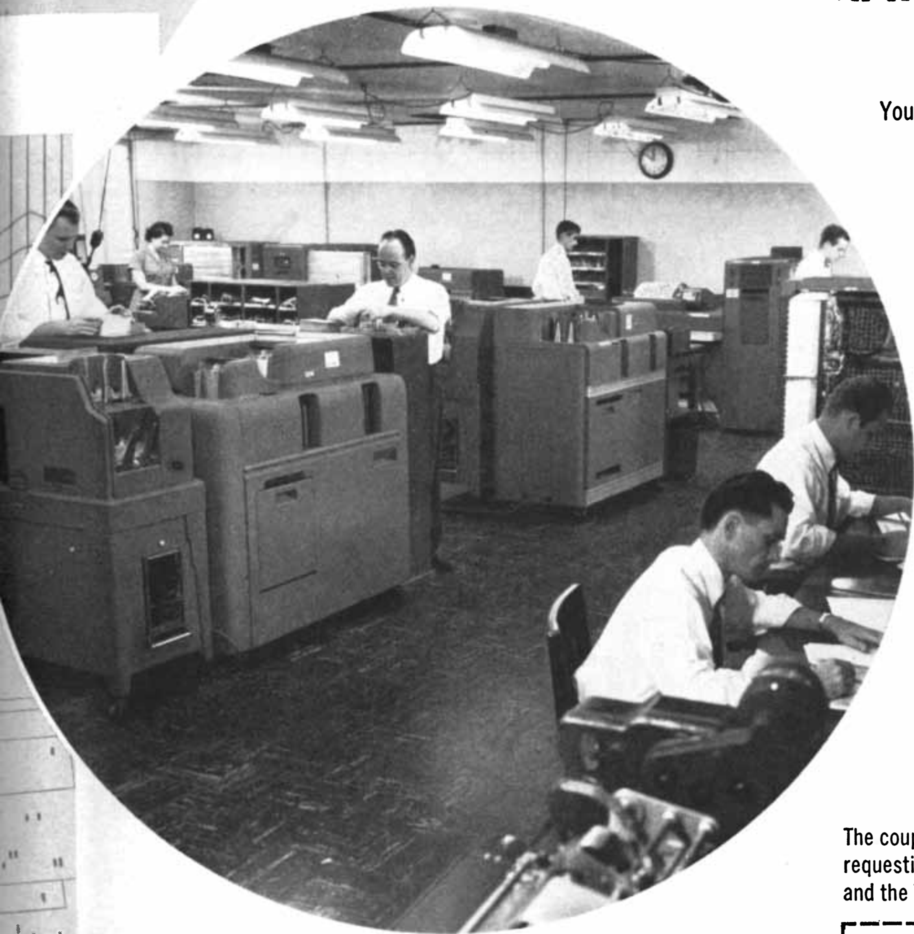

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- ☐ Telecordex Technical Bulletin TC 102
- ☐ Teleplotter Technical Bulletin TC 103
- ☐ Information on your Computing Service
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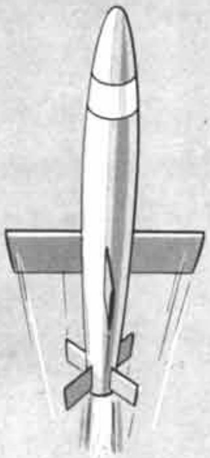
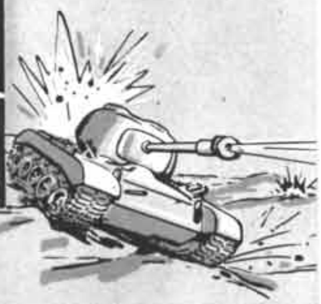


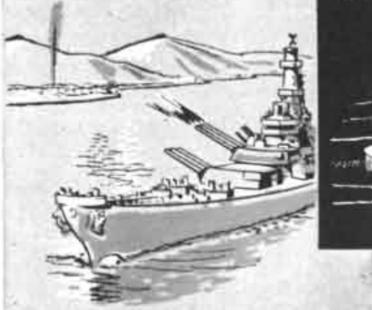
Controlling guided missiles in flight

Knowing your whereabouts under all circumstances



Stabilizing the guns on bouncing tanks

Shooting down jet planes from the unstable decks of ships



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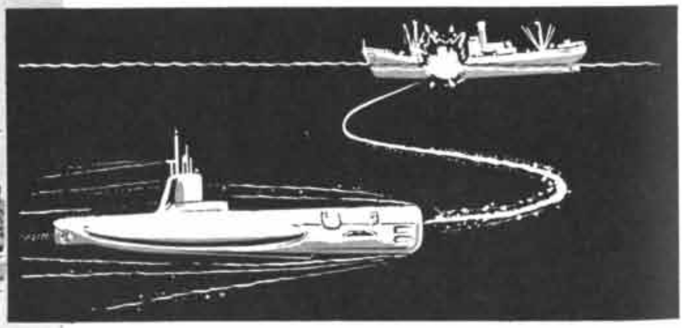

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7 Reasons why Regohm is a natural for *your* control system

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(1) **SMALL SIZE** · Regohm is a compact, plug-in device; lightweight, extremely rugged and position-free. The unit's small size does not limit its power-handling capacity. This makes Regohm a "natural" where economy of space and weight are your major considerations.

(2) **POWER AMPLIFYING** · Regohm is a high-gain electro-mechanical power amplifier. Milliwatt variations in signal energy can control energy changes millions of times greater.

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(4) **SYSTEM STABILIZING** · A thoroughly reliable, sturdy dash-pot aids in system damping. It can easily and readily be adjusted over a wide range to match the dynamic characteristics of the Regohm to those of your present system.

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(7) **LONG LIFE** · In properly engineered installations, Regohm's life is measured in years. Plug-in feature simplifies replacement and maintenance—there are no parts to renew or lubricate. Shelf life is substantially unlimited.

Our engineering and research facilities can help you apply Regohm to your servo system or regulator problem. Write for Bulletin 505.00, containing a complete discussion of Regohm's characteristics and applications. Address Dept. C, ELECTRIC REGULATOR CORP., Norwalk, Conn.

REGOHM

CONTROL COMPONENT IN: Servo systems • battery chargers • airborne controls • portable and stationary generators • marine radar • inverters • locomotive braking systems • mobile telephones • guided missiles • signal and alarm systems • telephone central station equipment • magnetic clutches • railroad communication systems.

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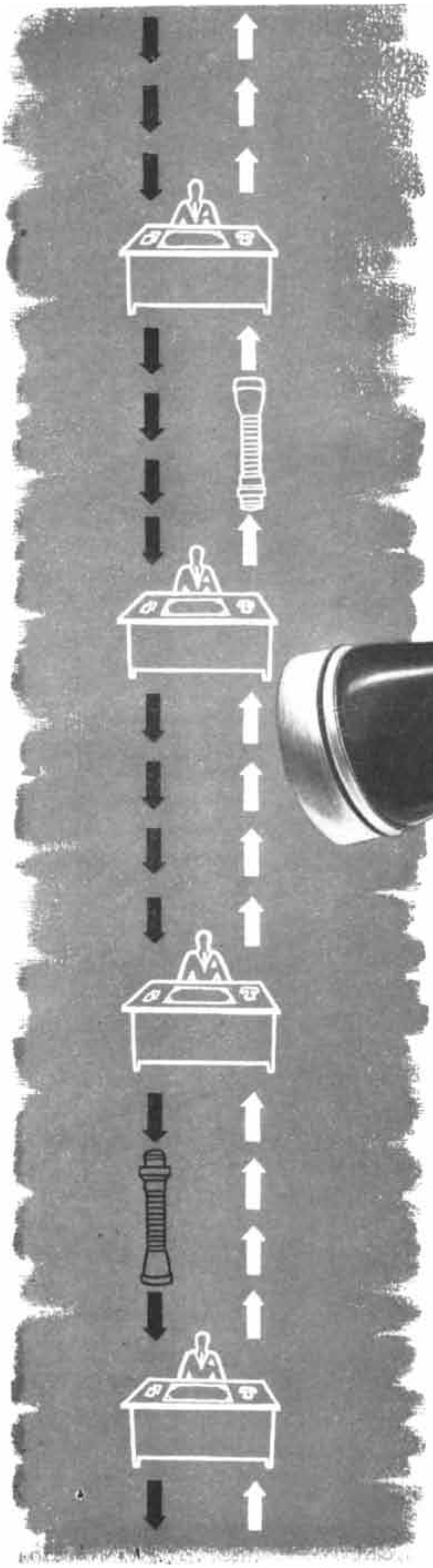

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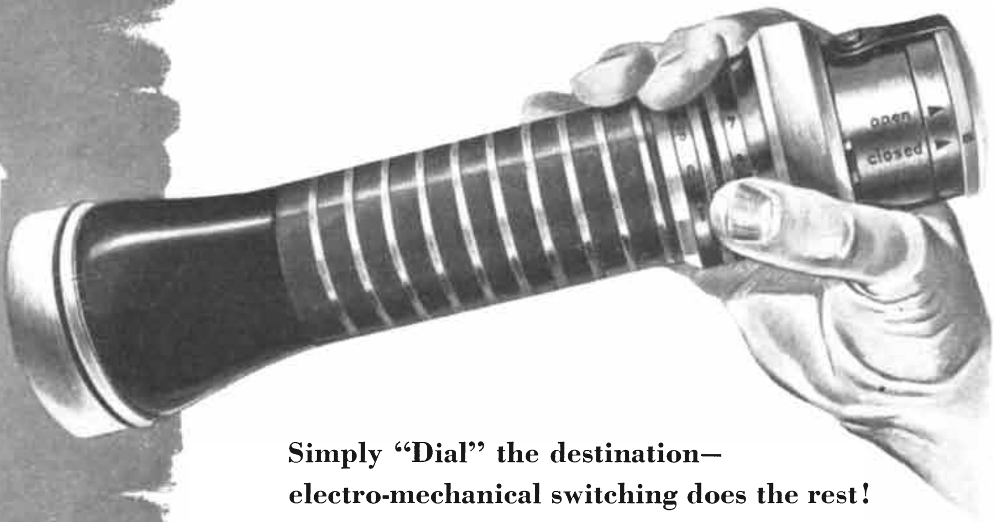
A Pneumatic Tube System that's Fully Automatic



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Adventurers in Research..

Dr. J. A. Hutcheson

SCIENTIST-ENGINEER

Director of the Westinghouse Research Laboratories. After graduation from the University of North Dakota in 1926, he came directly to the Westinghouse graduate student training course. In 1940 he was named Manager of the Radio Engineering Department, three years later Associate Director of the Research Laboratories, and in 1949 was appointed to the Director's post. In 1950 he became Vice-President.

In a conversation with Dr. J. A. Hutcheson about research, you will hear him express his guiding philosophy, "The more we know about a subject, the more intelligently we can deal with it". This philosophy probably explains why he is head of one of the world's largest industrial research laboratories—a position reached via engineering instead of test tubes.

Dr. Hutcheson's career was launched in radio engineering in the design of radio telephone and broadcast transmitters. He developed radio, radar and other electronic equipment that played a vital part in the successful completion of World War II.

Both during and after the war, Dr. Hutcheson was in intimate contact with the nuclear research program. He was one of the civilian observers at the postwar atomic tests at Bikini.

Dr. Hutcheson's outstanding ability to guide the work of others, in addition to his brilliant engineering and research record, made him ideally suited for the job of directing a large research institution. One might think that with a background predominantly engineering, he would emphasize applied rather than fundamental research. Such has not been the case. His years as a designer made him keenly aware of the limitations placed on the engineer by lack of fundamental knowledge.

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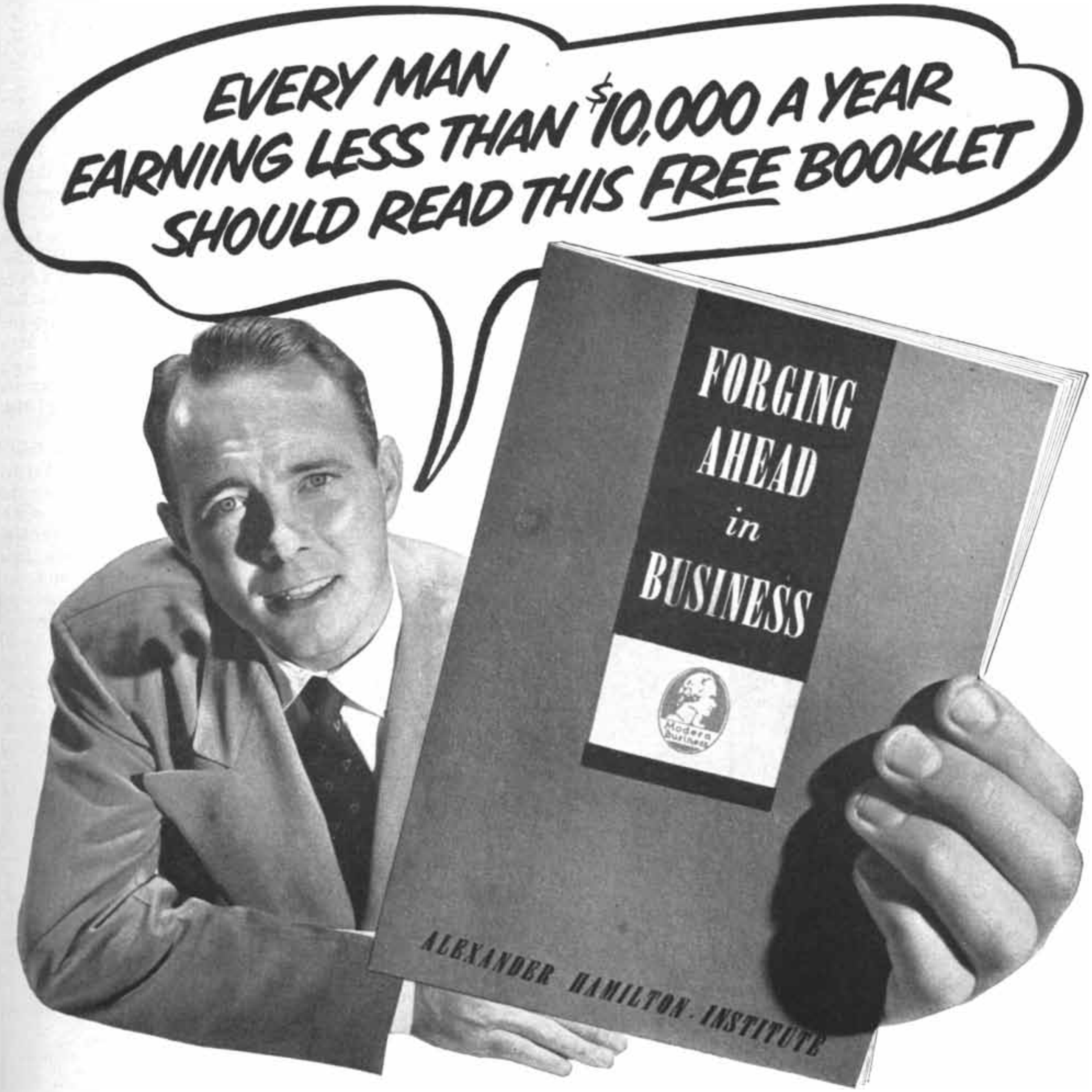

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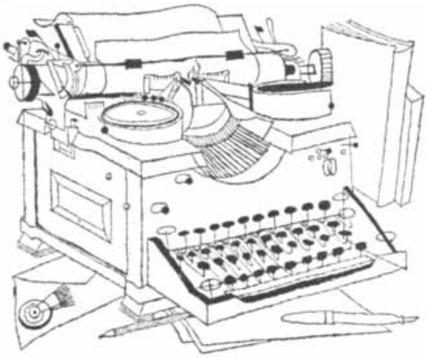

Sirs:

Recently the Stockton Astronomical Society was given the privilege of being the first to make public the announcement that Albert G. Ingalls, of your staff, had been honored by having a crater on the Moon named after him by H. P. Wilkins, at the suggestion of Albert H. Johns of Larchmont, N. Y.

I am one of the many amateurs who have been deeply grateful through the years for the guidance received from Mr. Ingalls' personal correspondence, as well as from his books on telescope making, and his columns on this subject in your magazine. There is nothing that could have given so much satisfaction to so many amateurs as this recognition of his lifework on their behalf, for it has expressed our appreciation while he is still alive. Crater Ingalls justly gives credit to a pioneer in the dissemination of knowledge about telescope making.

C. P. CUSTER, M.D.

Stockton Astronomical Society
Stockton, Calif.

Sirs:

The article in your July issue entitled "The Umbilical Cord" is of absorbing interest.

The author, Samuel R. M. Reynolds, makes the statement that an "artery does not swell as it pulsates." Data are generally available, however, to show that the arteries must swell and contract as the blood pressure varies with each heartbeat. Moreover, these data show the order of magnitude of the swelling. It is very small, too small to be detected easily by the methods the author describes.

Consider the case of the adult human. It has been stated that a given unit of blood passes through the circulatory system in about 30 seconds. From this and a heart rate of, say, 72 beats per minute, and some other approximate information, the changes in the volume and the diameter of the arteries may be roughly determined. During a single contraction of the ventricle, the volume of blood in the circulatory system is increased by 1/36. If we assume that the arterial system contains half of the blood (the correct figure is less than this), the volume of blood in the arterial system is increased about 1/18 of itself, and diminished by what passes from the arteries to the veins during that time. If we assume that the rate of departure is fairly uniform (it must be), and that the contraction of the ventricle occupies 1/3 of the total time of one heartbeat, we find that the volume of blood in the arteries varies by $2/3 \times 1/18 = 1/27$, or a little less than 4 per cent. This must be compensated by the increased diameter and/or the increased length of the blood vessels.

The length of the vessels in the limbs must be pretty definitely controlled by the dimensions of the skeleton, but the internal vessels, particularly the aorta, may increase in length enough to accommodate a portion of this expansion. In a pipe having isotropic walls not restrained by surrounding bodies, only 20 per cent of the expansion in volume produced by an increase of pressure could be accommodated by the longitudinal expansion. The other 80 per cent is accommodated by radial expansion. Thus we may say that the amount of volume change to be accommodated by radial expansion is of the order of 4 per cent—which requires a change of diameter of only 2 per cent. It is at once obvious why the volume change was not observed even by careful measurements of the sort described by Dr. Reynolds.

It is important to realize that the volume change of the artery during the pulse beat, small as it is, is of tremendous importance to life. Were the arteries not

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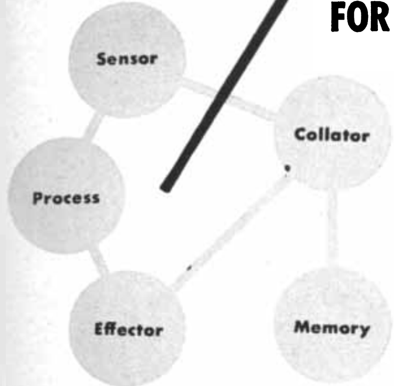

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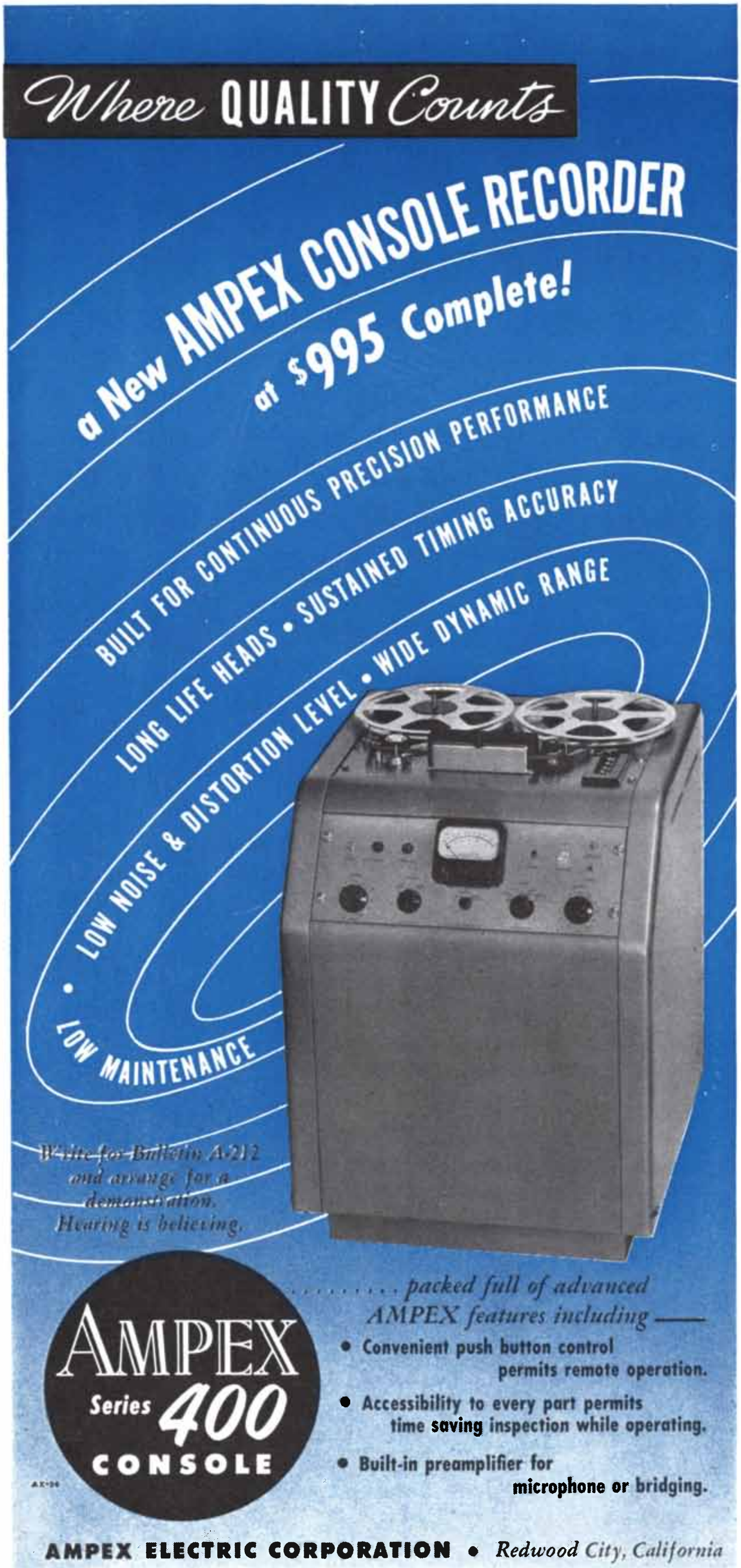

to vary in volume by this seemingly insignificant amount and thus change the pulsating flow of blood from the heart into a nearly steady flow through the capillaries and veins, the pressure which the heart would need to exert during systole would be more than doubled.

It is interesting to consider, in the light of the above, Dr. Reynolds' discussion of what a doctor feels when he takes the pulse. The explanation Dr. Reynolds suggests is probably pertinent. But in addition to *displacing* the artery by applying the pressure of his finger, the doctor partly flattens the vessel, as one flattens a hose by stepping on it. Just as a hose which is not under pressure is flattened and tends to become round again when water under pressure is let into it, so also the flattened artery must tend to become round as pulse pressure increases. This tendency to change might well be felt by a pressing finger.

I offer these comments to show how the thinking of the engineer and the physicist can be applied to the observations of the physiologist. Dr. Reynolds' report is for the most part novel and convincing, and it is for this reason that I have commented in so much detail on this one part of it.

R. W. ATKINSON

Director of Research
General Cable Corporation
Bayonne, N. J.

Sirs:

The criticisms and comments of Mr. Atkinson are penetrating and thoughtful. They deal with points which have concerned us, particularly our mathematical colleague F. W. Light, Jr. It is difficult in a short nontechnical article to discuss sufficiently for critical readers all the points which would need to be covered for their special information. Since Mr. Atkinson's calculations are reasonable for the information available to him, it would be well to point out why his assumptions are inadequate, and why any simple arithmetical approach will not yield final answers.

In the first place, the primary assumption that the entire arterial system behaves uniformly to intermittent filling with blood from the heart is wrong. We have made observations by direct cineangiography of the entire aorta and we have found, as did the German physiologist Timm, that the ascending aorta and the arch (*i.e.*, that part nearest the heart) does indeed expand enormously. We found the aortic diameter just outside the heart to increase 44 per cent, a figure confirming the data of Timm. In short, during one-third of the pulse cycle, the largest part of the arterial tree does dilate, enormously. At the same time, and during the diastolic part of the cycle, the volume of blood is distributed

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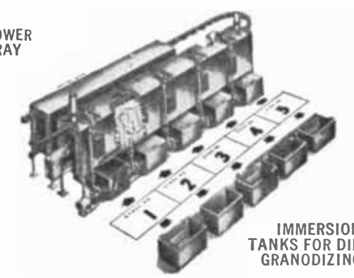

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with pulsating flow, and, as far as the descending aorta, renal arteries and umbilical arteries (all studied by us), without significant arterial dilatation. To judge this, excellent movies and enlargements of individual frames by some 8 to 12 diameters are available. Slight shifts in the position of the entire vessel are easily seen with pulsation, but no sign of arterial dilatation. This dilatation is largely—I do not say entirely—confined to the large arterial structure nearest the heart. This, in recovering from the expanded state while the heart relaxes, rests and fills during diastole, propels blood throughout the vascular tree during the *entire* pulse cycle. In this way the flow of blood in the arteries is equalized to a large degree. Our movies show, however, that the flow is strongly pulsatile, that the stream lines are reflected from curved parts of the arteries, and that at these points the vessel may be displaced by as much as 0.2 millimeters.

Study of the architecture of the distended arterial wall shows, too, that the stresses are mainly to resist extension. The muscles are intertwined spirals, partially extended, and the tough elastic tissue of the wall is in layers, all oriented longitudinally. In collapsed arteries the spiral muscles shorten, the elastic tissues re-coil and take random positions, and in undergoing radial reduction, the vessel shortens by 16 to 17 per cent and the thickness of the wall increases by 6 to 7 times. I might point out that the skeletal structures do not determine arterial length, not only in the umbilical cord, which lacks bones, but even in the body proper. The assumption that it is so, as Mr. Atkinson states, is unsupported by evidence, and pictures exist which show appreciable increase in length of the aorta, with the development of part of a spiral. This happens in rabbits receiving an injection of adrenalin, when the blood pressure increases to about 200 mm. of mercury.

I should like to take this opportunity to correct some errors in the illustrations of the article. The two sections showing the blood vessels of the umbilical cord collapsed and distended are from the same cord, and not from two cords, as the caption states. It should be mentioned that some photographs have been omitted from the sequences showing the flow of blood in the umbilical vessels. It should also be stated that the interval between the photographs of the second sequence is 0.5 second. The final illustration shows the pulsation of blood in the sheep's umbilical cord, and not the human.

S. R. M. REYNOLDS

Department of Embryology
Carnegie Institution of Washington
Baltimore, Md.

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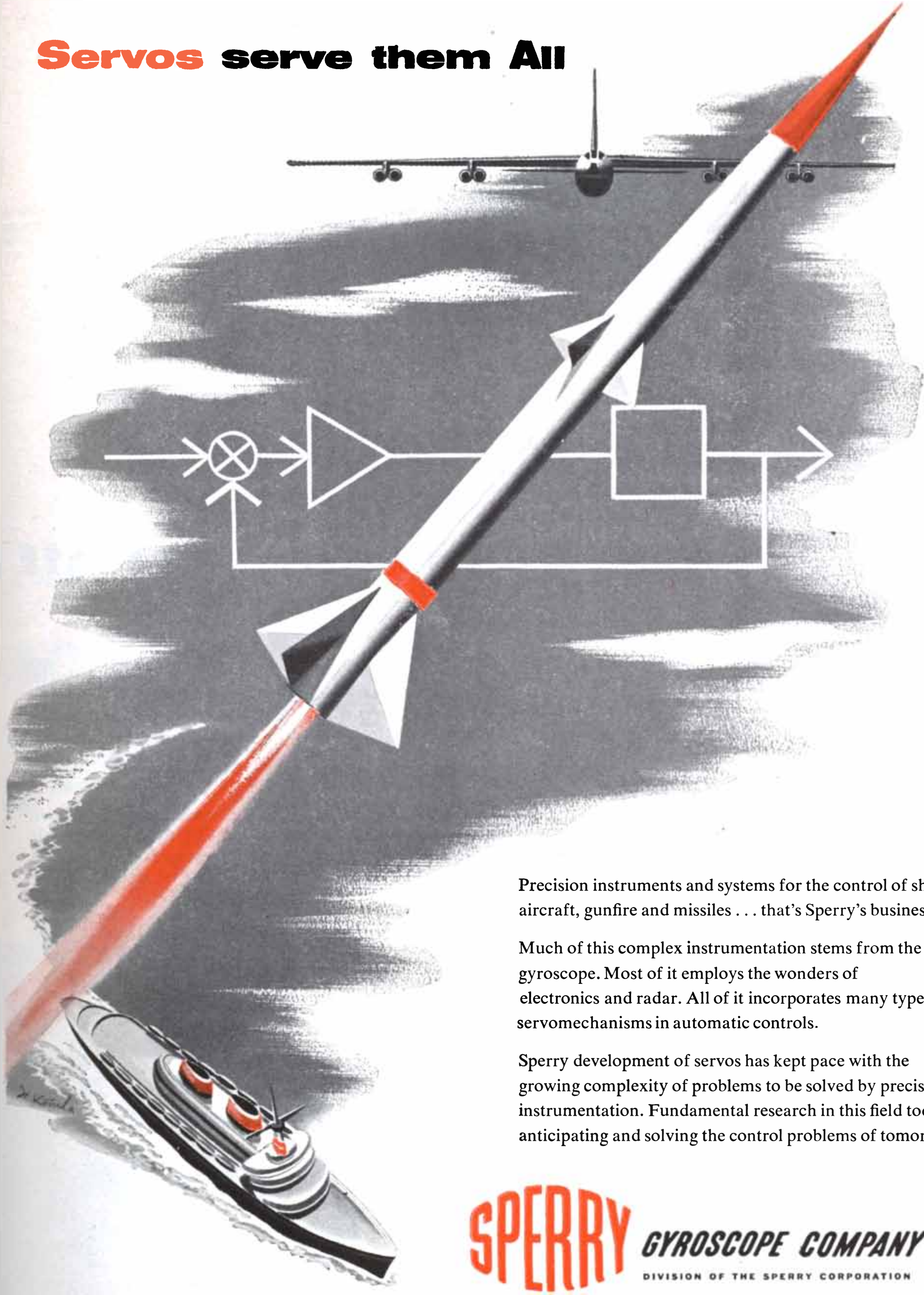

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Research begins,

where text books leave off . . .

THE VOCABULARY of the control scientist has advanced far beyond the everyday reference to primary elements, indicators, recorders and controllers. It now includes such expressions as "multiple-feed closed loop" and "proportional plus rate plus reset" . . . representing investigations that begin where text books leave off.

Research scientists at Honeywell's Industrial Division are engaged in activities aimed at solving technical problems of *real* importance to the users of industrial instruments and controls. Fundamental as well as developmental studies in the Honeywell laboratories are being translated into revolutionary controls for the further improvement of products and processes . . . for the practical realization of the automatic factory.

Perhaps the effectiveness of your own laboratory, pilot plant or full-scale operation can be materially improved through the cooperation of Honeywell . . . "First in Controls."

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HONEYWELL PRIMARY ELEMENTS LABORATORY. *Accelerating the response of primary elements keeps pace with demands of modern, high-speed processes.*

H HONEYWELL

Further information on these specific activities may be obtained by addressing correspondence to The Director of Research at the address listed above.

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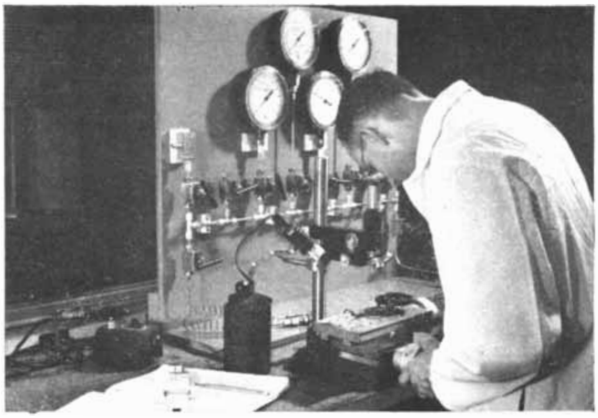

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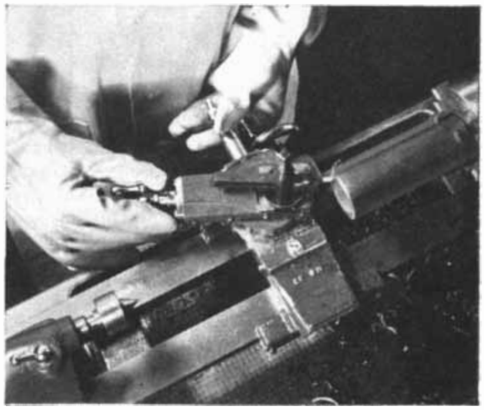

HONEYWELL SERVOMECHANISMS LABORATORY. *A new closed loop control system is studied with the aid of an automatic Nyquist plotter.*

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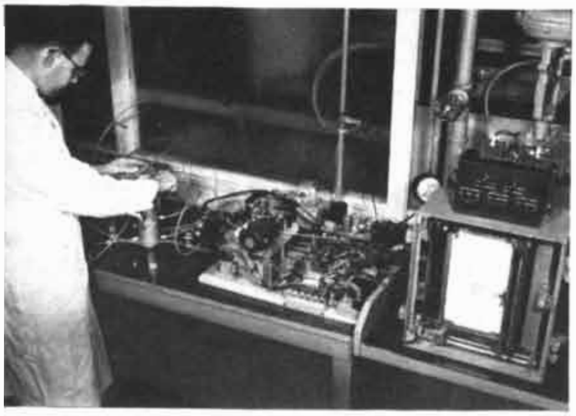

HONEYWELL TRANSISTOR RESEARCH LABORATORY. *Pioneering in the plotting of electrical characteristics of the minute cells sets the stage for their practical utilization.*

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50 AND 100 YEARS AGO

SEPTEMBER, 1902. "For the first time in its history the American Navy possesses a battleship with a speed of 18 knots and over. The distinction belongs to the new *Maine*, which, on August 23, was sent over the Cape Ann course for her official speed trials."

"Senator Berthelot, the well-known French chemist, has published an interesting paper anent the chemical synthesis of aliments, in which he foresees, in the difficulties it still presents, the economical emancipation of the human race, and the transformation of this planet into a vast pleasure ground. The more the conquest of electrical energy advances, the nearer it appears to M. Berthelot that mankind approaches toward the substitution of chemistry for agriculture. It is not long since the possibility of creating by synthesis all the organic matters was held to be chimerical; now the possibility has been demonstrated so often as to render it undeniable. Alimentary stuffs may be broadly divided into three fundamental classes—fats, sugars and albuminoids. As early as 1854 M. Berthelot by chemical synthesis created bodies exactly similar to natural fats. Sugar can now be produced in the chemist's laboratory. Chemical synthesis has not yet created the albuminoids, which are more complex and more liable to spoil. There is no doubt, however, but this feat will shortly be accomplished. M. Berthelot, however, utters a note of warning against the illusion of thinking that food can be condensed into lozenges and pills, and that one's meals can be carried in a small chocolate box in one's waistcoat pocket."

"After having vanished from view for more than a year, the planet Eros has been rediscovered. The planet was first observed in 1898 by Witt, of the Urania Observatory, Berlin, and given the name which it bears. Until 1898, as far as telescopes could show, Mars came nearer to the earth than any other planet, but after Witt's discovery it was found that Eros reached a point a little more than a third of the distance from earth to Mars. The honor of the rediscovery belongs to Professor G. D. Long, of the Chamberlin Observatory in Colorado."

"On September 5, Professor Rudolf Virchow, the Nestor of German pathologists, passed away. Only on October 13 last he had celebrated his 80th birthday. Virchow's greatest discovery was the self-propagating power of the cells in animal tissue, showing that whatever acted upon a cell from without produced a change, either chemical or mechanical, in the cell structure. These changes were the cause of disease. When Pasteur first made his startling discoveries of the bacteriological origin of disease, it was thought for a time that Virchow's theory was unfounded. But later research showed that the two doctrines really supplemented each other. Pathology as we know it today is Virchow's work."

"Although Lieutenant Peary returns to us once more without having reached the Pole, his expedition has not been inglorious. He has at least succeeded in outstripping all previous American Arctic explorers by penetrating to latitude 84 degrees 17 minutes. It cannot be denied that this is by no means the most northerly point ever reached, for the intrepid Nansen worked his way over the ice to latitude 86 degrees 14 minutes, and the Duke of Abruzzi forced his way to latitude 86 degrees and 33 minutes. The careful surveys made by Lieutenant Peary, however, the elaborate meteorological and geological studies undertaken, and the wealth of information collected fully compensate his failure to reach the Pole."

"At the annual meeting of the British Association for the Advancement of Science, Professor Dewar made a stirring appeal for the improvement of the national system of scientific education. As an instance of the importance of science to a country, he pointed out that the German chemical industries, which have grown up during the last 70 years, are worth £50,000,000 annually. Curiously enough, these chemical industries are founded on basic discoveries made by English scientists. 'It is in an abundance of men of ordinary plodding ability, thoroughly trained and methodically directed, that Germany at present has so commanding an advantage. It is the failure of our schools to turn out, and of the manufacturers to demand, men of this kind, which explains our loss of some valuable industries and our precarious hold on others. The really appalling thing is not that the Germans have seized this or that industry, or even that they may have seized a dozen industries. It is that the German population has reached a point in general training and specialized equipment which will take us two generations of hard and intelli-

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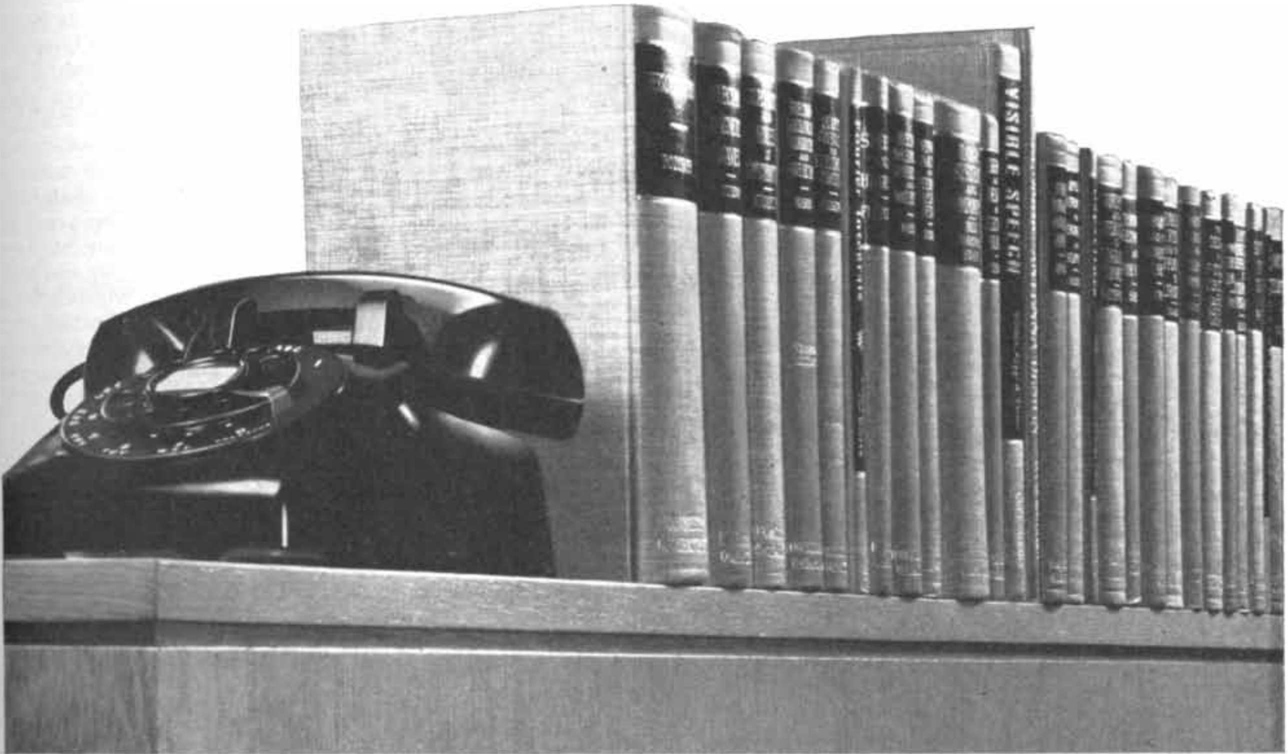
Telephone Science Shares Its Knowledge



The Bell Telephone Laboratories Series of books is published by D. Van Nostrand Company. Other technical books by Laboratories authors have been published by John Wiley & Sons. Complete list of titles, authors and publishers may be obtained from Publication Dept., Bell Telephone Laboratories, New York 14.

List of Subjects: Speech and hearing, mathematics, transmission and switching circuits, networks and wave filters, quality control, transducers, servomechanisms, quartz crystals, capacitors, visible speech, earth conduction, radar, electron beams, microwaves, waveguides, traveling wave tubes, semiconductors, ferromagnetism.

In their work to improve your telephone service, Bell Laboratories make discoveries in many sciences. Much of this new knowledge is so basic that it contributes naturally to other fields. So Bell scientists and engineers publish their findings in professional magazines, and frequently they write books.

Most of these books are in the *Bell Telephone Laboratories Series.* Since the first volume was brought out in 1926, many of the books have become standards . . . classics in their fields. Twenty-eight have been published and several more are in the making. They embody the discoveries and experience of one of the world's great research institutions.

Bell scientists and engineers benefit greatly from the published findings of workers elsewhere; in return they make their own knowledge available to scientists and engineers all over the world.

BELL TELEPHONE LABORATORIES

Improving telephone service for America provides challenging opportunities for individual achievement and recognition in scientific and technical fields.

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"Discovery"

IS AN EXCITING WORD

VERSENE*—VANGUARD OF ACHIEVEMENT

Explorers of old have been replaced by today's researchers. The vast unexplored areas that now remain are not far away. In fact, they are close at hand and quite within *your* own grasp. Equipped with the new chemistry of chelation and the Versenes (the most powerful chelating agents known) a whole new world of discovery lies before you.

VERSENE*—FAMED FOR VERSATILITY

Because the Versenes can control cations in solution with mathematical precision, these are some of the things that they can do: *preserve "goodness" in wet-packed foods; increase detergency in soaps; prevent metal stains in textiles and papers; stabilize latex, and cosmetics; control metal impurities in plating; clean boilers and heat exchangers; help purify drugs and stabilize pharmaceuticals; stabilize whole blood; promise cure for lead and other metal poisoning; scour Orlon to minimize crocking and bleeding of dyestuffs; control enzymes; remove heat-coagulable proteins from hides to increase usable yield; clean food process equipment.*

DISCOVER VERSENE* YOURSELF

When you want to explore the new chemistry of chelation and embark on your own era of "discovery" investigate the Versenes. Unduplicated in quality and guaranteed for uniformity of complexing (chelating) power, they are made only by the Bersworth Chemical Company, under patents and processes originated and developed by F. C. Bersworth. Exceptionally stable at elevated temperatures and throughout the pH range, the Versenes are available by gram or carload. Ask for Technical Bulletin #2 and samples. Chemical Counsel on special request. Write Dept. J.

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"Chemistry's most precise chemicals"

BERSWORTH CHEMICAL CO.

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gently directed educational work to attain; it is that Germany possesses a national weapon of precision, which must give her an enormous advantage in every contest depending upon disciplined and methodized intellect.' "

"The use of the automobile in connection with military service for mounting light artillery in this country originated with Major R. P. Davidson, Commandant at the Northwestern Military Academy of Highland Park, Ill. Twice he has essayed to make a record trip from Chicago to Washington with an automobile carrying a gun crew of four men and a rapid-fire gun. Owing to the wretched condition of the highways, which was further aggravated by rainy weather, each time the trip has been abandoned when partly completed. This year, the Cadet Corps of the Academy has been organized to include a bicycle and automobile gun detachment, which is probably the only military organization of its kind in the world. The motor vehicles are operated by 10 horsepower engines utilizing gasoline, giving a speed of 25 miles an hour on a country pike."

"If the reports of the daily press are to be credited, Alexander Graham Bell is the inventor of an airship which is shortly to be tested. As usual, no one but the inventor knows anything of the structural features of the contrivance."

SEPTEMBER, 1852. "We have received a communication from a highly respected subscriber and correspondent, in New Orleans, about such an Institution as the 'Ecole Centrale,' at Paris, where young men are educated in the theory and practice of engineering, manufacturing, and general machinery. He says if he cannot get his sons instructed at home in their own land, as he desires them to be, he must send them to France. He requests us to call the attention of our people to this subject. He has no desire to send them to a workshop or foundry, to serve an apprenticeship, as they would not be under the same general admonition and instruction as if under tutors. It would be a good thing for our country if some complete school of this kind were instituted; at present there is not one, so far as our information extends. A new Chair of Civil Engineering, under Professor Norton, has been established at Yale College; this is a judicious and wise movement of the Yaleites, and it shows they are awake to the improvements of this age."

"The motion of comets strikingly illustrates the almost absolute voidness of space. If they experienced any resistance while moving, their passage would be checked, although that resistance was many thousand times less than the hand

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PRODUCT CONTROL BY INFRARED ANALYSIS

How Six Leading Firms Cut Costs with Infrared

MERCK & COMPANY

For assay of penicillin G in fermentation broths. Cost $3.50/assay. Time: 2 hours. Faster, cheaper and less tedious than other methods.

A. B. DICK COMPANY

For selection and control of raw materials; control of finished graphic arts products. Most tests completed in 2 minutes compared to 2 days for conventional methods.

Perkin-Elmer Spectrometer at A. B. Dick Company

E. I. du PONT de NEMOURS & CO., INC.

For rapid, accurate determination of small amounts of water in Freon. Five minutes per determination—accurate to 1 ppm.

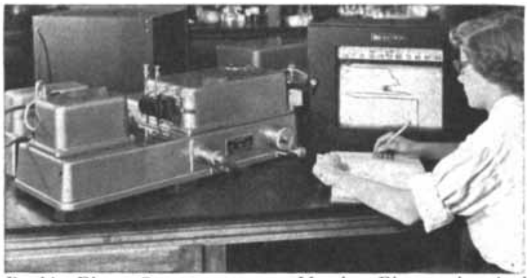
SMITH, KLINE AND FRENCH LABORATORIES

Assay khellin and visnagin, two new drugs, in seed extracts. Drugs are difficult to distinguish by conventional methods because of chemical similarity. It is a 20-minute routine for infrared.

Spectrophotometer at Smith, Kline and French

HOOKER ELECTROCHEMICAL CO.

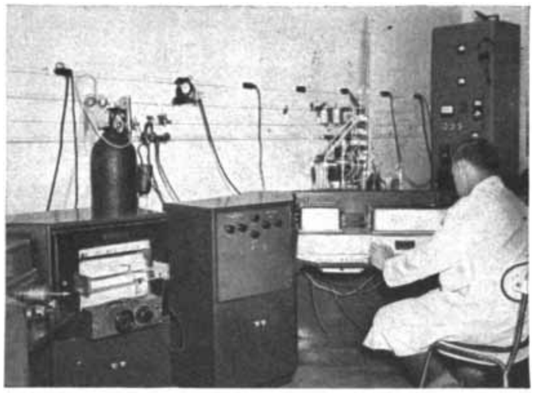
Concentration of gamma isomer in benzene hexachloride. Infrared routine completed in 10 minutes, at a fraction of cost and time by other means.



Perkin-Elmer Spectrometer at Hooker Electrochemical

JULIUS HYMAN & COMPANY

Production control for insecticides, raw material specification, etc. Two instruments run 24 hours a day on 8-hour shifts for 4000-5000 analyses per month. Less than 3% down time.



Perkin-Elmer Spectrometers at Julius Hyman & Co.

Bulletin #100 containing complete details on these case histories will be sent on request. Our laboratory is at your service for complete evaluation of infrared methods to your problems. For additional information write to: The Perkin-Elmer Corp., 875 Main Ave., Norwalk, Conn.

For Optical Design and Electro-Optical Instruments

PERKIN ELMER

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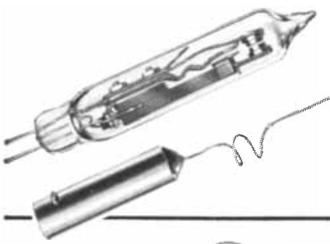
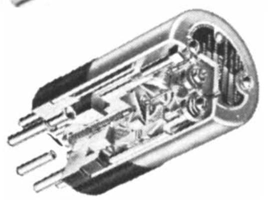
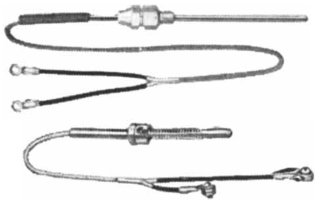
EDISON THERMAL TIMING RELAYS. Complete range of time delays from 2 seconds to 300 seconds within tolerance of ± 15% guaranteed for full life of relay. Standard RMA heater voltages. Both standard size and miniature relays meet shock, vibration and environmental requirements for aircraft application. Ask for free bulletins #3007 and 3027.



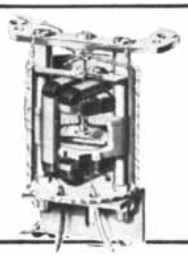
EDISON SEALED THERMOSTATS. Sealed-in-glass types break 115 volt 8 ampere *direct current* load with practically no contact arc. Type S1-1A holds control point within ± 0.1° over years without drift or apparent wear. Contacts cannot film or become contaminated even after years of inactivity as in fire alarm service. Write for free bulletin #3009.



EDISON SENSITIVE MAGNETIC RELAYS. SPST or SPDT contact arrangement—operate directly from d.c. current as low as 75 micro-amps. Contacts carry ⅓ amp non-inductive load. Copper-wound coils absorb overload to 10,000 times rated power. Separate coil leads to pins permit series or differential hookup. Send for free bulletin #3004.



EDISON ELECTRICAL RESISTANCE BULBS include the standard MIL approved types for aircraft and a wide variety of bulbs for industrial temperature alarm systems, hot bearing detection and process control applications. Latest bulbs are permanently sealed, require no maintenance. Free bulletin #3016.



EDISON RATIO MOVEMENT. A sensitive, rugged moving-magnet fixed-coil galvanometer developed primarily for use with the EDISON bridge as a temperature indicator free of voltage error. It may be used wherever an indication proportional to the ratio of two quantities, transferable into electrical terms, is required. For further information, write details of your requirements.

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feels when waved in the air. It is found that Encke's comet does indicate the presence of some such resistance—it goes slower and slower with each circuit. Upon the basis of this retardation, Professor Nichols has adopted the theory that there is a planetary ether, filling the space between the spheres, so that in the course of time Encke's comet will disappear. Whether it will do so or not, the future alone can tell. The idea of the ether filling all space was entertained by Euler in other days, but the cause of the retardation may not be an ether, but some heavenly body."

"Some of the members of the British Association for the Advancement of Science, recently made an ascent in a balloon for scientific purposes. They took up various instruments with them, and went up 19,200 feet. They had exhausted tubes and took down air in them from that height, in order to analyze it. No cloud was seen above them; all was clear and cold, 25 degrees below the freezing point."

"The steam frigate, *San Jacinto,* which received a very bad character at home, was sent abroad, not for the purpose of showing what the *people* could do in the way of building steamers, such as those of the Collins Line, but as a sample of the work of that distinctive body, the Government. It arrived at Constantinople on the 15th of last July, and a correspondent of the *New York Times,* writing from the City of the Turks about her, says: 'Aware of the usual reputation and abilities of American ships, a party of us were proudly waiting to see our national ship rapidly sweeping into the harbor, but after she hove in sight around the point of the Seraglio, and was in the presence of the three Cities of Constantinople, and of the whole Ottoman fleet stationed in the Bosphorus, what was our mortification to see the steamer unable to stem the current, and gradually disappearing again behind the point. The officers say the reason was, that, in obedience to orders of the Navy Department, they were so economical of coal.' This is humiliating, but the fact is, we have a very small number of steamers in our Navy, and a miserable lot they are."

"In Congress last week Senator Borland moved to appropriate $100,000 for Dr. Morton's ether patent. This was the means of eliciting a long debate, in which the claims of Drs. Jackson, Morton, and Wells to the discovery were distinctly presented. In our opinion, the claims of Dr. Wells are the strongest; we have seen no evidence to nullify them."

"Colonel Colt has received a silver medal from the Institution of Civil Engineers, in England, for a paper read before that body, on revolving fire-arms."

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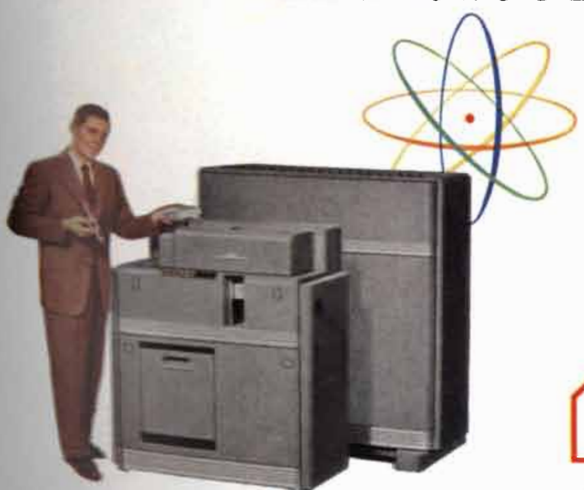
GETTING CLOSER TO *Infinity!*



Businessmen, engineers, and scientists now are solving problems in scientific and industrial data processing which, a few short years ago, would have been considered well-nigh infinite.

IBM Electronic Business Machines are making an important contribution to this progress. These machines accomplish once-overwhelming tasks with incredible speed and accuracy . . . freeing thousands of valuable minds for creative effort.

IBM

ELECTRONIC BUSINESS MACHINES
International Business Machines

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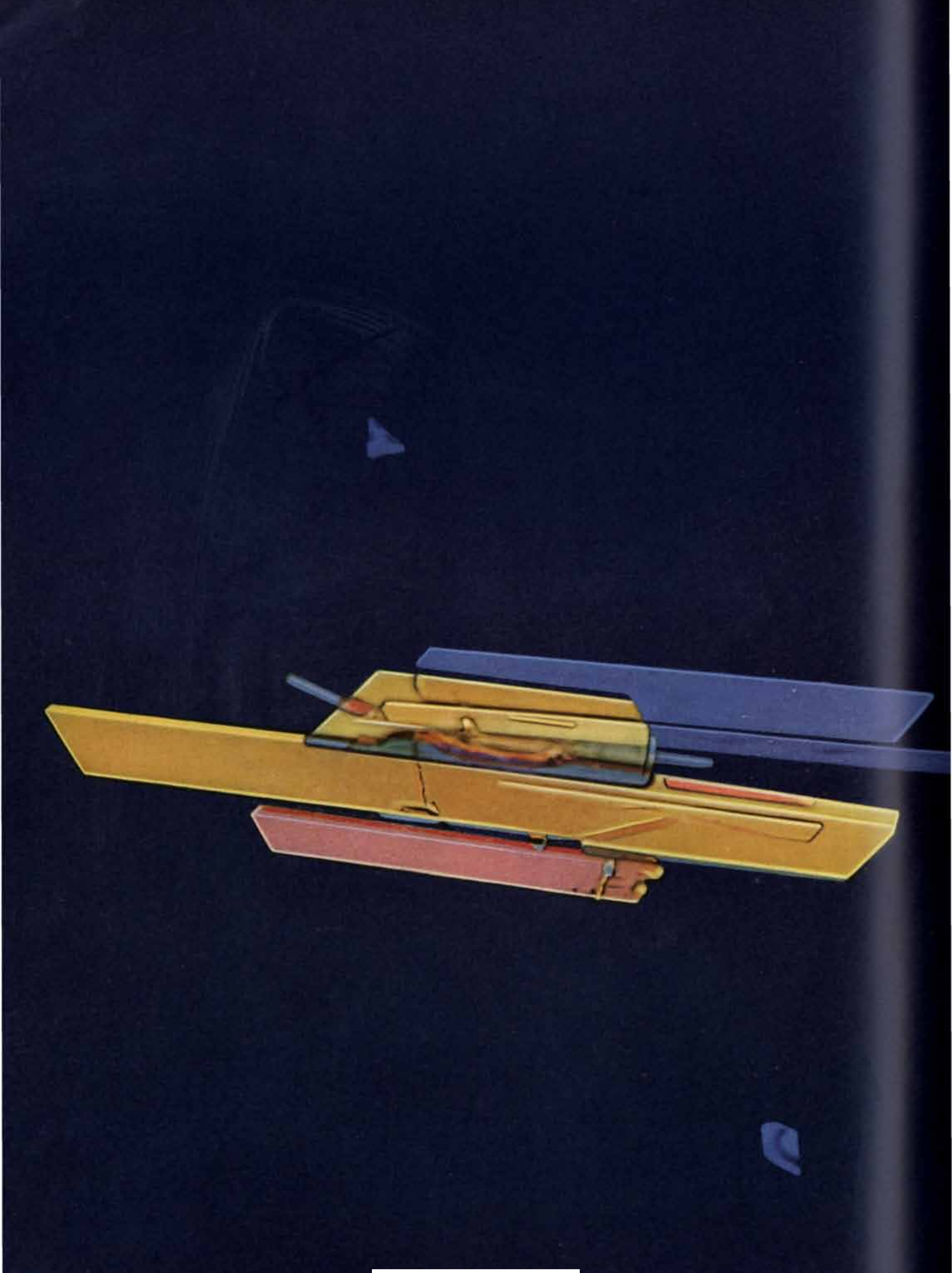

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A New Era in Medicine

Upjohn scientists have discovered a new method for producing ***cortisone*** synthetically. The most important step is performed by a common mold similar to bread mold. This process will produce cortisone in abundance and make it available to more people.

The crystals to the left and right are pure cortisone magnified a thousand times. The brilliant color is due to the crystals being photographed under a polarizing microscope.

Upjohn

Medicine... Produced with care
Designed for health

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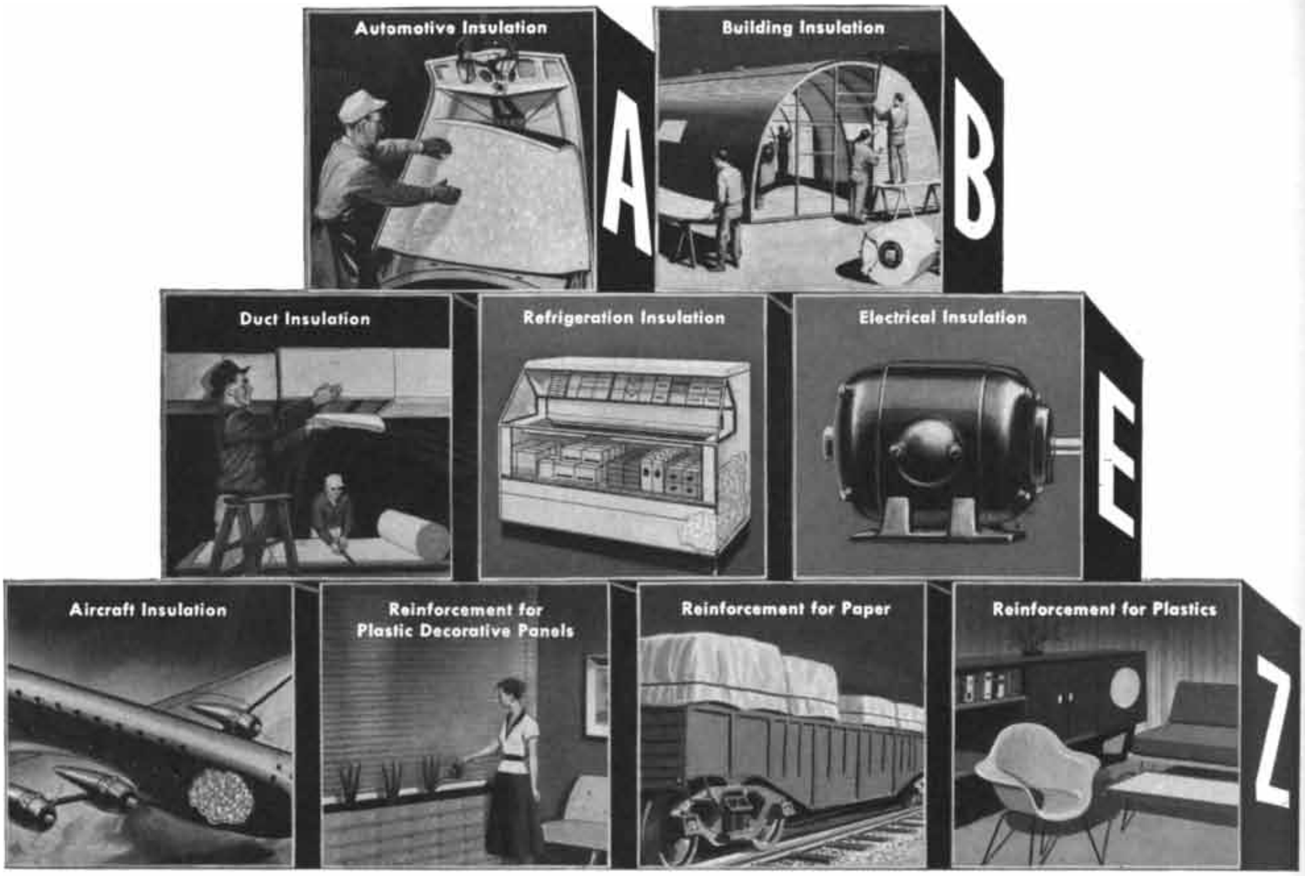

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"FEEDBACK?"

asked **RUTH WARD...**

SHE'D NEVER HEARD OF IT ... and of course it isn't particularly important that she should. It's just one of the simpler scientific principles, not particularly new, and not nearly as exciting to her as nuclear fission, the cathode ray tube, and X rays ... things she has heard of, even if she doesn't know much about them.

FEEDBACK is just one of the hundreds of relatively simple ideas that has been developed, and refined until an entire industry has grown up around it ... an industry that by serving hundreds of other industries, has helped make thousands of separate products available to Ruth Ward ... uniformly high quality products ... for less money.

AND the application of the feedback principle to automatic process control is over 50 years old!

BACK IN 1905, we were one of the first companies to offer industry an automatic temperature control instrument, embodying the feedback principle. Today, this same instrument, modified only slightly, is recommended and purchased for a wide variety of the more simple process control applications.

SINCE ITS INTRODUCTION, the idea of automatic control has been snowballing. We, together with others in our industry, have been striving to make automatic control applicable to more and more process variables . . . temperature, pressure, fluid flow, liquid level and others . . . and finding ways to control these variables more precisely. Taylor has pushed back established frontiers in the speed of response in controlling . . . and the necessary accompanying measurement, transmission, indication and recording of process variables . . . has transformed laboratory experimentation into practical mass production. Without these advances in instrument research and precision manufacturing facilities, the synthesis of many of our modern fibres, miracle drugs and the separation of U-235 from uranium could not have been possible.

AND RUTH WARD doesn't understand a single bit of it. She doesn't have to, in order to enjoy the countless material goods that automatic control ... an outgrowth of the feedback principle ... has helped make possible.

OF COURSE, we're proud that, in this highly specialized instrument industry, we have been a pacemaker since the beginning. From our first simple processing thermometers in 1851, we count many milestones, including the introduction of that early temperature controller (1905); production of one of the first recording thermometers (1910); line of completely adaptable FULSCOPE* Controllers (1939); wider application of the force-balance principle; and, since World War II, the development of our three-part TRANSET* Control System which has created new standards for measurement and control.

FOR INFORMATION on how we can help improve product quality, while cutting production costs, in almost any process industry, write: Taylor Instrument Companies, Rochester, N. Y. and Toronto, Canada.

* Reg. U. S. Pat. Off.

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What keeps automatic controls UNDER CONTROL?

BRUSH RECORDING ANALYZERS

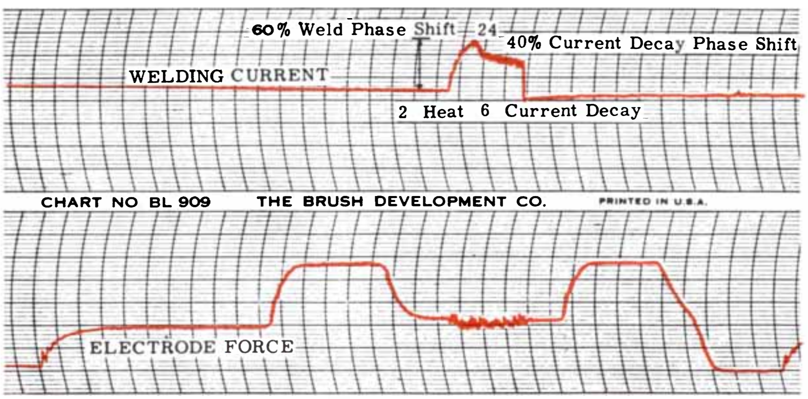
Industry is making giant strides forward with automatic control systems. And these strides are kept "on the beam" when controls are checked periodically the precision way . . . with Brush Recording Analyzers! It's simple!

These Brush Instruments measure and record variables . . . give written proof of the calibration and accuracy of the entire control system or any part of it. Chart records, which are instantaneously available, show the magnitude and timing of any factors involved . . . voltages, currents, strains, displacements, light intensities, temperatures, pressures and other static or dynamic conditions. Find out how you can simplify checking of *your* automatic controls with Brush Recording Analyzers.

Brush representatives are located throughout the U. S. In Canada: A. C. Wickman, Ltd., Toronto.

For complete information, write The Brush Development Company, Dept. B-38, 3405 Perkins Ave., Cleveland 14, Ohio.

EXAMPLE: Brush Recording Analyzer being used to check automatic control variables of a Sciaky 3-phase resistance welder. The dual chart records welding current and electrode force . . . shows contact gage settings, precompression force, welding force, forge force and timing in milliseconds. Here is written proof of accuracy and an instant clue to any flaws.



Put it in writing with a Brush Recording Analyzer

THE Brush DEVELOPMENT COMPANY

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Acoustic Devices
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THE COVER

The painting on the cover shows one of the earlier automatic control devices: the flyball-governor. It is mounted on a replica of one of James Watt's steam engines in Philadelphia's Franklin Institute.

THE ILLUSTRATIONS

Cover painting by Walter Murch

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58-60	James Egleson
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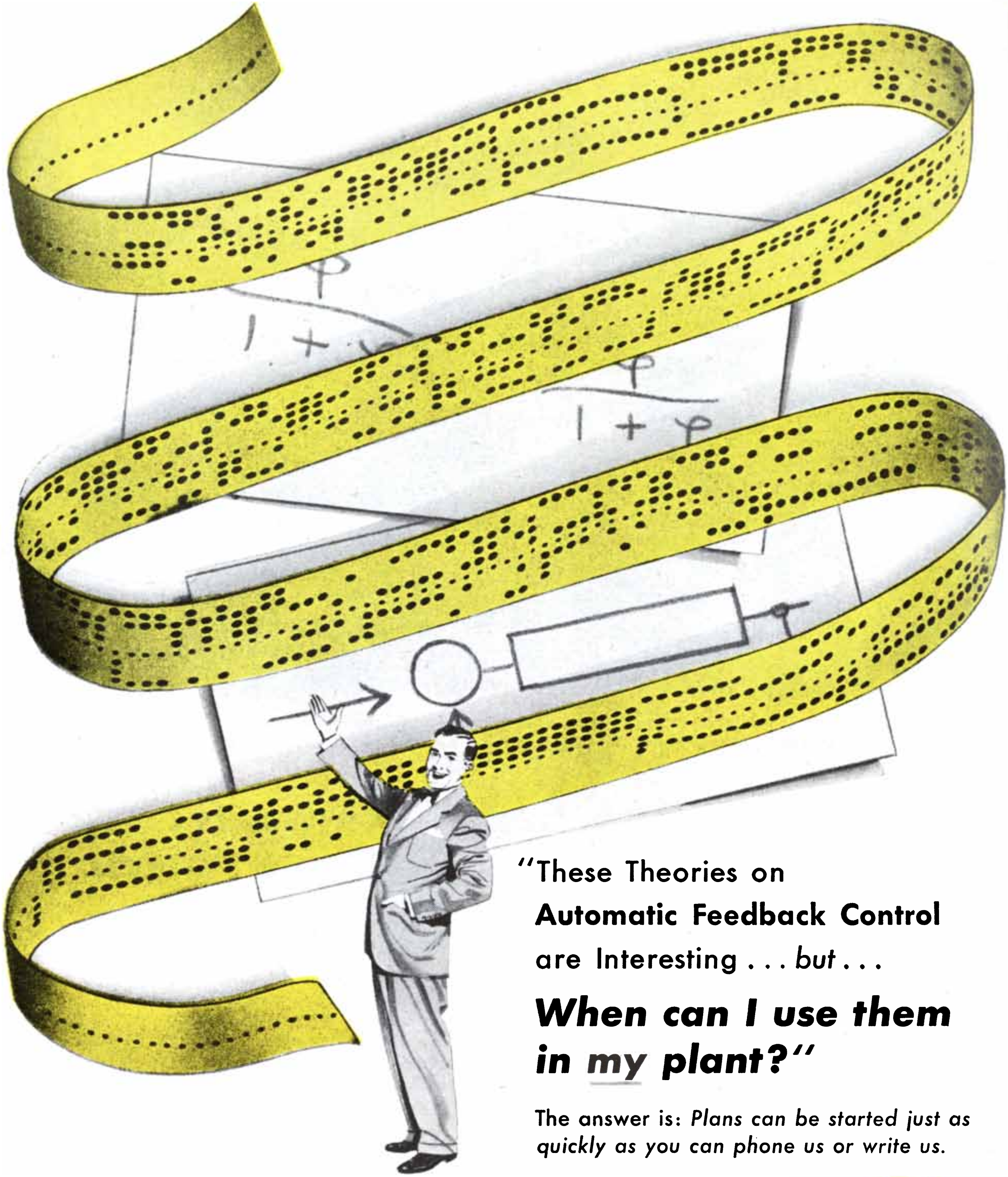

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SCIENTIFIC AMERICAN

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CONTENTS FOR SEPTEMBER, 1952 VOL. 187, NO. 3

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ARTICLES

DEPARTMENTS

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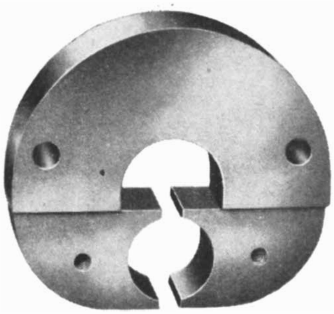
What's Happening at CRUCIBLE

about permanent alnico magnets

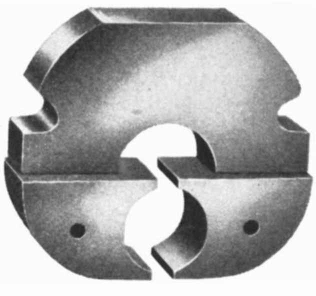
automatic control—permanent magnets are partners in industrial progress

One important part of the "automatic" factory is the requirement that measuring devices be accurate, rugged . . . and because of their use in such great volume they have to be low cost. It is a credit to instrument manufacturers that these meter miracles are being accomplished. Not only are the meters more sensitive, lower cost . . . but specialized problems in measurement are solved everyday with new and different instruments.



Former design of magnet assembly using Alnico II.

before



Note how redesigned magnet is made lighter because of reductions in area. The change from Alnico II to Alnico V with this design improved flux density.

after

Marion Meter, Model 53RN.

here's how Marion cut magnet costs 1/3 ...and built a better meter!

Marion Electrical Instrument Company, prominent meter manufacturer, embarked on a plan of redesigning their meters to give improved service. The Marion Meter, Model 53RN shown here, is a good example of what is being accomplished.

In redesigning their instruments, Marion worked closely with Crucible magnet specialists. The recommendation was made to change from Alnico II to Alnico V for the magnetic alloy used in the meter's D'Arsonval movement. Then the magnet itself was redesigned. The overall effect was to reduce the weight of the magnet by 35%, cut the cost ⅓ . . . and increase the gap flux density which resulted in a 15% increase in the torque of the movement. The illustration shows the old and new design.

This development is typical of how Crucible is working to increase measuring efficiency with permanent alnico magnets. Have you a magnet application we can cut costs on by ⅓?

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Preface

ON THE COVER of this issue of SCIENTIFIC AMERICAN is a painting of the flyball-governor invented by James Watt in 1788. Although the governor has been a commonplace to engineers for a century and a half, it has renewed significance today. Watt devised the governor to control the speed of his steam engine. The engine rotated the shaft in the center of the painting, causing the two iron balls to move outward and lower the arm at the upper left. The arm was linked to the throttle of the engine. When the engine went too fast, the balls tended to close the throttle and slow it down; when the engine went too slow, they tended to open the throttle and speed it up. In short, the engine was made to control itself.

The title of the painting, and of this issue, is "Automatic Control." The reader might well ask: "Automatic control of what?" The answer is the control of all things that are self-regulating or capable of self-regulation. Such control always involves the simple principle which is so admirably demonstrated by the flyball-governor. A portion of the output of a system is fed back to control the input; the familiar chain of cause and effect is closed in a loop of interdependent events. Life itself is such a self-regulating process. The principle can be seen at work in the ebb and flow of human affairs. This issue, however, is primarily concerned with the self-regulation of machines that do men's work.

Many such machines exist today. What is more significant is that the tempo of their evolution is quickening. A new kind of engineer thinks not only of automatic machines but also of automatic factories. It is not beyond the bounds of reasonable imagination to think of automatic industries: even now large sectors of the communications industry control themselves. This acceleration of tempo amounts to a technological revolution that must powerfully influence the future of man.

What is the origin of this revolution? In his introductory article Ernest Nagel points out, and Watt's governor reminds us, that self-regulating machines are not new. It is only recently, however, that we have come to appreciate their fundamental principle. Arnold Tustin describes this principle; Gordon S. Brown and Donald P. Campbell discuss its present and future application.

Although the fully automatic factory is not yet with us, many impressive examples demonstrate its imminence. Eugene Ayres tells how automatic control is used in a modern petroleum refinery; William Pease describes a recently developed fully automatic machine tool. The realization of the automatic factory awaits further progress in computing machinery and the handling of information, covered, respectively, by Louis N. Ridenour and Gilbert W. King. Wassily Leontief considers the economic and social impact of automatic control.

The last is the primary reason for the publication of this issue. Some readers will doubtless be depressed by the prospect of more automatic machines; it may seem that they can only further complicate man's existence and diminish his creative powers. Such possibilities are considered by the authors. But automatic control, like the release of atomic energy, is an inevitable outcome of history, and it is here. The central question is not whether it is good or bad, but how we may best use it. Fortunately the outlook is encouraging. Like every development in man's ability to harness the energy of nature, automatic control will further liberate him from the routine tasks of mere survival. It can only give him more time for the creative enjoyment of life and for the exploration of the universe.

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AUTOMATIC CONTROL

An introduction to seven articles about self-regulating machines, which represent a scientific and technological revolution that will powerfully shape the future of man

by Ernest Nagel

AUTOMATIC CONTROL is not a new thing in the world. Self-regulative mechanisms are an inherent feature of innumerable processes in nature, living and non-living. Men have long recognized the existence of such mechanisms in living forms, although, to be sure, they have often mistaken automatic regulation for the operation of some conscious design or vital force. Even the deliberate construction of self-regulating machines is no innovation: the history of such devices goes back at least several hundred years.

Nevertheless, the preacher's weary cry that there is nothing new under the sun is at best a fragment of the truth. The general notion of automatic control may be ancient, but the formulation of its principles is a very recent achievement. And the systematic exploitation of these principles—their subtle theoretical elaboration and far-reaching practical application—must be credited to the 20th century. When human intelligence is disciplined by the analytical methods of modern science, and fortified by modern material resources and techniques, it can transform almost beyond recognition the most familiar aspects of the physical and social scene. There is surely a profound difference between a primitive recognition that some mechanisms are self-regulative while others are not, and the invention of an analytic theory which not only accounts for the gross facts but guides the construction of new types of systems.

We now possess at least a first approximation to an adequate theory of automatic control, and we are at a point of history when the practical application of that theory begins to be conspicuous and widely felt. The future of automatic control, and the significance for human weal or woe of its extension to fresh areas of modern life, are still obscure. But if the future is not to take us completely by surprise, we need to survey, as this issue of SCIENTIFIC AMERICAN does, the principal content of automatic control theory, the problems that still face it and the role that automatic control is likely to play in our society.

THE CENTRAL ideas of the theory of self-regulative systems are simple and are explained with exemplary clarity in Mr. Tustin's essay which follows. Every operating system, from a pump to a primate, exhibits a characteristic pattern of behavior, and requires a supply of energy and a favorable environment for its continued operation. A system will cease to function when variations in its intake of energy or changes in its external and internal environment become too large. What distinguishes an automatically controlled system is that it possesses working components which maintain at least some of its typical processes despite such excessive variations. As need arises, these components employ a small part of the energy supplied to the system to augment or diminish the total volume of that energy, or in other ways to compensate for environmental changes. Even these elementary notions provide fruitful clues for understanding not only inanimate automatically controlled systems, but also organic bodies and their interrelations. There is no longer any sector of nature in which the occurrence of self-regulating systems can be regarded as a theme for oracular mystery-mongering.

However, some systems permit a greater degree of automatic control than others. A system's susceptibility to control depends on the complexity of its behavior pattern and on the range of variations under which it can maintain that pattern. Moreover, responses of automatic controls to changes affecting the operation of a system are in practice rarely instantaneous, and never absolutely accurate. An adequate science of automatic control must therefore develop comprehensive ways of discriminating and measuring variations in quality; it must learn how signals (or information) may be transmitted and relayed; it must be familiar with the conditions under which self-excitations and oscillations may occur, and it must devise mechanisms which will anticipate the probable course and sequence of events. Such a science will use and develop current theories of fundamental physico-chemical processes. It is dependent upon the elaborate logico-mathematical analyses of statistical aggregates, and upon an integration of specialized researches which until recently have seemed only remotely related. Our present theory of self-regulative systems has sprung from the soil of contemporary theoretical science. Its future is contingent upon the continued advance of basic research—in mathematics, physics, chemistry, physiology and the sciences of human behavior.

Automatic controls have been introduced into modern industry only in part because of the desire to offset rising labor costs. They are in fact not primarily an economy measure but a necessity, dictated by the nature of modern services and manufactured products and by the large demand for goods of uniformly high quality. Many articles in current use must be processed under conditions of speed, temperature, pressure and chemical exchange which make human control impossible, or at least impracticable, on an extensive scale. Moreover, modern machines and instruments themselves must often satisfy unprecedentedly high standards of quality, and beyond certain limits the discrimination and control of qualitative differences elude human capacity. The automatic control of both the manufacturing process and the quality of the product manufactured

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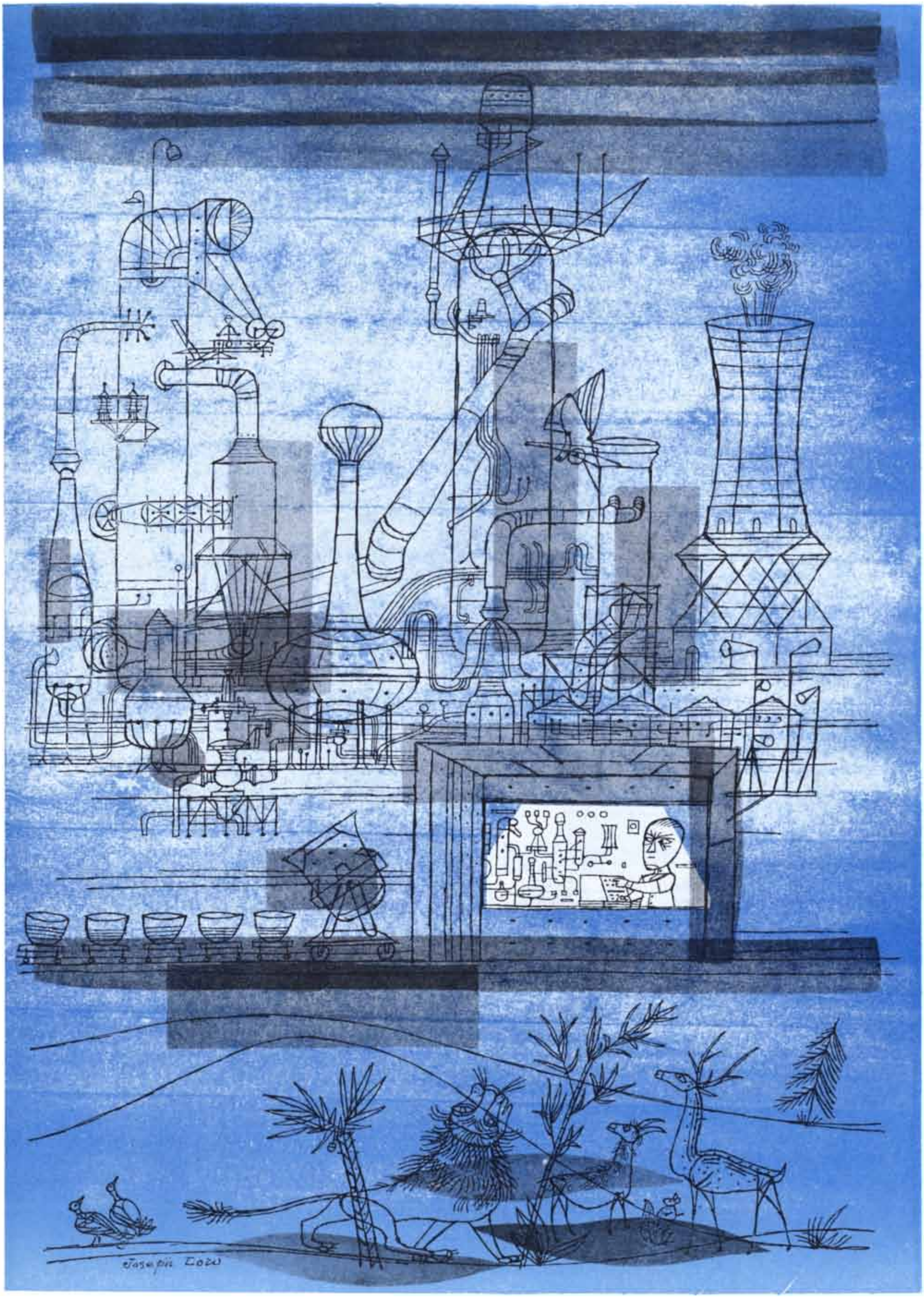

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THE LANGUAGE OF AUTOMATIC CONTROL

"When I use a word," Humpty Dumpty said in rather a scornful tone, "it means just what I choose it to mean—neither more nor less."

"The question is," said Alice, "whether you can make words mean so many different things."

The uninitiate may sometimes feel, with this issue of SCIENTIFIC AMERICAN, that he is playing Alice to the Humpty Dumpty of the control engineers. Part of their specialized vocabulary, to be sure, is openly and obviously technical, and here the reader will realize that he must find out what they are talking about. Some of their terms, however, will look like ordinary English, and the reader is warned that these everyday words have been made to mean just what the engineers choose them to mean. And where no word can be bent to their purpose, new ones have been invented. Special terms have been defined as they occur in each article; the most important are collected here for reference and as an introduction to the language of automatic control.

AUTOMATIC CONTROL: As used in this issue, automatic self-regulation by means of feedback (*see below*).

BINARY SCALE (OR BINARY SYSTEM): A numbering system based on 2, as the decimal system is based on 10, using only the digits 0 and 1.

BIT: Combined from binary digit. The unit of information. Information, as we will see below, is a choice between possibilities. Since a binary digit specifies a choice between only two possibilities: "zero or one," "yes or no," it is the least amount of information that can be imparted.

ERROR: In control systems, the difference between the actual value and the desired value of a controlled quantity. In communications theory, a mistake in a message (*below*).

FEEDBACK: This is the heart of the matter—the basic mechanism of all self-regulating systems. Information about the output at one stage of a process is returned, or fed back, to an earlier stage so as to influence its action and hence to change the output itself.

HUNT: To oscillate back and forth about a desired value. A characteristic of all feedback systems, which good design attempts to minimize or eliminate.

INFORMATION: What is transmitted in any communications system. The modern theory of communication considers information to be a measure of freedom of choice between possible messages, and shows it to have the properties of entropy.

MESSAGE: Information sent or received. The two may not be identical because of noise (*below*).

NOISE: Originally from radio engineering, where it had its usual meaning. Now any element in any message that was not put there intentionally by the sender. Thus "snow" on a television screen is noise.

SERVO-MECHANISM: An expert in the field has said "It is nearly as hard for the practitioners of the servo art to agree on a definition of a servo as it is for a group of theologians to agree on sin." A definition which, notwithstanding, many practitioners accept is: a feedback, power-amplifying control system.

is therefore frequently indispensable.

Once the pleasures of creating and contemplating the quasi-organic unity of self-regulative systems have been learned, it is only a short step to the extension of such controls to areas where they are not mandatory. Economic considerations undoubtedly play a role in this extension, but Messrs. Brown and Campbell are probably at least partly correct in their large claim that the modern development in automatic engineering is the consequence of a point of view which finds satisfaction in unified schemes for their own sake.

HOW LIKELY is the total automatization of industry, and what are the broad implications for human welfare of present tendencies in that direction? Crystal-gazing is a natural and valuable pastime, even if the visions beheld are only infrequently accurate. Some things, at any rate, are seen more clearly and certainly than others. If it is safe to project recent trends into the future, and if fundamental research in relevant areas continues to prosper, there is every reason to believe that the self-regulation of industrial production, and even of industrial management, will steadily increase. On the other hand, in some areas automatization will never be complete—either because of the relatively high cost of conversion, or because we shall never be able to dispense with human ingenuity in coping with unforeseeable changes, or finally because of certain inherent limitations in the capacity of any machine which operates according to a closed system of rules. The dream of a productive system that entirely runs itself appears to be unrealizable.

Some consequences of large-scale automatic control in current technology are already evident, and are noted by several contributors to this series of articles. Industrial productivity has increased out of proportion to the increase in capital outlay. Many products are now of finer quality than they have ever been before. Working hours have been generally reduced, and much brutalizing drudgery has been eliminated. In addition, there are signs of a new type of professional man—the automatic control system engineer. There has been considerable conversion and retraining of unskilled labor. A slow refashioning of educational facilities, in content as well as in organization, in engineering schools as well as in the research divisions of universities and industries, is in progress. In the main these developments contribute to human welfare.

However, commentators on automatic control also see it as a potential source of social evil, and express fears—not altogether illegitimate—concerning its ultimate effect. There is first the fear that continued expansion in this direction will be accompanied by large-

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scale technological unemployment, and in consequence by acute economic distress and social upheaval. As Mr. Leontief points out in his article, the possibility of disastrous technological unemployment cannot be ruled out on purely theoretical grounds; special circumstances will determine whether or not it occurs. But, as he also notes, the brief history of automatic control in the U. S. suggests that serious unemployment is not its inevitable concomitant, at least in this country. The U. S. appears to be capable of adjusting itself to a major industrial reorganization without uprooting its basic patterns of living. Large-scale technological unemployment may be a more acute danger in other countries, but the problem is not insurmountable, and measures to circumvent or to mitigate it can be taken.

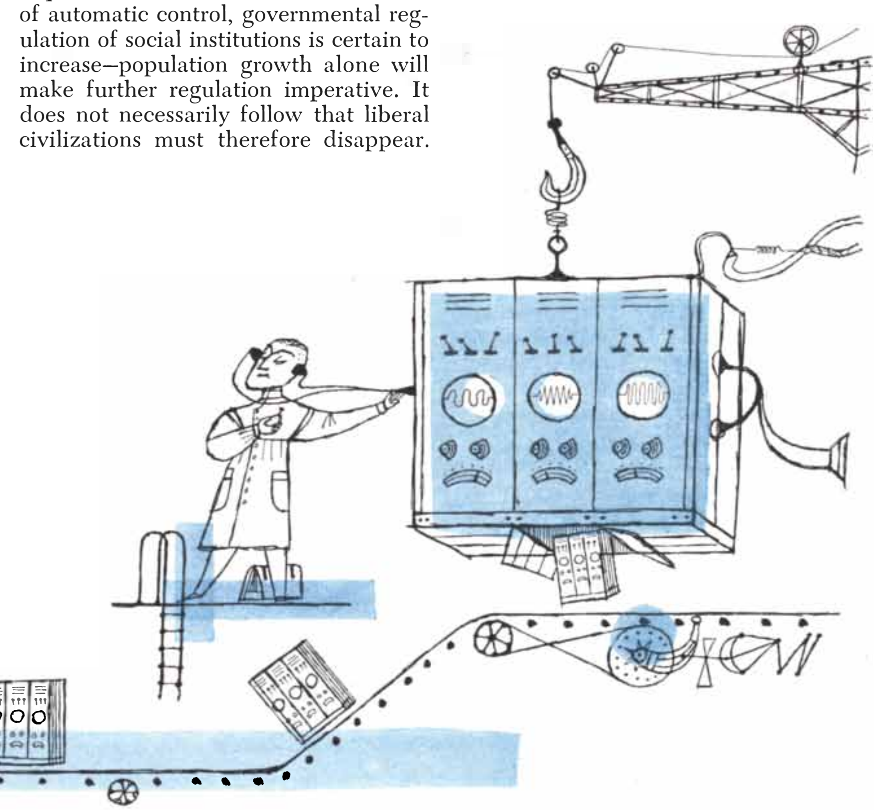
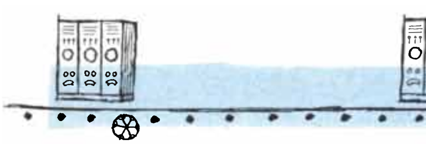
There is next the fear that an automatic technology will impoverish the quality of human life, robbing it of opportunities for individual creation, for pride of workmanship and for sensitive qualitative discrimination. This fear is often associated with a condemnation of "materialism" and with a demand for a return to the "spiritual" values of earlier civilizations. All the available evidence shows, however, that great cultural achievements are attained only by societies in which at least part of the population possesses considerable worldly substance. There is a good empirical basis for the belief that automatic control, by increasing the material well-being of a greater fraction of mankind, will release fresh energies for the cultivation and flowering of human excellence. At any rate, though material abundance undoubtedly is not a sufficient condition for the appearance of great works of the human spirit, neither is material penury; the vices of poverty are surely more ignoble than those of wealth. Moreover, there is no reason why liberation from the unimaginative drudgery which has been the lot of so many men throughout the ages should curtail opportunities for creative thought and for satisfaction in work well done. For example, the history of science exhibits a steady tendency to eliminate intellectual effort in the solution of individualized problems, by developing comprehensive formulas which can resolve by rote a whole class of them. To paraphrase Alfred North Whitehead, acts of thought, like a cavalry charge in battle, should be introduced only at the critical junction of affairs.

There has been no diminution in opportunities for creative scientific activity, for there are more things still to be discovered than are dreamt of in many a discouraged philosophy. And there is no ground for supposing that the course of events will be essentially different in other areas of human activity. Why should the wide adoption of automatic control and its associated quantitative methods induce a general insensitivity to qualitative distinctions? It is precisely measurement that makes evident the distinctions between qualities, and it is by measurement that man has frequently refined his discriminations and gained for them a wider acceptance. The apprehension that the growth of automatic controls will deprive us of all that gives zest and value to our lives appears in the main to be baseless.

THERE IS finally the fear that an automatic technology will encourage the concentration of political power; that authoritarian controls will be established for all social institutions—in the interest of the smooth operation of industry and of society but to the ruin of democratic freedom. This forecast is given some substance by the recent history of several nations, but the dictatorships differ so greatly from the Western democracies in political traditions and social stratifications that the prediction has dubious validity for us. Nevertheless, one element in this grim conjecture requires attention. Whatever the future of automatic control, governmental regulation of social institutions is certain to increase—population growth alone will make further regulation imperative. It does not necessarily follow that liberal civilizations must therefore disappear. To argue that it does is to commit a form of the pathetic fallacy. Aristotle argued that political democracy was possible only in small societies such as the Greek city-states. If our present complex governmental regulations in such matters as sanitation, housing, transportation and education could have been foreseen by our ancestors, many of them would doubtless have concluded that such regulations are incompatible with any sense of personal freedom. It is easy to confound what is merely peculiar to a given society with the indispensable conditions for democratic life.

The crucial question is not whether control of social transactions will be further centralized. The crucial question is whether, despite such a movement, freedom of inquiry, freedom of communication and freedom to participate actively in decisions affecting our lives will be preserved and enlarged. It is good to be jealous of these rights; they are the substance of a liberal society. The probable expansion of automatic technology does raise serious problems concerning them. But it also provides fresh opportunities for the exercise of creative ingenuity and extraordinary wisdom in dealing with human affairs.

Ernest Nagel is professor of philosophy at Columbia University.

The computing machine of the future gives birth to its kind

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FEEDBACK

It is the fundamental principle that underlies all self-regulating systems, not only machines but also the processes of life and the tides of human affairs

by Arnold Tustin

FOR hundreds of years a few examples of true automatic control systems have been known. A very early one was the arrangement on windmills of a device to keep their sails always facing into the wind. It consisted simply of a miniature windmill which could rotate the whole mill to face in any direction. The small mill's sails were at right angles to the main ones, and whenever the latter faced in the wrong direction, the wind caught the small sails and rotated the mill to the correct position. With steam power came other automatic mechanisms: the engine-governor, and then the steering servo-engine on ships, which operated the rudder in correspondence with movements of the helm. These devices, and a few others such as simple voltage regulators, constituted man's achievement in automatic control up to about 20 years ago.

In the past two decades necessity, in the form of increasingly acute problems arising in our ever more complex technology, has given birth to new families of such devices. Chemical plants needed regulators of temperature and flow; air warfare called for rapid and precise control of searchlights and anti-aircraft guns; radio required circuits which would give accurate amplification of signals.

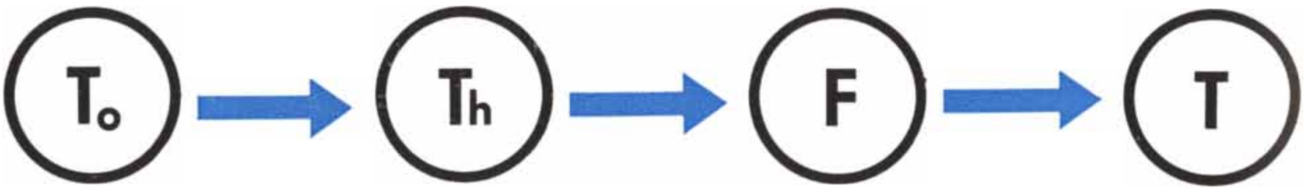
Thus the modern science of automatic control has been fed by streams from many sources. At first, it now seems surprising to recall, no connection between these various developments was recognized. Yet all control and regulating systems depend on common principles. As soon as this was realized, progress became much more rapid. Today the design of controls for a modern boiler or a guided missile, for example, is based largely on principles first developed in the design of radio amplifiers.

Indeed, studies of the behavior of automatic control systems give us new insight into a wide variety of happenings in nature and in human affairs. The notions that engineers have evolved from these studies are useful aids in understanding how a man stands upright without toppling over, how the human heart beats, why our economic system suffers from slumps and booms, why the rabbit population in parts of Canada regularly fluctuates between scarcity and abundance.

The chief purpose of this article is to make clear the common pattern that underlies all these and many other varied phenomena. This common pattern is the existence of feedback, or—to express the same thing rather more generally—interdependence.

We should not be able to live at all, still less to design complex control systems, if we did not recognize that there are regularities in the relationship between events—what we call "cause and effect." When the room is warmer, the thermometer on the wall reads higher. We do not expect to make the room warmer by pushing up the mercury in the thermometer. But now consider the case when the instrument on the wall is not a simple thermometer but a thermostat, contrived so that as its reading goes above a chosen setting, the fuel supply to the furnace is progressively reduced, and, conversely, as its reading falls below that setting, the fuel flow is increased. This is an example of a familiar control system. Not only does the reading of the thermometer depend on the warmth of the room, but the warmth of the room also depends on the reading of the thermometer. The two quantities are interdependent. Each is a cause, and each an effect, of the other. In such cases we have a closed chain or sequence—what engineers call a "closed loop" (*see diagram on the opposite page*).

In analyzing engineering and scientific problems it is very illuminating to sketch out first the scheme of dependence and see how the various quantities involved in the problem are determined by one another and by disturbances from outside the system. Such a diagram enables one to tell at a glance whether a system is an open or a closed one. This is an important distinction, because a closed system possesses several significant properties. Not only can it act as a regulator, but it is capable of



OPEN SEQUENCE of control is illustrated by a system for regulating the temperature of a room. T_o is a variation in the temperature outdoors. Th is the variation of a thermometer. F is the fuel control of a furnace. T is the variation of the temperature in the room. In such a system of control there is no feedback.

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various "self-excitatory" types of behavior—like a kitten chasing its own tail.

The now-popular name for this process is "feedback." In the case of the thermostat, the thermometer's information about the room temperature is fed back to open or close the valve, which in turn controls the temperature. Not all automatic control systems are of the closed-loop type. For example, one might put the thermometer outside in the open air, and connect it to work the fuel valve through a specially shaped cam, so that the outside temperature regulates the fuel flow. In this open-sequence system the room temperature has no effect; there is no feedback. The control compensates only that disturbance of room temperature caused by variation of the outdoor temperature. Such a system is not necessarily a bad or useless system; it might work very well under some circumstances. But it has two obvious shortcomings. Firstly, it is a "calibrated" system; that is to say, its correct working would require careful preliminary testing and special shaping of the cam to suit each particular application. Secondly, it could not deal with any but standard conditions. A day that was windy as well as cold would not get more fuel on that account.

The feedback type of control avoids these shortcomings. It goes directly to the quantity to be controlled, and it corrects indiscriminately for all kinds of disturbance. Nor does it require calibration for each special condition.

Feedback control, unlike open-sequence control, can never work without *some* error, for the error is depended upon to bring about the correction. The objective is to make the error as small as possible. This is subject to certain limitations, which we must now consider.

The principle of control by feedback is quite general. The quantities that it may control are of the most varied kinds, ranging from the frequency of a national electric-power grid to the degree of anesthesia of a patient under surgical operation. Control is exercised by negative feedback, which is to say that the information fed back is the amount of departure from the desired condition.

ANY QUANTITY may be subjected to control if three conditions are met. First, the required changes must be controllable by some physical means, a regulating organ. Second, the controlled quantity must be measurable, or at least comparable with some standard; in other words, there must be a measuring device. Third, both regulation and measurement must be rapid enough for the job in hand.

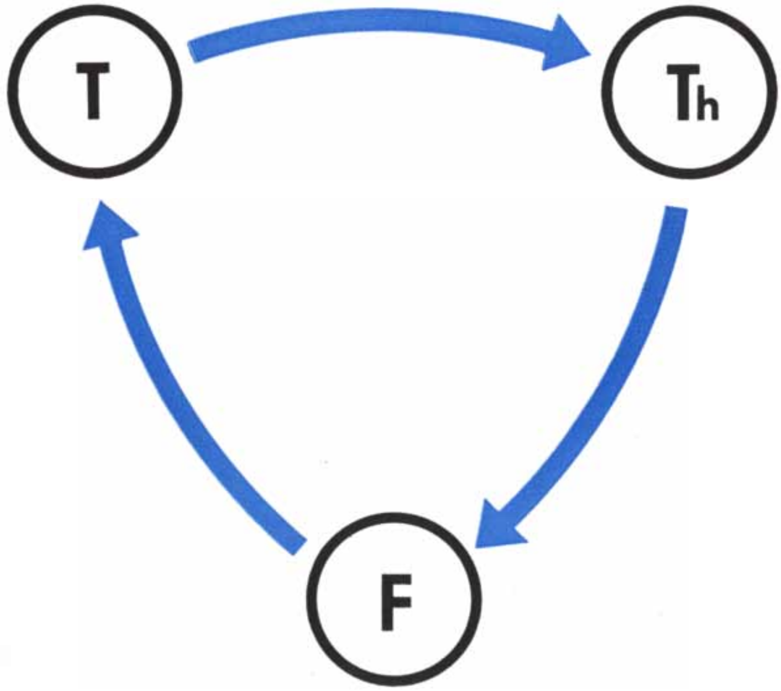
As an example, take one of the simplest and commonest of industrial requirements: to control the rate of flow of liquid along a pipe. As the regulating organ we can use a throttle valve, and as the measuring device, some form of flowmeter. A signal from the flowmeter, telling the actual rate of flow through the pipe, goes to the "controller"; there it is compared with a setting giving the required rate of flow. The amount and direction of "error," *i.e.*, deviation from this setting, is then transmitted to the throttle valve as an operating signal to bring about adjustment in the required direction (*see diagram at the top of page 53*).

In flow-control systems the signals are usually in the form of variations in air pressure, by which the flowmeter measures the rate of flow of the liquid. The pressure is transmitted through a small-bore pipe to the controller, which is essentially a balance piston. The difference between this received pressure and the setting regulates the air pressure in another pipeline that goes to the regulating valve.

Signals of this kind are slow, and difficulties arise as the system becomes complex. When many controls are concentrated at a central point, as is often the case, the air-pipes that transmit the signals may have to be hundreds of feet long, and pressure changes at one end reach the other only after delays of some seconds. Meanwhile the error may have become large. The time-delay often creates another problem: overcorrection of the error, which causes the system to oscillate about the required value instead of settling down.

For further light on the principles involved in control systems let us consider the example of the automatic gun-director. In this problem a massive gun must be turned with great precision to angles indicated by a fly-power pointer on a clock-dial some hundreds of feet away. When the pointer moves, the gun must turn correspondingly. The quantity to be controlled is the angle of the gun. The reference quantity is the angle of the clock-dial pointer. What is needed is a feedback loop which constantly compares the gun angle with the pointer angle and arranges matters so that if the gun angle is too small, the gun is driven forward, and if it is too large, the gun is driven back.

The key element in this case is some device which will detect the error of angular alignment between two shafts remote from each other, and which does not require more force than is available at the fly-power transmitter shaft. There are several kinds of electrical elements that will serve such a purpose. The one usually selected is a pair of the miniature alternating-current machines known as selsyns. The two selsyns, connected respectively to the transmitter shaft and the gun, provide an electrical signal proportional to the error of alignment. The signal is amplified and fed to a generator which in turn feeds a motor that



CLOSED SEQUENCE of control is illustrated by a system for regulating the temperature of a room by means of a thermostat. Here Th is a thermostat rather than a thermometer. In such a system there is feedback.

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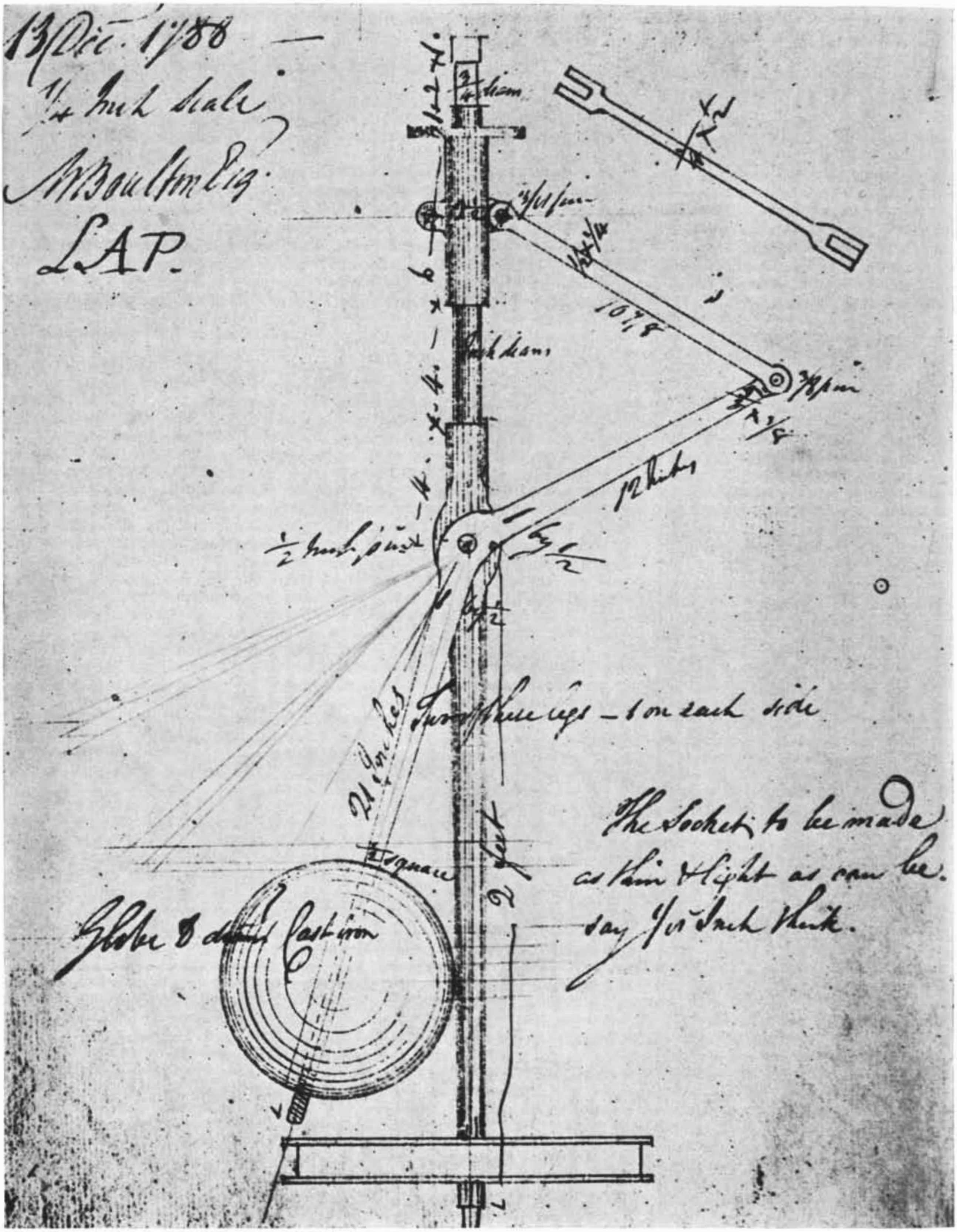

EARLIEST KNOWN DRAWING of the flyball-governor was made in 1788. The governor was invented by James Watt. At the upper left appear the date and the name of Watt's associate Matthew Boulton. Only half of a governor is shown in the drawing, but below the center are the words: "Two of these legs—1 on each side." Later Watt attempted to prevent the oscillation of the governor by fitting it with stops for the balls, one to keep them from coming too close together and the other to prevent them from "opening too wide asunder."

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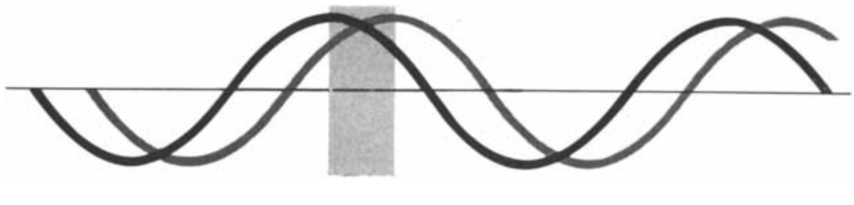
drives the gun (*see diagram on the next page*).

THIS GIVES the main lines of a practicable scheme, but if a system were built as just described, it would fail. The gun's inertia would carry it past the position of correct alignment; the new error would then cause the controller to swing it back, and the gun would hunt back and forth without ever settling down.

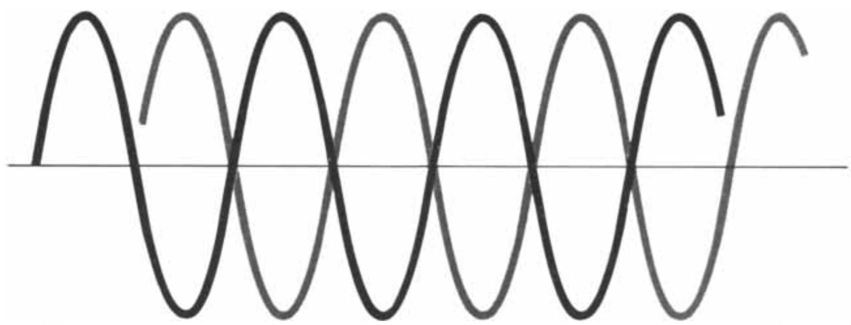
This oscillatory behavior, maintained by "self-excitation," is one of the principal limitations of feedback control. It is the chief enemy of the control-system designer, and the key to progress has been the finding of various simple means to prevent oscillation. Since oscillation is a very general phenomenon, it is worth while to look at the mechanism in detail, for what we learn about oscillation in man-made control systems may suggest means of inhibiting oscillations of other kinds—such as economic booms and slumps, or periodic swarms of locusts.

Consider any case in which a quantity that we shall call the output depends on another quantity we shall call the input. If the input quantity oscillates in value, then the output quantity also will oscillate, not simultaneously or necessarily in the same way, but with the same frequency. Usually in physical systems the output oscillation lags behind the input. For example, if one is boiling water and turns the gas slowly up and down, the amount of steam increases and decreases the same number of times per minute, but the maximum amount of steam in each cycle must come rather later than the maximum application of heat, because of the time required for heating. If the first output quantity in turn affects some further quantity, the variation of this second quantity in the sequence will usually lag still more, and so on. The lag (as a proportion of one oscillation) also usually increases with frequency—the faster the input is varied, the farther behind the output falls.

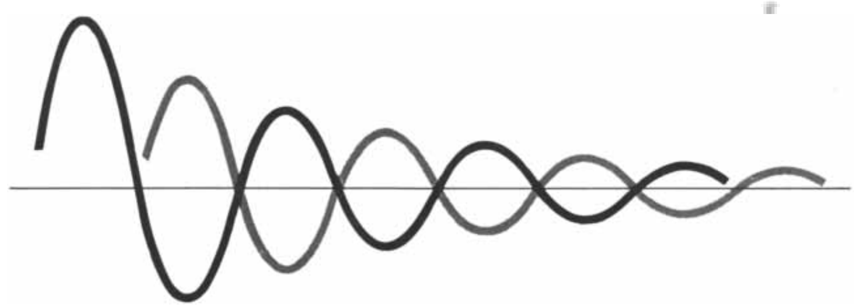
Now suppose that in a feedback system some quantity in the closed loop is oscillating. This causes the successive quantities around the loop to oscillate also. But the loop comes around to the original quantity, and we have here the mechanism by which an oscillation may maintain itself. To see how this can happen, we must remember that with the feedback negative, the motion it causes would be opposite to the original motion, if it were not for the lags. It is only when the lags add up to just half a cycle that the feedback maintains the assumed motion. Thus any system with negative feedback will maintain a continuous oscillation when disturbed if (a) the time-delays in response at some frequency add up to half a period of oscillation, and (b) the feedback ef-



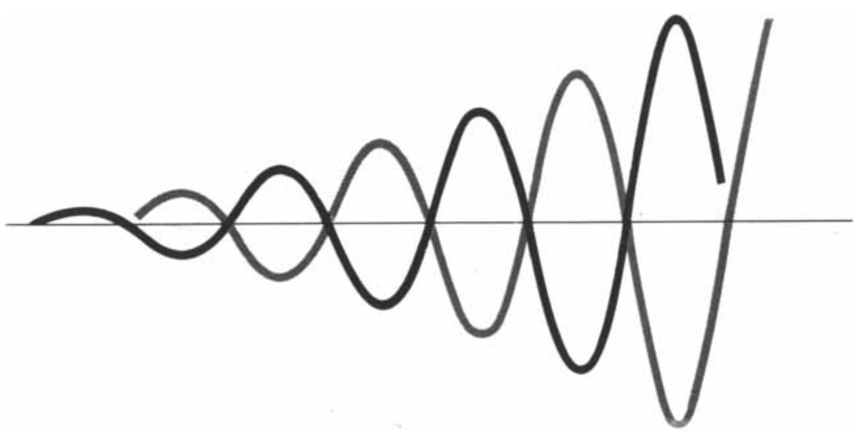
REGULAR OSCILLATORY VARIATION of a quantity put into a feedback system (*black curve*) is followed by a similar variation in the output quantity (*gray curve*). The gray rectangle indicates the time-delay.



ONE TYPE OF OSCILLATION occurs when the feedback (*gray curve*) of a system is equal and opposed to its error (*black curve*). Here the term error is used to mean any departure of the system from its desired state.



SECOND TYPE OF OSCILLATION occurs when the feedback (*black curve*) of a system is less than and opposed to the error (*gray curve*). This set of conditions tends to damp the disturbance in the system.



THIRD TYPE OF OSCILLATION occurs when the feedback (*gray curve*) of a system is greater than and opposed to the error (*black curve*). This set of conditions tends to amplify the disturbance in the system.

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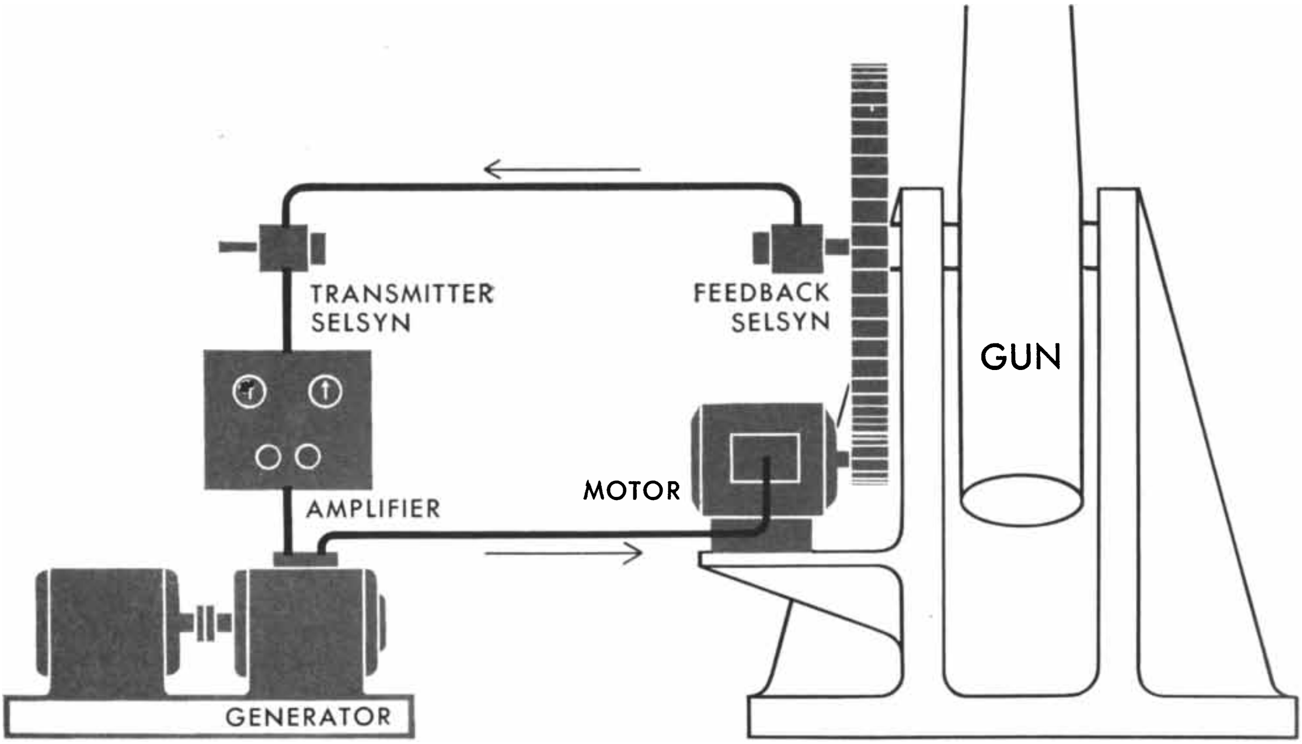

ELEVATION OF A GUN is controlled by an electrical feedback system. The closed sequence, or closed loop, runs from the position of the gun through the feedback selsyn, the transmitter selsyn, the amplifier and the generator to the motor. The selsyn is an electrical device which transmits position or speed of rotation.

fect is sufficiently large at this frequency.

In a linear system, that is, roughly speaking, a system in which effects are directly proportional to causes, there are three possible results. If the feedback, at the frequency for which the lag is half a period, is equal in strength to the original oscillation, there will be a continuous steady oscillation which just sustains itself. If the feedback is greater than the oscillation at that frequency, the oscillation builds up; if it is smaller, the oscillation will die away.

This situation is of critical importance for the designer of control systems. On the one hand, to make the control accurate, one must increase the feedback; on the other, such an increase may accentuate any small oscillation. The control breaks into an increasing oscillation and becomes useless.

TO ESCAPE from the dilemma the designer can do several things. Firstly, he may minimize the time-lag by using electronic tubes or, at higher power levels, the new varieties of quick-response direct-current machines. By dividing the power amplification among a multiplicity of stages, these special generators have a smaller lag than conventional generators. The lag is by no means negligible, however.

Secondly, and this was a major advance in the development of control systems, the designer can use special elements that introduce a time-lead, anticipating the time-lag. Such devices, called phase-advancers, are often based on the properties of electric capacitors, because alternating current in a capacitor circuit leads the voltage applied to it.

Thirdly, the designer can introduce other feedbacks besides the main one, so designed as to reduce time-lag. Modern achievements in automatic control are based on the use of combinations of such devices to obtain both accuracy and stability.

So far we have been treating these systems as if they were entirely linear. A system is said to be linear when all effects are strictly proportional to causes. For example, the current through a resistor is proportional to the voltage applied to it; the resistor is therefore a linear element. The same does not apply to a rectifier or electronic tube. These are non-linear elements.

None of the elements used in control systems gives proportional or linear dependence over all ranges. Even a resistor will burn out if the current is too high. Many elements, however, are linear over the range in which they are required to work. And when the range of variation is small enough, most elements will behave in an approximately linear fashion, simply because a very small bit of a curved graph does not differ significantly from a straight line.

We have seen that linear closed-sequence systems are delightfully simple to understand and—even more important—very easy to handle in exact mathematical terms. Because of this, most introductory accounts of control systems either brazenly or furtively assume that all such systems are linear. This gives the rather wrong impression that the principles so deduced may have little application to real, non-linear, systems. In practice, however, most of the characteristic behavior of control systems is affected only in detail by the non-linear nature of the dependences. It is essential to be clear that non-linear systems are not excluded from feedback control. Unless the departures from linearity are large or of special kinds, most of what has been said applies with minor changes to non-linear systems.

LONG BEFORE man existed, evolution hit upon the need for anti-oscillating features in feedback control and incorporated them in the body mechanisms of the animal world. Signals in the animal body are transmitted by trains of pulses along nerve fibers. When a sensory organ is stimulated, the stimulus will produce pulses at a greater rate if it is increasing than if it is decreasing. The pattern of nerve response to an oscillatory stimulus is shown in the diagram on page 54. The maximum response, or output signal, occurs before the maximum of the stimulus. This is just the anticipatory type of effect (the time-lead) that is required for high-

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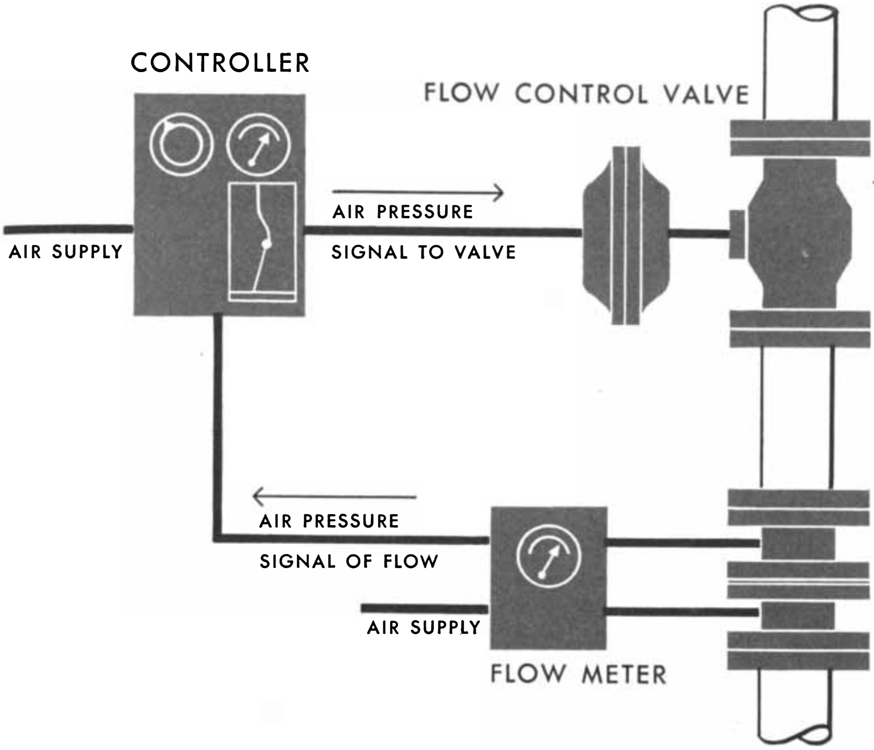


RATE OF FLOW IN A PIPE is controlled by a pneumatic feedback system. Here the closed loop runs from the flow of fluid in the pipe through the flow meter and the recording controller to the flow-control valve.

accuracy control. Physiologists now believe that the anticipatory response has evolved in the nervous system for, at least in part, the same reason that man wants it in his control mechanisms—to avoid overshooting and oscillation. Precisely what feature of the structure of the nerve mechanism gives this remarkable property is not yet fully understood.

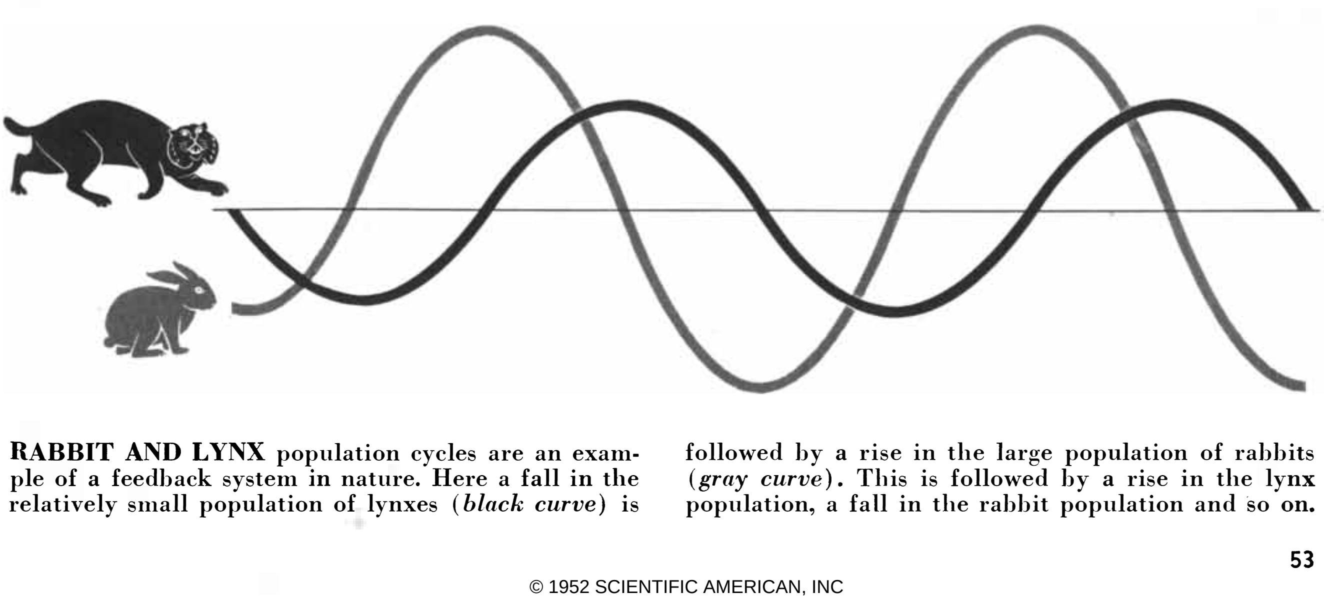
Fascinating examples of the consequences of interdependence arise in the fluctuations of animal populations in a given territory. These interactions are sometimes extremely complicated. Charles Darwin invoked such a scheme to explain why there are more bumblebees near towns. His explanation was that near towns there are more cats; this means fewer field mice, and field mice are the chief ravagers of bees' nests. Hence near towns bees enjoy more safety.

The interdependence of animal species sometimes produces a periodic oscillation. Just to show how this can happen, and leaving out complications that are always present in an actual situation, consider a territory inhabited by rabbits and lynxes, the rabbits being the chief food of the lynxes. When rabbits are abundant, the lynx population will increase. But as the lynxes become abundant, the rabbit population falls, because more rabbits are caught. Then as the rabbits diminish, the lynxes go hungry and decline. The result is a self-maintaining oscillation, sustained by negative feedback with a time-delay (*see diagram below*).

Curves of variation such that when R is large L is rising, but when L becomes large R is falling must have the periodic oscillatory character indicated. This is not, of course, the complete picture of such phenomena as the well-known "fur cycle" of Canada, but it illustrates an important element in the mechanisms that cause it.

THE PERIODIC booms and slumps in economic activity stand out as a major example of oscillatory behavior due to feedback. In 1935 the economist John Maynard Keynes gave the first adequate and satisfying account of the essential mechanisms on which the general level of economic activity depends. Although Keynes did not use the terminology of control-system theory, his account fits precisely the same now-familiar pattern.

Keynes' starting point was the simple notion that the level of economic activity depends on the rate at which goods are bought. He took the essential further step of distinguishing two kinds of buying—of consumption goods and of capital goods. The latter is the same thing as the rate of investment. The money available to buy all these goods is not automatically provided by the wages and profits disbursed in making them, because normally some of this money is saved. The system would therefore run down and stop if it were not for the constant injection of extra demand in the form of new investment. Therefore the level of economic activity and employment depends on the rate of invest-



RABBIT AND LYNX population cycles are an example of a feedback system in nature. Here a fall in the relatively small population of lynxes (*black curve*) is followed by a rise in the large population of rabbits (*gray curve*). This is followed by a rise in the lynx population, a fall in the rabbit population and so on.

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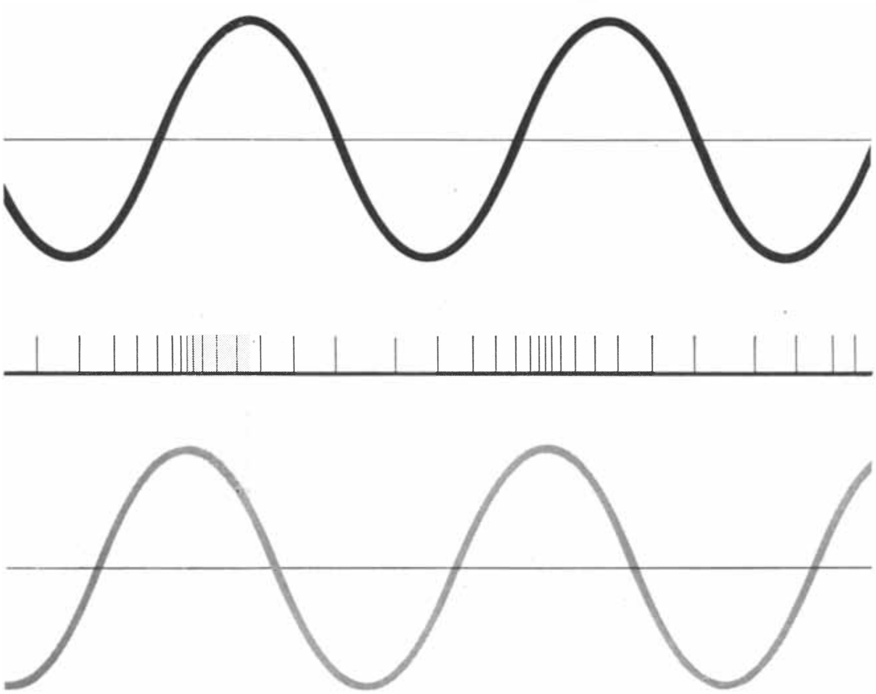

FEEDBACK IN THE NERVOUS SYSTEM has a sophisticated feature: the anticipation of the input signal by the output. The black curve at the top of this diagram represents the input signal. The row of vertical lines in the middle indicates the number of nerve pulses in a given time. The gray curve at the bottom translates these pulses into an output signal. The gray rectangle indicates how much the output signal leads the input.

ment. This is the first dependence. The rate of investment itself, however, depends on the expectation of profit, and this in turn depends on the trend, present and expected, of economic activity. Thus not only does economic activity depend on the rate of investment, but the rate of investment depends on economic activity.

Modern theories of the business cycle aim to explain in detail the nature of these dependences and their characteristic non-linearities. This clarification of the mechanisms at work immediately suggests many ways in which, by proper timing of investment expenditure, by more rational business forecasting, and so on, a stable level of optimal economic activity may be achieved in the near future. The day when it can unequivocally be said that slumps belong to the past will certainly be the beginning of a brighter chapter in human history.

THE EXAMPLES of feedback given here are merely a few selected to illustrate general principles. Many more will be described in other articles in this issue. In this article on "theory" I should like to touch on a further point: some ways in which the properties of automatic control systems or other complex feedback systems may be investigated in detail, and their performance perfected.

Purely mathematical methods are remarkably powerful when the system happens to be linear. Sets of linear differential equations are the happy hunting ground of mathematicians. They can turn the equations into a variety of equivalent forms, and generally play tunes on them. For the more general class of non-linear systems, the situation is quite different. There exact determination of the types of motion implied by a set of dependences is usually very laborious or practically impossible.

To determine the behavior of such complex systems two principal kinds of machines are being used. The first is the "analogue" computer. The forms of this type of computer are varied, but they all share a common principle: some system of physical elements is set up with relationships analogous to those existing in the system to be investigated, and the interdependence among them is then worked out in proportional terms. The second kind of aid is the new high-speed digital computer. In this type of machine the quantities are represented by numbers rather than by physical equivalents. The implications of the equations involved are explored by means of arithmetical operations on these numbers. The great speed of operation of these modern machines makes possible calculations that could not be attempted by human computers because of the time required.

The theory of control systems is now so well understood that, with such modern aids, the behavior of even extremely complex systems can be largely predicted in advance. Although this is a new branch of science, it is already in a state that ensures rapid further progress.

AT THE commencement of this account of control systems it was necessary to assume that the human mind can distinguish "cause" and "effect" and describe the regularities of nature in these terms. It may be fitting to conclude by suggesting that the concepts reviewed are not without relevance to the grandest of all problems of science and philosophy: the nature of the human mind and the significance of our forms of perception of what we call reality.

In much of the animal world, behavior is controlled by reflexes and instinct-mechanisms in direct response to the stimulus of the immediate situation. In man and the higher animals the operation of what we are subjectively aware of as the "mind" provides a more flexible and effective control of behavior. It is not at present known whether these conscious phenomena involve potentialities of matter other than those we study in physics. They may well do so, and we must not beg this question in the absence of evidence.

Whatever the nature of the means or medium involved, the function of the central nervous system in the higher animals is clear. It is to provide a biologically more effective control of behavior under a combination of inner and environmental stimuli. An inner analogue or simulation of relevant aspects of the external world, which we are aware of as our idea of the environment, controls our responses, superseding mere instinct or reflex reaction. The world is still with us when we shut our eyes, and we use the "play of ideas" to predict the consequences of action. Thus our activity is adjusted more elaborately and advantageously to the circumstances in which we find ourselves.

This situation is strikingly similar in principle (though immensely more complex) to the introduction of a predictor in the control of a gun, for all predictors are essentially analogues of the external situation. The function of mind is to predict, and to adjust behavior accordingly. It operates like an analogue computer fed by sensory clues.

It is not surprising, therefore, that man sees the external world in terms of cause and effect. The distinction is largely subjective. "Cause" is what might conceivably be manipulated. "Effect" is what might conceivably be purposed.

Man is far from understanding himself, but it may turn out that his understanding of automatic control is one small further step toward that end.

Arnold Tustin is professor of electrical engineering at the University of Birmingham.

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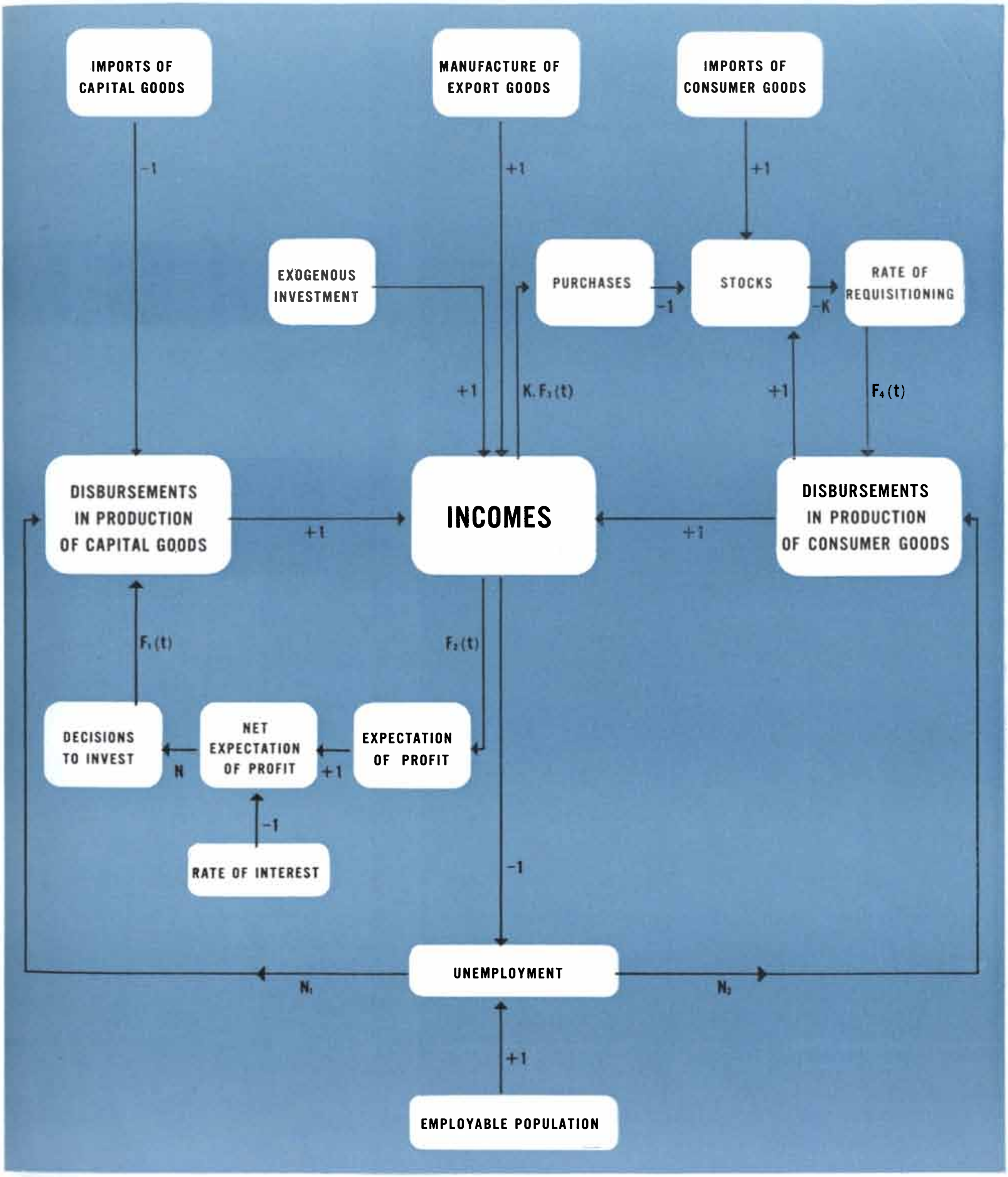

FEEDBACK IN AN ECONOMIC SYSTEM is blocked out in this diagram by the author. The scheme of dependence is based upon the ideas advanced by the late J. M. Keynes. Total incomes arise from disbursements for consumer goods on the one hand and capital goods on the other. But each of these is dependent in turn, *via* its subsidiary closed loop, upon total incomes. Keynes was especially concerned with the factors which determine the relationship between the two loops and the relative flow of money into them from total incomes. He showed this to be a highly sensitive relationship, since a comparatively small increase in the flow of money around the capital-goods loop is amplified *via* the consumer-goods loop into a much larger change in total incomes. This is precisely analogous to the behavior of similarly coupled electrical feedback circuits. Pursuing the analogy, the author has entered on the diagram some symbols for values that would have to be defined to design a complete electrical analogue for the economic system. K, for example, is Keynes' "propensity to consume"; F_1 (t) represents the time-lag between the decision to invest and the purchase of capital goods; N_1 and N_2 stand for non-linear functions which curtail increase in production as unemployment approaches zero.

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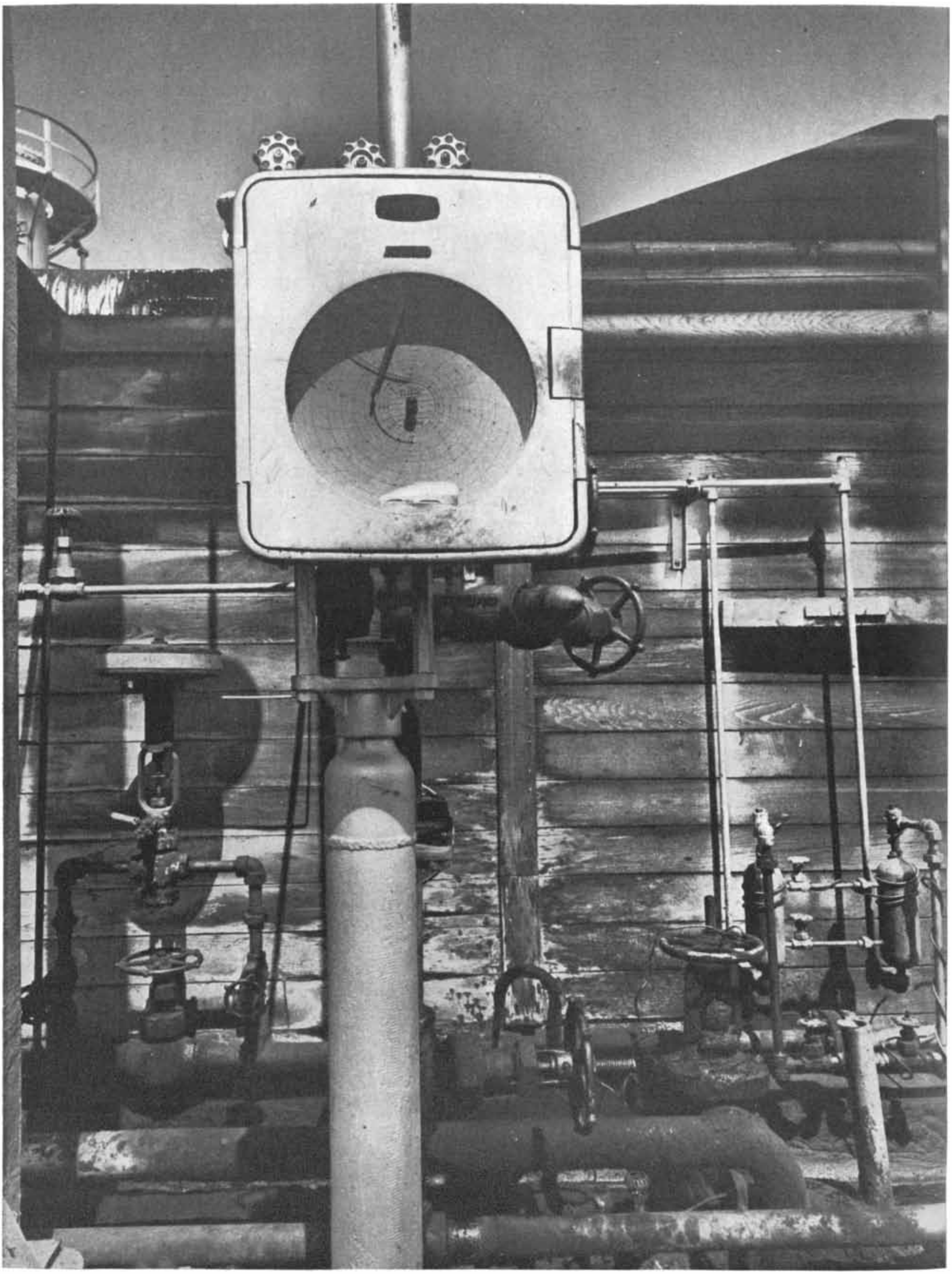

PNEUMATIC LOOP controls the flow of petroleum in the refinery of the McMurrey Refining Co. near Tyler, Tex. At the lower right is the flowmeter. At the top is an instrument that records the information from the meter. At the lower left is a pneumatic actuating device which operates a valve beneath it.

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CONTROL SYSTEMS

Many machines already run themselves by feedback. A new species of engineer is now required to orchestrate a whole technological process and its controls in a unified system

by Gordon S. Brown and Donald P. Campbell

FEEDBACK control systems have become our servants in many more ways than most of us realize. In the U. S. we now have tens of millions of them at work—in industry, in the military establishment, in offices and in the home. We are increasingly dependent upon this great army of robots. They minister to our comfort, protect our health and safety, relieve us of drudgery and operate difficult and dangerous enterprises which we would not dare undertake without them.

Everyone knows about the thermostat, which keeps radiators hot and the refrigerator cold. Most of the other controls are less familiar. A governor at the power station makes our electric clocks keep correct time. Electrical and electronic governors stabilize the performance of our radio and TV sets. A series of relays keeps the auto generator from overcharging the battery. Robots set the pitch of airplane propellers and trim the control surfaces to extract maximum performance from the engines and smooth the flight for the passengers. Process controllers supervise the manufacture of plastics, synthetic fibers, drugs, the whole range of products of the chemical industry. Intricate networks of instruments run our great petroleum refineries. Our communications system is one vast feedback circuit. Throughout industry the conversion of energy, from the process of combustion to the rotating of the shafts of heavy machinery, is conducted under automatic control. In sum, if the controls already operating in our economy were suddenly shut off, there would be chaos. The robots are here.

And this is only the beginning. The fully automatic factory is not yet here—but coming. The self-guiding missile is an inevitable prospect. One's imagination need not be restricted to industrial and military possibilities. We can look forward to feedback controls in homemaking, salesmanship, education, research, medicine and even contract-writing, designing and entertainment. If we can have feedback circuits in our radio and TV sets, why not an automatic program discriminator which could tell classical from popular music, if not Democratic from Republican orators? The thermostat suggests the possibility of a year-round program for the automatic heating and cooling of houses, responsive to the outdoor cycle of weather and season. Businessmen and administrators will think of ways to employ feedback circuits in such functions as inventory control and sales strategy. Physicians, who already use the feedback principle to control anesthesia and X-ray and diathermy treatments, will learn to extend the body's principle of homeostasis to control other aspects of therapy. In the sciences, we can look forward to probing the star-filled skies, the depths of the sea and the micro-dimensions of time and space with automatically controlled instruments.

A ROBOT simulates the functions of a human being, and to understand how it works this is where we must start. Modern industry began with manual and semi-automatic controls. A human operator read the instruments and applied corrections to a process. He detected deviations of the actual performance from some desired standard and performed a corrective manipulation of valves, levers or rheostats. The human operator served as the feedback link, the error-detector, the controller and corrector. He decided what the reading was, what it meant, what should be done about correcting the process and whether or not the last correction was sufficient. This is the essence of control: measure, compare, correct and check the result.

As the tempo and complexity of technology rose, human operators began to fall behind: they could not keep up with the demands of the machine. It became necessary to give the instruments, which had merely measured and indicated, the function of control as well. Power amplification was added to them, to replace the service of human muscles. Mechanisms were devised to approximate some elementary abilities of the human brain—proportioning, anticipating and integrating. For many specific operations these devices closed the feedback control loop and made the human link unnecessary.

This liberation of technology from the limitations of the human system has already had great practical consequences—far greater than the labor-saving resulting from the reverse liberation of human beings from control jobs. It is revolutionizing the controlled processes themselves. Instead of merely hanging the new instruments on old plants, industry is redesigning the plants to take advantage of the opportunities offered by automatic control. Entirely new processes which deal with matter and energy in terms of quantum mechanics and probability, can now be engineered for control by feedback loops. This new approach is the province of a new and growing profession—feedback system engineering.

Servo-mechanisms, regulators and process controllers will thus play increasingly important roles. Simple controllers, which measure and control but one variable (*e.g.*, temperature), are giving way to complex controllers which scan many variables, compute and govern the total plant performance. The robot specialists are being organized to function in teams. Combinations of automatic controllers and their respective processes function more and more as systems in the broadest sense—in energy conversion, transportation, communication, mechanized computation, the processing and synthesis of materials and the manipulation of machinery.

Let us consider three typical control circuits.

A RED-HOT ingot of steel as big as a ranch-house kitchen, moving ponderously down the ways from an oven, is suddenly caught by giant rollers. They whip it back and forth three or four times, pressing it down into a slab 100 feet long and six inches thick. The slab moves on to the trimming and cutting machines, and another ingot comes down the ways. Two men, sitting com-

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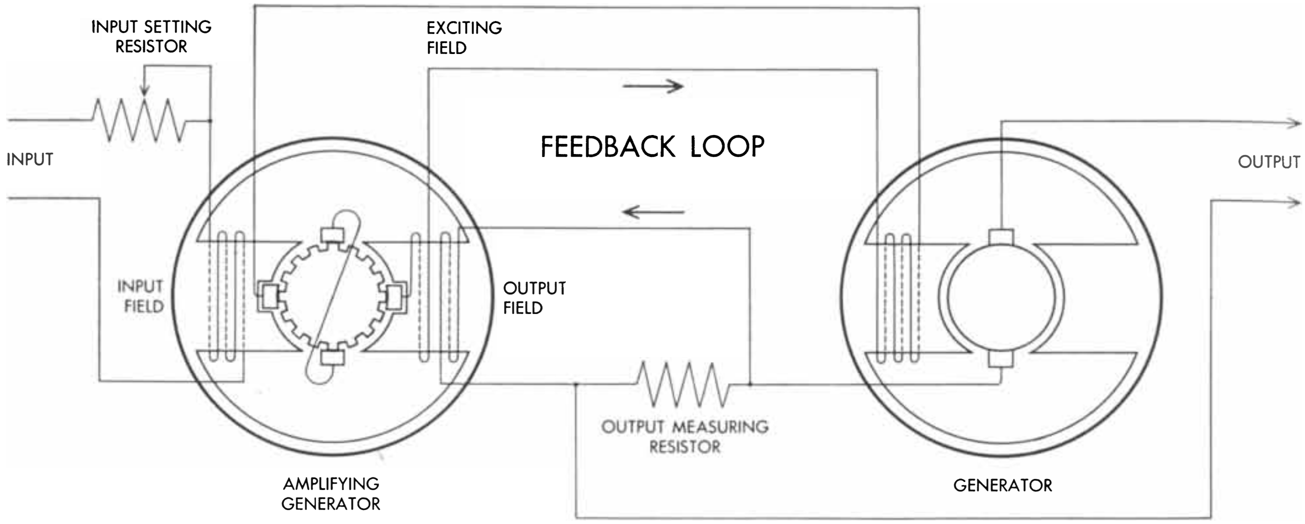

DIRECT-CURRENT SERVO-MECHANISM is widely used in the control of heavy industrial motors and generators. In this current-control circuit the amplifying generator compares any deviation in the output of the main generator to the input set point and generates a correcting current in its exciting field.

fortably in leather chairs high above the heat and sparks, handle it all with levers. The rotating armatures of the electric motors that drive these mills are as big as an automobile; they deliver 5,000, sometimes 10,000, and next, perhaps, 25,000 horsepower. Yet these machines are lightning-fast. They zip the ingot from almost standstill to full speed in about one second; they stop it just as quickly.

The system "feels" the resistance of the ingot to the squeezing of the rolls and summons an exactly sufficient surge of current to keep the rolls turning at the speed demanded by the operator's hand on the lever. This is accomplished by a feedback circuit employing the direct-current servo-mechanism illustrated above. The circuit is closed at the control lever. Here the actual speed of the mill-rolls, continuously reported back by a tachometer on the spinning drive-shaft, is compared with the speed set by the operator's hand. Any error is transmitted to the drive as a tiny electrical signal and is amplified through a cascade of dynamos, each larger than the last, until it becomes the force needed to turn the rolls as directed. The human operator still controls other factors; he knows just how much to squeeze down the ingot at each pass through the rolls, and just how many times it must be passed to develop the metallurgical properties desired. But control engineers think that a feedback loop could take over these functions also. The equations for this "quality" loop will some day be written, bringing control of product quality and control of process together in a single system.

A radar dish tirelessly sweeps a beam of tiny electromagnetic pulses across the sea and sky. A target is discovered. The reflected pulses close a feedback circuit and freeze the radar on the target. Now the tracking of the dish puts computers to work, integrating the target position with weather and ballistic data. The solutions to these equations, fed through feedback circuits, start guns tracking the point in the sky where the trajectory of the shells and the course of the target will intersect. The final link in the system is a proximity fuse, which explodes a shell as it nears the target. This is diverse control, cutting across a half-dozen fields of engineering. Signals are translated with limitless virtuosity from discrete digital to continuous analogue statements, from electric and electronic impulses to mechanical and hydraulic action. But already these achievements in control technology are shaded by more recent developments in guided missiles.

The third illustration is a feedback loop which will control the ruling of diffraction gratings by a ruling engine (SCIENTIFIC AMERICAN, June). In a ruling engine a tiny diamond cuts a series of grooves in the aluminized surface of a small square of glass. The grooves, so close together that they are individually imperceptible to the human eye, must be exactly parallel, and they must be spaced accurately with a tolerance of less than a millionth of an inch. The problem of ruling a large grating (12 inches or more wide) with such accuracy has so far defied the machine and its human operators. But in the spectroscopic laboratory at the Massachusetts Institute of Technology a new automatically controlled engine is on the verge of achieving this objective. The measuring instrument in its feedback loop is an interferometer, which accurately measures distances as short as a wavelength of light. As the carriage on which the grating lies is shifted into position beneath the diamond for the ruling of each successive groove, the interferometer continuously measures its travel. If the carriage is more than one-50 millionth of an inch from the correct position, a signal is fed back to the motor that turns the screw that shifts the carriage, and it makes the necessary correction.

IN AN automatically controlled system, as in the human organism, the whole is far greater than its parts. The instruments, circuits, tubes and servo-mechanisms are but the hardware of the grand design. In the present state of the art there is a growing recognition among engineers and scientists that they cannot deal with control systems part by part, but must design each system as a unitary whole. Automatic control as we wish to speak of it here means the synthesis of product, process, plant and instruments. This implies designing the plant for control as much as designing controls for the plant. System engineering therefore calls for the pooled resources and efforts of professionals in many fields—mathematicians, scientists, engineers and administrators. It must integrate information and art from many branches of technology: mechanical, electrical, hydraulic, pneumatic, electronic, optical and chemical. Considering the specialization and complexity of each field, this is a formidable challenge. But the first generation of feedback system engineers—men who can grasp and synthesize the whole picture—is emerging. They have already left their mark on the chemical and electronics industries, in terms of better products and better coordination of plant operation.

LIKE MANY ideas which seem novel if we choose to ignore history, the system idea has a past. It began, in

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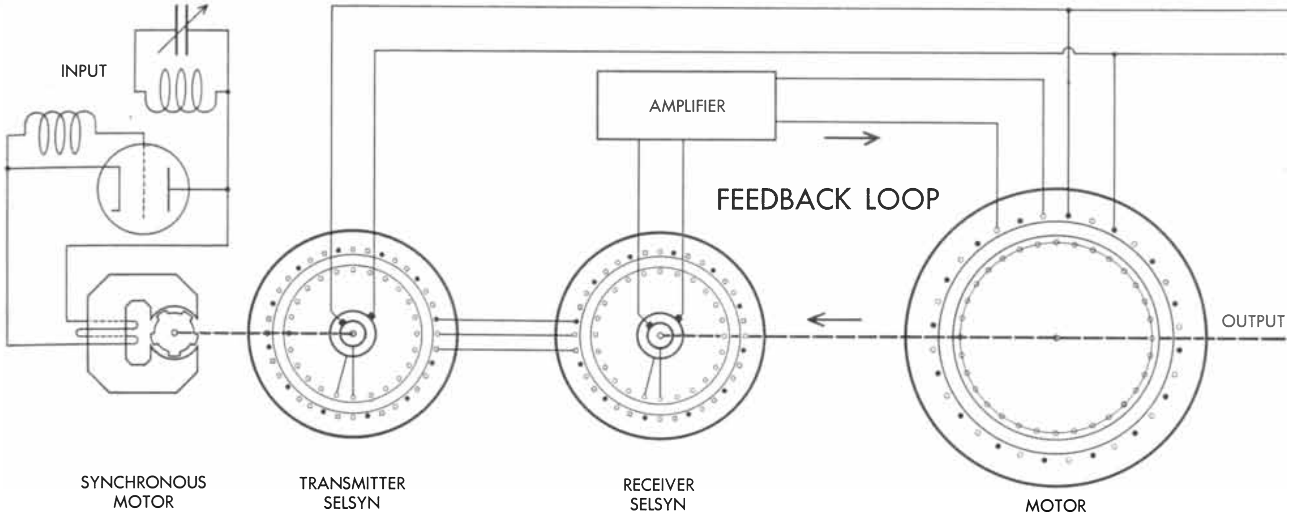

ALTERNATING-CURRENT SERVO-MECHANISM is used in systems requiring high sensitivity. Here two selsyn motors compare the speeds of the input and output motor shafts (*dotted lines*). Deviation in speed sets up a corresponding current in the selsyn linkage to bring the output motor back to desired speed.

fact, with Watt's flyball-governor. This device betrays an inherent weakness of all feedback systems: a tendency to oscillate, or hunt, as Arnold Tustin explains in the preceding article. It was the mathematician who began to build the theory to bridge this difficulty. He showed how both oscillation and the damping of oscillation could be expressed in differential equations. By 1900 the theorems of Laplace and Fourier, the studies of Routh in analytical dynamics, the work of Kirchhoff in circuit analysis, the physical studies of Lord Kelvin and Heaviside and others had laid the foundations for a theory of control. But not until the 1920s did the exploitation of theory by practice really get under way.

During World War II great numbers of men were brought together from different fields to pool their abilities for the design of weapons and instruments. As a result, the specialists of engineering and science found themselves talking to one another for the first time in generations. Mechanical engineers exploited techniques of circuit theory borrowed from the communications engineers; aeronautical engineers extended the use of electrical concepts of measurement and of mathematical presentation; mathematicians working with engineers and experimental scientists discovered entirely unsuspected practical uses for forgotten theorems. The enforced collaboration soon focused attention on the essential principles that apply to all control systems. The general theory of control systems which now emerged was enriched in turn with the lore of experience from many different technologies. With the theoretical means at hand to write the equations for motors, amplifiers and hydraulic transmissions, it became possible to design control-system components with entirely new properties to meet predetermined needs. Moreover, these new parts could be used in many different types of control systems, and they could be manufactured in quantity.

IT IS ONE thing to design a system, and quite another to make it operate true to the theory. Its performance has to be tested and tuned. There were few precedents to guide the development of adequate testing methods. Earlier control systems had accepted some looseness in performance; their users were satisfied if equipment could be described as "fast" or "instantaneous," without more precise definition. In a radar feedback system, however, designers had to find ways to measure the dynamic, instant-by-instant behavior of each element to be sure that control signals would travel undistorted around the circuit. To accomplish this they developed various methods, borrowing ideas from half a dozen fields, particularly electrical and communications engineering.

The simplest way to test the behavior of the components in a circuit is to apply a sudden increase or decrease of voltage to the system. The shock produces different reactions in the various elements of the circuit, and measurement of the transient variations in voltage in the individual components provides important information about the performance of those parts and about the layout of the circuit as a whole. This so-called "step-function" test proved a valuable method of testing feedback circuits. Moreover, an analogous method can be used to test non-electrical systems. A disturbing force or a hammer blow applied to the proper point sets up transient vibrations, corresponding to the voltage variations in a circuit. Plotting of these vibrations and of the time required for their decay can help the mechanical engineer to determine the mechanism's natural modes of vibration and the damping forces inherent in the system.

Another test for feedback circuits was based on one used in communications work. A radio or telephone message, transmitting music or a voice, is made up of a certain range of frequencies. In testing an amplifier, it is important to measure its performance in amplifying each of those frequencies. Communications engineers do so by applying a modified, distinguishable signal at each frequency and observing how the amplifier handles that frequency. Thus they can find out what will happen to a complex message in terms of what happens to the individual frequency components of the message. In the same way it is possible to test the behavior of equipment in a feedback circuit at various frequencies, and thereby to map the behavior pattern of the whole system. The frequency-response test opened the way to precise study of the dynamic behavior of such mechanisms as hydraulic transmissions and motor-generator sets. It defined the ability of these machines to transmit messages over wide ranges of operation—fast or slow, at low-power and high-power levels. Is it strange that high-power units such as hydraulic drives should be appraised in terms of their message-transmitting ability? Not at all, for in all feedback control systems the performance depends uniquely upon how the signals are acted upon by each and every mechanism operating in the closed path—individually and in unison. The practical bearing of this fact was illustrated vividly during the war: there were times when it was found that the entire performance of a $50,000 antiaircraft gun-director was ruined by the

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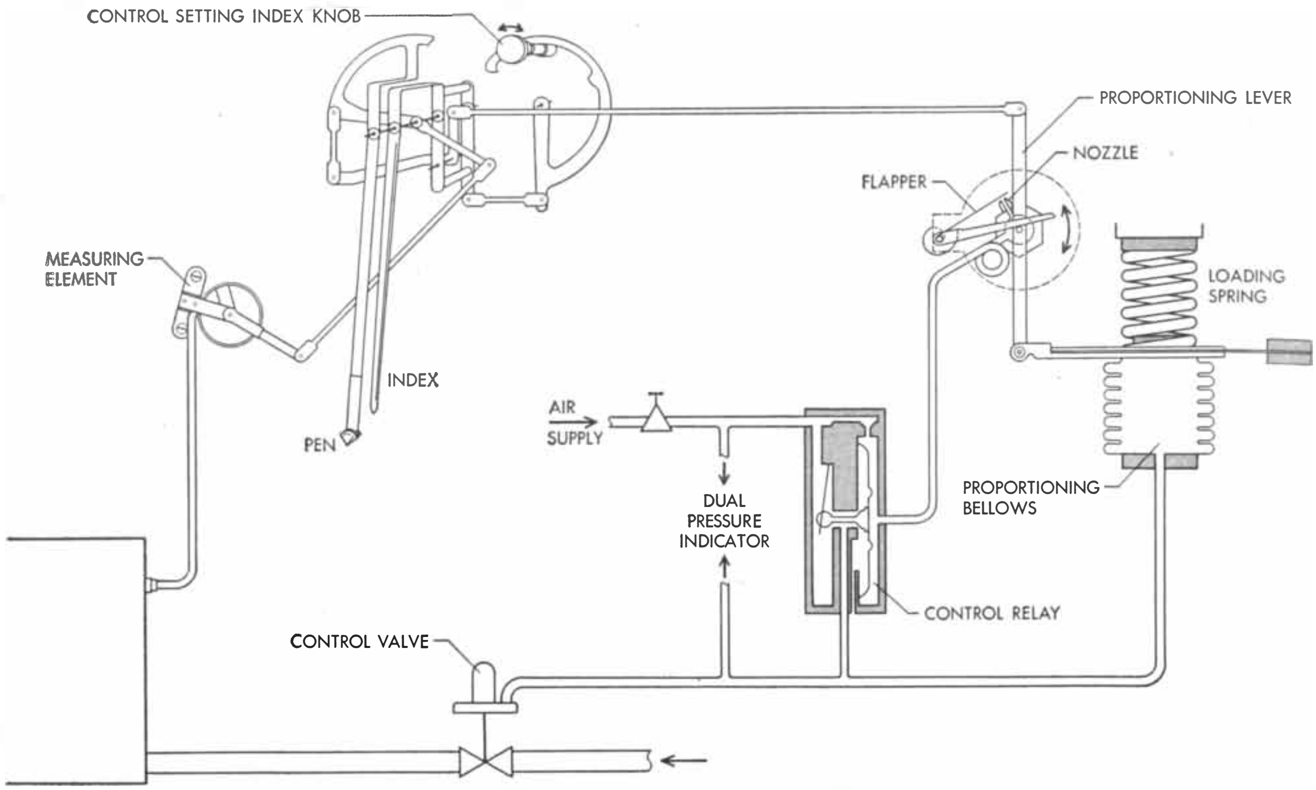
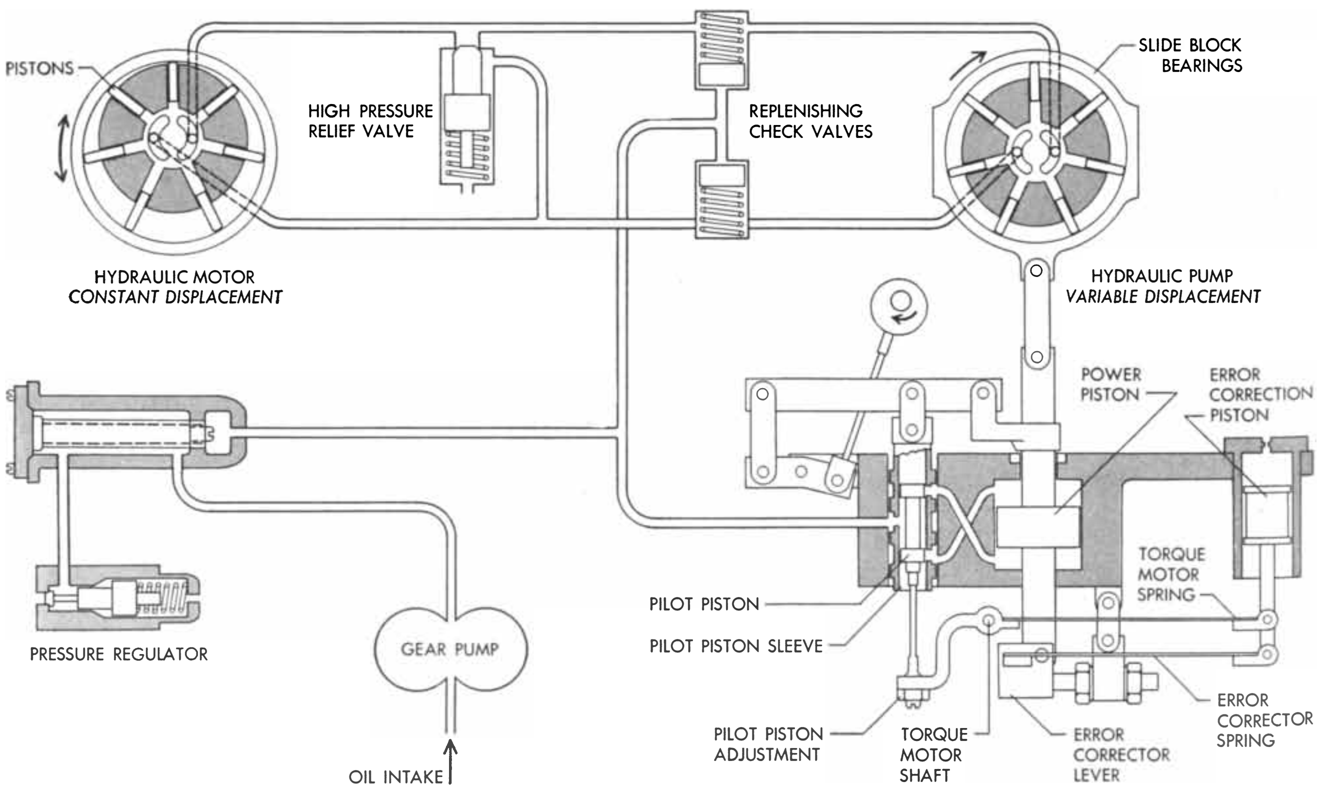


PNEUMATIC SERVO-MECHANISM is often found in chemical plants, where the use of electrical equipment has been prohibited to prevent fires. In this diagram the measuring element (*left*) moves the flapper (*right*) by way of a recording instrument. When the flapper is lifted, air escapes from one side of a diaphragm in the control relay and admits air from the air supply to the other side. This air actuates the control valve.



HYDRAULIC SERVO-MECHANISM is used for mechanical drives such as that of an anti-aircraft gun. In this diagram a pilot piston (*lower right*) moves a power piston (*to right of pilot piston*) by admitting fluid to one side of it or to the other. The power piston then moves the slide block of a constant-speed hydraulic pump (*upper right*) in such a way as to vary the flow of fluid to a variable-speed hydraulic motor (*upper left*).

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faulty behavior of just one $50 torque motor in the system.

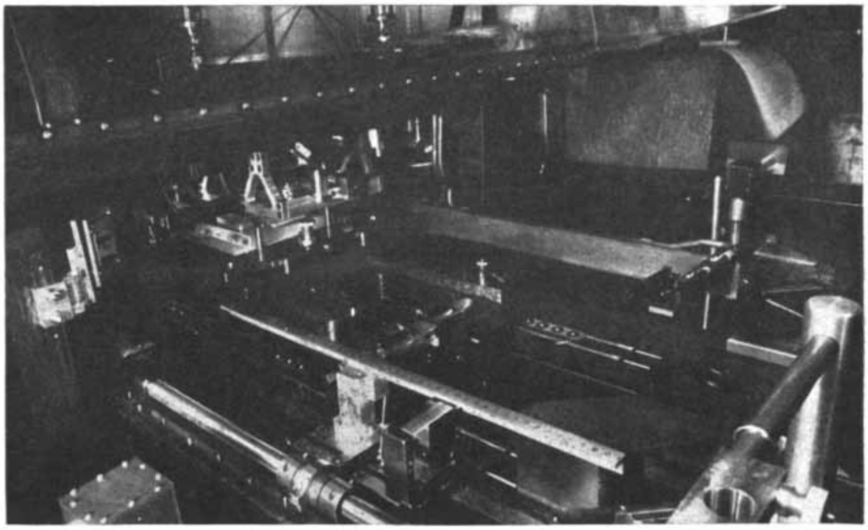
WORLD WAR II was fought with servo-controlled turrets, servo-steered torpedoes, radar eyes and closed-loop missiles like the V-1, carrying a black box of automatic guidance. After the war the momentum of automatic control did not slacken but speeded up. The fever is still rising. We seem to be rushing forward both in practice and in the state of the art. Men excitedly speak of the robot factory, of the remotely controlled spaceship, of giant submarines that will respond to the touch of a little finger, of incredible new industrial processes. New industries are springing up every month to build heretofore unheard-of mechanisms. Older industries have shifted over to new lines of equipment. Researchers are probing new frontiers. Their work is not focused solely on iron mechanisms. We have taken a sudden new interest in the feedback mechanisms of the human system—chemical, physiological and psychological. Already we have the artificial feedback kidney and the mechanical heart.

It is not hard to view the race toward automatization with alarm. Can we realize all the dreams with a reasonable chance of avoiding economic chaos and without reducing the human nervous system to a state of uncontrolled oscillation?

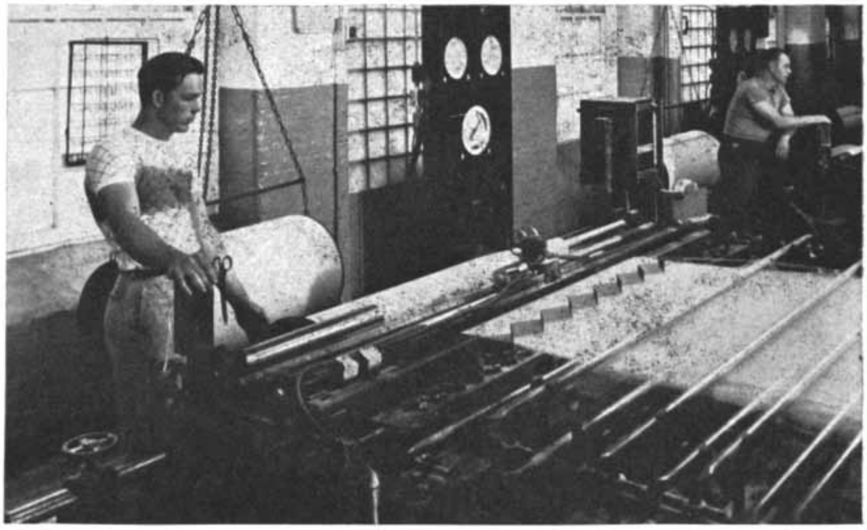
The problems of system engineers grow steadily more difficult. They have encountered physical systems which do not respond to conventional mathematical treatment: for example, short-lived happenings in the atomic nucleus, new chemical processes, new types of machines such as the jet engine. Processes which formerly appeared to be linear are now recognized to be complicated non-linear ones. Thus the search goes deeper into advanced physics and mathematics. The system engineer must study non-linear systems, matters related to probability theory and statistics, and the new mathematics that is associated with sampling, the handling of discontinuous data and number theory.

LET us take the main parts of the system in order. The problem of measurement is always first and foremost. A few years ago we wanted temperature and pressure measurements to accuracies of one part per hundred; now it is one part per thousand or per ten thousand. A thermocouple which responded in one second was fast; now we wish to measure temperatures fluctuating at several thousand cycles per second! And we shall need to measure entirely new things.

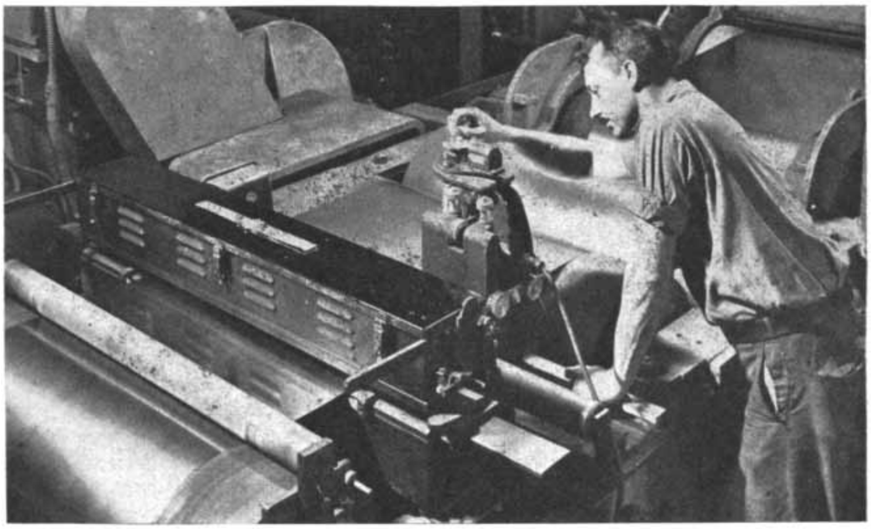
Up to now we have usually measured the variables in the production process,



INTERFEROMETER in M.I.T. ruling engine measures the position of the diffraction-grating blank and controls the turning of the lead screw.



MOISTURE METER (*center*) senses moisture in textile yarn by electrical conductivity and controls the speed of drying drum by feedback.



PHOTOCELL looks for pinholes in fast-moving strip of tin plate and instructs the shear table ahead to chop out and reject a defective segment.

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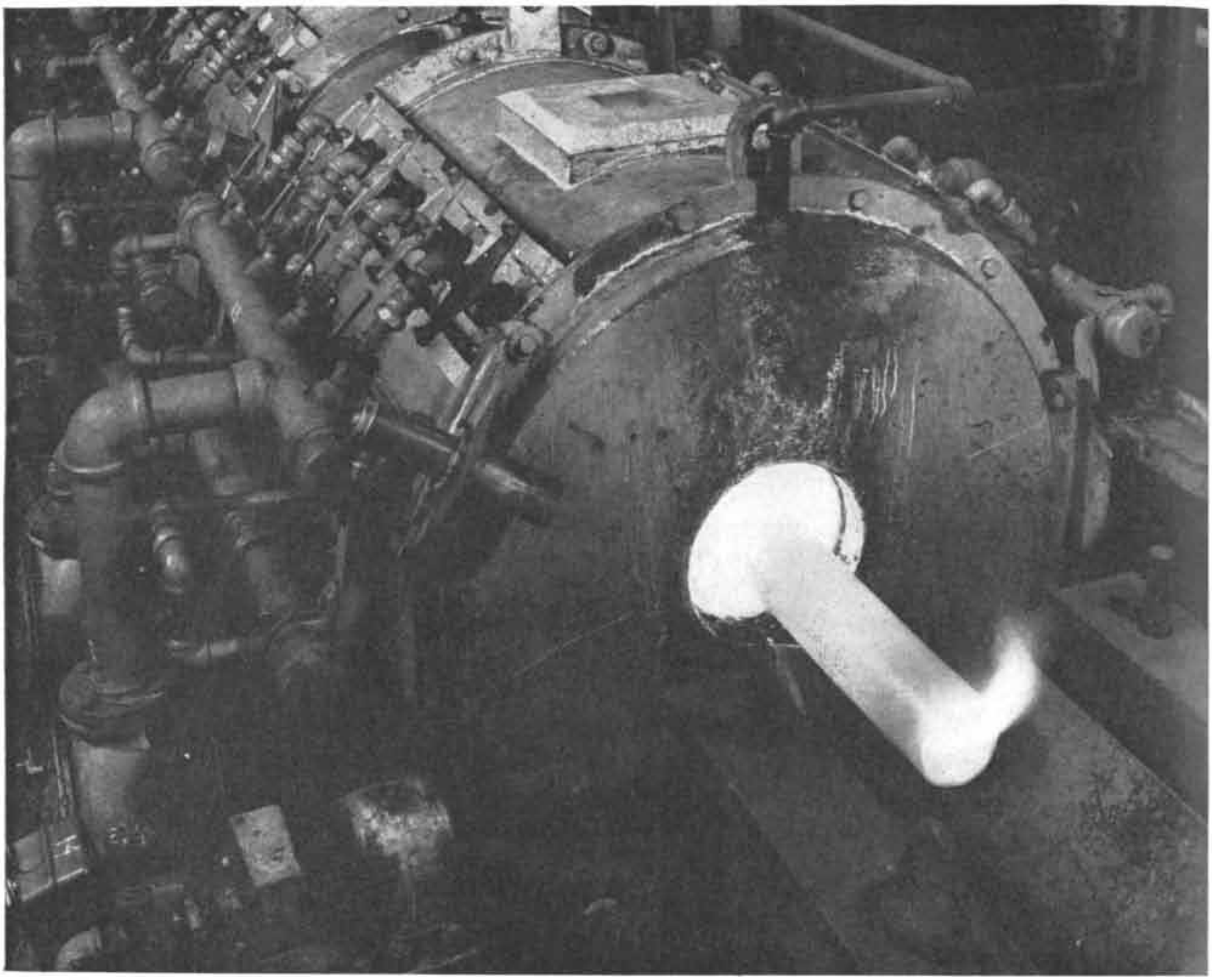

TUBE REHEATING FURNACES in the Gary plant of the United States Steel Corporation's National Tube Division are controlled by radiation pyrometers, one of which is mounted on the left side of the front furnace.

such as flow, temperature and pressure, rather than the character of the product itself. The trend in the future will be toward more emphasis on primary measurements. Instead of measuring the molecular weight of a substance by its viscosity, we are beginning to measure the molecular weight directly, with instruments such as the mass spectrograph (*see diagrams on pages 88 and 90*). But as we seek finer and finer resolution in our measurements, we shall have to cope with the interference of noise. Moreover, how shall we measure product quality? The sales department may have different ideas from the engineers. It may be difficult to correlate a customer's satisfaction and pleasure in a chemical product with the molecular weight, the shape of the molecule and possibly the odor. Finally, there is the tough technical problem of measuring quantities in a way that will enable a human or automatic controller to make decisions, *e.g.*, as to which valve to turn.

Basically control is no better than the intelligence we give it, and this applies to human as well as to automatic control. But the engineers are not being caught napping. They have on their drafting boards designs for yet more discerning primary detectors, faster-responding instruments, plants capable of swifter and steadier production. And these engineers are conscious that quality of product is the ultimate objective, even though we may lack as yet the instruments with which to measure it fully.

At the next link in the control loop, the controller itself, equally fundamental changes are on the way. The typical industrial controller today is a simple analogue computer. It can deal only with one variable. The analogue device compares the measuring instrument's report on this variable with a set point fixed by the human operator, and generates a correcting signal proportional to the error. In the future, as Louis Ridenour explains in this issue, the versatile digital computer will take over master control, perhaps supervising analogue devices assigned to specific jobs. The digital computer can handle many variables and provide continual solutions of complex groups of equations.

The controllers will have the problem of processing and translating the messages from the measuring instruments. For example, a message from an analogue device, say a voltage, must be translated into pulses to be handled by a digital computer, and the pulses in turn must be converted to another form of energy to jog a valve. Again, before the error signal can reach an appropriate valve or switch, the message may have to be sent long distances over pipelines, wires, radio links or even television channels. Single messages and multiple messages must be transmitted. And often they must be coded, among other reasons in order to avoid fouling one another. Certainly it would be unfortunate if two guided missiles tuned in on each other's data systems and fell to gyrating around instead of closing in for a hit.

Redesign is also in store for the actuator elements, the muscles of the feedback loop. Many present control

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BLOOMING MILL in the Lorain Works of the National Tube Division is operated by a direct-current servo-mechanism. Here two men in the "pulpit" reduce an ingot to the size required for the manufacture of pipe.

systems use pneumatic energy, especially where the fire hazard from electric sparking is great. An air-pressure signal comes from the controller to a big diaphragm, which huffs and puffs to move the valve-stem. In control systems of the future the valve-actuators will need more zip. New motors of all types, tiny in size, but with greater power, are required. Already there are miniature flow-valves, no thicker than a lead pencil, which can control hydraulic motors of one to five horsepower. By proper study of the heat-dissipation problem and by addition of cooling, such systems may become small enough to be carried in a coat pocket. At the other extreme, we shall need actuators of perhaps as much as 200,000 horsepower.

FEEDBACK control-system engineering is a rapidly growing profession. The proper use and training of this new kind of talent demand a new type of thinking, both on the part of engineering management and of engineering schools. Every level of our industrial force, from the financial managers down to the maintenance workers, must be prepared to become acquainted with the benefits, operation and limitations of automatic control. Compromises must be made between costs and performance. Old methods of process design may be forced to yield to new ones, taking into account the limits of instruments rather than the cost and strength of steel tanks.

Control-system engineers will need a broad engineering education, an understanding of both the theory and practice of automatic control and an environment in which people are not afraid to experiment.

The training of such men offers educators a real challenge. Engineering schools will have to organize a new kind of program for them. The schools are usually organized in departments, such as mechanical and electrical, and within these divisions specialties like thermodynamics, electronics and circuit theory may be isolated areas of activity. A systems engineer cannot be trained by simply adding together the old specialties. What is wanted is not a jack-of-all-trades but a master of a new trade, and this will require a new synthesis of studies. It will call for advanced work in the fields of mathematics, physics, chemistry, measurements, communications and electronics, servo-mechanisms, energy conversion, thermodynamics and computational techniques. The control engineer will need to know the mathematics of differential equations, functions of a complex variable, statistics and non-linear techniques, and to have a thorough grounding in modern physics and chemistry. He will also need to be familiar with computational aids, such as differential analyzers and computers.

Industrial management also must raise its thinking to the system level. Its technical staff, headed by a qualified system engineer, will have to work as a team; the chief electrical engineer cannot have exclusive control over all matters electrical, nor the mechanical engineer over all things mechanical.

Many schools are now offering short concentrated programs on feedback

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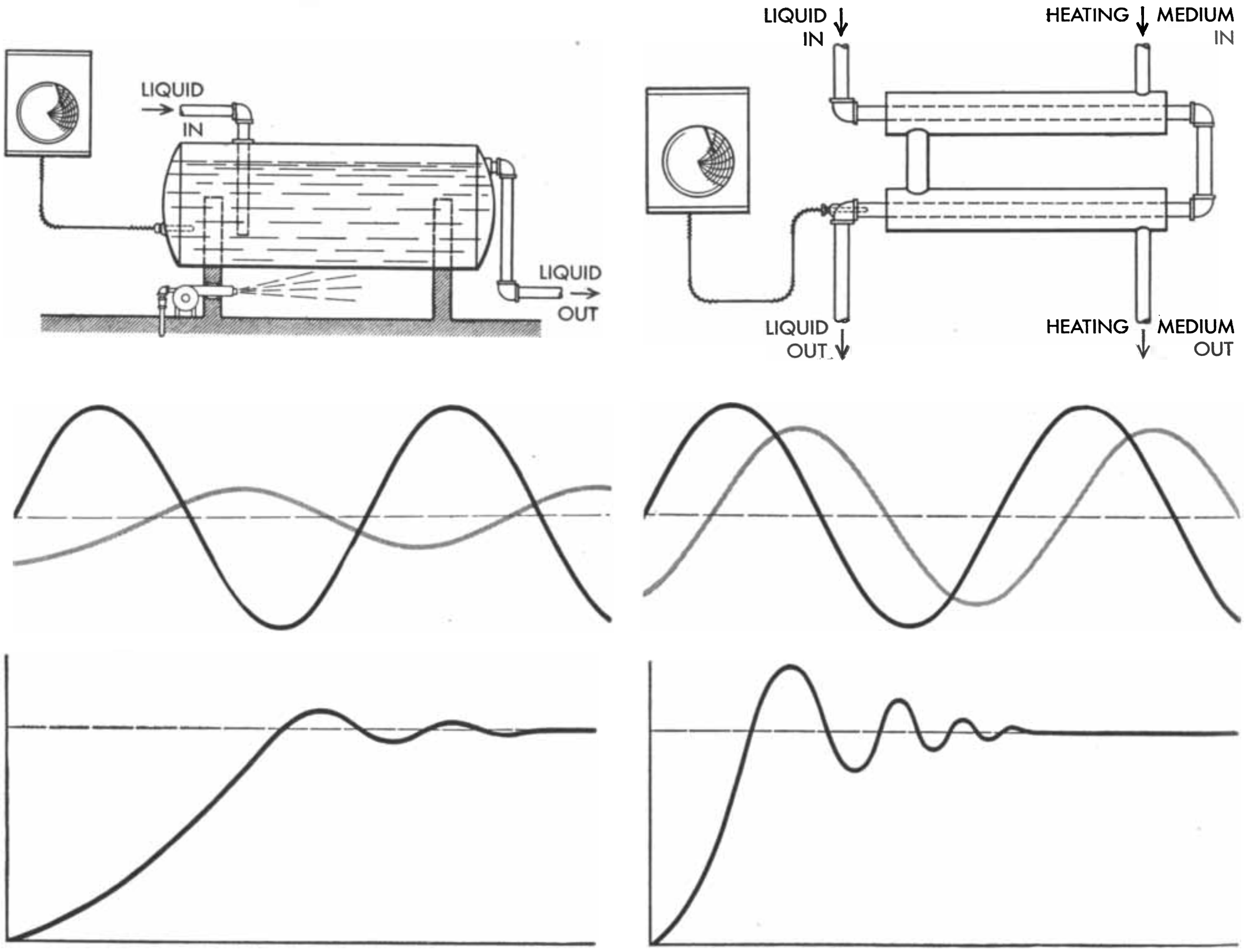
controls, computers, advanced mathematics, information theory and statistical communication theory for engineers in industry and research centers.

Most businessmen, understandably, have forgotten their calculus and advanced mathematics. They may nevertheless want to know what the system engineer means when he speaks of "process lags" and "time constants"—what he says may have a great deal to do with production, sales and profits. These expressions refer to the ratio between the volume of material held in a processing plant at any instant and the rate of production. The "hold-up" of material may have great significance, even in terms of minutes or hours. Too much hold-up means unnecessary capital outlay for the processing equipment. At the other extreme, a small amount of hold-up with a tremendous through-put may mean that too much is being spent on the control system. We cannot build the plant first and hang the controls on later and expect the best results. What we need is the best compromise between all plant and no control, and all control and no plant.

WHAT ABOUT the men who will operate and maintain these plants? *Even in the most robotized of the automatic factories there will be many men, and they will have interesting and responsible jobs.* They will be freed from the tiring, nerve-racking or even boring jobs of today's mass manufacturing. To win this freedom, however, they will have to upgrade themselves in skill and sophistication. The new controllers and instruments will call for a higher level of precision of repair and maintenance. A $50,000 controller cannot be hit with a hammer if the shaft doesn't fit into the hole on the first try. Men who have heretofore thought of electronics equipment as merely a metal chassis with tubes will become conversant with switching, flip-flop, peaking and other circuits. They will have to judge when to repair and when to throw away rather than stop production. We have here a paradox: today we cannot afford *not* to have lots of control, because a half-day shutdown of a plant may mean a $100,000 loss in potential sales.

These robots are not hurting the workman—they merely coax him none too gently into taking more responsible jobs, making bigger decisions, studying and using his mind as well as his hands.

Gordon S. Brown is professor of electrical engineering at the Massachusetts Institute of Technology. Donald P. Campbell is associate professor of electrical engineering at the same institution.



FREQUENCY RESPONSE of two boilers with high (*left*) and low (*right*) heat-holding capacity is here contrasted. When the heat input to the two systems is varied regularly at the same frequency (*black curves in the center charts*), the temperature in each boiler (*gray curves in the center charts*) responds differently. The temperature in the high-capacity boiler varies with smaller amplitude and lags further behind the input frequency than that of the low-capacity system. A similar contrast between the two systems is developed by an abrupt increase in the heat input, as from the base line to the dotted line in the lower diagrams. In the high-capacity boiler, the temperature ascends slowly and oscillates gently above and below the set point before it levels off. The temperature curve in the low-capacity boiler shows a steeper increase, oscillates at higher frequency and damps out sooner. Response tests are made to determine performance of control systems.

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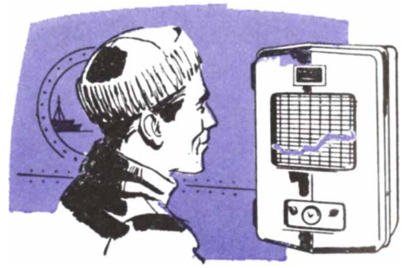

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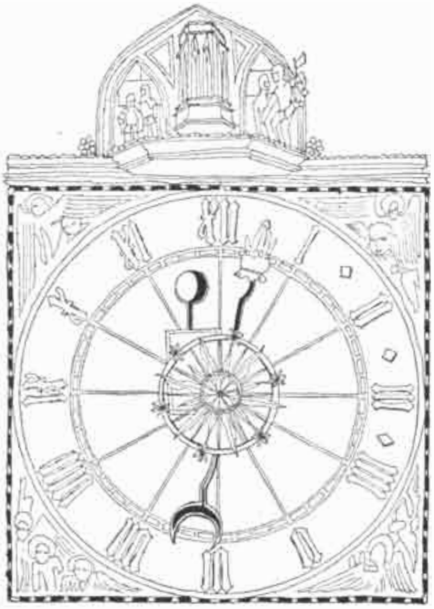

Frankenstein, Q.E.D.

IS it possible to build a "real" brain—a machine that will produce cleverness of its own and not just give back the ingenuity put into it? The answer, says a British scientist, is yes. W. Ross Ashby, writing in *The British Journal for the Philosophy of Science,* presents a theoretical analysis of the problem and offers some general principles for building a chess-playing machine that would outplay its designer.

Ashby points out that evolution is an example of a "machine" which puts out more design than goes into it. "Take a planet with some carbon and oxygen; irradiate it with sunshine and cosmic rays; leave it alone for a few hundred million years"—and it produces a complex design such as a bird. It does so by the comparatively simple process of natural selection, operating according to the rules of the machine's construction upon random data (mutations).

Ashby proposes a chess-playing machine built on the same "Darwinian" plan. It will be provided by its designer with a certain scheme of selection. Then it will be fed a large amount of "unorganized" or "chaotic" data, such as thermal noise or the output of a Geiger counter under random bombardment by cosmic rays. By applying its rules of selection it will create new and highly organized entities (*i.e.,* chess strategies) from its chaotic input in the same way as natural selection evolves new forms of life.

The British scientist is the designer of a well-known little self-regulating machine called the "homeostat." It is a simple system designed to maintain its own stability, like the human body, in the face of varying conditions. The machine consists of four interconnected computer units, each with an indicator needle. The object is to keep the needles at the equilibrium "zero" position on the dials. The behavior of the needles is governed by 16 variable components in the machine, and the values of these variables in turn are determined by numbers taken by the machine at random from a table of numbers hooked up to the mechanism. Whenever any needle deviates from the "zero" position by more than a certain amount, the machine automatically takes a new set of figures from the table for the values of the adjustable components. Thus the device tries one after another random configuration until it finds one that will give it stability. If new design conditions are imposed, say by changing the polarity of a connection or hooking two of the needles together, the machine will again start a hunt through the table for a stable combination under the new conditions.

Thus the homeostat demonstrates how a machine might use unorganized data. Ashby concedes that it does not put out nearly as much information as has been used in its design. He believes, however, that it points the way toward a true thinking machine, and, apparently undaunted by the fate of Mary Shelley's Frankenstein, he proposes eventually to build one.

Feedback and Life

IN evolution the feedback loop operates so crudely and slowly that it is hard to see in operation. But at the Cold Spring Harbor Biological Laboratory, Vernon Bryson has succeeded in setting up a quick-acting closed loop in which organisms control the environment as well as *vice versa.*

Bryson is studying the ability of bacteria to develop new strains resistant to antibiotics or other germicides. In an apparatus called the "turbidostatic selector," he reports in *Science,* bacteria are grown in a colorless nutrient broth. As the colony multiplies, the culture becomes more and more cloudy. A light-beam and photocell arrangement measures its turbidity, and whenever the cloudiness reaches a certain value, it trips a relay and lets more broth flow into the test tube.

The added broth contains a little antibiotic or other poison. In each succeeding cycle the process automatically brings in a higher concentration of the poison. Thus the bacteria are exposed to a more and more rigorous environment. Eventually it becomes too poisonous for any of the original strain of bacteria to survive. But meanwhile new mutant strains that thrive on the poison have developed. As they grow, they auto-

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matically change the environment so that it contains more and more of the originally harmful substance. This in turn brings further changes in the bacterial colony. Thus the system automatically controls its own evolution.

Mach 2

At a recent show for aviation writers a military officer inadvertently disclosed the frontier of speed at which airplanes are now operating. The Douglas Skyrocket, he said, has flown in level flight at more than 1,300 miles per hour. This is nearly twice the speed of sound, or, in the parlance of aeronautical engineers, Mach 2. The plane also went to the unprecedented altitude of 79,494 feet—15 miles.

To avoid cooking its pilot the Skyrocket must carry about 500 pounds of refrigerating equipment—enough to air-condition a large theatre. At its top speed the friction between the skin of the plane and the atmosphere generates a temperature of more than 200 degrees. This is hot enough to weaken aluminum alloys by 10 per cent. At Mach 3 the temperature would be over 500 degrees, and the loss in strength of aluminum about 90 per cent. Thus before aircraft can push much farther into supersonic regions, better materials and more efficient cooling systems will have to be developed.

Fastest Electrons

A NEW synchrotron at the California Institute of Technology has accelerated electrons to an energy of 460 million electron volts, it was announced last month. Racing around their circular track at almost the speed of light (one-tenth of a mile per second slower), the electrons weighed more than 900 times as much as when at rest.

Like the recently completed cosmotron at Brookhaven, Caltech's synchrotron speeds up its particles by boosting them periodically with a radio frequency oscillator as they circle the evacuated core of a huge circular magnet. The machine is expected soon to be operating at 500 million electron volts, and in about a year its output will be increased to a billion electron volts. Its purpose is to produce extremely energetic X-rays for research work.

Resources

In 25 years the U. S. will need nearly twice as much minerals as it uses now, two and a half times as much wa-

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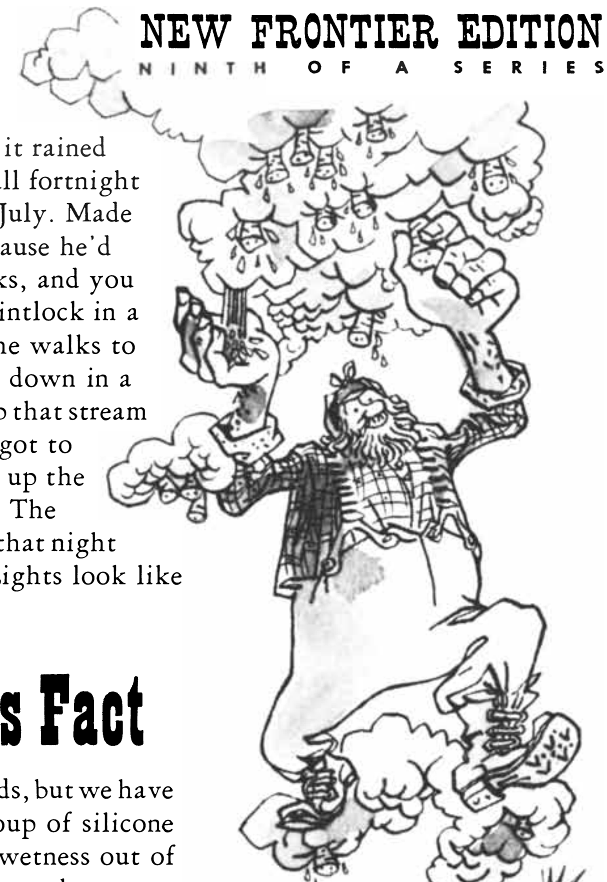
Tall Tale



They tell of the time it rained cats and dogs for a full fortnight before the Fourth of July. Made Paul Bunyan boil because he'd just invented fireworks, and you couldn't even fire a flintlock in a deluge like that. So he walks to where the rain comes down in a solid stream. Swam up that stream like a salmon 'til he got to the top, and plugged up the holes in the clouds. The fireworks Paul set off that night made the Northern Lights look like a firefly's ghost.

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This and many other fabulous facts are described in our new publication, "What's A Silicone?" We'll be glad to send you a copy. Simply address your request to Dow Corning Corporation, Department W-21, Midland, Mich.

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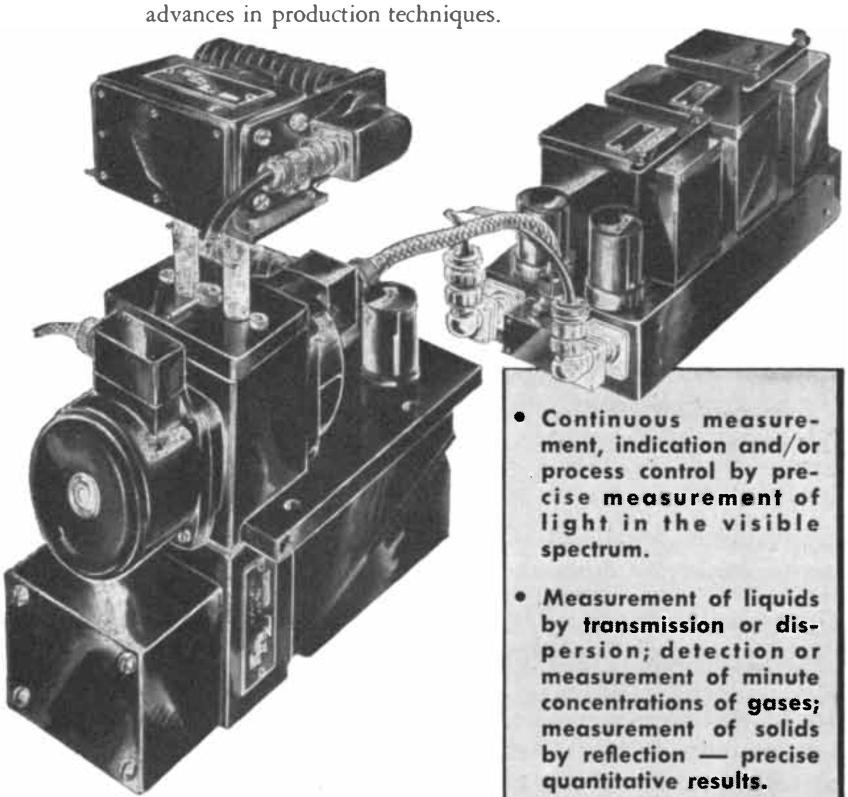

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ter and twice as much energy. This is the gist of a comprehensive report by the President's Materials Policy Commission, headed by William S. Paley. The five-volume report, entitled *Resources for Freedom*, has been analyzed in recent issues of *Chemical and Engineering News*.

"Consumption of almost all materials is expanding at compound rates and is thus pressing harder against resources which, whatever else they may be doing, are not similarly expanding," says the report. The Commission adds that the U. S. must resign itself to importing an increasing share of its raw materials. Their cost, it points out, is bound to rise. In the case of some materials the shortage is already worldwide. The U. S. military services have laid out a jet-plane program, for example, which calls for more cobalt than is available in the world.

The Commission urges research on mineral-finding techniques, on exploitation of the oceans as a source of minerals and water, on corrosion of metals, on recycling of materials in process industries, and on uses of new materials such as titanium and zirconium.

AEC Report

DURING the next few months three per cent of the entire construction labor force in the U. S. will be working on atomic energy installations. In its 12th semiannual report, released last month, the AEC gave some details of its enormous expansion program.

Its appropriation for the fiscal year 1953 has been raised to more than $4 billion—nearly four times the original budget for the year. A considerable portion of the additional funds will be for new production facilities for fissionable materials. Some $2 billion will be spent for additions to the gaseous diffusion plants at Oak Ridge, Tenn., and Paducah, Ky., and a third gaseous diffusion installation will be started, probably in the Ohio River Valley. Plutonium production will be expanded through additional reactors to be built at Hanford and at the Savannah River project now under construction. Shortly after it issued its semiannual report the Commission announced a contract for a new power reactor. The Westinghouse Electric Corporation will build one "suitable for propulsion of large naval vessels, such as aircraft carriers."

Reporting on research developments, the Commission disclosed that the fission of a plutonium atom releases three neutrons (uranium 235 yields 2.5), and that the radioactive fission product xenon 135 is a "remarkably effective absorber of thermal neutrons," which may make it useful in reactor control.

Four workers at the Argonne National Laboratory who were exposed to dangerous levels of radiation during a

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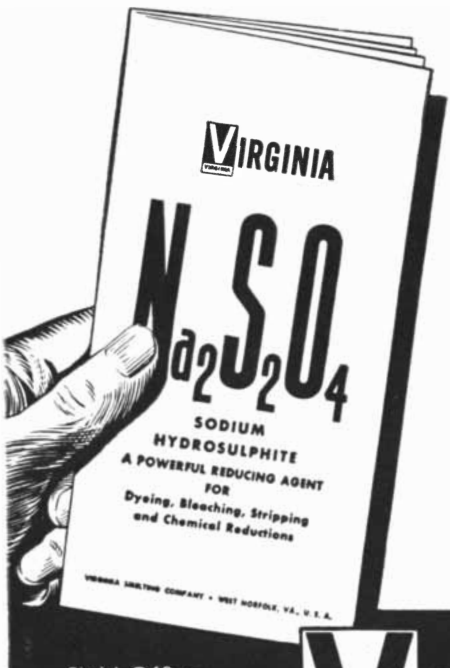
"Virginia" VANOL successfully copes with the organic colloidal substances which contaminate the sugar solution. These colloids are very hard to handle—to filter, coagulate and remove. They congeal and form sticky, resinous massecuite on repeated boilings.



The proper use of VANOL ("Virginia" $Na_2S_2O_4$) makes the massecuite more filterable; the molasses separates more easily from the sugar crystals. Thus the molasses may be more completely discharged—more sugar extracted from a given amount of cane.

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chain-reaction experiment last June have suffered no ill effects from their brief exposure, the Commission said. All have returned to work.

Pauling and Passport

AFTER having rejected his application three times, the State Department has issued a "limited passport" to Linus Pauling, Chairman of the Department of Chemistry and Chemical Engineering at the California Institute of Technology. The passport expires October 1 and is good for travel only to France and the United Kingdom. The Department stated that its action was taken after considering "new evidence" and "re-evaluating" the whole case, and after Pauling had filed a statement that he is not now and never has been a member of the Communist Party.

Isolationism

MORE and more U. S. scientists are losing touch with research done outside this country's borders, according to a joint committee of the National Research Council and the U. S. National Commission for UNESCO. "Studies of literature citations in scientific publications in the U. S. show an increased trend to mention only U. S. research reports," the committee declares. "Ignorance of foreign literature leads to wasteful duplication of work, slowing up the progress of science, and failure to utilize discoveries for useful practical purposes." The committee suggests that UNESCO develop more efficient abstracting and indexing services for international scientific literature and call the trend toward scientific isolationism to the attention of college and university teachers.

The Chloromycetin Problem

A CLOUD of suspicion has fallen on chloromycetin, one of the most widely used antibiotics. Reports on 11 patients who developed fatal anemias after treatment with the drug appeared last month in *The Journal of the American Medical Association*. The U. S. Food and Drug Administration is now conducting a nationwide survey to assess the effects of chloromycetin on the blood.

Several million people have been successfully treated with chloromycetin, the Food and Drug Administration points out, and it has probably saved thousands of lives. Until recently there had been virtually no evidence of harmful effects. Although it contains nitrobenzene, a substance known to be toxic to the blood, extensive toxicity tests had indicated it was safe. One death attributable to the drug was reported in 1950, however, and 12 this year. In all the cases the patients had taken the

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Photography makes it easy to see why it is hard

The pattern in this photomicrograph of etched molybdenum carbide (× 1000), having a microhardness of 1740 to 2122 Vickers pyramid number, is the result of crystal orientation. The hardness varies with orientation and the photograph provides a permanent, indisputable record of the structure.

The metallurgist finds photomicrography a valuable tool in many ways. He uses it to study the results of abrasion, corrosion, and thermal treatment—to compare quality with specifications and check machining, welding, and cutting properties.

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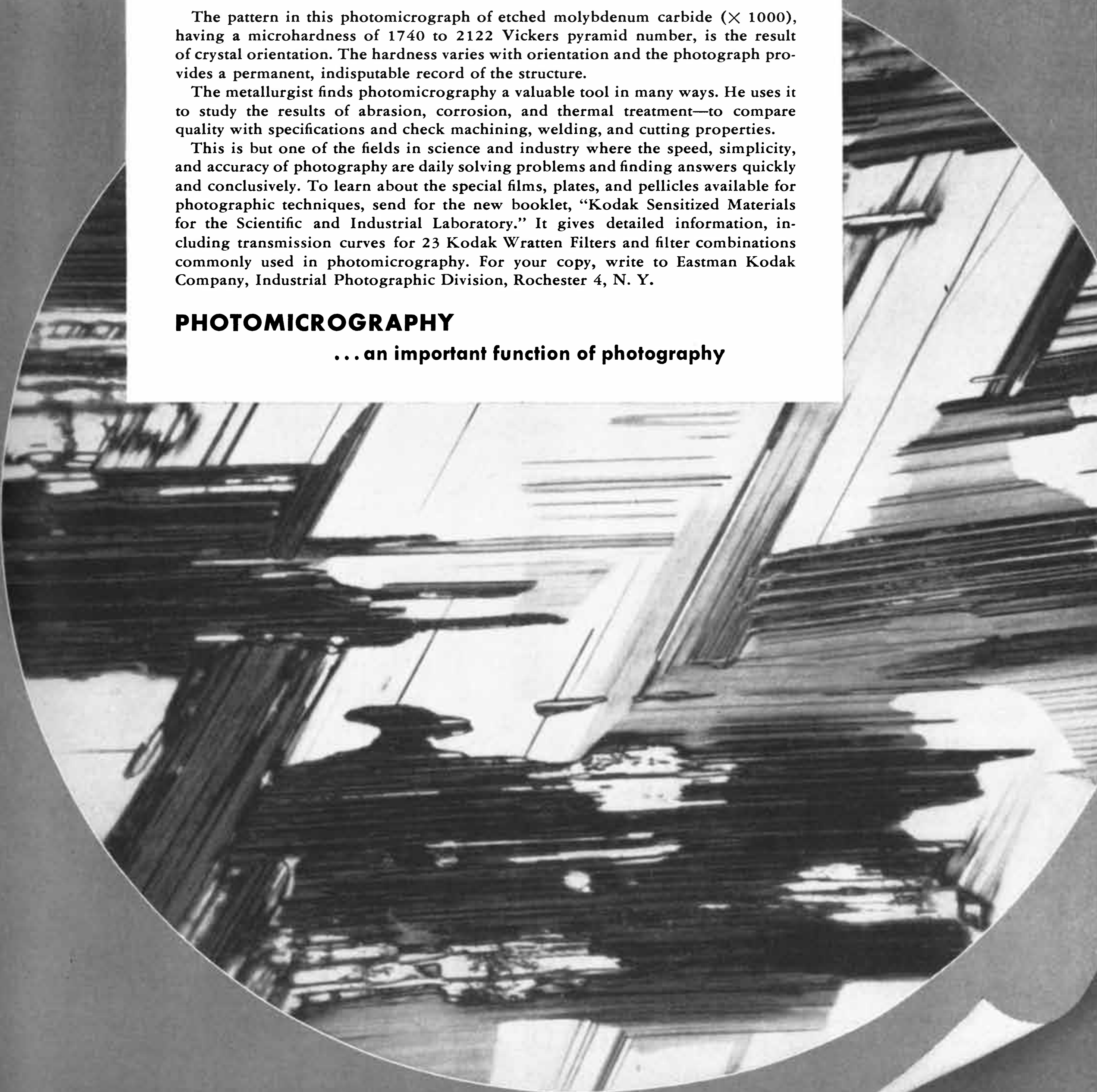

Photomicrograph made by Gordon C. Woodside, Climax Molybdenum Co. Etched in solution of 10% NaOH and 30% $K_3Fe(CN)_6$.

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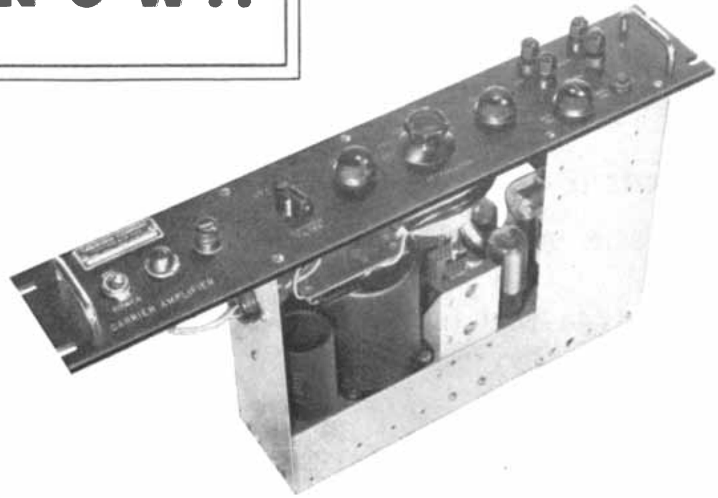

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drug for a long period. According to one of the reporting physicians, the adverse effects of chloromycetin are probably limited to a small minority of people who happen to be unusually sensitive to this chemical. The physicians agree that chloromycetin should be used less freely.

New Antibiotic

A PROMISING new broad-spectrum drug has successfully passed its early clinical tests. Isolated from a *Streptomyces* mold in a Philippine soil sample by chemists of Eli Lilly and Company, the substance has been found effective against a wide variety of bacteria, particularly the gram-positive group, and some viruses. It also has low toxicity. The substance is called erythromycin, and the Lilly drug is tradenamed Ilotycin.

Obese Mice

A NEW genetic strain of house mouse, predestined to become fat, is helping researchers learn more about some problems of metabolism and disease. At a recent conference on obesity held at the Roscoe B. Jackson Memorial Laboratory in Bar Harbor, Jean Mayer of the Harvard Medical School outlined the results of a two-year study of the corpulent mice.

They eat only a little more than their normal fellows, but grow some two and a half times heavier. Mayer believes that all animals adjust their food intake so as to keep the level of glucose in their blood nearly constant. These mice have an unusually high level of blood glucose, and it is exceptionally sensitive to lack of food, falling greatly after a period of fasting. Thus the mice seem to need more food to keep up the glucose level, and they put on weight. Glandular disturbance, often blamed for overweight, does not appear to be a factor in their hereditary obesity, for removal of the thyroid or adrenal glands has no effect on their weight.

When offered a free choice among fat, carbohydrate and protein foods, the animals pick a high-fat, low-carbohydrate diet. Their choice reminded Mayer and his co-workers of a diet prescribed for diabetics. Further investigation showed that the obese mice do develop diabetes and that their disease is resistant to insulin. Doses of the drug which would kill ordinary mice did not even reduce their blood sugar. This finding interests clinicians, because some human diabetics also are resistant to insulin.

The obesity mutation in the mice was discovered three years ago by Margaret M. Dickie of the Jackson Laboratory. Breeding of the new strain was held up by the fact that the obese individuals do not mate, and the gene is recessive.

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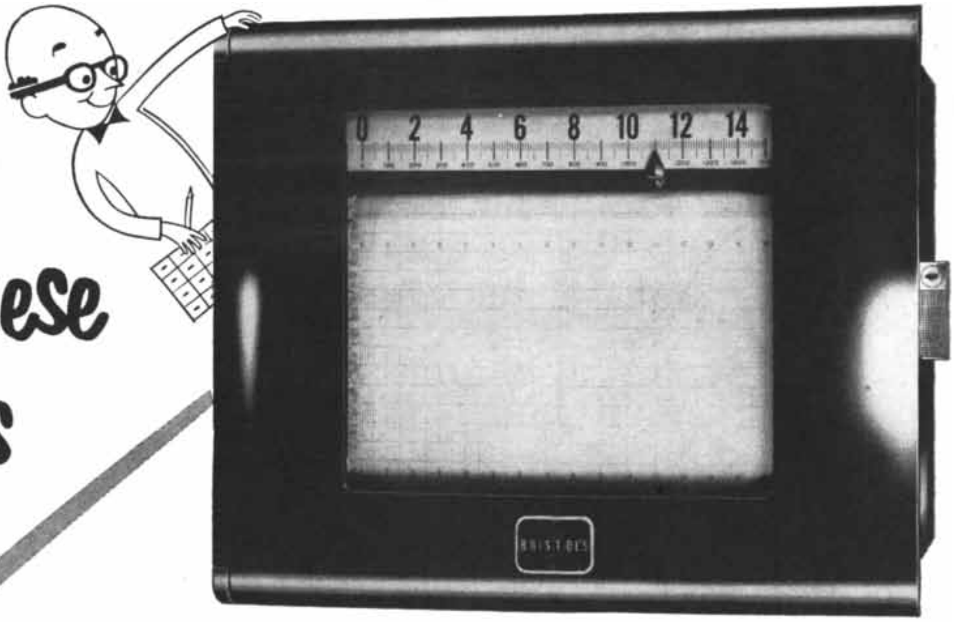

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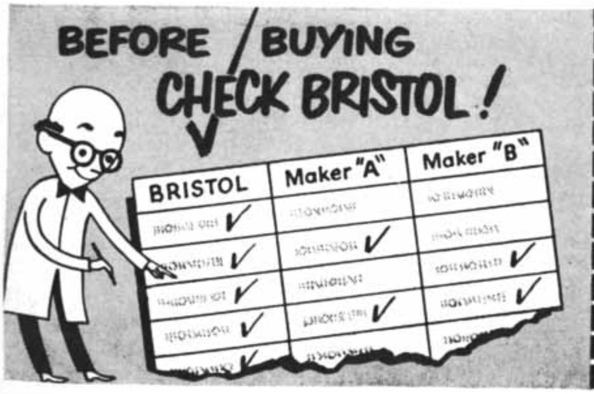

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But the laboratory is now producing 75 fat mice a month by artificial intervention: the egg of an obese female is transplanted into a normal female, and it is then fertilized by a male carrier of the obese gene. Half of the offspring are obese.

Mayer does not go so far as to assert that fat people who have an irresistible urge to reach for a bonbon are victims of a heredity like that of the high-glucose mice. But he is inclined to think that human obesity may sometimes be inherited.

Normal Children

ABNORMAL children get plenty of attention, but psychologists seldom study normal boys and girls. For 24 years a University of California research team headed by Jean Walker MacFarlane has been concentrating on normal youngsters in an effort to learn "the facts of development" and "the problems, bafflements and satisfactions" that beset children (and their parents) in the process of growing up. The psychologists have studied the children of 250 families, tracing their development from birth to adulthood.

The group has now reported some of its findings. Dr. MacFarlane said that the most rewarding part of the study has been "to see how sturdy and tough and adaptable the human organism is, and how much punishment it can absorb and utilize in the process of developing into a mature person." Growing up in a period of depression and wars, the children in general have come through as "substantial, mature and zestful adults."

Among the specific findings: Intelligence tests are an unreliable measure of children's mental capacities, particularly at preschool age. Even at the later ages, between 6 and 18, 85 per cent of the children varied in scores by more than 10 points on different tests, and one out of three fluctuated by 20 points or more. Performance on a particular test varied with the child's mood, health, desire to do well on the test and his interest at that stage of his development in intellectual achievement as opposed to other spheres, such as social or athletic activities.

Physical development is more predictable. On the average the height of a boy at 26 months is just half of what it will be when he is full-grown, and a girl reaches half her final height at 20 months. The final height of 7 out of 10 boys and girls can be predicted accurately on this basis.

At adolescence the average girl is two years more mature physically than the average boy, and the spread may be as much as seven years. Dr. MacFarlane points out that the disparity unsettles children. When junior high school girls begin, with "biological appropriateness," to turn their charms on their male

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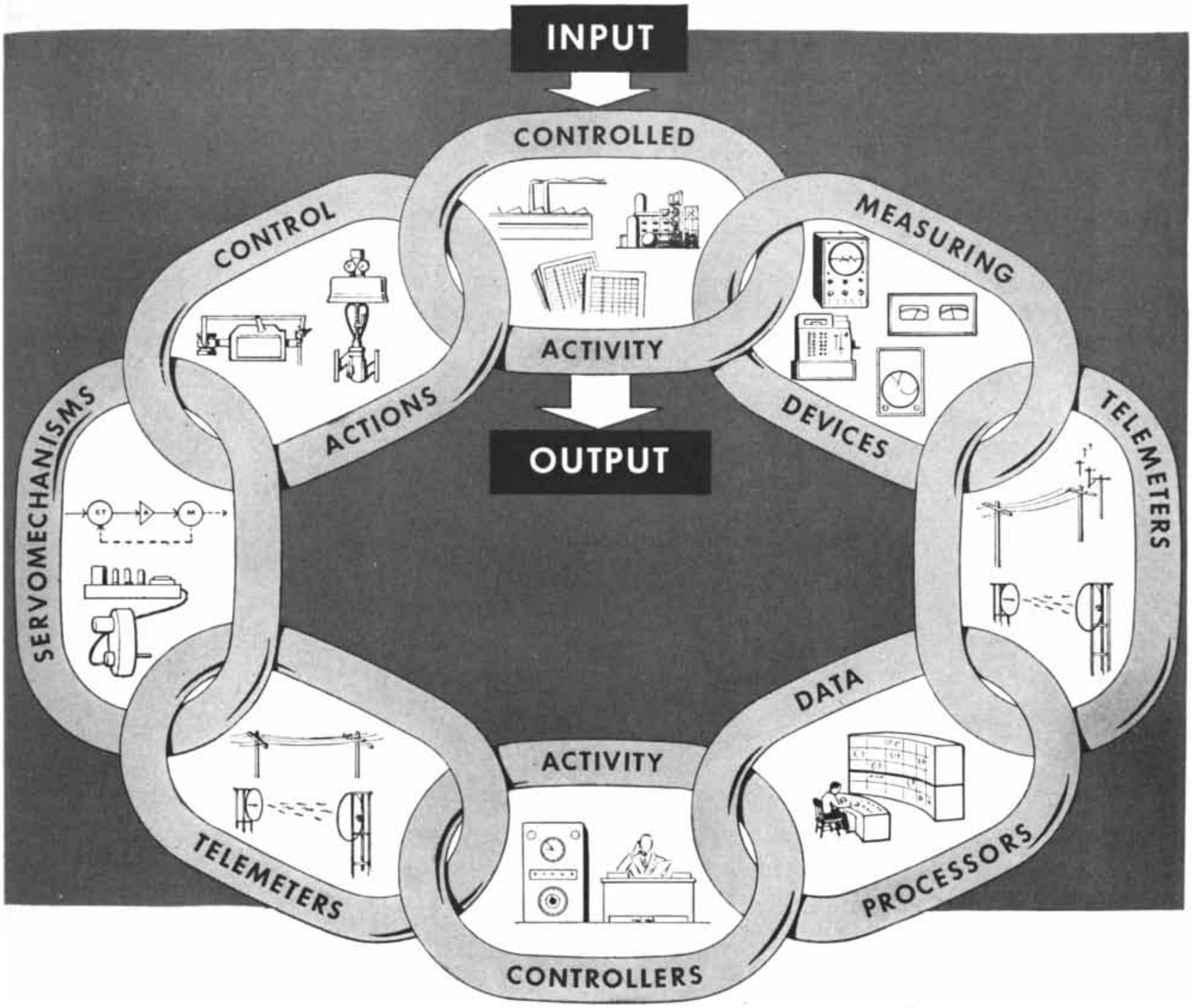

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schoolmates, the boys become uncomfortable. The boys' rebuffs in turn make the girls nervous and unsure of themselves.

Boys and girls also show differences in personality development. Girls are amenable to toilet training at an earlier age. Girls usually get over temper tantrums by the age of 7, boys not until about 13. At the age of 4 most girls learn to side-step trouble by lying; boys do not hit on this device until the age of 6.

Open, direct and expressive parents promote more stability in their children than do quiet, patient ones who are always well-behaved. A young child has trouble divining a stoical parent's moods and attitudes toward himself, and, in bafflement, may become anxious.

A Plague on the Rabbits

DURING the past two years a great rabbit plague has run like a scared rodent across the length and breadth of Australia. It has killed tens of millions of rabbits. The epidemic was man-made, and Australia thinks that it has finally found the answer to its century-long struggle with the fabulously prolific bunny.

In 1859 two dozen rabbits were imported into Australia by one Thomas Austin, who intended to breed them for game. But their reproductive powers proved mightier than the shotgun. Six years later the unhappy hunter had slaughtered 20,000 rabbits, and estimated that 10,000 were still ravaging his estate. Today the continent is overrun with their descendants, who eat enough grass to support 40 million sheep.

Australian farmers have tried hawks, weasels, snakes and whatnot; the Government put a bounty on rabbits; their warrens were attacked by bulldozers; thousands of miles of costly wire fence were built; strychnine poison was broadcast—all to little avail. Then someone thought of myxomatosis, a virus disease which is fatal to rabbits but does not affect farm animals or people. Infected rabbits develop symptoms like those of a very bad cold and die in 10 to 12 days. The early attempts to plant the disease in the rabbit population failed. But two years ago the Australians discovered that mosquitoes and other insects spread the disease from one animal to another. That was the key.

The rabbit-exterminators round up a large number of rabbits, inoculate them with a preparation of the myxomatosis virus and shave their coats to provide bare patches on which mosquitoes can easily feed. The greatest success in propagating the disease has been near swampy areas, where mosquitoes breed best. Australia does not expect the disease to kill all the rabbits, but it hopes to keep them under control.

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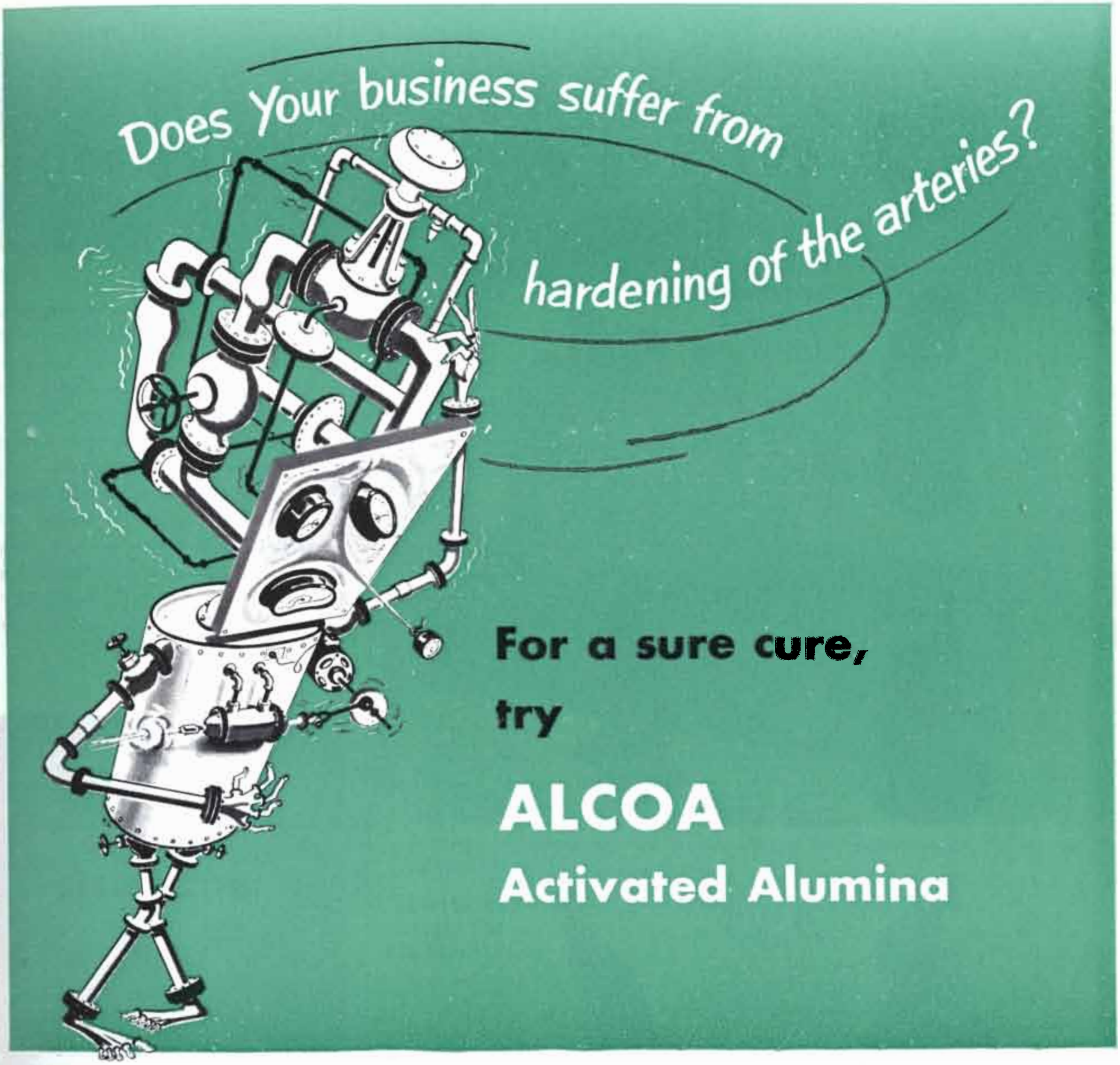

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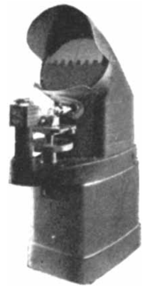

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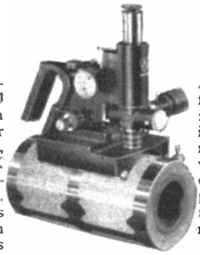

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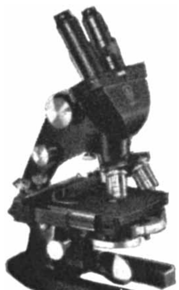

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Reveals details in living organisms and tissues, slightly pigmented or faded preparations, emulsions, plastics and other material too transparent to be seen with the bright field microscope.

AO OPTICAL MEASURING INSTRUMENTS

By comparison of color densities concentration in liquids can be determined with the Direct Result AO Colorimeter. Other useful AO instruments for measuring optical properties include refractometers and spectrometers.

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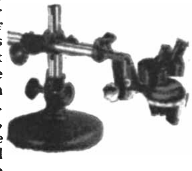

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A modern instrument for the metal working industry. For routine control, *all operational functions are performed by the metallographer from a sitting position.* Parfocality of visual and photographic systems assures photomicrographs without the need for focusing the image on the ground glass screen. Infinity corrected Americote "Apergon" objectives are parfocal on revolving turret. Photographic eyepieces on positioning slide expedite changing magnifications. All optics and camera settings are engraved in terms of standard ASTM magnifications. A choice of motor driven carbon arc, zirconium arc and ribbon filament lamps is offered. A second metallograph #2400P, for metallurgical research, has recently been announced.

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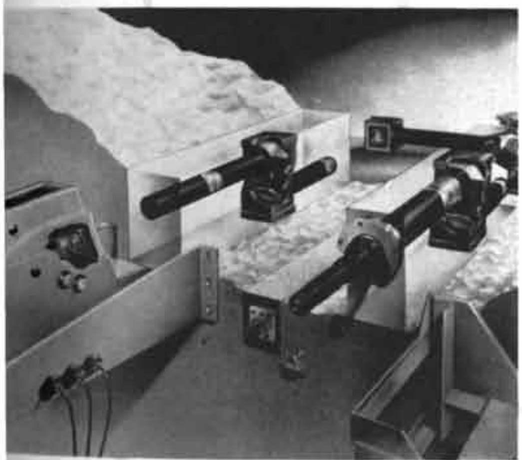

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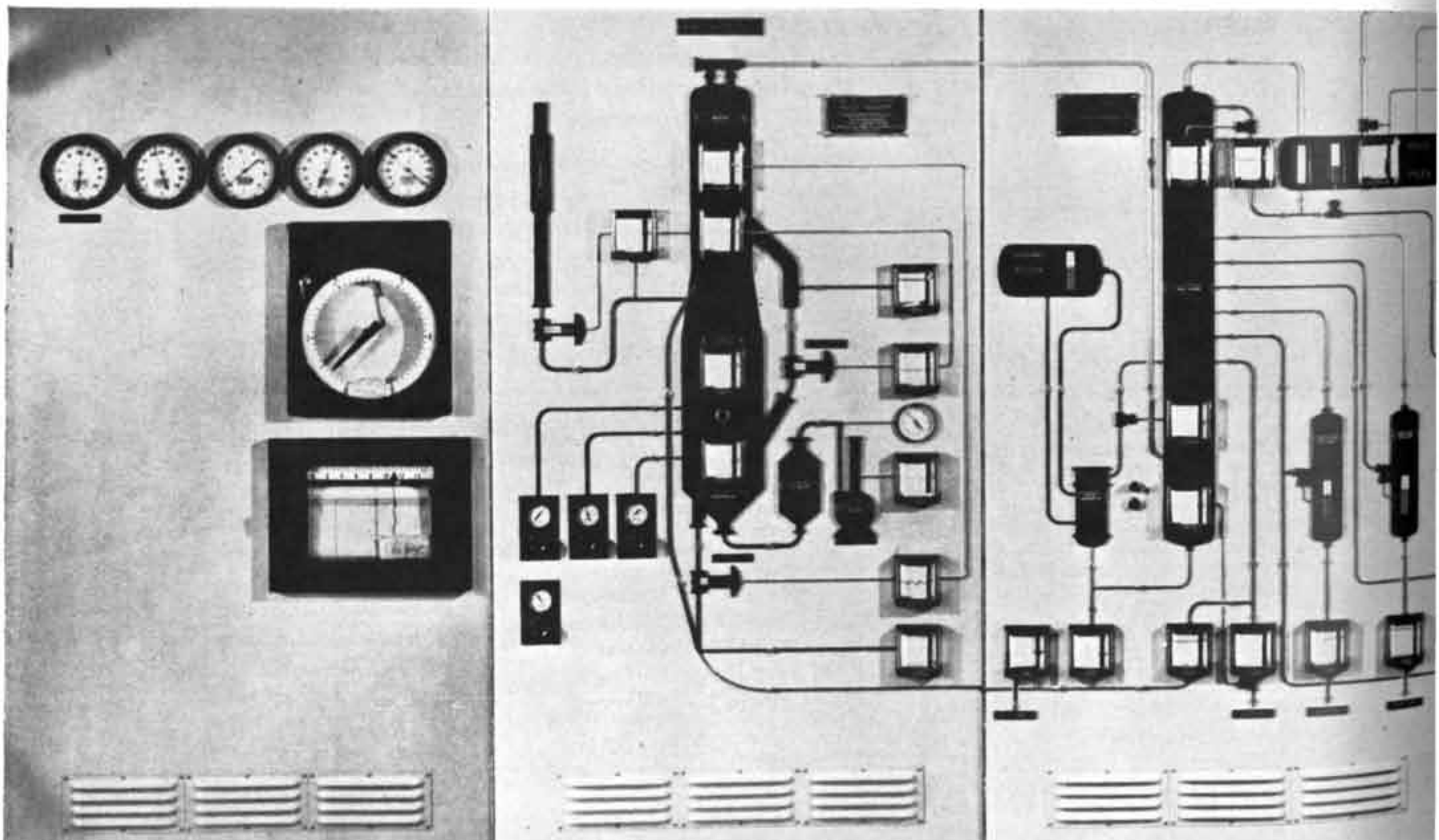
An Automatic Chemical Plant

The art of feedback control has attained its highest development in the modern petroleum refinery. Such refineries are not quite fully automatic, but in them we see the shape of plants to come

by Eugene Ayres

LAST YEAR one of the countries of Asia employed a U. S. contracting firm to design a modern oil refinery. The firm submitted a design for a $50 million plant, and it included the usual array of control instruments. After studying the plans, the officials of the country, which has an embarrassing surplus of manpower, asked the designers to eliminate all automatic controls from the plant. The country could provide any number of thousands of men to record measurements and to control processes, and it was prepared to pay the price of lower efficiency and poorer-quality products to create this opportunity for employment. The contracting firm gave sympathetic consideration to the request, but its engineers finally decided that under no circumstances could control instruments be eliminated from the design. It was not just a question of operating costs or efficiency: without suitable control instruments a modern refinery simply could not operate at all.

If the 50,000 control devices in the



CONTROL PANEL for the petroleum refinery of the McMurrey Refining Co. near Tyler, Tex., graphically represents the operation of the refinery. Each silhouette represents an actual unit of the refinery. Mount-

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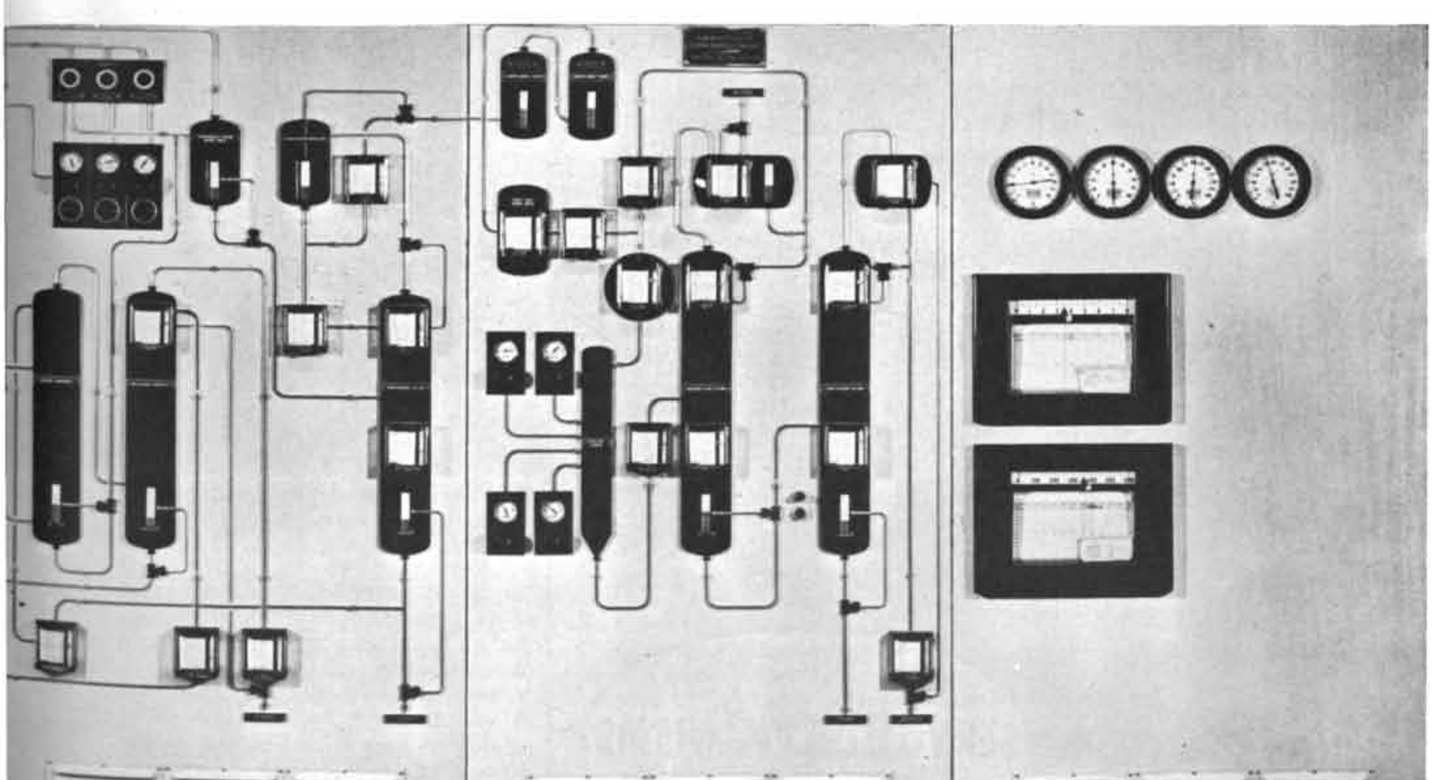
oil refineries of the U. S. should go "on strike," we would be faced with social disaster. The refineries would become lifeless industrial monuments. If we undertook to replace them with old-fashioned, manually operated refineries to supply our present motor-fuel needs, we would have to build four or five times as much plant, cracking and some other modern chemical processes would have to be eliminated, yields of motor fuel from crude petroleum would drop to a quarter of those at present, costs would skyrocket, and quality would plummet. Automobile engines would have to be radically redesigned to function with inferior fuel. And because of lower motor-fuel yields, we would need to produce crude petroleum several times as rapidly as we produce it now. Technology in refining would be set back to the early 1920s.

In a sense the prediction that the machine age is now about to be followed by the age of automatic control is an oversimplification. Mechanical controls came in with the very beginning of the machine age, and made it possible. What we are now seeing, and shall see increasingly in the future, is a rapid extension of such control. Machines, processes and combinations of machines and processes will become more and more automatic.

The role that automatic control already plays in technology can be seen by considering the unhappy situation of Great Britain. One measure of a country's industrialization is its capacity for consuming fuel. This capacity depends largely upon the quality of mechanization, which in turn depends upon automatic control. In fuel-consumption capacity Britain's industries have declined steadily, in relation to the rest of the world, ever since 1875. This has happened in spite of her abundant coal resources (until recently) and the fact that she has some of the world's best-informed technologists. Her industrial leaders in the main have failed to understand the philosophy of automatic control. Little more than a tenth of the textile looms in Lancashire, for example, are automatic. Lancashire textiles cannot compete in world markets, and a business depression is under way. Some other British industries show the same backwardness in application of automatic control. In the U. S., by contrast, the intense competition in cost, yield and quality has driven us steadily toward more and more automatization.

THE petroleum industry is a leading example. Excluding taxes, the price of motor fuel today is little higher than in 1920, in spite of the shrinking dollar and rising costs, and almost the sole reason is improvement in process equipment made possible by automatic control. Automatization has reduced costs in two ways: by yielding more production per dollar's worth of equipment while the plant is running, and by reducing shutdown time. When a plant is not operating, fixed charges go on just the same. Ten years ago, when cracking units were reasonably well equipped with control devices, the units could be counted on to operate an average of 87 per cent of the time. Today they are more likely to operate 93 per cent of the time. About half of this recent six per cent gain has come from improvements in the control systems themselves—development of new devices and more intelligent use of old ones. Most of the other half has come from changes in operation and design made possible by improvements in automatic control.

When the gain in operating factor is translated into dollars, it seems that the extra cost of control systems and the changes in process equipment that the control systems have made possible, have in general been amortized in less than a year of plant operation—a performance that far surpasses normal investment in refinery equipment. And



ed on the silhouettes are the appropriate instruments. The second panel represents a catalytic cracking unit; the third, a fractionating unit; the fourth, a gas concentration unit; the fifth, a polymerization unit.

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REFINERY controlled by the panel on the preceding two pages is shown

the gain in operating factor is only part of it: there has been a much more important gain in the production capacity of our refineries.

A refinery is a model case of the kind of manufacturing operation known as continuous process, in contrast to the discontinuous step-by-step operation of, say, an automobile assembly-line. Crude petroleum feeds in at one end of the plant, flows continuously through a series of treatment chambers and pipes, and pours out a variety of finished products at the other end. Such an

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at sunset. The panel is behind the window at right center. Behind it is the catalytic cracking unit. Here the catalytic unit is at the right; on the control panel it is at the left so that the operator can read it from left to right.

operation is particularly amenable to automatic control. Let us look at a typical refinery as an example of the application of machine control to a continuous process.

IT IS A bewildering kind of factory, with metallic towers rising 20 stories high, hundreds of miles of pipe, and only an occasional modest building. A few lonely men wander about the spectral monster doing supervisory or maintenance tasks here and there. The plant is almost noiseless, all but devoid of visible moving parts. Despite its apparent inertness, however, the plant is throbbing with internal heat and motion. Every day a quarter of a million barrels of oil flow unobtrusively into its maw, and about as many flow out in the form of dozens of finished petroleum products—all profoundly and specifically altered by processing. Forty tons of catalyst are being circulated every minute of the day and night. Great volumes of chemicals are being consumed in processing, and greater volumes of chemical intermediates are being manufactured. Scores of unit processes are interlocked, with a meticulous balance of energy distribution.

The nerve center of this mechanical organism is the control room with its control panel. Here are ensconced the human operators—attendants upon the little mechanical operators of the plant. The human operators watch, they sometimes help or correct the instruments, but only occasionally do they take over the major part of operating responsibility. Barring emergencies, they take over completely only when the plant is

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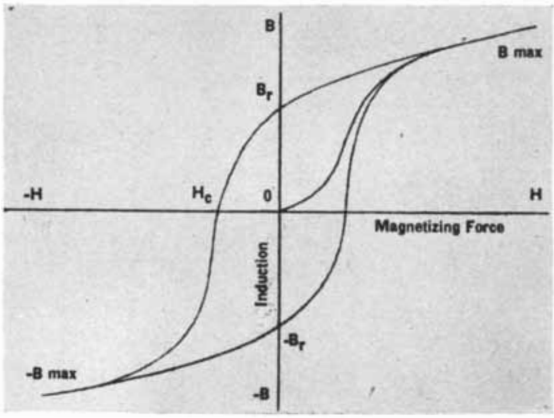

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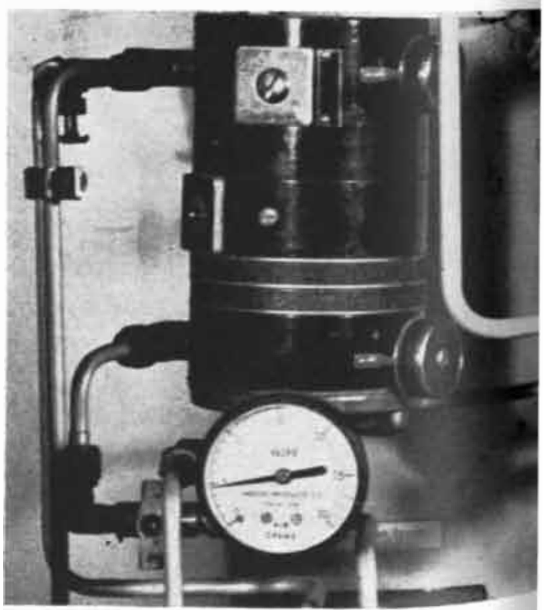
starting up or shutting down—normally only about once a year in a catalytic cracking plant.

Some of the automatic control instruments are mounted on the control panel; some are tucked away behind it; most are located in the refinery yard near the jobs they have to do. On the control panel are many things—indicators of measurements, indicators of valve positions, indicators of settings of controllers, knobs for changing these settings, facilities for shifting from automatic to manual control, knobs for effecting manual control, alarms and safety devices, recordings of measurements for operation analysis, and recordings of measurements for accounting. The restful appearance of the control panel and the refinery is deceptive. Five hundred controllers, 400 motor-operated valves, 1,500 indicators and 800 recorders are in slight but significant motion at all times—like the steering wheel of a speeding motorcar on a straight road. But while the little compensatory movements (this way and that) of the steering wheel have only direction to control, instruments on a refinery panel board must control a hundred variables—many of them dependent upon others.

Indicating instruments are merely to be observed. Like the clinical thermometer, they call for action only when the indication is abnormal. Some little thing may go wrong with one of the controllers. Some unpredictable variation may occur in the flow of fluids or in the strength of materials. Corrosion may start a leak in a pipeline. A fuse may blow out in an electric circuit. A storm may cause structural damage. Like a physician, the human operator becomes sensitive to abnormalities and promptly seeks to apply corrective measures. All



CONTROLLERS are mounted on the back of the McMurrey Refining Co. panel on pages 82 and 83. These

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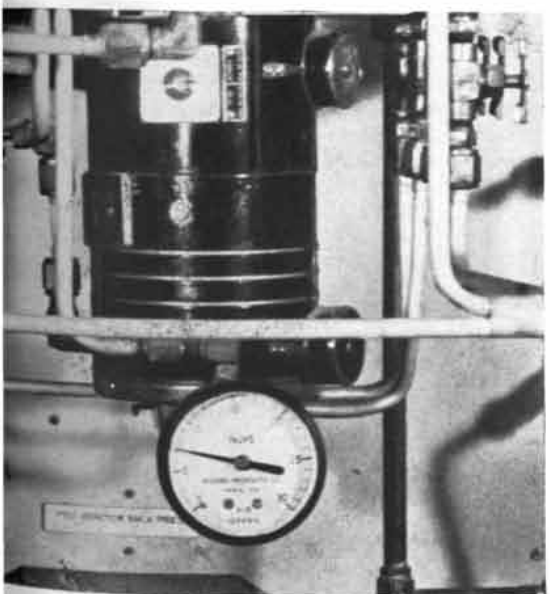
factors for correction are on the control panel.

PERIODICALLY the operators receive reports from analytical laboratories, where chemists are testing the composition and quality of the products. The operators must know how to make manual adjustment of controller "settings" to conform with analytical trends.

While the operator stands guard over his mechanical helpers, automatic controllers reciprocate by standing guard sleeplessly over the safety of the operator and the plant. Any out-of-the-way event touches off a visible or audible alarm, warning the operator of trouble to come. And automatic controls immediately set in motion the first necessary steps for safety, more quickly than the operator could.

Refineries and other mechanically controlled continuous processes have become so complex that control panels of the types used just a few years ago would today be too large and too difficult to learn to understand. Long steps have been taken in the direction of developing smaller instruments and bringing the pattern of the flow of materials and energy within the ready comprehension of the operator. One important step has been the design of graphic instrument panels in which instruments of greatly reduced size are placed at appropriate locations on a simplified flow diagram of the plant. Even with small instruments, however, such a diagram sometimes would be 100 to 200 feet long, so that compromises must be made to bring the instruments into more compact arrangement. Flow lines on the panel are given distinguishing colors to make interpretation as easy as possible.



units are a more elaborate form of the pneumatic servo-mechanism that appears at the top of page 60.

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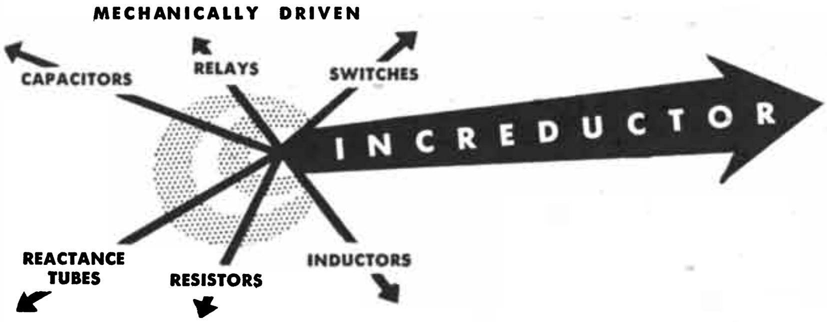

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Hold an Alnor Pyrocon in your hand . . . feel the fine balance . . . notice the all-metallic case and shatter-proof glass. These things speak of quality design and particular attention to detail. *BUT* that isn't enough to judge performance of a Pyrocon—or any instrument. Look closely at a Pyrocon!

Look at the Yoke . . . where the thermocouples are attached. Notice that neither plate connection is grounded. With plates of chromel and constantan alloy . . . a feature developed by Alnor.

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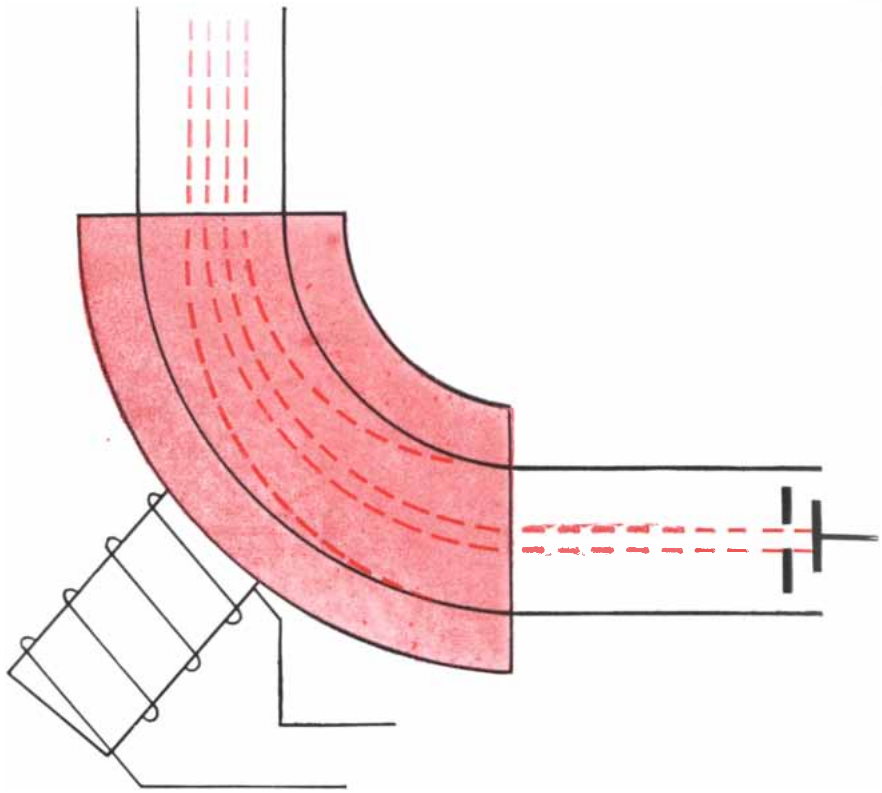

MASS SPECTROMETER, which can be used to analyze the stream of molecules in a petroleum refinery, operates on the principle shown in this drawing. The ionized molecules of a sample are accelerated from upper left to lower right. As the molecules pass through the field of a magnet (*light red area*), the lighter ones are curved more than the heavier.

The diagram of the catalytic cracking process alone requires more than a dozen colors, for we are concerned with flows of several different systems and materials—hydrocarbons, water, steam, air, electric power, catalysts and other chemicals.

NOW LET US look into this maze and see what we are trying to control. If we could set up an unvarying set of conditions and depend on the system to operate constantly at the same rate of flow, temperature, pressure, and so on, we would need no control devices. But physical factors are imperfect. Mistakes are made by pumps as well as by people. The composition of the charge flowing into a process is likely to vary. Deposits may form in a valve. The heat losses from equipment will not be the same on cool nights as on hot afternoons. A shift in wind direction or velocity may alter the draft in a chimney.

We have two kinds of variables to control. First there are the conditions that determine the yield and quality of the product; these must be kept constant at optimum levels. Then we have another group of conditions which can be made to vary widely. The formidable job of the control devices is to keep changing the latter conditions in such ways as may be required to keep the determining conditions nearly constant. In other words, inanimate devices are charged with the responsibility of correcting inanimate mistakes.

The relationships among the variables are bewilderingly complex. Consider a fluid catalytic cracking plant. Essentially the process involves converting petroleum to gasoline and other products by heating it in the presence of a solid catalyst in the form of a fine powder; the catalyst makes it possible to operate at lower temperature and pressure than in simple thermal cracking. The main reactions take place in a large chamber called a "reactor," which is charged with a mixture of crude oil, steam and hot powdered catalyst. The heating in the reactor drives off oil vapors and steam to a fractionating column. The powdered catalyst flows to a "stripper" for stripping off oil vapor trapped in it, then to a "regenerator" for burning off residual carbonaceous material, and finally is returned to the reactor to be used again. In the fractionating column gasoline fractions from the top of the column are subjected to various other fractionating operations to provide a product of desired boiling range, and the heavier oil in the column may be recycled for further breakdown.

Thus the catalytic cracking operation is a combination of several distinct processes. In a modern plant they are indissolubly linked together through control mechanisms. In the past 12 years about 70 fluid catalytic cracking

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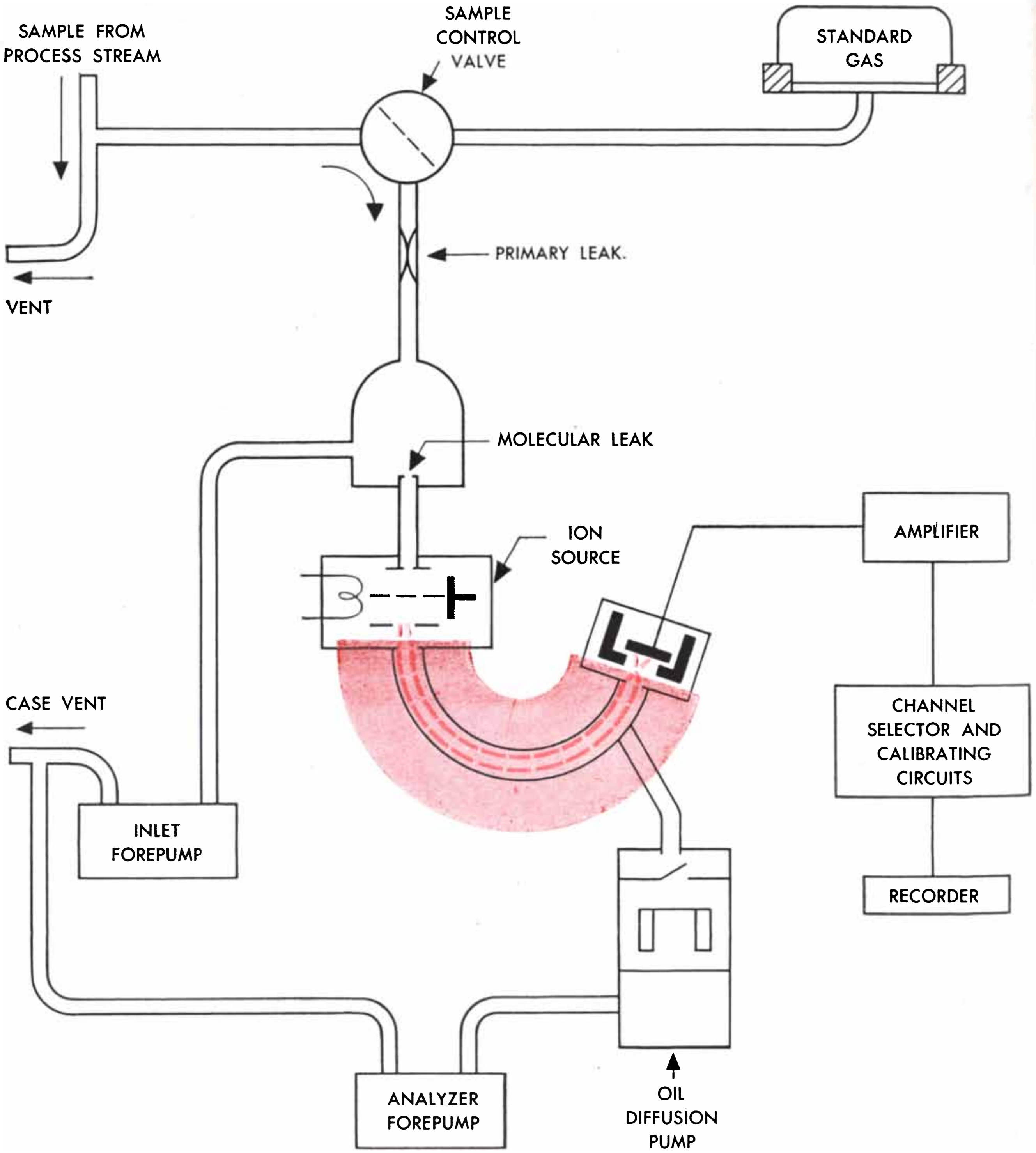
units have been built in the U. S. Significantly, each unit has had more instrumentation than the one before. The earliest units had about 100; one of the most recent has about 500. Many of these are simply indicating or measuring instruments, but about 150 are for automatic control, and many of the control instruments also make records of measurements. A diagram showing all the linkages between the controllers and the process equipment looks as complicated as a blackberry bramble, and it takes a full-sized book to list the controllers with concise descriptions of their functions and linkages.

I CAN mention here only a few of the more interesting aspects of the control system in such a plant. One of the chief problems, of course, is control of the temperature. Part of the heat may be generated by combustion of fuel in a furnace. The rate of heat generation is one of the secondary conditions that may be made to vary within certain limits to compensate for changes in the flow of oil or for variations in heat losses. Now combustion itself has its own determining variables for efficiency. Naturally we want to get the maximum yield of heat from a given amount of fuel. Automatic control has increased combustion efficiency in a cracking plant roughly fivefold since 1930.

The temperatures of the components in the cracking process are all related to one another, and their nerve center is the reactor. The reactor temperature is



APPLICATION of the mass spectrometer in a refinery is shown in this diagram. If the spectrometer were used to analyze a final product of the refinery, its data could be fed into the controls of the refining process.

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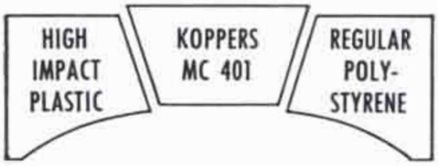
Modified Polystyrene —Koppers MC 401— bridges the gap!



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WRITE FOR BULLETIN C-2-161-T which details the molding characteristics, physical and chemical properties and other data about Koppers MC 401. This bulletin also contains information about Koppers Modified Polystyrenes MC 185 and MC 301. Our technical staff is anxious to help you develop new product applications for all Koppers Plastics. Phone, write or wire, and a Koppers representative will gladly call to discuss your problem.

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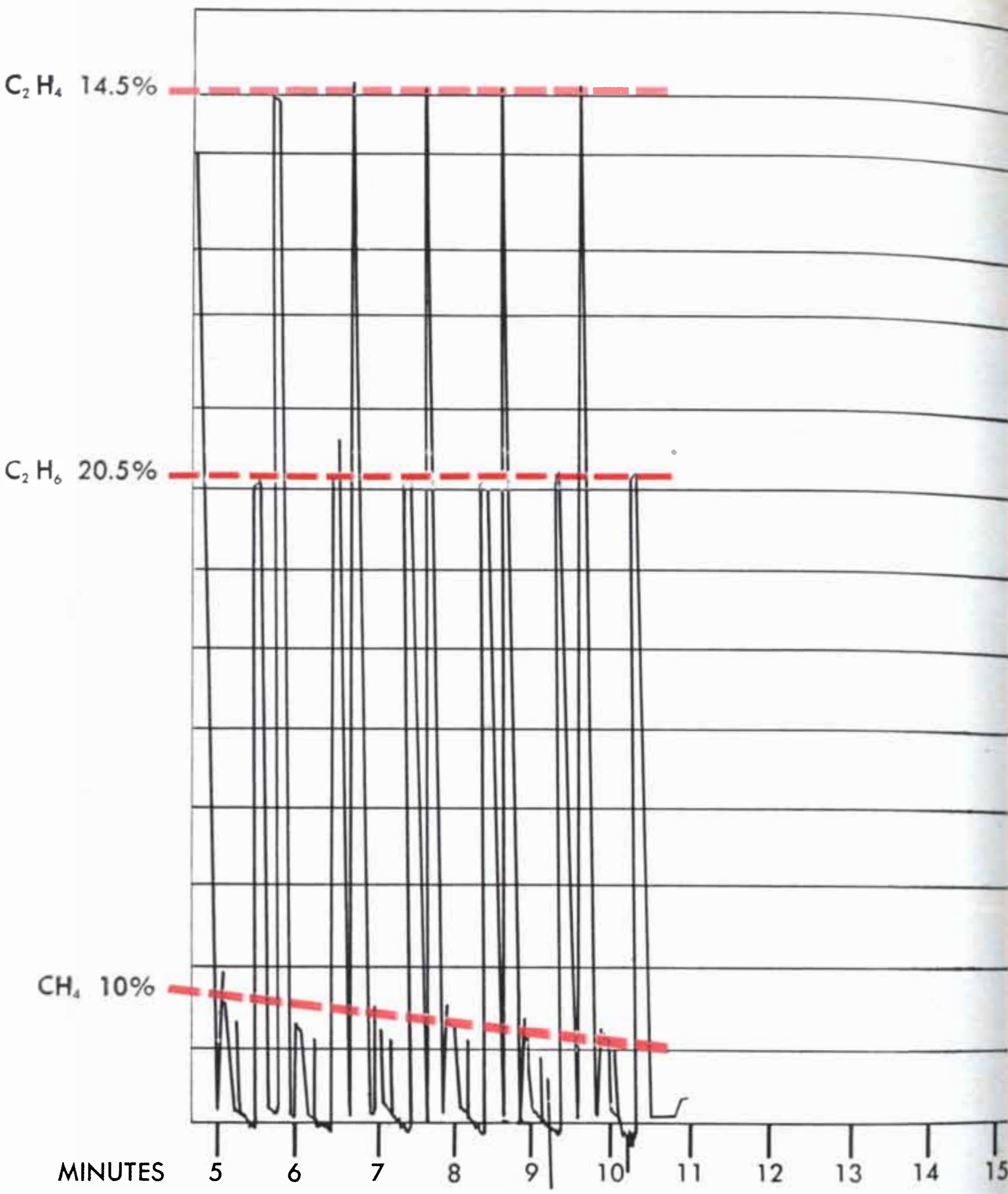

MASS SPECTROMETER RECORD shows how the instrument is used to record a change in the process stream after a change of operating conditions. The record at the far left shows that the stream contains 14.5 per cent of ethylene, 20.5 per cent of ethane and 10 per cent of methane.

one of the determining conditions for the yield and quality of gasoline. It depends not only on the temperature of the preheated oil fed to the reactor but also, to a greater extent, on the temperature and the amount of hot catalyst recycled into the chamber. The reactor temperature is thus sensitive to the rate at which regenerated catalyst is recycled. This rate must be controlled by the reactor temperature. The amount of regenerated catalyst is another determining variable, but this is not controlled; at least one degree of freedom must be provided in any continuous system. The temperature of the regenerated catalyst is controlled largely by the rate of circulation of some of it through a cooler. The flow of air to the regenerator, for burning carbon off the catalyst, is varied to take care of combustion requirements—sometimes by the composition of the spent combustion gas.

Many other controllers are required for this part of the process. Some are in the steam system. Steam, generated by the catalyst cooler and by whatever other waste heat is available, forms part of the mixture flowing to the reactor and also serves to remove hydrocarbon material from spent catalyst before regeneration. All these operations require mechanized control to maintain thermal and material balance. The extensive air system requires controls to blow air at proper rates to proper points. The flow of recycled oil from the fractionating columns must be controlled. Spent catalyst must be replaced by fresh catalyst as fast as it deteriorates. These and many other details (such as intermediate storage-tank levels and gravity

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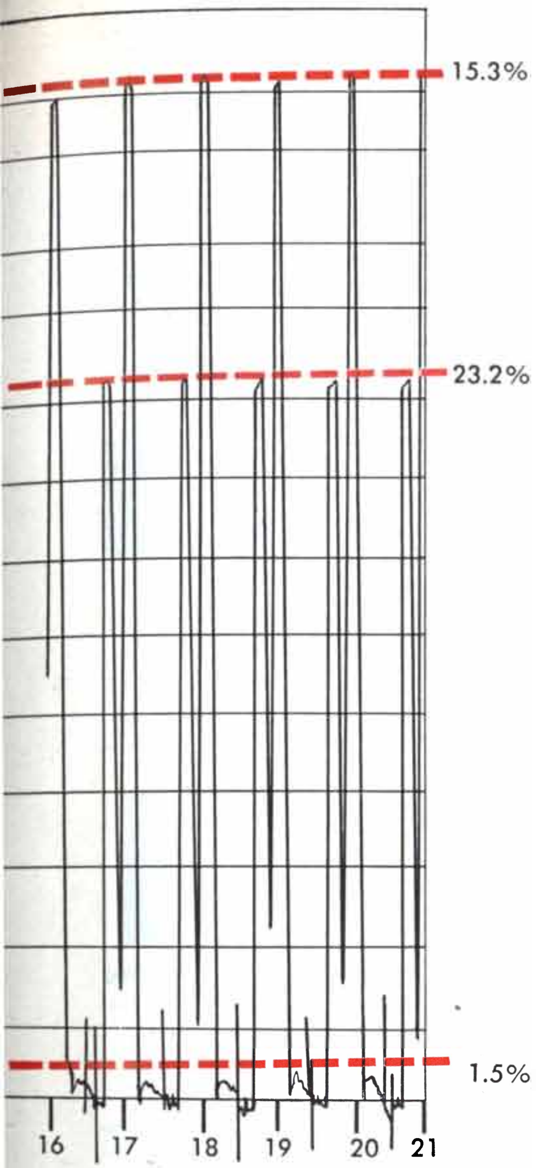

The proportion of methane is decreasing. The record at the right, made after resetting the instrument, shows how all proportions changed.

separators) require appropriate controls.

Compared with other continuous processes, fluid catalytic cracking is unique in several respects. Vapor containing abundant, finely divided solid catalyst acts like a liquid instead of a gas. For example, levels may be determined by pressure differentials. But to maintain the hydraulic properties of the mixture, it must be kept continuously in motion at a certain minimum rate. The automatic controls must operate massive equipment: the slide valves that control the flow of catalyst, for instance, sometimes weigh 10 tons.

The fractionating towers present another set of control problems. The temperature and pressure at the top of the tower control the rate at which vapor is pumped into the tower. The level of liquid in the bottom of the tower (or in

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Transmitters	AY201-1	26V, 400~, 1 ph.	225	1.25	25+j115	11.8	9.5	3.5	15
	AY201-4	26V, 400~, 1 ph.	100	0.45	45+j225	11.8	16.0	6.7	20
Receivers	AY201-2	26V, 400~, 1 ph.	100	0.45	45+j225	11.8	16.0	6.7	45
Control Trans-formers	AY201-3	From Trans. Autosyn	Dependent Upon Circuit Design				42.0	10.8	15
	AY201-5	From Trans. Autosyn	Dependent Upon Circuit Design				250.0	63.0	15
Resolvers	AY221-3	26V, 400~, 1 ph.	60	0.35	108+j425	11.8	53.0	12.5	20
	AY241-5	1V, 30~, 1 ph.	3.7	—	240+j130	0.34	239.0	180.0	40
Differentials	AY231-3	From Trans. Autosyn	Dependent Upon Circuit Design				14.0	10.8	20
**Also includes High Frequency Resolvers designed for use up to 100KC (AY251-24)									
AY-500 (PYGMY) SERIES									
Transmitters	AY503-4	26V, 400~, 1 ph.	235	2.2	45+j100	11.8	25.0	10.5	24
Receivers	AY503-2	26V, 400~, 1 ph.	235	2.2	45+j100	11.8	23.0	10.5	90
Control Trans-formers	AY503-3	From Trans. Autosyn	Dependent Upon Circuit Design				170.0	45.0	24
	AY503-5	From Trans. Autosyn	Dependent Upon Circuit Design				550.0	188.0	30
Resolvers	AY523-3	26V, 400~, 1 ph.	45	0.5	290+j490	11.8	210.0	42.0	30
	AY543-5	26V, 400~, 1 ph.	9	0.1	900+j2200	11.8	560.0	165.0	30
Differentials	AY533-3	From Trans. Autosyn	Dependent Upon Circuit Design				45.0	93.0	30

For detailed information, write to Dept. S.

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a "reboiler") is controlled by the outflow of oil recycled to the catalyst reactor and of oil sent to a "stripper" for separation of its light hydrocarbons. The temperature at the bottom of the tower is controlled by the temperature pressure condition at the top or by the flow of charge or by both. Various side streams are withdrawn from the tower at controlled (usually constant) rates. Liquid levels in the "stripper" are controlled by rates of flow to storage and to other parts of the plant.

An interesting thing about fractionating-tower control is that its control instruments must be designed to function slowly and deliberately. They must not change secondary conditions more rapidly than the tower achieves equilibrium—otherwise the operation of the tower will be uneven or impossible. The tower attains equilibrium slowly because of its relatively large volume of liquid. Hence the tower-controls must respond to signals slowly and adopt for their slogan "easy does it."

SINCE 1920 oil refineries have been revolutionized by three basic advances in design, which have brought a sensational increase in production capacity per ton of equipment steel. All three were made possible only by automatic controls. The first was the replacement of the shell-still, in which large batches of oil were heated like water in a teakettle, by tubular heaters, in which oil is passed continuously and rapidly through pipes in a furnace. The tubular heating system, which speeded up the flow of oil and decreased the volume of liquid "in process," brought drastic reductions in operating hazards and costs. The second development was a change in furnace design to supply heat by radiation from flames or hot brickwork instead of depending upon actual contact with hot vapors of combustion. This brought about a sixfold increase in the rate of heat transfer—from 2,000 to 12,000 British thermal units per square foot per hour. The third advance was the improvement of furnace combustion efficiency that I have mentioned.

Within a decade, between 1930 and 1940, these contributions of automatic control doubled the plant capacity that could be built at a given cost. And aside from cost, improvements in automatic controls and consequently in equipment design have probably been responsible for the conservation of 100 million barrels of petroleum per year in the U. S.

Yet we have gone only part way along the road. There will be further improvements in the control devices and in the design of equipment to take advantage of them. And we are certain to see the one capping major advance that will make the refinery almost fully automatic—end-point control. What this means is simply a master controller which will continually analyze the end products,

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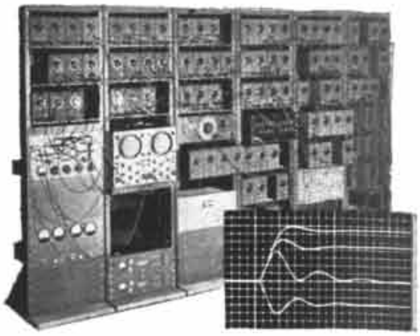
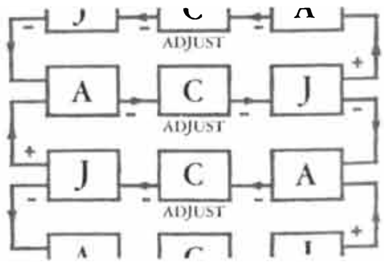


Perhaps you need an assemblage this size for solving 36th-order differential equations, or possibly the equipment in the left-hand rack alone will suffice. In either case your "building blocks" are provided by our standard *Computing Components.* Shown below in order are the Adding, Coefficient, and Integrating Components (A, C, and J), the three most popular units in the GAP/R K3 Series:

Even with these types alone you can synthesize, and display solutions for, any linear structure or problem, whether in mechanical vibrations or electric circuitry. In fact, your block diagrams will *come to life,* whatever the job. For example, note here the typical usage of A, C, and J Components to represent operational elements in an important form of recurrent structure:



Beside these basic types, there are *ten* others in the K3 Series, and *five* of the larger and more specialised K4 models. Taken in combination, the components of these versatile assortments can embody any conceivable dynamic effect. Full data on GAP/R analog techniques are available in our latest catalog.

Investigate!

These little "black boxes", and the computing systems easily assembled from them, can magnify your brainpower and diminish your time scales They are fast, accurate, economical, and ready & willing to work (on *your* problems).

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compute what changes must be made in the process conditions, and signal instructions back to appropriate points.

At first thought this may seem an unnecessary refinement. If the determining variables within the process are held constant by controllers at each point, will not the composition of the product be constant? In many cases it may. But for some processes the most important criterion is the concentration of some specific component in the product. An example is the catalytic cracking of distillate oil to get a maximum yield of butenes, needed for aviation fuel. To maintain the concentration of such desired products at constant optimum levels, we must have electronic instruments which can continually change certain secondary variables.

THE petroleum industry is at the very beginning of development of such end-point control. Certain preliminary steps have been taken. Among the most important of these has been the development of methods of continuous stream analysis by infrared spectroscopy, mass spectrometry and X-ray photometry. Infrared methods are being applied to continuous determination of various olefines, carbon dioxide, carbon monoxide, sulfur dioxide and methane. The mass spectrometer can make almost continuous determinations of eight hydrocarbon components at once. The X-ray photometer can make continuous determinations of tetraethyl lead in the range of concentrations used in motor fuel.

The next step, now being prosecuted vigorously, is the incorporation of continuous analytical equipment in process control systems. Up to now there has been little incentive for any general application of end-point control to motor-fuel manufacture, because no one has succeeded in finding analytical criteria for the quality of motor fuel. But some petroleum processes are even now being controlled by a single property of the product, such as its viscosity, its refractive index, its density or its *p*H. And end-point control is being applied to supplementary motor-fuel processes such as catalyst regeneration, isobutane recovery and de-ethanization.

Automatic is a relative term. The so-called "push-button" factory, into which category a modern refinery falls, is of course not completely automatic—people still have to push the buttons. And even when button-pushing or valve-setting is replaced completely by impulses from end-point controllers involving continuous analysis, a refinery will still not be fully automatic. Some unpredictable variable is always likely to remain to tax the minds of human operators.

With all the help that science and art can give, refinery operators must possess a high order of intelligence. Automatic controls have not and never will substi-

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AUTOMATIC ELECTRIC

ORIGINATORS OF THE AUTOMATIC TELEPHONE

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tute for intelligence. Indeed, they have raised the quality of personnel requirements to new high levels. The fact that robots can be devised to do nearly any routine operation performed by man, and much more besides, does not mean that our minds are to become less necessary. On the contrary, in a collective sense our minds are being taxed more seriously. The maintenance and operation of automatic systems calls for clarity of mind and technical intuition. And controllers have no intelligence except that which mathematical and engineering genius builds into them. The design of controlled systems to accomplish tasks that have no precedent in experience requires the utmost in imagination and inventiveness.

One of the most serious problems in automatic control has been the lack of men with an over-all understanding of the control system and the plant and process to which it is applied. This problem of management has retarded the progress of mechanization. There are many qualified specialists in instrumentation, but their specialization hampers communication and the integration of a plant. So someone has invented the term "system engineering" to include not only the control system but the plant itself. For in a very real sense the whole plant is a huge instrument, and the control devices are merely component parts. The system engineer must be distinguished in electronics, pneumatics, cybernetics—and common sense. The system engineer, if he can be developed, will have a great future.

MEN HAVE ever regarded the machine as a mixed blessing. Machine-made goods are to many a synonym for inferior goods. Will automatization remove the last drops of human creativeness and variety from man's products? Such a fear is ill-founded. To be sure, textiles made by the machine-loom have lacked the traditional charm of those woven by hand. But the shortcomings of the machine are not inevitable. With modern automatic controls, machine-made textiles can approach the beauty and quality and individuality of the "hand-made." Machines can now be designed not only to surpass the regularities of careful hand-manipulation but also to duplicate faithfully the irregularities of the artist's inspiration. Similarly, the immense standardized output of motor fuel from controlled refineries is approaching equality with the best "hand-made" laboratory fuels that technologists have been able to devise. It is becoming more and more practicable to translate subtle improvements in functional quality from the research laboratory to commercial production.

Eugene Ayres is a chemist with the Gulf Research and Development Company.

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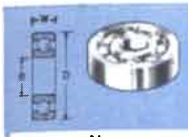

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Bearing No.	100	2	2½	★ 3	★▼4	★▼5
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Bore (B)	.0250″	.0400″	.04687″	.0550″	.07812″	.09375″
Width (W)	.03125″	.04687″	.0625″	.07812″	.09375″	.10937″
Balls	7-.65 mm	8-1/32″	10-1/32″	8-3/64″	8-1/16″	10-1/16″
Load Rating (lbs.) 5000 rpm	1.5	2.1	3.5	4.6	8.0	9.2

TOLERANCES (D) + .0000″ — .0002″ (B) + .0000″ — .0002″ (W) + .000″ — .001″
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O. D. (D)	.2500″	.3125″	.3125″	.3125″	.3125″	.3750″
Bore (B)	.1250″	.1250″	.15625″	.1875″	.21875″	.2500″
Width (W)	.09375″	.10937″	.10937″	.10937″	.10937″	.1250″
Balls	15-1 mm	11-1/16″	15-3/64″	16-3/64″	26-1/32″	25-1 mm
Load Rating (lbs.) 5000 rpm	4.9	9.5	7.2	7.2	4.2	6.5

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For applications of medium speed, light load, low torque and minimum clearances. Stainless steel snap retainers.

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Bore (B)	.07812″	.09375″	.1250″	1875″
Width (W)	.09375″	.10937″	10937″	10937″
Balls	5-1/16″	5-1/16″	6-1/16″	7-3/64″
Load Rating (lbs.) 1000 rpm	11.5	11.5	13.2	8.2

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Bore (B)	.0550″	.07812″	.09375″	.1250″
Width (W)	.07812″	.09375″	.10937″	.10937″
Balls*	5-3/64″	5-1/16″	7-1/16″	8-1/16″
Load Rating (lbs.) 5000 rpm	3.8	6.6	8.2	9.5

*Subject to variations with non-metallic retainers.
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O. D. (D)	.0590″	.1181″	.1575″	.1968″	.2953″	.3937″
Width (W)	.0472″	.0709″	.0945″	.1181″	.1772″	.2362″
Shaft (S) Min.	.020″	.030″	.040″	.050″	.075″	.100″
Balls	4-1/64″	4-1/32″	4-3/64″	4-1/16″	4-3/32″	4-1/8″
Load Rating R & T 1000 rpm	.55	2.7	6.0	10.8	25.0	41.0

TOLERANCES (D) + .0000″ — .0002″ (W) ± .002″
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O. D. (D)	.1250″	.1875″	.2500″	.3750″	.3750″
Width (W)	.04687″	.0700″	.09375″	.14062′	.1406″
Shaft (SE) Max (without cone)	.032″	.048″	.063″	.094″	.1250″
P Shaft (S) Min.	.042″	.062″	.0850″	.124″	.150″
Cone (C) Max.	60°	60°	60°	60°	60°

TOLERANCES (D) + 0000″ — .0002″ (W) + .000″ — .002″ Eccentricity same as for Pivot Series. Consult Engineering Department for other angles and speeds

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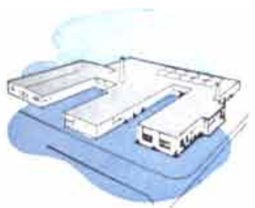

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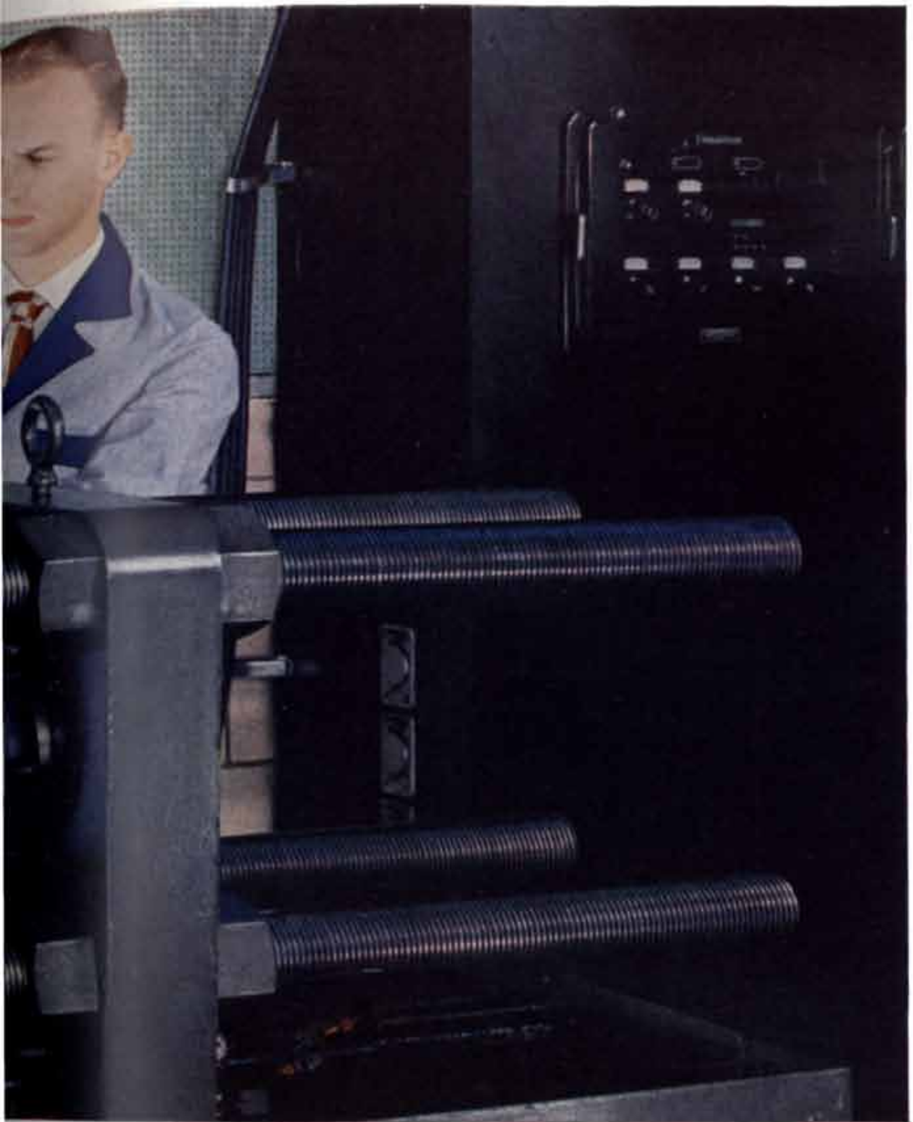

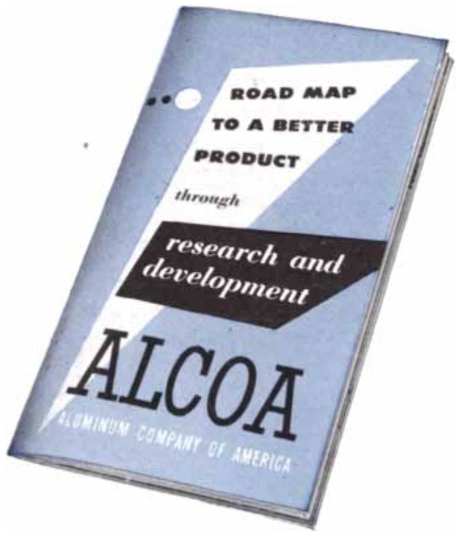

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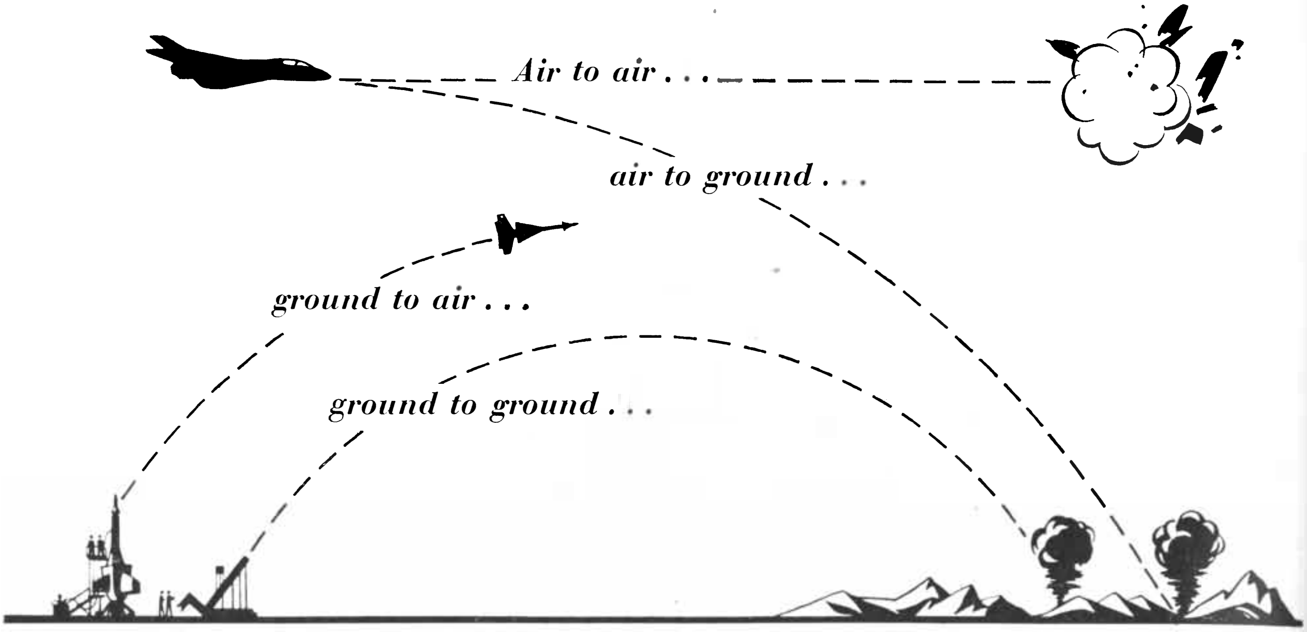

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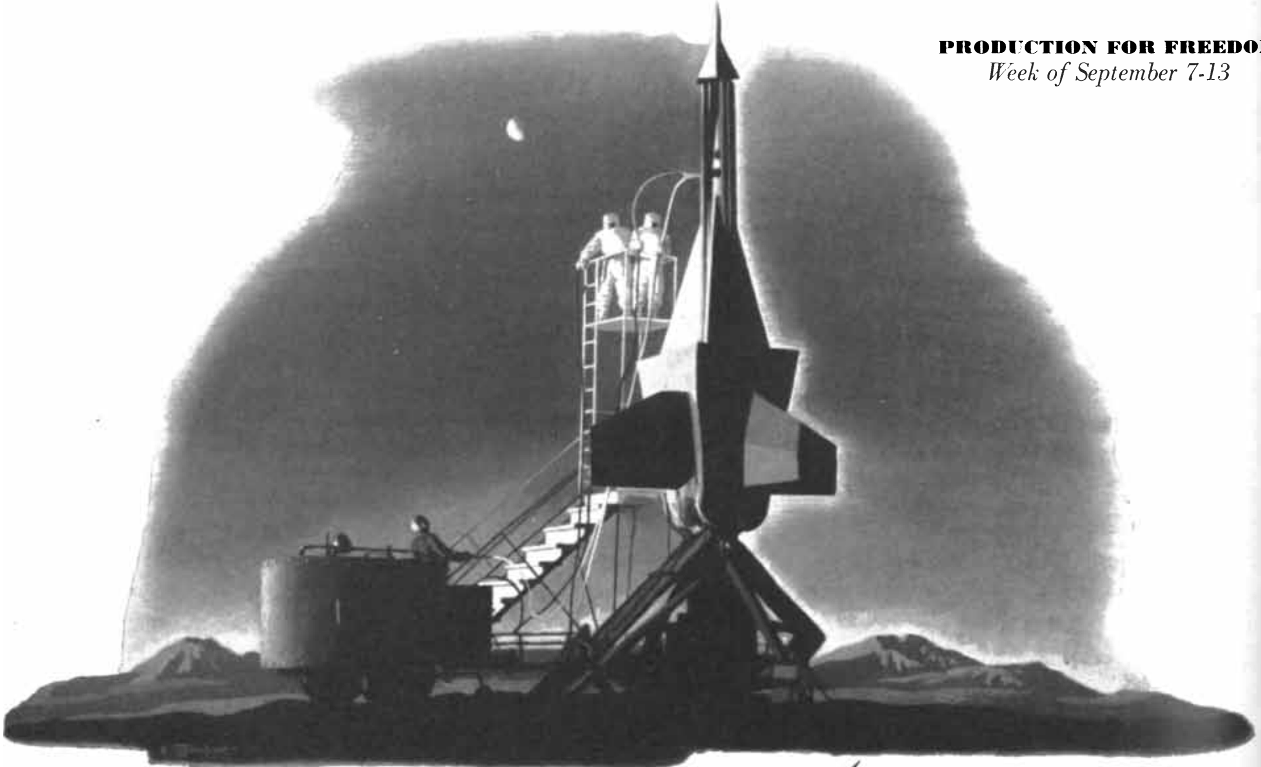

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An Automatic Machine Tool

Feedback control has begun to advance in the working of metals. Presenting the first account of a milling machine that converts information on punched tape into the contours of a finished part

by William Pease

THE metal-cutting industry is one field in which automatic control has been late in arriving. The speed, judgment and especially the flexibility with which a skilled machinist controls his machine tool have not been easily duplicated by automatic machines. Only for mass-production operations such as the making of automobile parts has it been feasible to employ automatic machinery. New developments in feedback control and machine computation, however, are now opening the door to automatization of machine tools built to produce a variety of parts in relatively small quantities.

The problem will be clearer if we first review briefly the history of machine tools and their relationship to manufacturing processes. The story begins in the last quarter of the 18th century. Prior to that time the tools of the millwright, as the machinist of that day was called, consisted chiefly of the hammer, chisel and file. His measurements were made with a wooden rule and crude calipers. His materials were prepared either by hand-forging or by rudimentary foundry casting. Crude, hand-powered lathes were already in existence, but they were used only for wood-turning or occasionally for making clock parts.

The first machine tool in the modern sense of the word was a cylinder-boring device invented in 1774 by John Wilkinson. Wilkinson is by no means as well-remembered as James Watt, but it was his invention that enabled Watt to build a full-scale steam engine. For 10 years Watt had been struggling vainly to turn out a cylinder true enough for

SAMPLE PRODUCT of the automatic machine tool described in this article is the cam shown at right. The instructions which direct the cutting of the cam from a square blank are encoded on paper tape.

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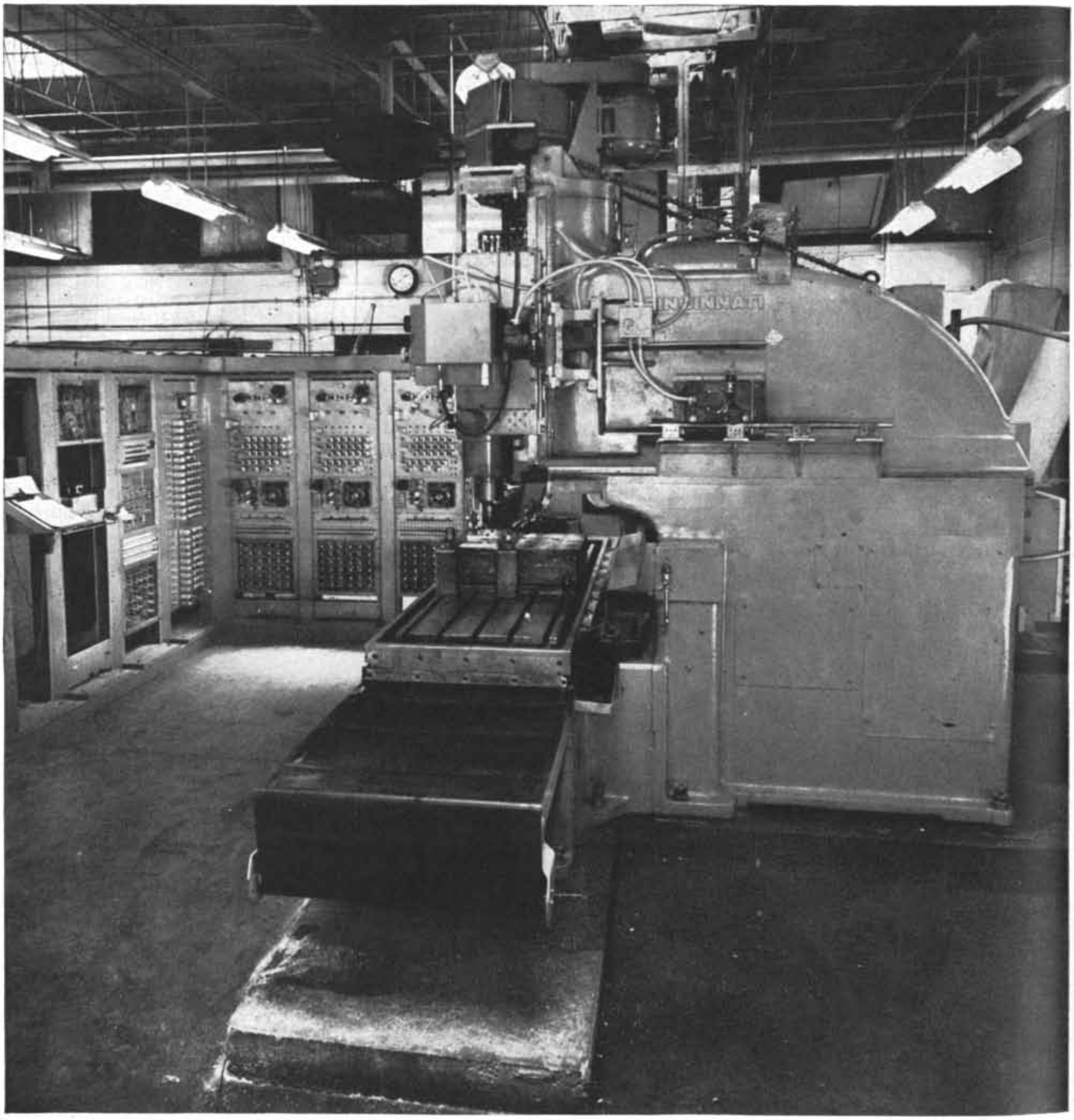
the job. After one effort he reported in discouragement that in his cylinder of 18-inch diameter "at the worst place the long diameter exceeded the short by three-eighths of an inch." But in 1776 Watt's partner, Matthew Boulton, was able to write: "Mr. Wilkinson has bored us several cylinders almost without error; that of 50 inches diameter, which we have put up at Tipton, does not err the thickness of an old shilling in any part." The importance of Wilkinson's boring machine cannot be overestimated. It made the steam engine a commercial success, and it was the forerunner of all the large, accurate metal-working tools of modern industry.

Another productive Englishman of the same period was Joseph Bramah. His inventions included one of the most successful locks ever devised, the hydraulic press, various woodworking machines, the four-way valve, a beer pump and the water closet. To manufacture his inventions he and an associate, Henry Maudslay, created several metal-cutting machines. The most significant of these was a screw-cutting lathe with a slide rest and change gears remarkably like our modern lathes.

THE NEXT great step forward in machine technology was pioneered by Eli Whitney. Although he is remembered mainly as the inventor of the cotton gin, his greatest contribution was an innovation of much more general import: interchangeability of manufactured parts. In 1798 Whitney, hav-



MACHINE AND CONTROL are shown here in entirety. For details of the control panels (*left*) see pages 104 and 105. The machine has universal motion: the "head," holding the cutting tool, moves vertically; the "cross slide" moves the head back and forth across table; the table moves from side to side under tool. The control system coordinates all three motions simultaneously to perform the operations shown on the opposite page.

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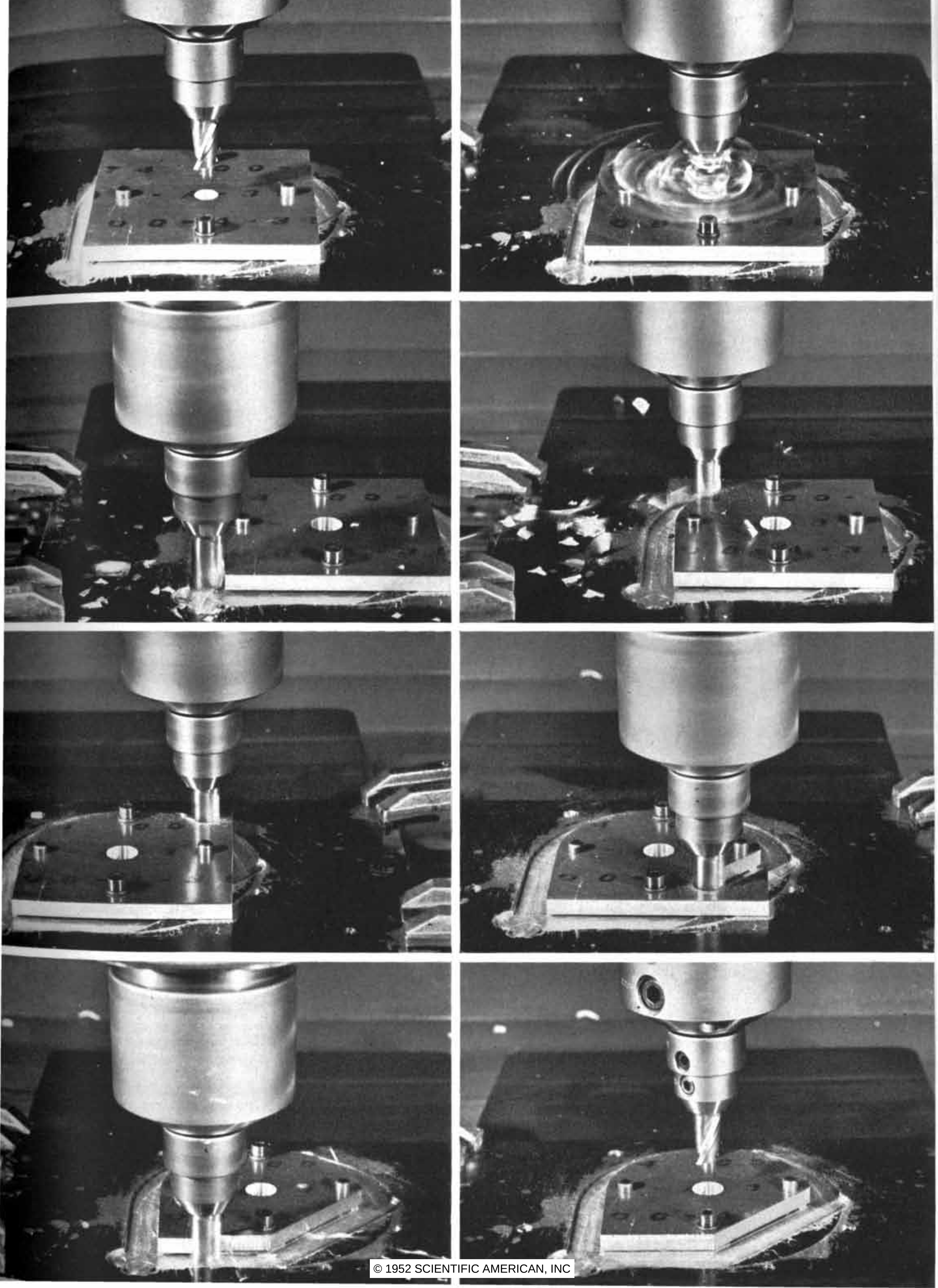

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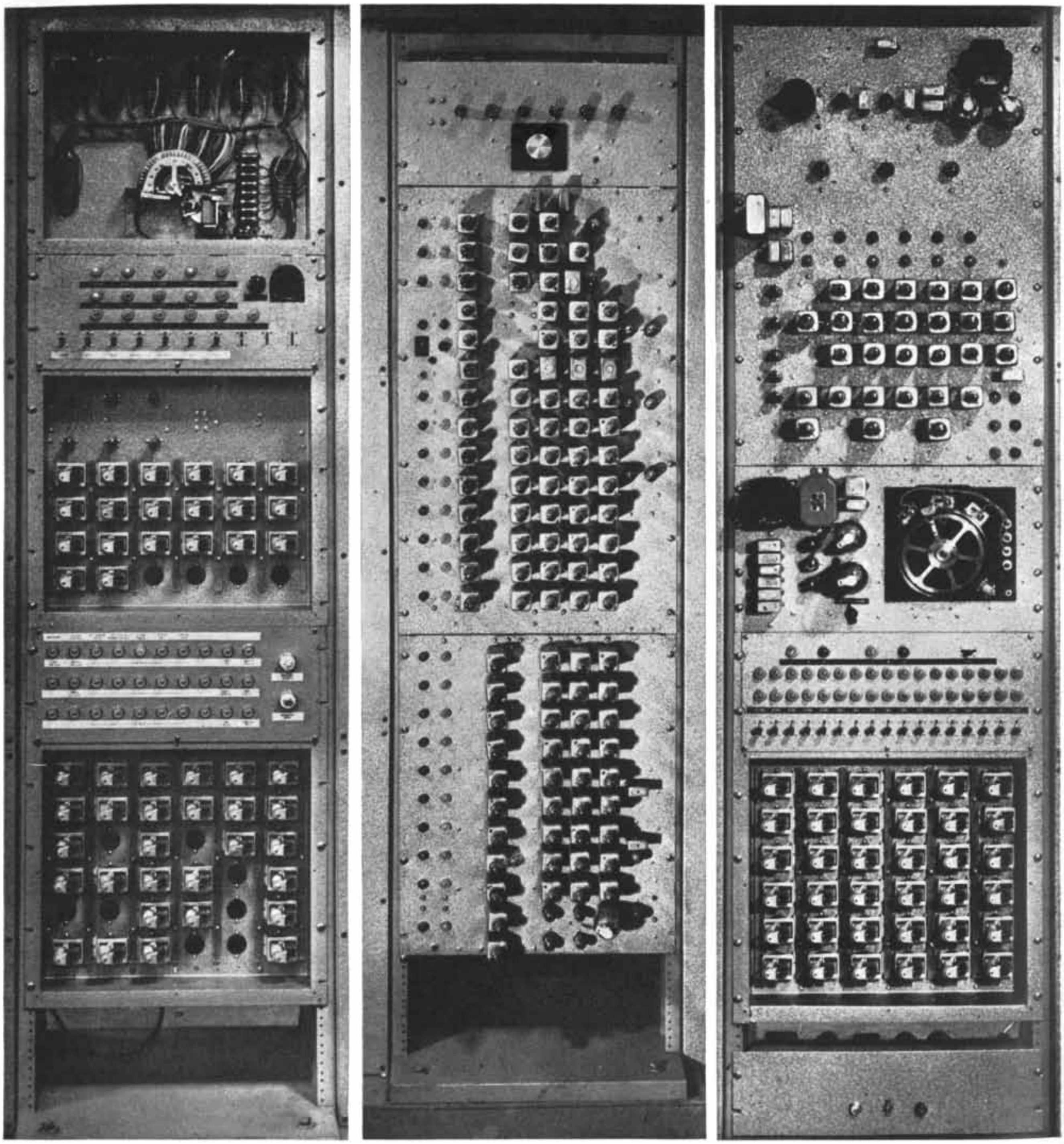

CONTROL-SYSTEM panel at left distributes commands to banks of relays in three panels at right, one for each motion of the machine. An electronic oscillator "clock" at top of second panel generates steady flow of pulses. These are blocked or passed on by flip-flop switches in data-interpreting system below clock,

ing made little money from the cotton gin, set up in New Haven as a manufacturer of muskets for the U. S. Government. He employed on this contract the interchangeable system of manufacture which was at that time still considered impractical by most experts. In fact, two years later it was necessary for Whitney to go to Washington to reassure the Secretary of War and officers of the Army that his idea was sound. Displaying 10 muskets, all tooled as nearly alike as he could make them, he showed that the gun parts could be interchanged among all 10 without affecting the guns' operability. He went on to prove in his New Haven shop that precision machinery operated by relatively unskilled labor could make parts accurately enough for interchangeability, so that expensive handwork was no longer required.

Whitney's idea was received with skepticism, but it eventually won out. Interchangeable manufacture is a fundamental principle of all quantity production as we know it today. Automobiles and washing machines, typewriters and egg beaters—every common machine we use is manufactured with interchangeable parts.

The two primary tools of interchangeable manufacture are the lathe and the milling machine. The modern lathe owes its form mainly to Maudslay, but about 1854 the addition of the tool-changing turret equipped the lathe and its cousin, the automatic screw-cutting machine, for interchangeable manu-

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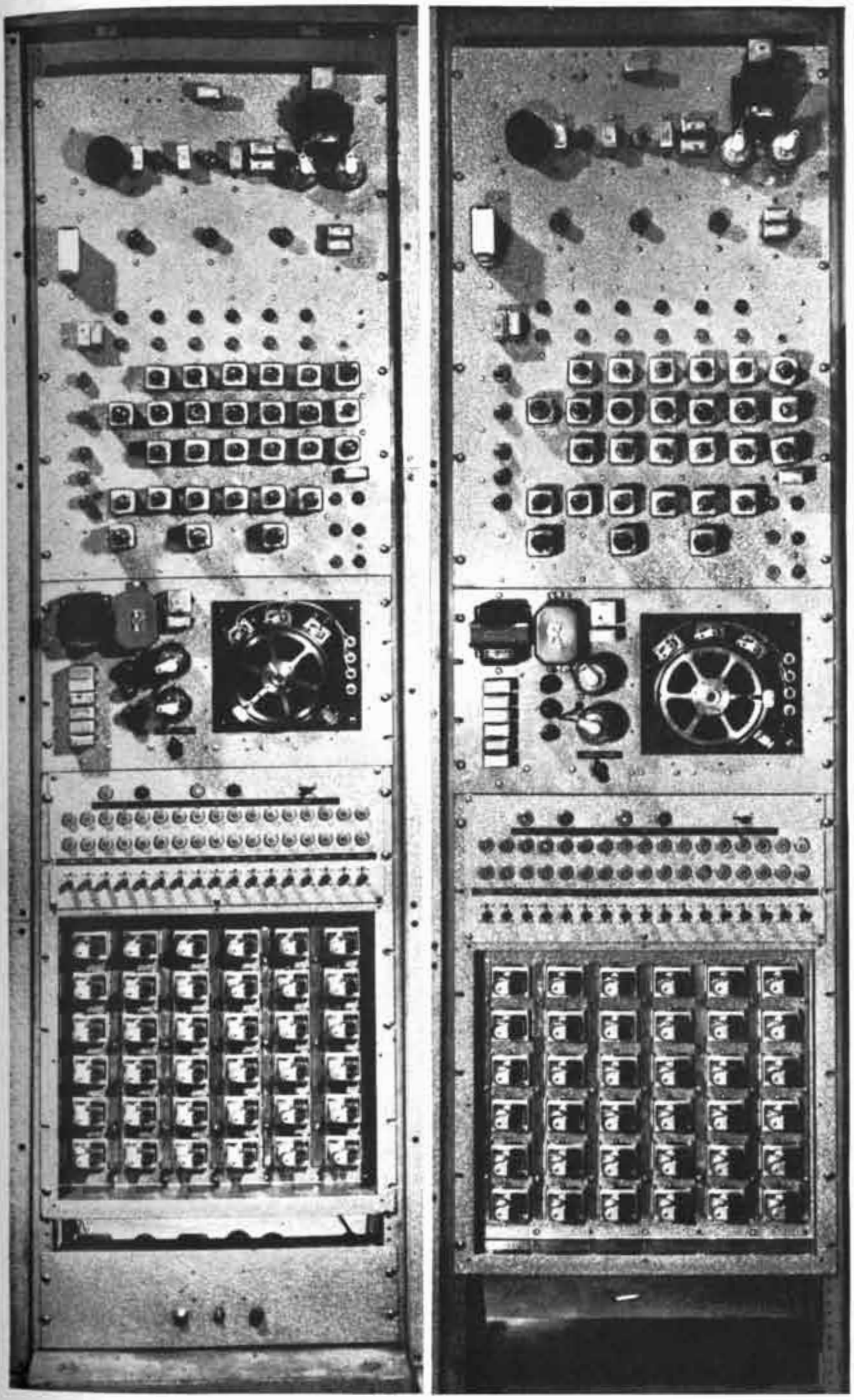

in accord with commands stored in relays. Now coded in pulses, commands flow to decoding servo-mechanisms in three panels at right. These convert pulses into continuously varying signals that drive machine.

facture. The first milling machine suitable for interchangeable manufacture was built by Whitney. In 1862 the Providence inventor Joseph R. Brown developed the universal milling machine, the type in common use today. To these basic tools the 19th century added machines for drilling, punching, sawing and shaping metal.

In a sense the guides, tracks and other devices built into machinery to raise its precision level are a kind of automatic control. This type of automatism is no new concept in the metal-cutting industry. From the beginning machine tools were created to reduce the amount of human skill required in manufacture. These automatic aids to proficiency, always adhering to the double principle of accuracy for interchangeability and speed for economy, have increased through the years.

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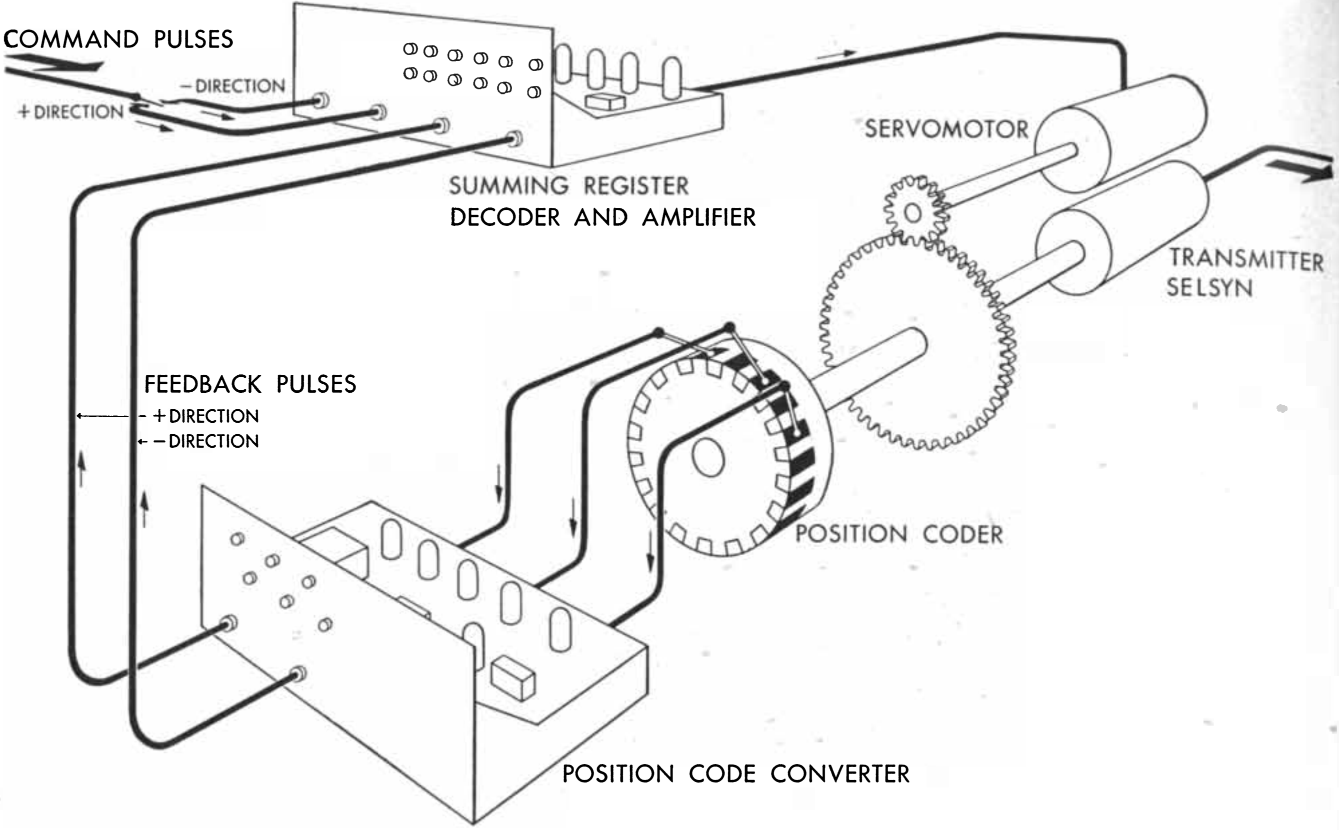
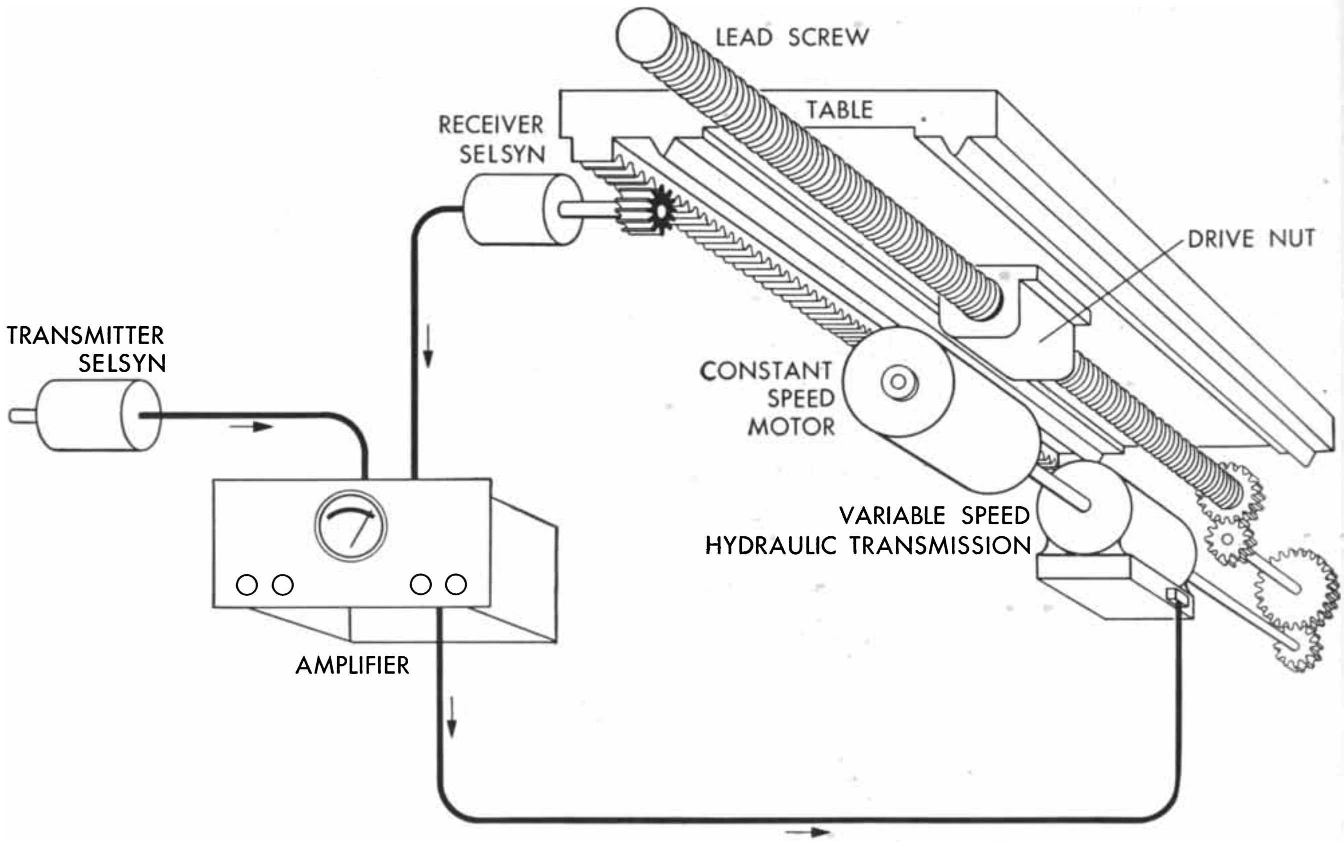


DECODING SERVO-MECHANISM ensures that commands are correctly translated from pulse form into the analogue form of a varying shaft angle. Pulses from amplifier cause servomotor to rotate the transmitter shaft one degree per pulse. Rotation is sensed by brushes on position coder, which feed back one pulse to amplifier for each degree of rotation. Transmitter selsyn converts shaft motion into varying electrical signal.



MACHINE-DRIVE SERVO-MECHANISM ensures that commands in the form of a varying electrical signal from decoding servo-mechanism transmitter are correctly reproduced by the motions of the milling machine. Receiver selsyn under table at right feeds back to amplifier a signal corresponding to the motion of the table. This signal is compared with the transmitter signal and a corrected signal is sent to the table drive.

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manufacturing technique. The reason why they have thus far been untouched by automatic control can be given in terms of the concepts of information flow and feedback control.

A rough measure of the cost of automatic control is the amount and nature of the information the automatic machine must handle. To perform a complicated operation such as manufacturing a metal part, we must build into the machine a great deal of information-handling capacity, for it has to carry out a whole complex of instructions. This initial equipment is expensive. If the machine is to manufacture only a single product, say an automobile crankshaft, in large quantities, the investment is spread over many items and the cost of each crankshaft is small. In such a case the automatic machine is worth its cost.

But suppose we want an automatic machine which will make not one particular product, or part, but a number of different kinds of products, and only a few of each—as the versatile machine tool must do. Now the machine must handle a different set of instructions for each product, instead of the single set of instructions for the crankshaft. In other words, it must be able to deal with more information. And the cost of the information-handling capacity needed for each product is spread over only a few items instead of many. This is the essential problem in automatizing machine tools.

Obviously one way to attack the problem is to economize in the information requirements of the machine for the various operations. What are these requirements? To begin with, the machine tool must orient itself continuously toward the material on which it is working; if it is to drill a hole in a piece of metal, it must drill the hole in the right place and to the right depth.

Early in their history machine tools began to acquire automatic feed mechanisms. Maudslay's screw-cutting lathe, which controlled precisely the distance that the cutting tool was advanced for each revolution of the work piece, was an expression of this principle. Another step toward automatization was Thomas Blanchard's invention in 1818 of the "copying" lathe for turning gunstocks—the first of a class of tools now known as "cam-following" machines. This type of tool is automatically oriented to machine irregular shapes. The information required to specify the irregular shape is stored in a cam built to represent that shape. An important weakness of these machines is that all the force required to position the cutting tool is furnished by the cam itself. It is costly to build a mechanism strong and accurate enough to transfer motion from the cam to the work piece, and the cam wears out.

Feedback control made its first sig-

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Many control systems use relays to perform a switching function responding to electronically computed problem solutions. Sigma makes relays that will do a good job as slaves in such systems.

A Sigma specialty, however, is the design of relays to perform an integral part of the computation. Here are some of the ways that Sigma Sensitive Relays may be used in such a manner.

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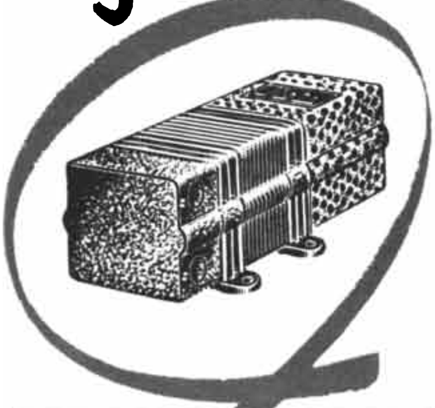

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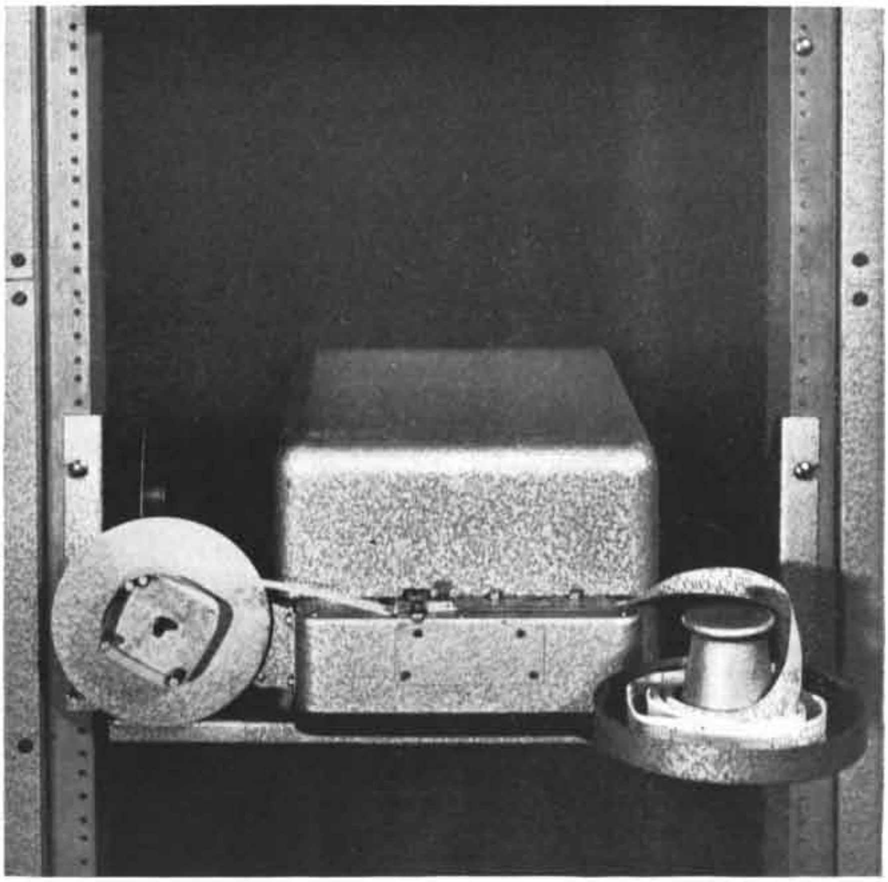
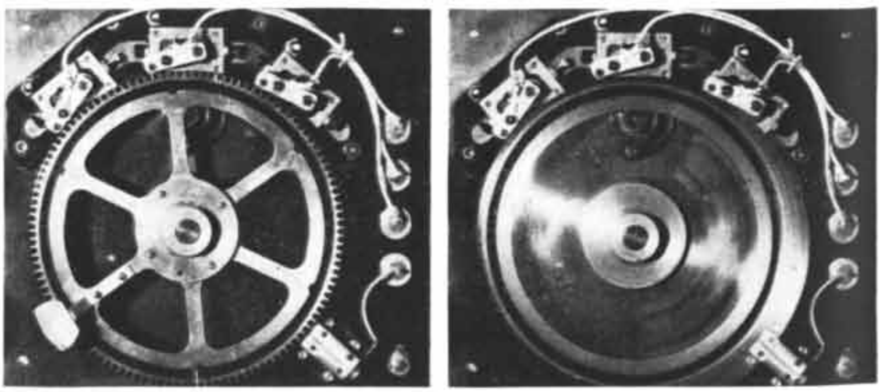


TAPE READER transfers commands from paper tape to relays in control system. Each punch hole closes a relay. Paper tape is not subject to dimensional instability which afflicts cams and other analogue controls.

nificant entrance into the machine-tool field in 1921, when John Shaw, working in the shop of Joseph Keller, invented the Keller duplicating system. In this system the information source is not a cam but a plaster-of-paris or wood model of the part to be machined. An electrical sensory device traces the model shape and transfers the information to the tool. By permitting the use of soft, easily fabricated models, the method reduces the cost of information storage. Modern versions of the duplicating system are embodied in the die-sinking machines of the Pratt & Whitney Division of the Niles-Bement-Pond Company. An hydraulic form of it was originated by Hans Ernst and Bernard Sassen at the Cincinnati Milling Machine Company in 1930. Since World War II a number of manufacturers have developed systems of this kind, employing a variety of electrical, mechanical and optical devices.

A further step in the reduction of the cost of information storage and



POSITION CODER translates the continuous rotation of the decoding servo-mechanism shaft back into pulse code. As the wheel spins, electrical contacts around its rim close circuits with brushes mounted above.

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transfer is promised through the use of digital information processes. A number of applications of digital processes to machine-tool control are currently being made. Let us look in detail at one of the most ambitious of these completed this year at the Massachusetts Institute of Technology.

THE M.I.T. system combines digital and analogue processes under feedback control to govern a milling machine whose cutting tool moves in three planes relative to the work piece. In this case the "model" of the object to be fabricated is supplied to the machine in the form of a perforated paper tape similar to that used in teletype systems. For a typical operation, 10 feet of tape will keep the machine busy for an hour.

The components of the M.I.T. system are grouped into two major assemblies. The first of these, called the "machine," comprises the milling machine itself, the three servo-mechanisms employed to operate its moving parts, and the instruments required to measure the relative positions of these parts. The second assembly, called the "director," contains all the data-handling equipment needed to interpret the information on the tape and to pass it on as operating commands to the machine. The director contains three major elements—a data-input system, a data-interpreting system and a set of three decoding servo-mechanisms.

The purpose of the data-input system is to take the original instructions off the tape and feed them into the interpretive and command elements of the director. It consists of a reader, whose metal fingers scan the tape and report the presence or absence of holes by electrical signals, and a set of six relay registers (two for each of the basic machine motions) which store and transmit this information in numerical form. The registers are supplied in pairs, so that while one of them is in control of the machine, the other can receive information from the tape. At the end of each operating interval, command is transferred instantaneously from one register to the other.

The data-interpreting system picks up the numerical instructions stored in the registers and transmits them as pulse instructions to the decoding servo-mechanisms. These pulses are generated by an electronic oscillator, the "clock," which acts as the master time reference for the entire system. By means of a series of flip-flop switches, and in accordance with the instructions stored in the registers, these pulses are sent on to each of the three decoding servo-mechanisms.

Up to this point in the process, information has been handled in digital form. The three servo-mechanisms now convert the instructions to the analogue

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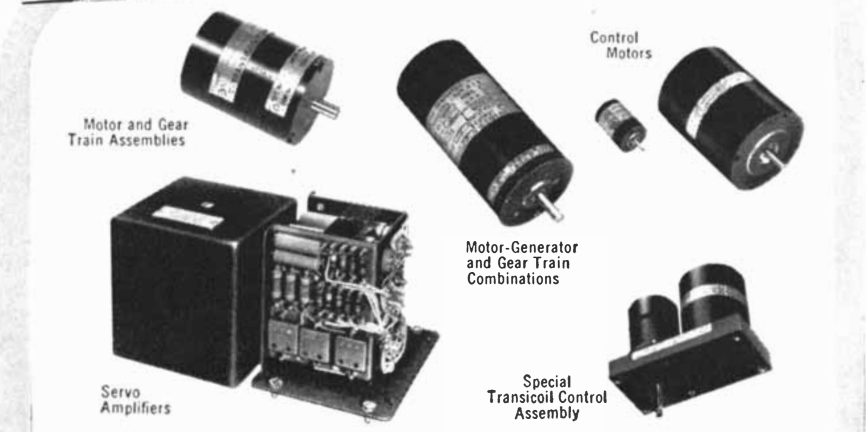

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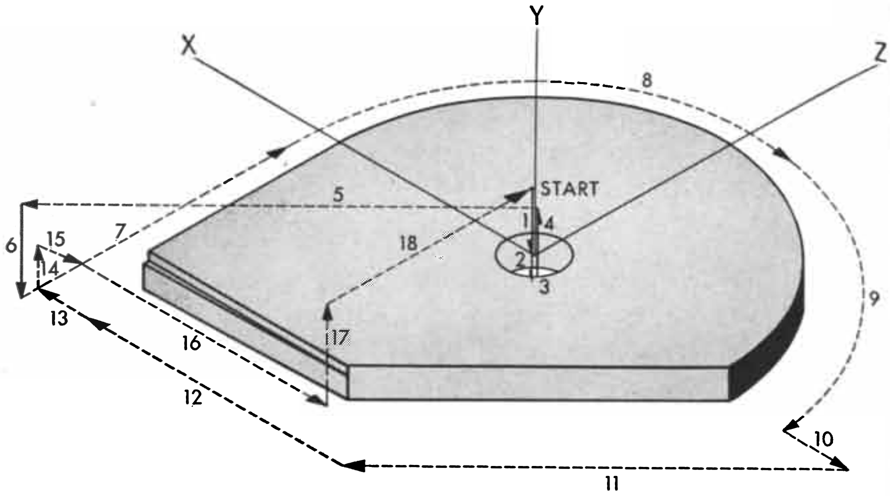
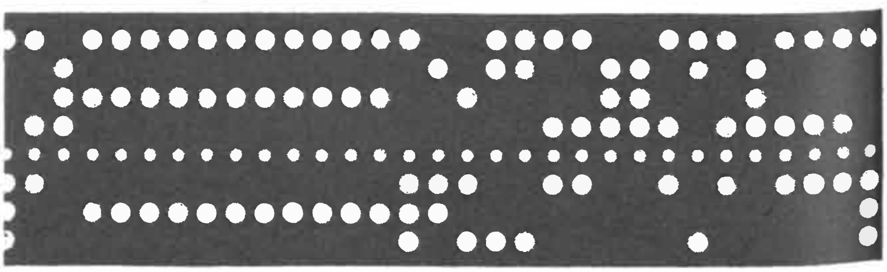


WORK LAYOUT breaks down cam-cutting operation into separate steps for encoding on instruction tape (*below*). Instructions for each motion of the machine may be computed directly from the engineering drawings.

form required by the machine tool. Pulses from the data-interpreting system are translated into the rotation of a shaft—one degree of rotation for each pulse. The shafts are connected to synchro transmitters which are themselves connected to the drive servo-mechanisms of the machine. A feedback circuit, inserted at this point in the director, makes certain that the conversion from digital to analogue information has been accurately carried out. It works as follows:

The mechanical element of each decoding servo-mechanism consists of the shaft connected to the synchro transmitter, a unit called a "coder" and a small two-phase induction servo-motor with appropriate gearing. The coder generates a feedback signal in the form of one electrical pulse for each degree of shaft rotation. The number of these feedback pulses is then compared with the number of pulses emanating from the data-interpreting system by a device called a "summing register." If the two counts agree, the summing register is at zero; if they do not agree, an electric voltage is generated and the two-phase servo-motor rotates the shaft to bring the count to zero. Thus a feedback path makes certain that the output shaft position faithfully corresponds with the series of command pulses from the frequency divider. Information, coded first on tape, converted to digital and then to analogue form, is now transmitted to the working elements of the machine.

Each motion of the machine is accomplished by a lead screw driven by a hydraulic servo-mechanism (*see diagram on page 106*). The motor converts electrical commands received from the decoding mechanisms into the mechanical motions of the machine. Feedback is again introduced at the point of actual cutting to make certain that each element moves according to the instructions of its own decoding mechanism. A standard synchro receiver is coupled to each of the moving elements of the mill in such a way that each .0005 inch of tool travel causes the shaft of the synchro receiver to rotate one degree. The feedback signal derived from this shaft position is compared with the shaft position of the synchro transmitter at the decoding mechanism. Any difference of position between the two shafts appears as an alternating-current voltage which controls the speed of the hydraulic transmission. Thus the ma-



TAPE encodes commands in punch holes. The three lower horizontal rows contain commands for cross-slide, head and table motions, from top to bottom. Small holes in center engage sprocket drive of tape reader; four upper rows contain checking signals. The vertical line of four holes at either end and middle are "block" signals dividing commands into steps as shown in work layout above. Commands are for steps 6 and 7.

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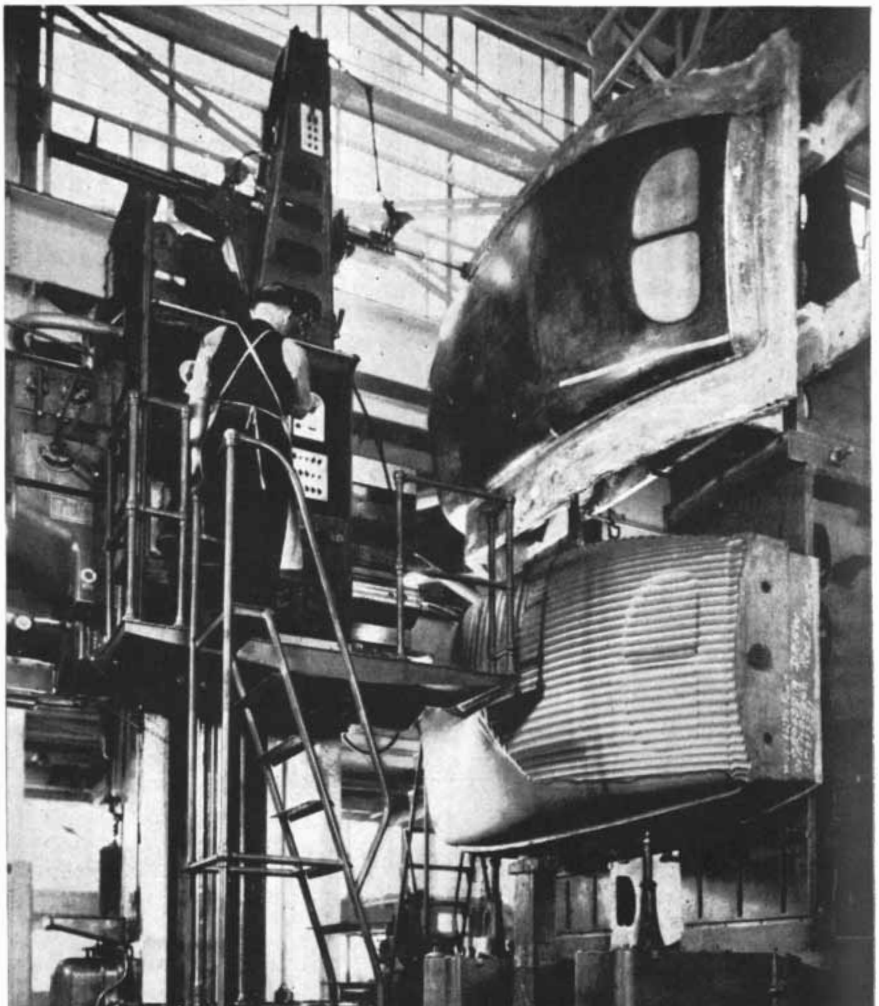
chine element follows continuously the rotations of the synchro transmitter in the ratio of .0005 inch of linear travel to each degree of rotation.

HOW ARE the instructions for the machine's job put on the tape? The desired path of the cutting tool over the work is reduced to incremental straight-line segments; the segments are specified by numbers, and these are then translated into a code which can be punched on the tape.

The cutting path and the speed at which the work is to be fed to the machine are based on a number of factors: the amount of stock to be removed, the sequence of the machining operations, the setup of the work on the machine, spindle speeds, and so on. After the human operator determines the locus of the cutter center which will produce the desired cutting path, he divides the locus into a series of straight-line segments. They should be as long as possible without differing from the ideal tool-center locus by more than the machining tolerance. The dimensions of each straight-line segment are then resolved into components parallel to each of the three directions of motion of the machine. For each straight-line segment, a time for execution is chosen to produce the desired feed rate. All this—the cutter motions and the time—is tabulated in a predetermined order to form a single set of control instructions. A separate set of instructions is made for each segment, in the order in which they will be used by the machine. The instructions, translated into patterns of holes, are punched in the paper tape by a special typewriter keyboard.

By inserting a new reel of tape for



KELLER MACHINE shapes die for an auto top. Via a feedback loop, contour follower on surface of model at top guides cutting tool on work below.

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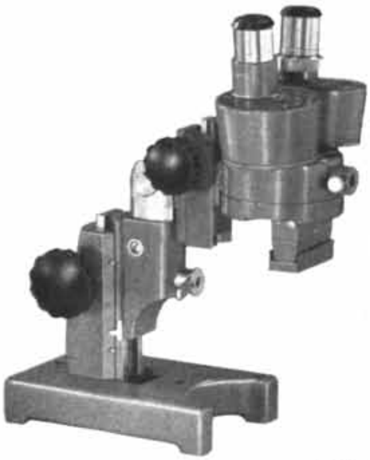

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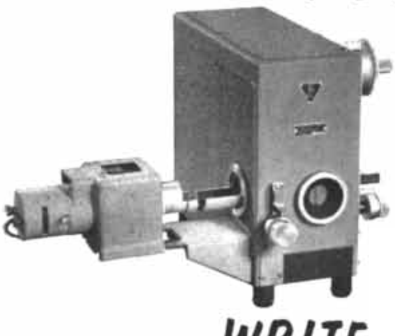

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single product. Huge investment must be written off on mass production.

will perform any kind of work without the guidance of a human hand. The possible economic effects of such machines, on many industries besides metal-cutting, are beyond prediction. Automatized general-purpose machine tools, combined with high-production special-purpose tools, would make possible the automatic metals-fabricating factory. Nor are we restricted to metals. With digital machines in control we can conceive of factories which will process, assemble and finish any article of manufacture.

It is unlikely that the automatic factory will appear suddenly. Like the machine tool itself, it will just grow by steps until eventually it is here.

William Pease is associate professor of electrical engineering at the Massachusetts Institute of Technology.

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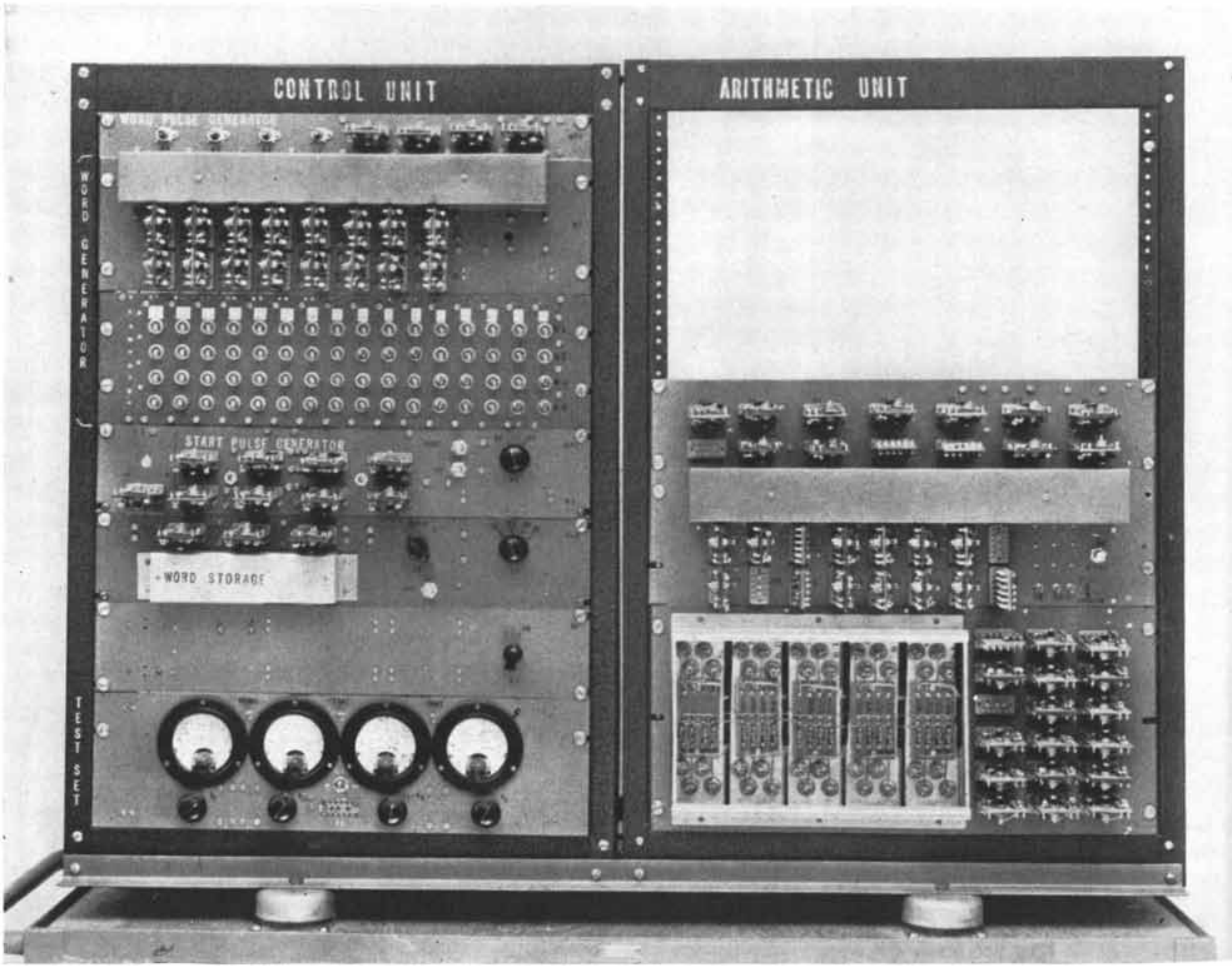
THE ROLE OF THE COMPUTER

The multifarious control loops of a fully automatic factory must be gathered into one big loop. This can best be done by means of a digital computing machine

by Louis N. Ridenour



COMPUTER OF THE FUTURE is suggested by this experimental machine built by J. H. Felker of Bell Telephone Laboratories. Instead of vacuum tubes or relays it uses germanium diodes as its logic elements. It also uses the germanium triode, or transistor, as an amplifier. Because these germanium devices are about the size of a pea, a computer utilizing them is much smaller than an equivalent machine employing vacuum tubes or relays. The germanium diodes and triodes also use very little power; the entire computer draws only 5 watts. The machine is capable of multiplying 4,000 16-digit binary numbers a second. One of its interesting features is that each of its 80 transistors is part of an identical plug-in unit (*see pages 124 and 125*).

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IF THE thermostat is a prime elementary example of the principle of automatic control, the computer is its most sophisticated expression. The thermostat and other simple control mechanisms, such as the automatic pilot and engine-governor, are specialized devices limited to a single function. An automatic pilot can control an airplane but would be helpless if faced with the problem of driving a car. Obviously for fully automatic control we must have mechanisms that simulate the generalized abilities of a human being, who can operate the damper on a furnace, drive a car or fly a plane, set a rheostat to control a voltage, work the throttle of an engine, and do many other things besides. The modern computer is the first machine to approach such general abilities.

Computer is really an inadequate name for these machines. They are called computers simply because computation is the only significant job that has so far been given to them. The name has somewhat obscured the fact that they are capable of much greater generality. When these machines are applied to automatic control, they will permit a vast extension of the control art—an extension from the use of rather simple specialized control mechanisms, which merely assist a human operator in doing a complicated task, to over-all controllers which will supervise a whole job. They will be able to do so more rapidly, more reliably, more cheaply and with just as much ingenuity as a human operator.

To describe its potentialities the computer needs a new name. Perhaps as good a name as any is "information machine." This term is intended to distinguish its function from that of a power machine, such as a loom. A loom performs the physical work of weaving a fabric; the information machine controls the pattern being woven. Its purpose is not the performance of work but the ordering and supervision of the way in which the work is done.

There are in current use two different kinds of information machine: the analogue computer and the digital computer. Several excellent popular articles have discussed the characteristics of these two types of computer; here we shall briefly recall their leading properties and then consider their respective possibilities as control mechanisms.

THE ANALOGUE machine is just what its name implies: a physical analogy to the type of problem its designer wishes it to solve. It is modeled on the simple, specialized type of controller, such as a steam-engine governor. Information is supplied to the machine in terms of the value of some physical quantity—an electrical voltage or current, the degree of angular rotation of a shaft or the amount of compression

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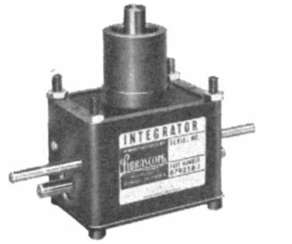

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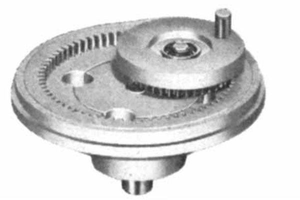
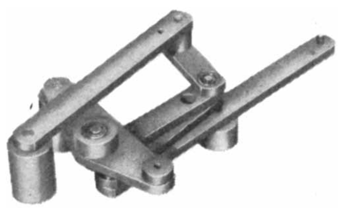


LINKAGES

For addition, subtraction, multiplication, division and generation of arbitrary functions.



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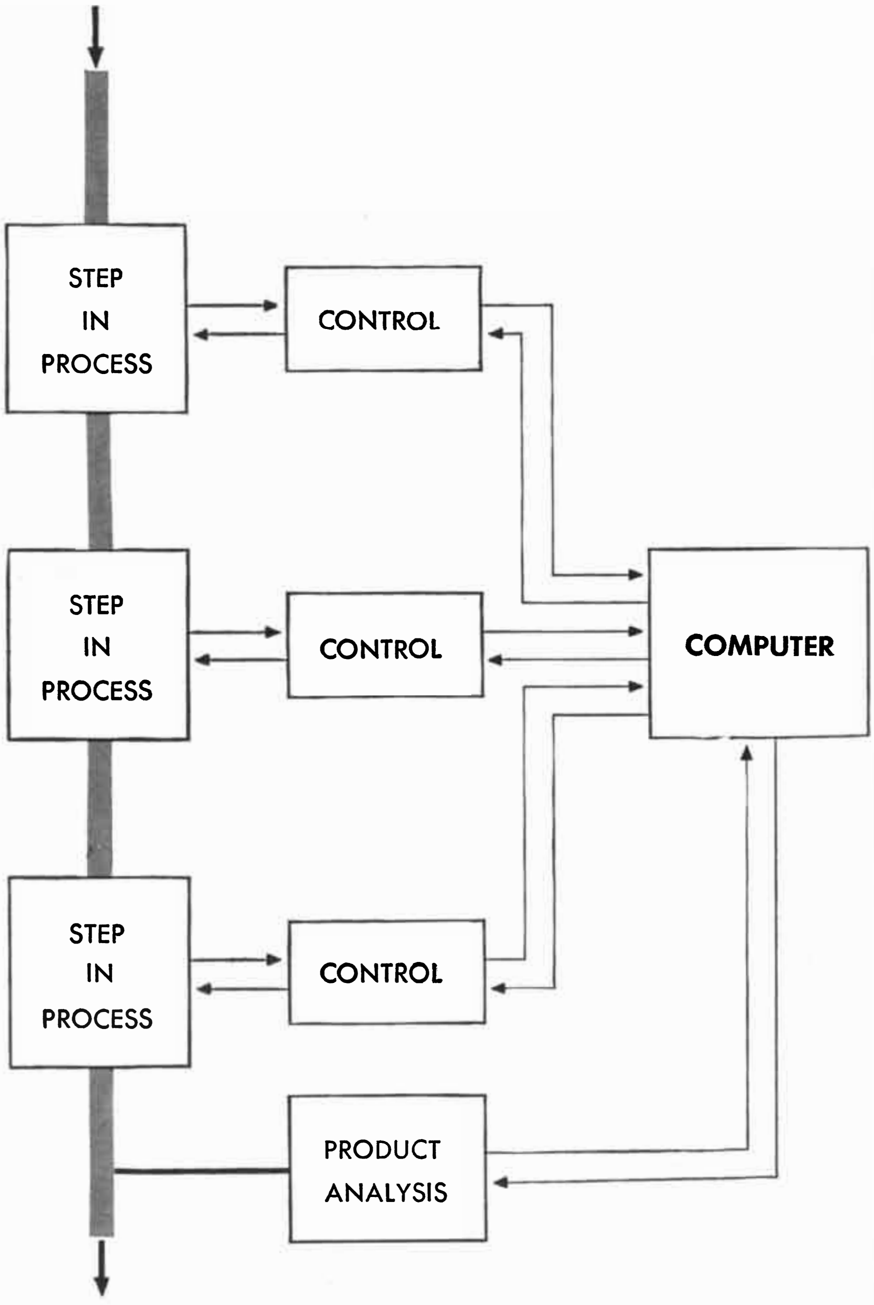
of a spring. The machine transforms this physical quantity into another physical quantity in accordance with the rules of its construction. And since these rules have been chosen to simulate the rules governing the problem, the resulting physical quantity is the answer desired. If the analogue machine is being used as a control device, the final physical quantity is applied to exercise the desired control.

Consider, as an example, the flyball-governor pictured on the cover, whose purpose is to hold a steam engine to a constant speed. We notice, first, that information on the engine speed reaches the governor in the form of the speed of rotation of a shaft, while the output of the governor is expressed as the motion of a throttle which is closed or opened as the whirling balls rise or fall. Second, we notice that the relation between these two physical quantities is determined by the actual construction of the governor. The design of the controller has been dictated by its function.

In contrast to the analogue machine, a digital machine works by counting. Data on the problem must be supplied in the form of numbers; the machine processes this information in accordance with the rules of arithmetic or other formal logic, and expresses the final result in numerical form. There are two major consequences of this manner of working. First, input and output equipment must be designed to make an appropriate connection between the log-



ROLE OF THE COMPUTER is shown in block diagram. Computer receives information from product analysis and feeds it into the various control loops.

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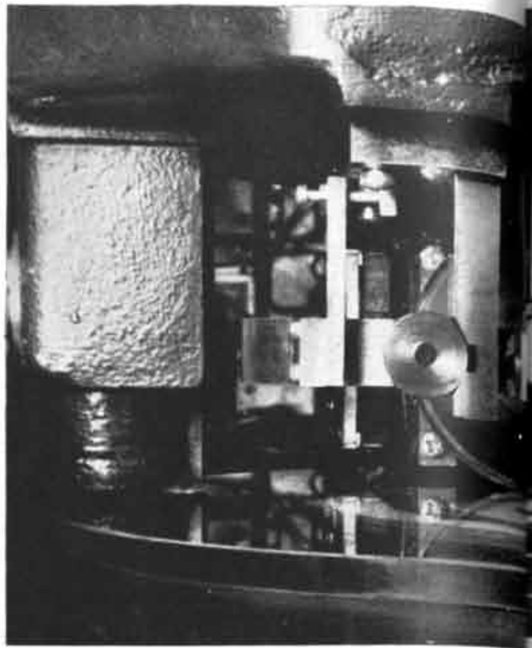
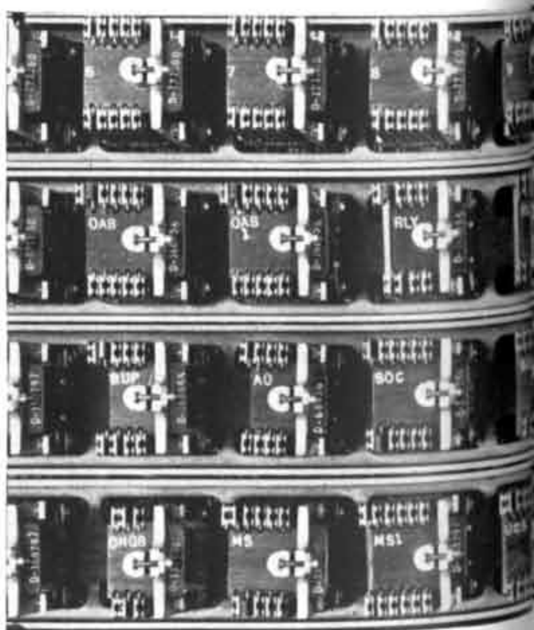


ANALOGUE DEVICE integrates variables with two disks. One variable

ical world of the digital machine and the physical world of the problem being solved or the process being controlled. Second, the problem to be solved must be formulated explicitly for the digital machine. In the case of the analogue machine, the problem is implicit in the construction of the machine itself; construction of a digital machine is determined not by any particular problem or class of problems but by the logical rules which the machine must follow in the solution of *any* problem presented.

Thus far the need for specialized input and output equipment, more than any other factor, has restricted the role of digital information machines to computing. In a computation, both the in-



DIGITAL DEVICE such as the relay does not measure but counts. Shown

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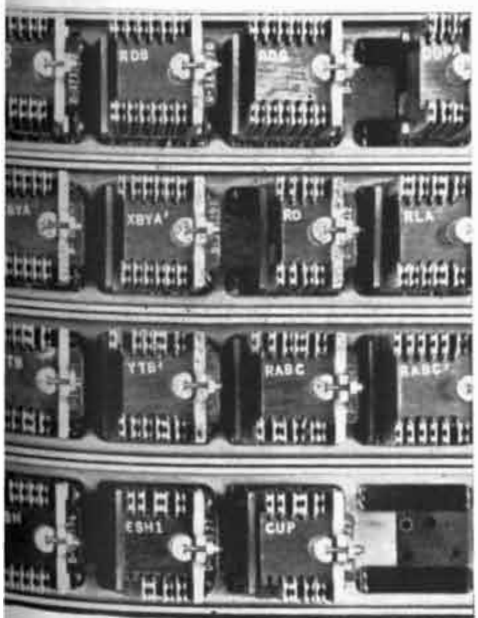
is given by position of small disk; the other, by angle of large disk.

put and the output quantities are numbers, so the most rudimentary equipment will suffice to introduce the problem and register the result. There is no need (as there would be in a control application) to transform various physical quantities into numerical form before submitting them to the machine, or to transform the results of the calculation into a control action, such as moving a throttle. To use a digital information machine as a computer it is necessary only to provide (1) an input device such as a teletypewriter, which with the help of a human operator can translate printed numbers into signals intelligible to the machine, and (2) an output device such as a page-printer or electric



here is part of a panel of relays in a Bell Laboratories digital computer.

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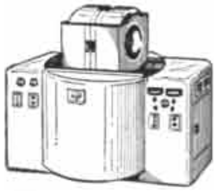

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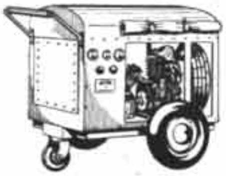

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ADVANCED EQUIPMENT

LARGE ANALOGUE COMPUTER is exemplified by the machine of Project Typhoon, built by the Radio Corporation of America to simulate the

typewriter, which can translate the signals generated by the machine into the printed numbers intelligible to men. Even this simple requirement, however, has not always been well met by the designers of information machines.

When a digital information machine is to be used as an instrument of control—and we can confidently expect that this will eventually be its major role—the design of input and output equipment becames a more formidable task. While it is true that the structure of the machine itself depends on principles of logic rather than on the nature of its application, this is by no means true of the input and output elements. The input devices, or receptors, can use standard elements for receiving the program of instructions, but they must also receive data specifying the state of the particular process being controlled, and for this the detailed design will vary widely from one application to another. Similarly the effectors, which exercise the machine's control, must be designed in terms of the nature of the process or device being controlled.

In comparing digital and analogue machines as instruments for automatic control, we observe, first, that for simple control applications the analogue machine is almost always less elaborate than a digital machine would be. Even the most elementary digital machine requires an arithmetical (or logical) unit, a storage unit, a control unit, receptors and effectors. For simple problems, this array of equipment is wastefully elaborate. In contrast, an analogue machine need be no more complicated than the problem demands. A slide rule, for example, is a perfectly respectable information machine of the analogue type. The analogue machine's ability to do simple work by simple means explains its current predominance in the field of automatic control. The whole control art is so new and so little developed that most of the problems thus far tackled have been of a rather elementary nature.

As the control task becomes more complex, however, the analogue machine loses its advantage, and we begin to see a second fundamental difference

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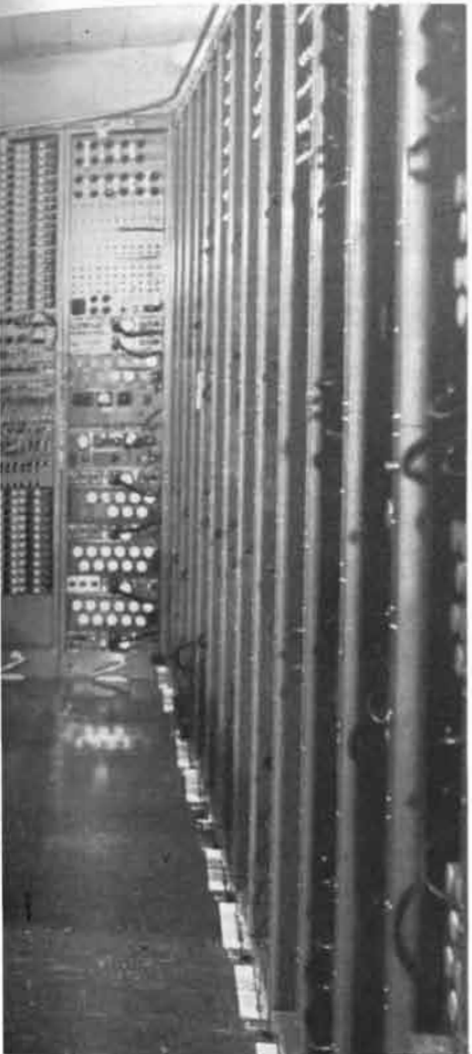

performance of guided missiles, aircraft, ships, submarines and so on.

between the two types of machine. The analogue machine is a physical analogy to the problem, and therefore the more complicated the problem, the more complicated the machine must be. If it is mechanical, longer and ever-longer trains of gears, ball-and-disk integrators and other devices must be connected together; if it is electrical, more and more amplifiers must be cascaded. In the mechanical case, the inevitable looseness in the gears and linkages, though tolerable in simple setups, will eventually add up to the point where the total "play" in the machine is bigger than the significant output quantities, and the device becomes useless. In the electrical case, the random electrical disturbances called "noise," which always occur in electrical circuits, will similarly build up until they overwhelm the desired signals. Since "noise" is far less obtrusive than "play," electrical analogue machines can be more complicated than their mechanical equivalents, but there is a limit. The great machine called Typhoon, built by the Radio Corporation of America for the simulation of flight performance

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SPEED OF OPERATION—basic pulse rate 120 kcs., average time for internal operations 40 milliseconds, tape instructions approximately 1¼ seconds per block, typing out operation at rate of 10 characters per second.

TYPEWRITER—Flexowriter fully controlled by machine. Programmed output operation calls for typing out blocks of 64 words on eight lines with automatic carriage returns and spaces between words, using octal representation, or typing out any number of words using *decimal and alphabetic* representation. Manually initiated input of single word to any desired address, or sequences of words with any desired starting address. *Input may be either octal or decimal and alphabetic.*

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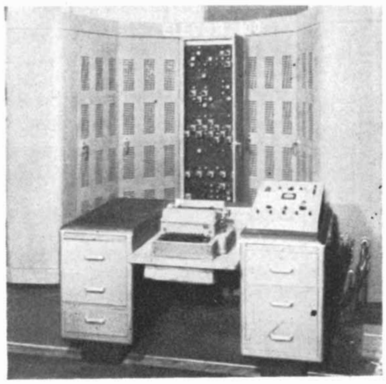

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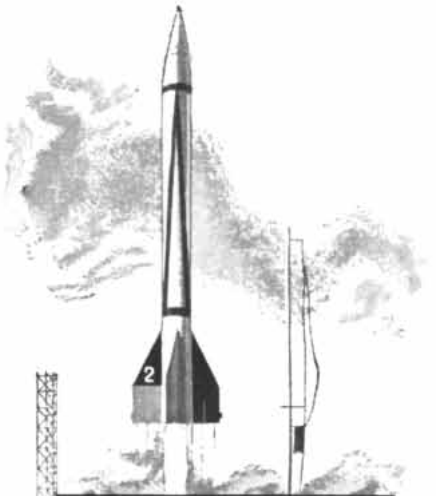

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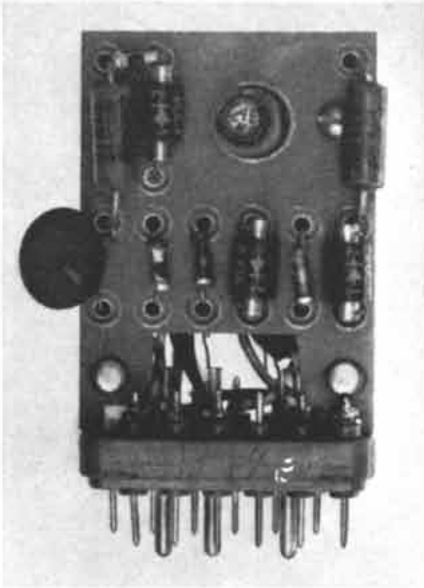

AMPLIFIER for the Bell Laboratories computer on page 116 is a standard unit an inch and a half wide.

in guided missiles, closely approaches that limit. It is perhaps the most complicated analogue device ever built, and very possibly the most complicated that it will ever be rewarding to build.

The digital machine, on the other hand, is entirely free of the hazards of "play" and "noise." There is no intrinsic limit to the complexity of the problem or process that a digital machine can handle or control. The switching system of our national telephone network, which enables any one of 50 million phones to be connected to any other, is a digital machine of almost unimaginable complexity.

THE THIRD important difference between analogue and digital machines is in their accuracy potential. The precision of the analogue machine is restricted by the accuracy with which physical quantities can be handled and measured. In practice, the best such a machine can achieve is an accuracy of about one part in 10,000; many give results accurate to only one or two parts in 100. For some applications this range of precision is adequate; for others it is not. On the other hand, a digital machine, which deals only with numbers, can be as precise as we wish to make it. To increase accuracy we need only increase the number of significant figures carried by the machine to represent each quantity being handled. Of course in a control operation the machine's over-all precision is limited by possible errors in translating physical quantities into numbers and *vice versa*, but this does not alter the fact that where high precision is required, a digital machine is usually preferable to the analogue type.

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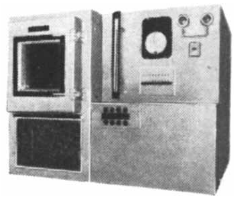

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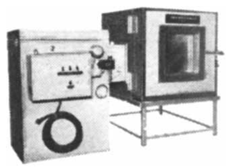

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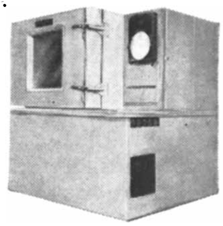

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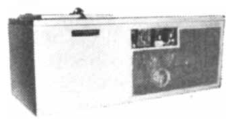

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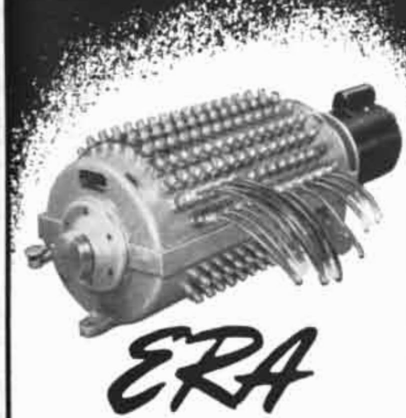

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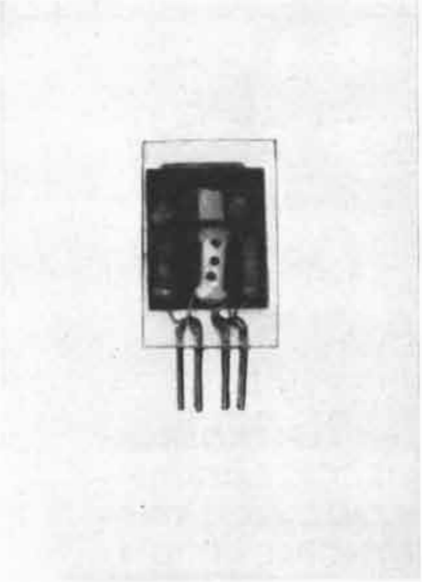

REFINEMENT of amplifier on opposite page is only 3/4 inch wide, suggesting even smaller computers.

two machines differ. An analogue machine works in what is called "real time." That is, it continuously offers a solution of the problem it is solving, and this solution is appropriate at every instant to all the input information which has so far entered the machine. If the machine is doing a mathematical problem, for example, it need not formulate explicitly the equations to be solved and then go through the steps of solving them, as a digital machine would have to do. The equations are inherent in the very structure of the machine, and it solves them by doing just what it was built to do. It can thus respond promptly to changing input data, and offer an up-to-date solution at every moment. This property of working in "real time" is very important in most problems of automatic control. An autopilot flying a plane must respond at once to an attitude change resulting from a gust of wind; the most precise information on how to adjust the flight controls will be worthless if it comes 30 seconds too late.

Since a digital machine works by formulating and solving an explicit logical model of the problem, it can work in "real time" only if the time it requires to obtain a solution, given new input data, is short compared with the period in which significant changes can take place in the system being controlled. Present-day digital machines can achieve this speed for many important problems—flight control of aircraft, for example—but they are not yet fast enough to handle all the "real-time" problems that we should like to turn over to them. It has been estimated that the fastest existing digital machines are some 20 times too slow to deal with the problem of simulating the complete flight performance of a high-speed guided missile—the

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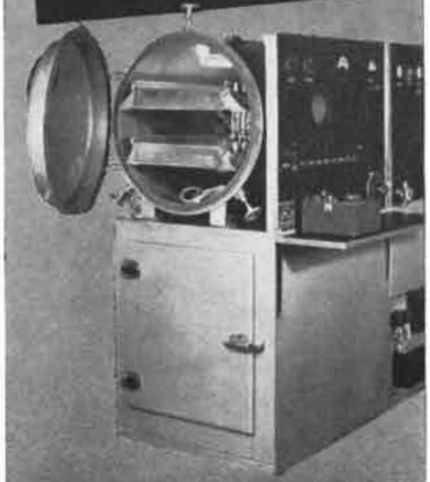

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problem that Typhoon was built to handle. As development proceeds, the operating rates of digital machines can be expected to increase rapidly.

We see, then, that both analogue and digital machines can be used for automatic control, and each has advantages in its own sphere. For simple applications in which no great precision is required, an analogue controller will usually be preferable. For complex problems, or problems in which high precision is required, a digital controller will be superior. Where "real-time" computations must be made, analogue machines are almost always used now, though digital machines are beginning to achieve speeds that fit them for this type of application.

All this refers to the present state of the art of automatic control. What can we guess about the developments to come?

The simple specialized analogue controllers already in use will surely be extended to wider application. But the most significant and exciting prospects reside in the digital machine. We can expect that it will soon open up a new dimension of control. The meaning of this prediction can be admirably illustrated in terms of the highly instrumented catalytic cracking plant which Eugene Ayres has described in a preceding article.

Mr. Ayres tells us of a plant in which there are some 150 different analogue controllers, each governing some aspect of the continuous process that the plant performs. Several hundred indicators on a central control panel offer the most detailed information on system performance. Many of these indicating instruments also provide continuous recordings. Manual controls which can override any automatic controller are present for use in emergency. The instruments and controls have been arranged on a flow diagram which simulates the organization of the plant and helps the human operator to find his way through the complexities of instrumentation. And the most important process-controls are adjusted manually according to the results of a periodic product analysis.

Clearly the human operator is still the master of this "automatic" plant. However elaborate the instrumentation, the readings of the instruments are still presented to men; however competent the automatic controllers, provision for human veto of their action is built into every one of them. Men are expected to meet emergencies, and to take control under "conditions of unstable equilibrium such as starting up or shutting down." The cracking plant is automatic only when the unexpected is not happening; in times of stress it falls back on human control, and its whole design is dictated by this necessity.

To this scheme there will soon be

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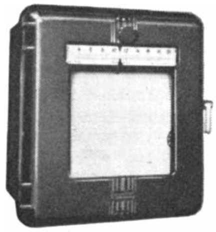

● The operating precision of the thousands of Speedomax Recorders and Controllers which serve industry and science begins with the engineering of components like this Converter. Our specifications apply at all stages—all the way back to the plants which make metals, insulation materials, etc., for us. These specs represent also the best thinking of our suppliers' engineers. The resulting materials are thus quality-controlled for us—and us alone.

From these materials our engineers tell our factory how to make converter parts to truly tight specifications. Some parts require principally flatness, or elasticity, or dimensional stability. Reeds need correct natural frequency. Many parts of course combine various needs; each gets its requirements.

Life tests show Fidelity and Stamina. Ingenious and often original design creates from these parts a converter with noise level equivalent to only 0.2 microvolt in an emf potentiometer circuit. And this fidelity promotes accurate measurement and control.

Running on life tests since 1948, present-model converters are today still well inside performance tolerances. Such a run equals 21.9 years of 8-hours-a-day, 200-days-a-year-service—or 1.9 years more than the present age of the first Speedomax.

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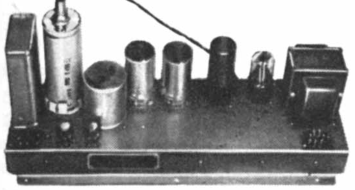
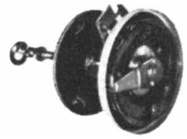
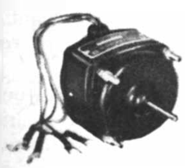


Good engineering shows in this Amplifier's thorough filtering, high impedance, and plug-in connection to the rest of the Speedomax.



Good engineering shows in this Slidewire's non-inductive winding and in absence of any flexible leads which might form inductive loops.



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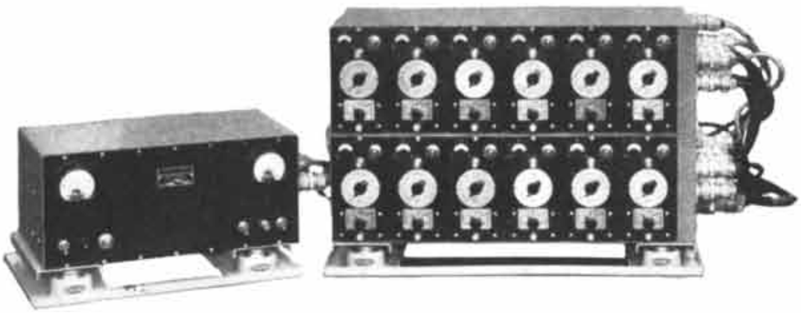

The Century Vibration and Stress Analysis System provides all of the necessary equipment to amplify and record vibration and stress-strain phenomena over a frequency range from 0 to 2000 cps.

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added end-point control—continuous adjustment of the main process-controls on the basis of a continuous product analysis within the system itself. This modification will improve performance, but it will leave the situation essentially as it was before: more routine responsibility will be given to machinery, but the human supervisor will still be vital to proper operation.

THE DIGITAL information machine, employed as an instrument of supervisory automatic control, can change this picture radically. Since such a machine can be instructed to perform any set of logical operations, however complicated, it can be programmed at the outset to react in emergencies precisely as would a well-instructed human operator—and it can react at least a thousand times faster. Further, the machine can be given a set of criteria for appraising the relative success of its various acts, and can be enabled to alter its own program of instructions in the light of experience on the job. Hence it will be capable of "learning" and of finding a better way to perform its operations than the one prescribed in the original instructions. And this universally adaptable machine can encompass the tremendous job of orchestrating the joint behavior of the hundreds of individual analogue controllers built into a modern cracking plant. The same machine can regulate the performance of the factory and keep the necessary accounting records.

The replacement of human operators in a refinery by a control machine would probably result in substantial economies, both in first cost and in operating cost per unit of product. Most of the saving in first cost would come from the elimination of the costly display and recording instruments that human operators require. In a machine-controlled plant, display would be unnecessary. The measurements vital to the process would be communicated directly to the control machine and processed there. The machine would issue the necessary commands to the specialized controllers which served it, and would print out in fully digested form the summary records of plant performance.

The saving in operating cost would come, not from eliminating the salaries of the few displaced operators, but simply from the fact that the machine could do a more efficient job. A human operator, even one of the greatest virtuosity, is a bottleneck in modern plant performance. Mr. Ayres has told us how the modern cracking plant simply cannot be operated, even by throngs of men, if its individual automatic controllers are left out. The cracking plant of tomorrow, controlled by a suitable information machine, will similarly be beyond the powers of human operators, even skillful ones equipped with all the control instrumentation—of

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To solve this problem—to keep strip from running crooked—all sorts of schemes have been tried; crowned rolls, higher tension on the strip, side guides. None of them worked as hoped for. Each merely added new problems of its own. To make matters worse, with recent trends to longer strip, to higher speeds and longer processing lines, these tracking and aligning difficulties were further aggravated.

But the answer has been found. In the development of the Lorig Aligner, United States Steel has come up with a novel, yet surprisingly simple solution. For these rolls, named for the inventor—a U. S. Steel engineer—are *automatically* self centering. Set in the continuous-annealing line shown here, they now track the strip—no matter what its speed—relentlessly toward the center of the roll. These remarkable rolls even *anticipate* trouble and realign wayward strip 30 feet *before* it reaches the roll.

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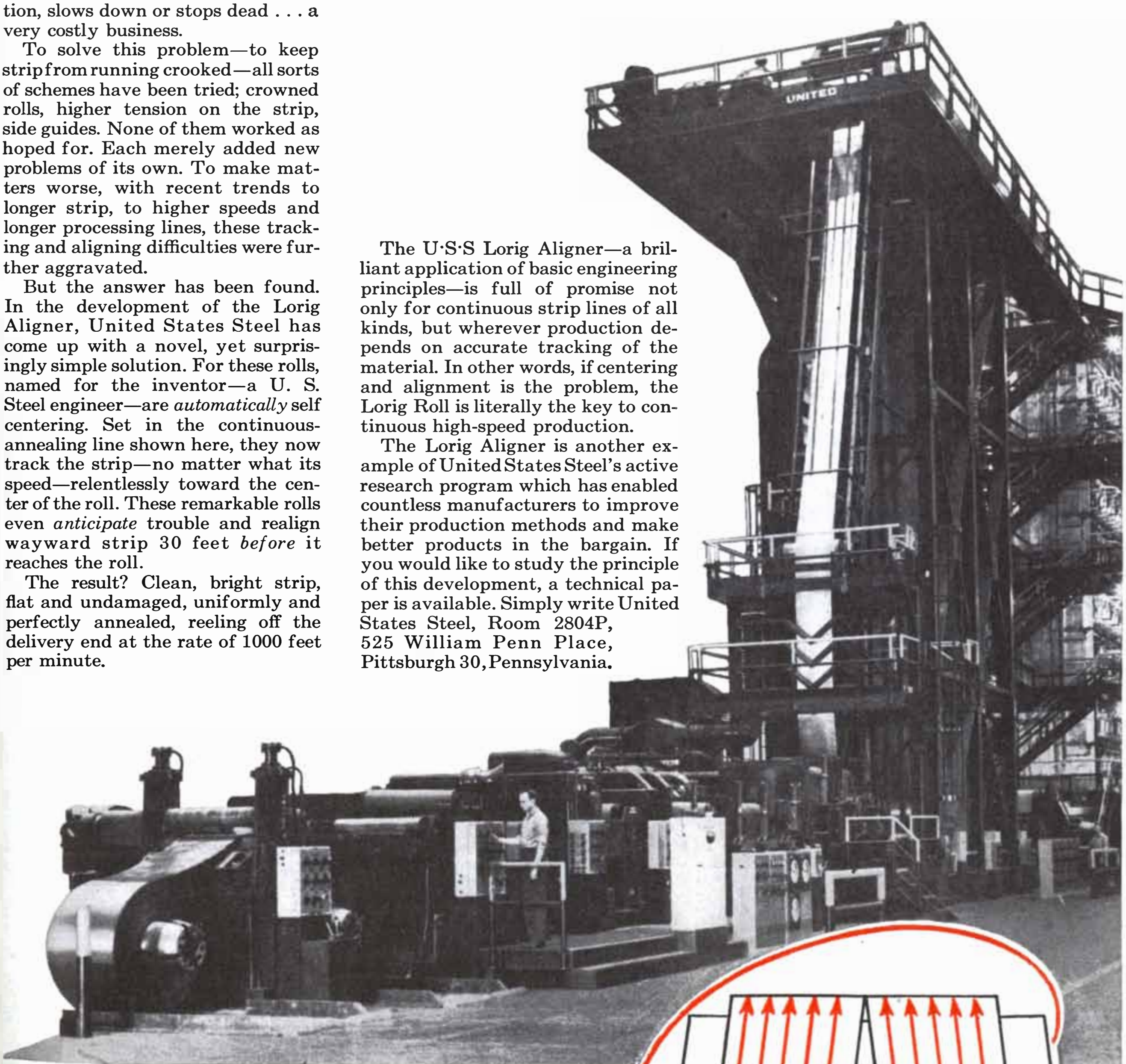
The U·S·S Lorig Aligner—a brilliant application of basic engineering principles—is full of promise not only for continuous strip lines of all kinds, but wherever production depends on accurate tracking of the material. In other words, if centering and alignment is the problem, the Lorig Roll is literally the key to continuous high-speed production.

The Lorig Aligner is another example of United States Steel's active research program which has enabled countless manufacturers to improve their production methods and make better products in the bargain. If you would like to study the principle of this development, a technical paper is available. Simply write United States Steel, Room 2804P, 525 William Penn Place, Pittsburgh 30, Pennsylvania.



THE U·S·S LORIG ALIGNER consists of a divided roll (conical effect exaggerated at the right) with each conical half running on a common rotating axle that is slightly deflected in the center so that the upper surfaces of the cones form a straight surface. As the strip passes over the roll, strongly converging lateral forces are set up to exert a powerful centering action on the strip that immediately corrects any deviation and keeps the strip running straight and true.

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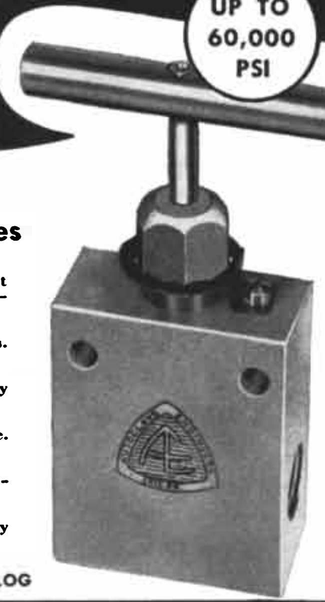

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the present variety—that can be devised.

The difficulty of designing a control room which will not baffle the operators is already substantial in present plants. This means that designers cannot increase the complexity of the plant, or its speed of operation, even though such changes might enhance efficiency. Removal of the limitations of human supervisors will open the way to vast design improvements. The information machine can remove them.

SOME CHEMISTS think that a big new development in industrial chemistry lies just ahead, a development based on exploiting certain new types of reactions. These are fast reactions which take place within microseconds, reactions of gases flowing at velocities above the speed of sound, and reactions that will make it possible to capture valuable but fleeting intermediate products in a chemical system by preventing the system from reaching equilibrium. The enthusiasts say that the jet engine is the model of the chemical plant of the future. A supersonic chemical plant of the kind envisioned cannot be operated by men in white overalls reading carefully arranged gauges in an elaborate control room; the speed of nerve impulses from eye to brain to muscle is just too slow for that. Reactions occurring in microseconds must be controlled by machines that can respond in microseconds. Men will design these machines, build them and give them instructions, but men will never be able to compete with their performance.

If this last assertion seems outrageous, it is not more outrageous than it once was to assert that a man could design and build a derrick which would lift a load no man could ever budge. We are familiar with power machinery, and we take for granted its superiority to human muscles. We are not yet familiar with information machinery, and we are therefore not prepared to concede its superiority to the human nervous system. Nevertheless, a digital information machine can surpass human capabilities in any task that is governed by logical rules, no matter how complicated such rules may be.

Man's machines are beginning to operate at levels of speed, temperature, atomic radiation and complexity that make automatic control imperative. As an instrument of over-all automatic control the digital information machine has a great but as yet untouched potential. In the next few years this potential will begin to be realized, and the results are certain to be dramatic.

Louis N. Ridenour, physicist, was formerly Chief Scientist of the Air Force. He is now vice president of the International Telemeter Corporation.

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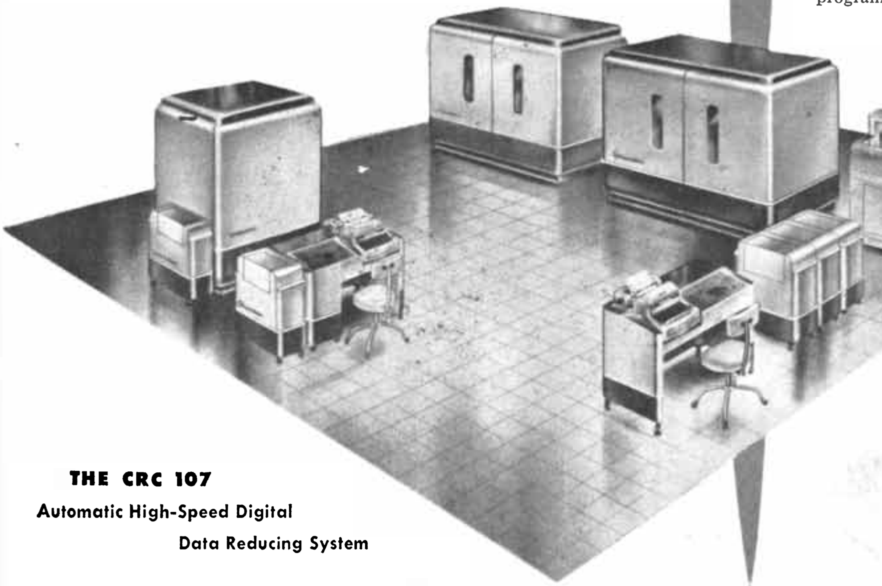

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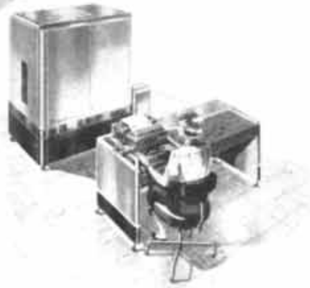

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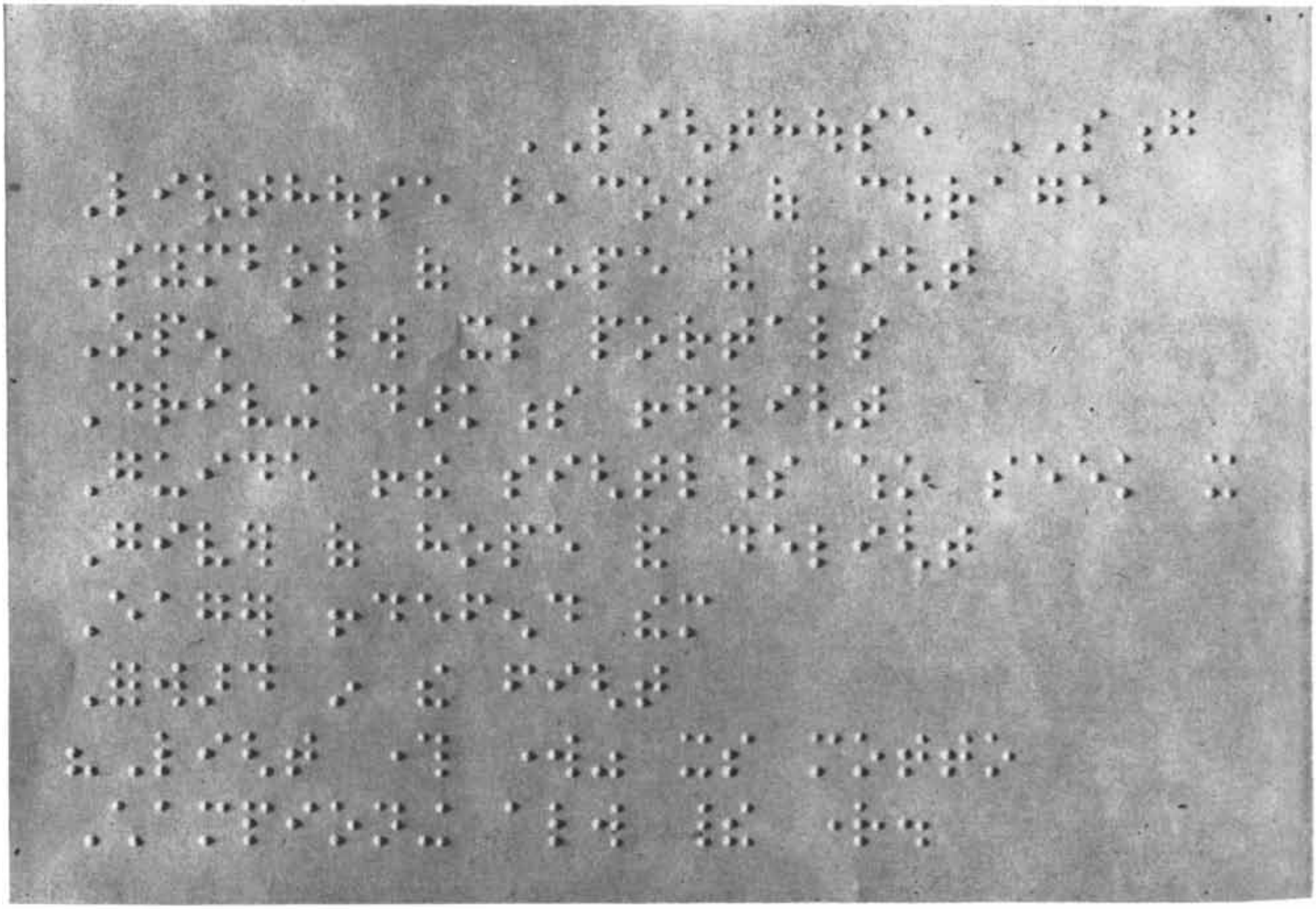
Information

The surprising discovery that it is subject to the same statistical treatment as heat facilitates its storage and handling in automatic control systems

by Gilbert W. King

THE "lifeblood" of automatic control is information. To receive and act on information is the essential function of every control system, from the simplest to the most complex. It follows that to understand and apply automatic control successfully we must understand the nature of information itself. This is not as simple as it may seem. Information, and the communication of it, is a rather subtle affair, and we are only beginning to approach an exact understanding of its elusive attributes.

Think of a thermocouple that records the temperature of a furnace. The instrument translates the temperature into a voltage. This information seems straightforward enough. But as soon as we put it into a practical feedback loop to control the furnace temperature, we discover that the voltage signal is not a "pure" translation; it is contaminated by the heat due to random motion of the electrons in the thermocouple. The contamination is known as "noise." If we want to control the furnace temperature within a very small fraction of a degree, this noise may be sufficient to defeat our aim. In any case, the situa-



BRAILLE is a binary code system (*dot equivalent to 1, no dot to 0*). Arrangement of six digits in two columns offers 63 combinations, providing for numbers, punctuation, diphthongs, etc., as well as the alphabet.

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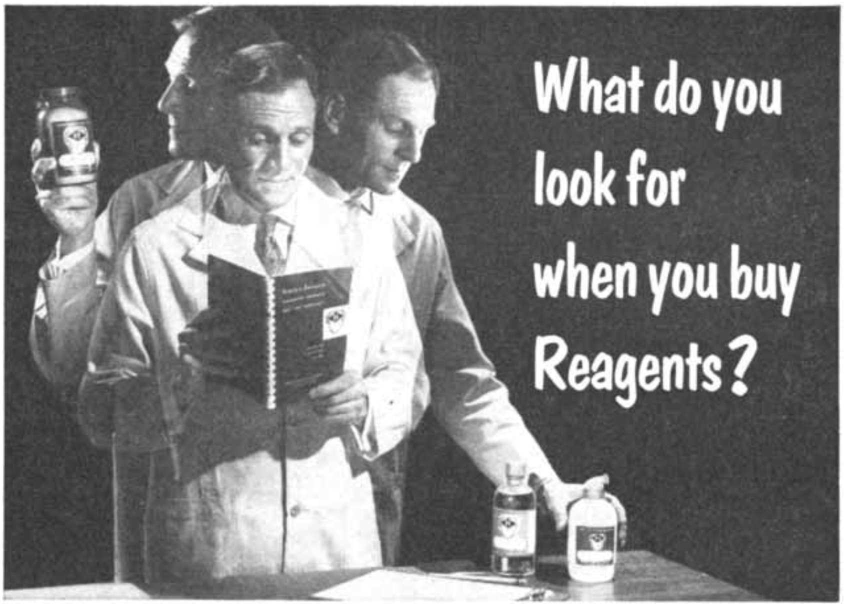
tion illustrates a fundamental property of information: in any physical system, it is never available without some noise or error.

Information can take a great variety of forms. In a thermocouple the voltage is a continuous signal, varying as the temperature varies. But information may also be conveyed discontinuously, as in the case of a thermostat, which either does or does not make an electrical contact. It gives one of two distinct signals—"on" or "off." The signals used in control may be numbers. The financial structure of the country is to a large extent controlled automatically (but not, as yet, mechanically) by the messages sent on ticker tape to hundreds of brokers, whose reactions affect the capital structure. Railway traffic is controlled by means of information transmitted on a teletype tape. Automatic control may include the human mind in the feedback loop, and in that case information takes the form of language messages, which may control the actions of people and nations. All literature, scientific or otherwise, represents messages from the past, and a literature search is a form of feedback loop which controls further thought and action.

During the past decade mathematicians have discovered with surprise and pleasure that information can be subjected to scientific treatment. Indeed, it meets one of the strictest requirements: it can be measured precisely. Information has been found to have as definite a meaning as a thermodynamic function, the nonpareil of all scientific quantities. It has properties like entropy. Recently the mathematical physicist L. N. Brillouin has shown that information is, in fact, negative entropy. For the moment, however, we shall merely state that information is something contained in a message which may consist of discrete digits and letters or of a varying but continuous signal. Signals convey information only when they consist of a sequence of symbols or values that change in a way not predictable by the receiver.

HUMAN BEINGS have developed a number of systems, using sets of discrete symbols, for communication. These can be analyzed in quantitative terms. To keep track of a bank account of less than $1,000.00, for example, requires five "places" in a counting machine: units, tens and hundreds for dollars, units and tens for cents. Experience seems to have shown that 60 letters or places (12 words) are sufficient for most telegraph messages. In the decimal system we do all our counting with 10 digits; in the English language we use 26 letters. And there are many other sets of symbols, such as the dots and dashes of the Morse code, and so on.

In a control system, however, such



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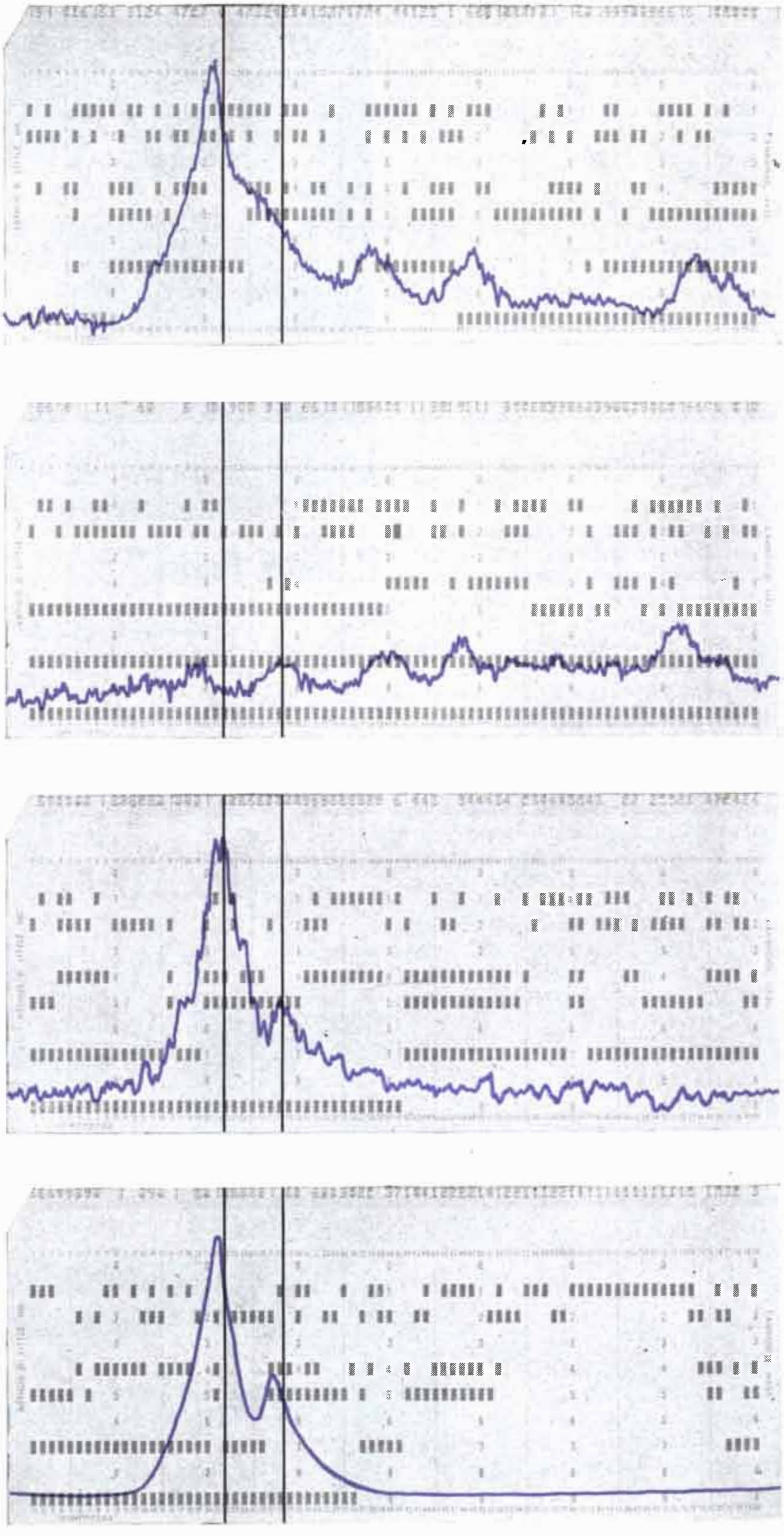

INFRARED SPECTRA are shown in analogue (*curves*) and digital (*punch-card entries for 80 points on each curve between vertical lines*) form. At top is a compound plus water; the second is water alone. Subtraction of the second from the first yields the third spectrum of the pure compound. This, and the smooth, "noiseless" curve at the bottom, can more easily be derived from information on punched cards than from plotted curves.

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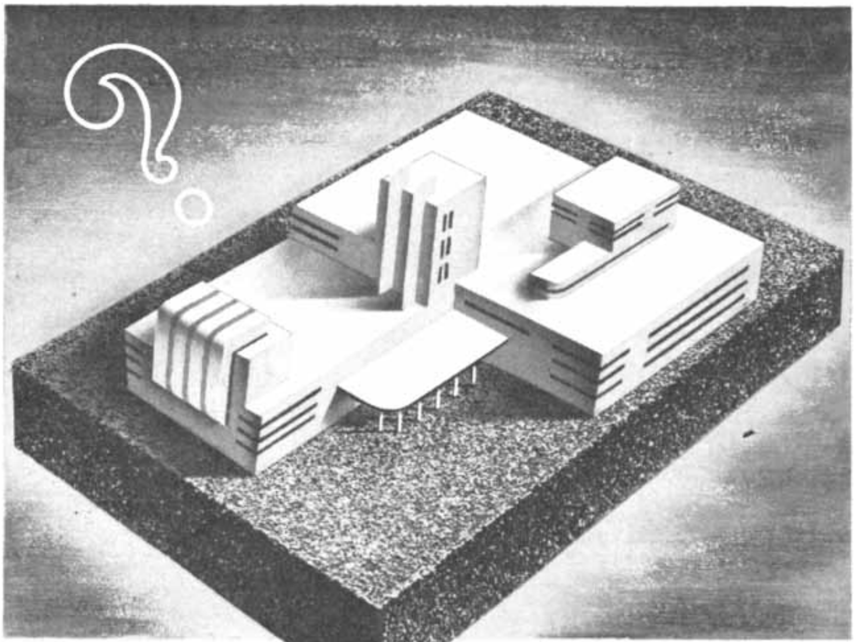
sets of symbols may be too complex and cumbersome. The simplest type of components that we can use in a control loop is the kind of device (*e.g.*, a relay or thyratron tube) that can assume only two states—"on" or "off." This means that it is most convenient to express message symbols on a binary scale, which has only two symbols: 0 and 1. Communication consists essentially in the progressive elimination and narrowing of the totality of all possible messages down to the one message it is desired to convey. If we visualize a recipient looking at a teletype awaiting the next symbol, we appreciate that each symbol reduces the number of possible messages by a factor proportional to the number of different symbols that might be sent. In the binary notation each symbol represents a simple choice between just two possible ones, and this has many advantages for expressing information.

In a message consisting of binary digits, each digit conveys a unit of information. From "binary digit" the mathematicians John Tukey and Claude Shannon have coined the portmanteau word "bit" as the name of such a unit of information. It is almost certain that "bit" will become common parlance in the field of information, as "horsepower" is in the motor field.

The number of bits in a message is a measure of the amount of information sent. This tells us exactly how much we are learning, and how much equipment is needed to handle the messages expected. Take as an example the recent suggestion that the contents of books be broadcast by television from a central library, thus doing away with the need for regional libraries. It takes seven bits to identify one letter or other character; on the average there are five letters in a word and 300 words on a page. Thus it would take only about 10,000 bits to transmit each page as a coded message. To televise a page, however, would require a great many more bits than that. In order to make the page legible, the screen would have to carry at least 250,000 black or white spots (corresponding to 500 lines vertically and horizontally). The image would have to be repeated 300 times, to allow the reader 10 seconds to read a page. Hence the required number of bits would be 75 million ($300 \times 250{,}000$) instead of 10,000. Since an increase in the amount of information sent requires an increase in the bandwidth of the broadcasting channel, it is clear that the televising of books is not an efficient method.

CAN information in the form of a continuously changing voltage be of the same nature and be measured in the same units as numbers from a counting machine or words in a communication network? At first sight this does not seem possible, for it has long been con-



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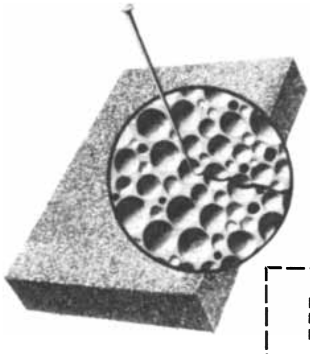

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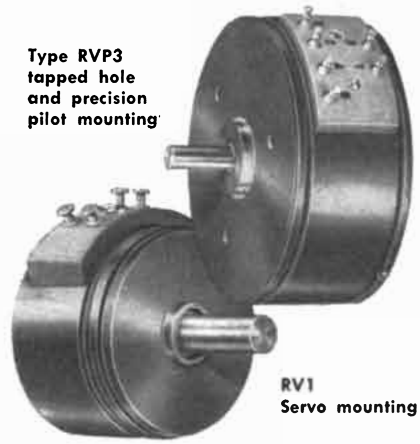

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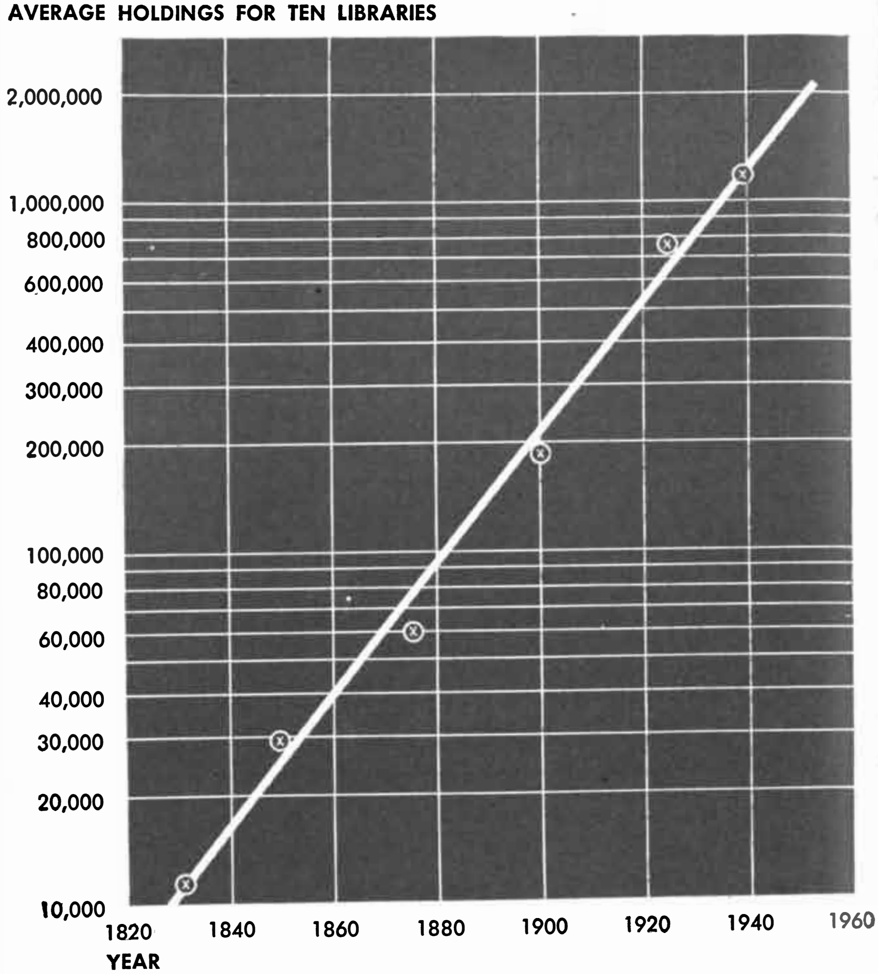

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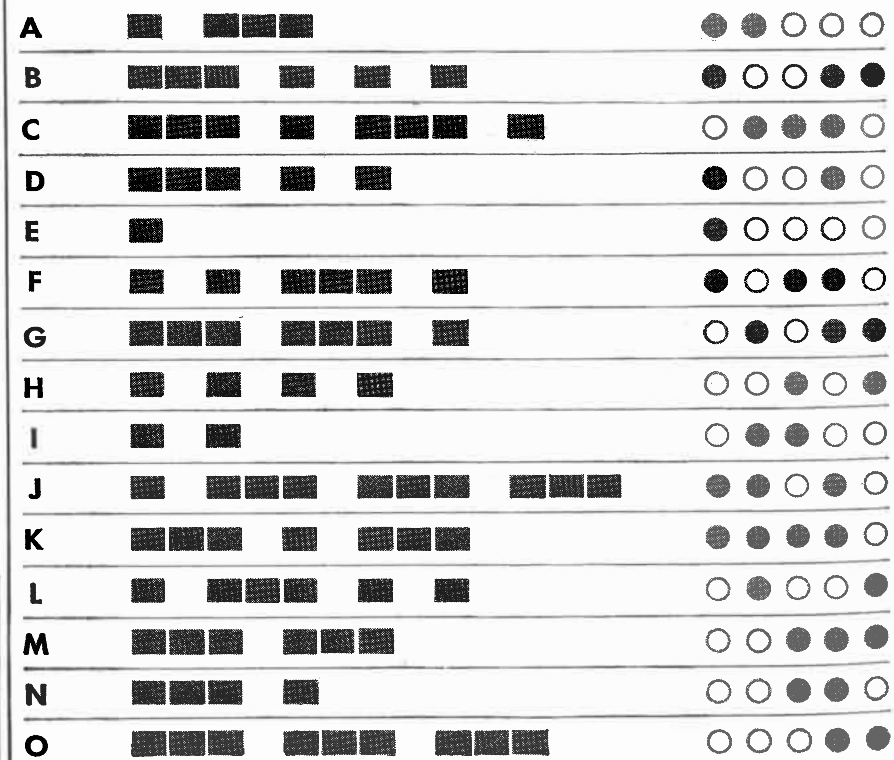

DOT-DASH CODE (*left*) is compared with holes in five-place tape (*gray dots at right*). Dash requires three units to differentiate it from dot.

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sidered axiomatic that a record of a continuous variable contains an infinite amount of significant information. Actually that is not so, for the reason that no physical measurement can resolve all of the information. The resolving power of a microscope, for example, is determined by its aperture, which is finite and therefore sets a limit on the fineness of discrimination. This theorem can be generalized to all instruments. Now Shannon, in his famous theorem on communication theory, has shown that when such a limitation exists, one can collect all the available information in a continuous signal by sampling it at certain finite intervals of time. Conversely, it can be proved that the continuous signal can be exactly reconstructed from the finite points, provided, of course, they are taken at the required frequency, determined by the aperture. A series of numbers, or of amplitudes sampled periodically, will completely specify the signal. Hence a message of this kind can be expressed as a series of binary digits.

So far the most extensive application of the principle has been the recording of infrared spectra in digital form on punched cards. With the information in this form, a spectrum can be read and interpreted by means of automatic computing machinery, much more rapidly than one could read the conventional graphic record by visual inspection. The diagrams on page 134 illustrate a simple case. They show a conventional recording of the infrared spectrum of solid cyclopropane, and the same spectrum as recorded in digital form on punched cards on the basis of 500 sample readings. The recording, however, includes the spectrum of water vapor in the air within the spectroscope, which must be subtracted to get the true spectrum of the compound under study. The subtration would be very tedious to do by hand on the graphs, but it is easily done by a computer from the punched cards. It reveals that the infrared spectrum of the compound has two distinct peaks. By certain numerical treatments, suggested by communication theory, we can reduce "noise" in the record and smooth the curve to show the peaks more clearly. In short, the computing machine extracts more information from the record than we could otherwise obtain.

SO FAR we have used "message" and "information" interchangeably, but there is a distinction between them. The information content of the signals is reduced by the noise that comes with the message. The central problem of information theory, now undergoing investigation, is to determine the best methods of extracting the sender's message from the received signal, which includes noise. A magnetic storm can garble the telegram "I love you" into

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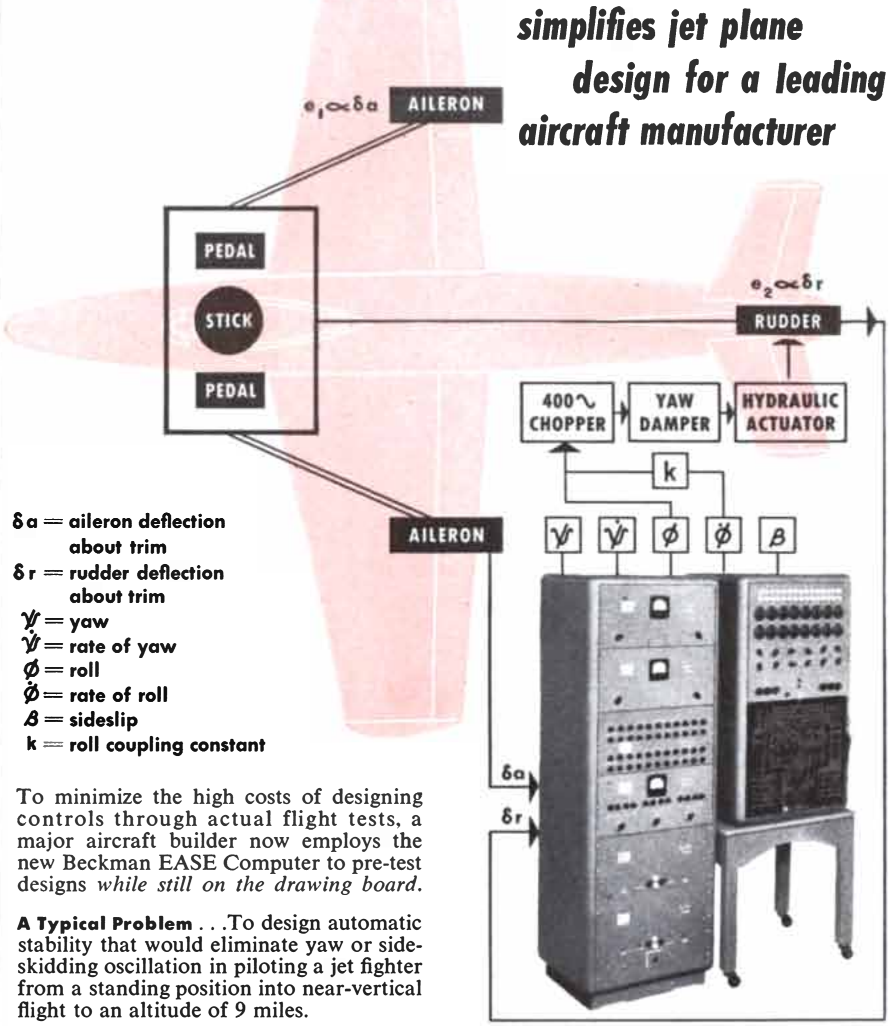

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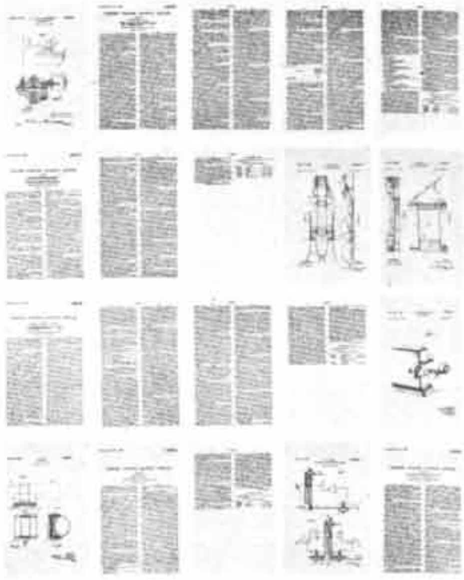

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"I hate you." In fact, there is absolutely no way of being certain of transmitting a given message. Nothing is certain except chance.

One method of reducing the probability of error is to repeat the message. This does not improve the reliability very much and is expensive in bandwidth. The amount of "snow" in a television picture, for instance, could be halved by repeating each picture four times in the same interval of time, but this would demand four times the channel width. And the band available for television channels is limited and valuable. On the other hand, to get more information through a given bandwidth usually requires more hardware in the transmitter and the receiver, the amount increasing exponentially.

A more economical procedure for reducing the probability of error is to use redundancy. For instance, the message could be sent as "I love you, darling." This increases the chances of correct reception of the meaning without requiring as much extra time or bandwidth as mere repetition of the message would.

One of the cleanest examples of automatic control is the solution of a mathematical problem by such a procedure on a computing machine. A computing machine is a communications network in which messages (numbers) are sent from one part to another. The reduction of errors, naturally, is most important. However carefully the machine is constructed, errors inevitably creep in. Now usually there is no redundancy—the number 137 means one thing, and 138 distinctly another. But we can add redundancy, say by the method of carrying along the digit left after casting out nines, and can test these extra digits

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after each arithmetic operation. This requires more equipment (or bandwidth in a general sense), but a 20 per cent increase is sufficient to handle enough redundancy to reduce the possibility of overlooking an error to one part in 100 million.

The classic device for reducing extraneous noise in ordinary signals is a filter. For example, by cutting out high frequencies in a radio signal we can eliminate the high-pitched hissing components of noise without loss of message content, for the original message seldom contains such high frequencies. But to reduce the noise within the frequency range of the message itself is more difficult. Noise is universal and insidious, and elaborate devices are needed to overcome it. A wide variety of approaches, collectively called "filter theory," has been considered. The most fascinating is in the direction of suitable coding of messages with the aid of computers.

LET US examine a simplified illustration based on the problem of using radar for "Identification of Friend or Foe." We can send out a radar pulse of a specific pattern, which a converter in a friendly plane will change to another pattern but which an enemy plane will reflect unchanged. At long range, however, noise may confuse the pattern so that we cannot tell friend from foe. The question is: What is the most suitable pulse shape, and to what shape should it be converted, to give the smallest chance of making a mistake? Let us assume that the pulse wave can be above or below or at the zero level. We can therefore express the information in a ternary (instead of binary) notation of three digits: −1, 0, 1. We shall also as-

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sume (as often happens in practice) that a noise pulse of 1, added to a signal pulse of 1, gives 1 in our limited detection equipment. Now it is easy to see that if we merely used a positive pulse for "friend" and a negative pulse for "foe," one would frequently be converted into the other when the noise-to-signal ratio was high. Let us then introduce some redundancy by using a double pulse.

There are nine possible signals. They can be represented as vectors in two dimensions (*see diagram on page 146*). Now of the nine vectors we need only two for our message. Which two should be chosen to give the least chance of error due to noise? It turns out that the best choice is the pair of vectors directly opposite to each other, because the noise patterns required to convert one to the other would in these cases be the least frequent.

Messages as a rule can be mapped with a great number of dimensions. And in such cases it proves to be feasible to select the vectors entirely at random rather than by definite rules (which are too complicated to work out). Now a random signal, by definition, is noise. In other words, we have the paradox that the best way to encode a message is to send it as a typical noise pattern. The selected noise patterns correspond

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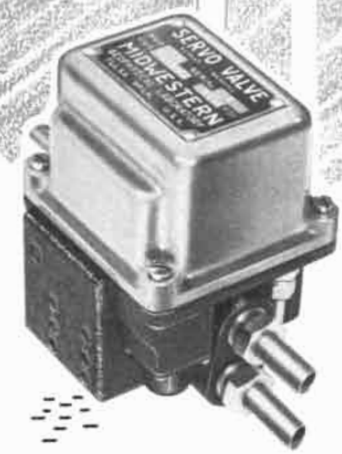

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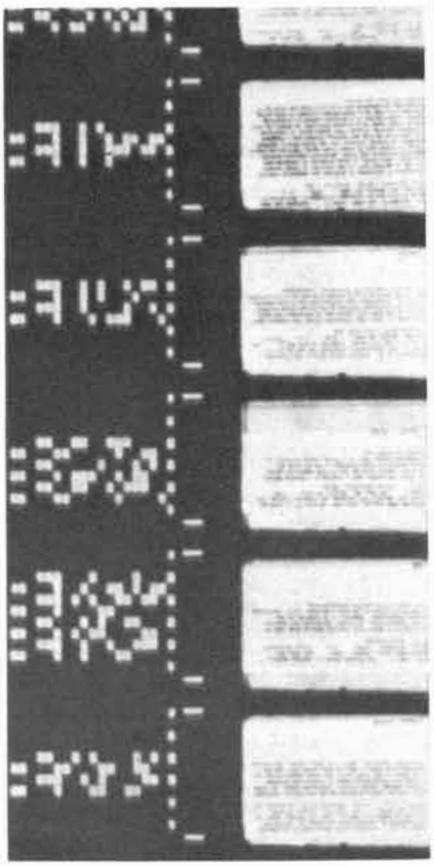
to an ambassador's code book. The patterns can be decoded mechanically at high speed in a computing machine. Methods of this type seem to be the ultimate in maximizing the rate of transmittal of information.

Every system of communication presupposes, of course, that the sender and the receiver have agreed upon a certain set of possible messages, called "message space." In the Western Union system this message space consists of all possible strings of English words of reasonable length, but it does not permit foreign words. Wall Street has a more restricted set of messages. A reader of ticker tape could expect the message "Ethyl 24-1/4" but would be taken aback by "Ethel pregnant."

Messages used in technological applications of automatic control also are restricted to a definite space. For example, a thermocouple used to control a furnace measures temperatures only within certain limits, and if the message came through as "one million degrees," one could legitimately expect the whole feedback system to throw in its hand. If information is to be used for automatic control, the message space must be defined, and safeguards such as fuses or switches must be provided to eliminate all messages outside the established message space. This prevents



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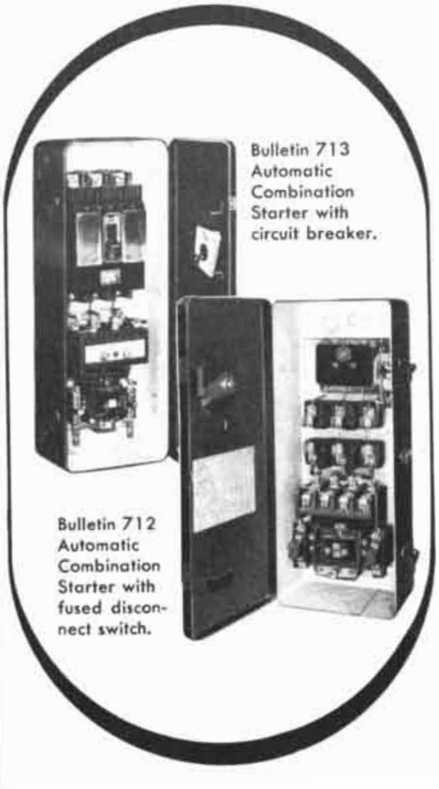

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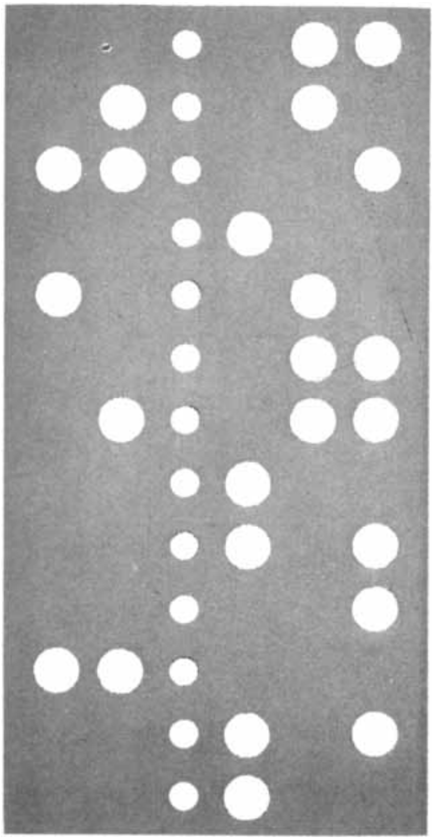

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the control from going wild. For instance, in a given process certain quantities may be known to be never negative, and the control program must provide that if a test does show a minus sign, the process is stopped or repeated.

AUTOMATIC control requires the storage of information received from the system's sensory instruments. For this a digital device, which simply stores numbers, is better than an analogue device. And the binary system is especially convenient. The most efficient known mechanism for the retention of information is the human brain. Recent physiological experiments suggest that the brain operates not with continuous signals but with sampled digital information, probably on a binary system; nerves seem to transmit information by the presence or absence of a pulse. The brain, with its ability to store vast amounts of information in a tiny space and to deliver specified items on demand, is the model which automatic control design strives to imitate.

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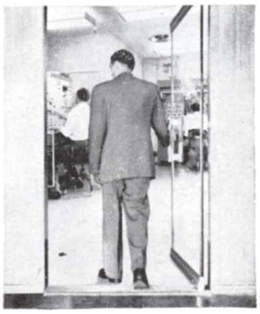

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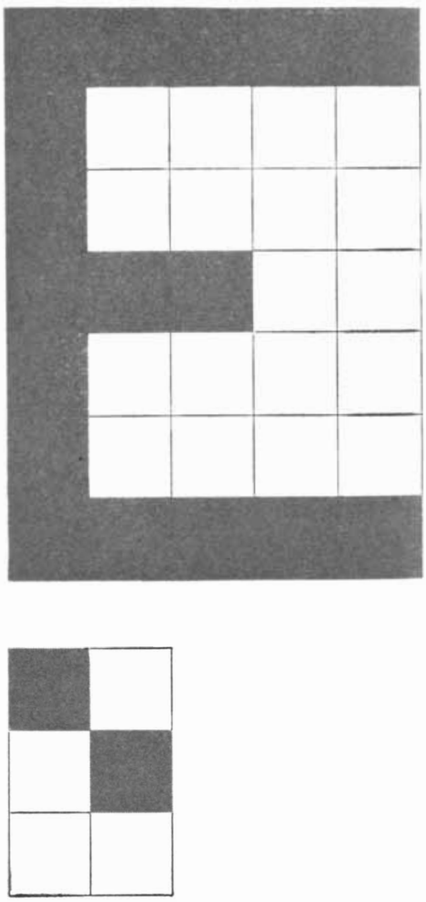
The recording of information in the conventional form of printed matter is wasteful of space, even when the print is reduced by photography to microscopic dimensions. The printing of a letter requires a certain area of paper, which we can imagine as a grid with certain squares blackened to form the letter (*see diagram below*). Some modern high-speed printers actually use this method, pushing forward certain pins from a matrix to mark each letter. In order to print passably legible letters the matrix must have at least 35 pins. In contrast, the binary digit notation needs only five places (instead of 35) to record the 26 letters of the alphabet, and only seven to give all the symbols of printing, including capitals, numerals and punctuation. Louis Braille recognized this when he used a binary system



LETTERS need 35 bits (*here black and white squares*) for graphic reproduction. Braille uses but six bits.

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for his method of recording information for the blind.

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Storage on photographic emulsion is not yet practicable because of the difficulties of retrieval: reading microfilm is not particularly easy or convenient. There are available, however, other means of compact storage—punched cards or tapes, magnetic tape or drums, electronic storage tubes, printed circuits with miniature tubes or transistors.

AUTOMATIC control requires storage of information for various purposes. In many cases the fact that information is stored is not apparent, but analysis shows that there is a delay during which the reported condition of the system is compared with certain standards. Discrepancies are discovered and corrected by feedback to the control organs. This is often done "instantaneously" by voltages stored in condensers, but more sophisticated control demands storage of a considerable history. We have seen that if a serious attempt is made to reduce noise associated with the message, sections of the received signal must be stored for a time to allow "filtering" of the signal by comparison with the code book.

This kind of control is "non-linear," because the control signals are not simply proportional to the information supplied by the sensing instruments. Many aspects of these problems lie in new fields of applied mathematics, which when more thoroughly understood will open up wider fields of automatic control.

Some kinds of automatic control depend on statistical analyses of information received and stored in an extensive memory device. For example, electric-power companies have to control their production continuously as the load varies from hour to hour, day to day and season to season. A feedback loop from the immediate load is not sufficient, because stocks of fuel have to be accumulated in advance. The load must be anticipated many hours or even weeks ahead, and this can only be done with statistical knowledge. The power companies would be delighted to have good weather prediction, particularly for next winter, in order to increase their stockpile of fuel in ample time.

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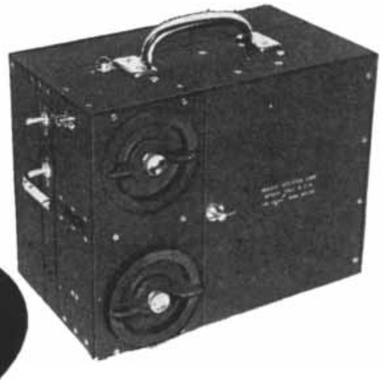

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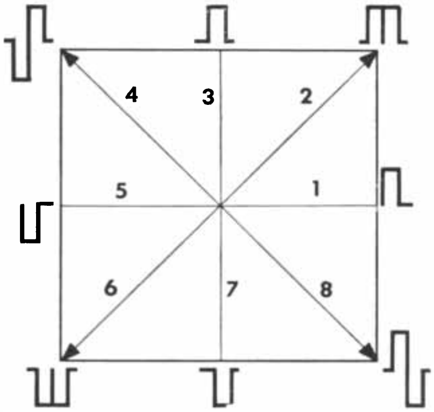

SIMPLE CODE system shows how redundancy can help secure transmission of "yes" and "no." Pulse wave can be at, above or below zero—1, 0 or -1. But noise might easily distort 1 to -1. With double pulse, as shown, 11 is less liable to be distorted to -1-1. Message 11 is like "yes, please"; -1-1 is like "no, thanks."

pate a substantial degree of automatic control based on statistical analyses is in the recently developed inventory machines used by stores. As each sale is made, a record is sent to a central computer, which in its most elementary form merely subtracts one from the inventory of the item sold. When the stock is reduced to a certain level, the machine prints instructions to replenish it.

This field of control comes under the head of operational analysis, which substitutes precise formulations for human opinion. It attempts to describe a business phenomenon by a working model, usually in the form of a set of equations. It is not difficult to visualize the possibility of using these formulas for automatic control of the routine part of a store's business. For example, the number of items to keep in stock depends on the probable sales, the profit and the cost of storage. After an operational analysis has yielded an answer to this complex problem, the solution can be inserted in an inventory type of computing machine as simple control numbers. A more complicated situation arises in judging when to fill stocks of several items which are interchangeable to a certain degree, *e.g.*, shirts of different styles. The inventory machine now has to do a little arithmetical manipulation of the numbers of the various interchangeable items in its storage. A further elaboration comes when the inventory machine has to take into account the effect on sales of the onset of Christmas or of a competitor's sales promotion.

A working demonstration of the possibilities in this field is provided by the addressing machines now employed by large mail-order houses. Out of a

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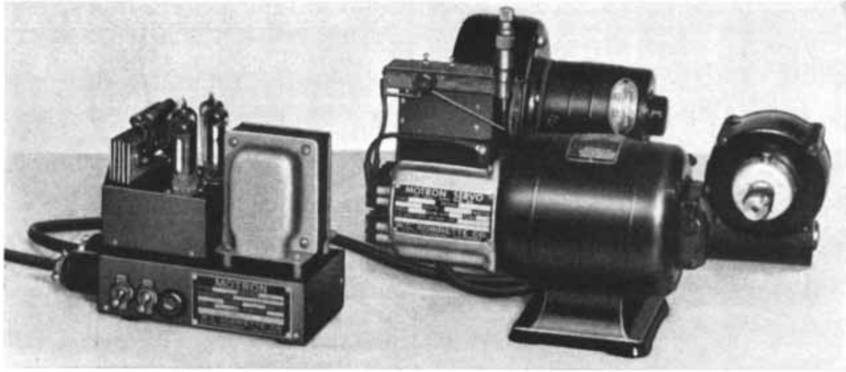
list of, say, 15 million names, it has been customary to choose about half for the semiannual mailings of the catalogue. The selection of names, in the past, was made manually by rule-of-thumb procedures, such as any merchandizer might be expected to develop over a lifetime of experience. Today the names are processed on stencil plates in which a considerable variety of information bearing on the customer's prior sales history is encoded. With such information available to mechanical manipulation, it is possible to bring a high order of sophistication to bear upon the task of selection. In fact, fairly complicated equations are employed, with general economic and market trends factored into the weighting of the information on the stencils. The result has been to improve the net return on catalogue mailings by many millions of dollars.

We can expect to see in the future automatic machines which will make decisions in business and military operations by the application of the theory of games, developed by John von Neumann and others. One can readily imagine the inventory machines of two large department stores waging a battle for domination of a market. It is known, for example, that a sales campaign by one store sometimes stimulates sales in a competitor. One inventory machine may suspect, from a spurt in the sale of shirts by the store during an ordinarily quiet period, that the competitive store is in short supply of shirts. If it finds that its own store has a large stock of shirts, it will automatically suggest a sales campaign to put the competitor in an embarrassing position.

Explorations in the field of machine-devised game strategy are already being made. It is rumored that a computing machine in the U. S. will play a machine in England at chess. These machines will not attempt to play by arithmetic evaluations of all possible plays. They will have to learn to play the game and develop their own strategies. Learning is to a large extent the putting of information into a memory and the development of an ability to recognize connections. Appropriate or even ingenious actions may then be taken on the basis of the learned and stored experiences. Computing machines are capable of these processes.

THE game-playing performances of machines will serve as valuable guides to the art of control in more important fields of endeavor. Research in science or engineering, for example, involves elements of automatic control. New experiments done in the laboratory, or new designs, are controlled by the success or failure of what has been done in the past. But the feedback is sadly incomplete. So much information is being produced that no research work-



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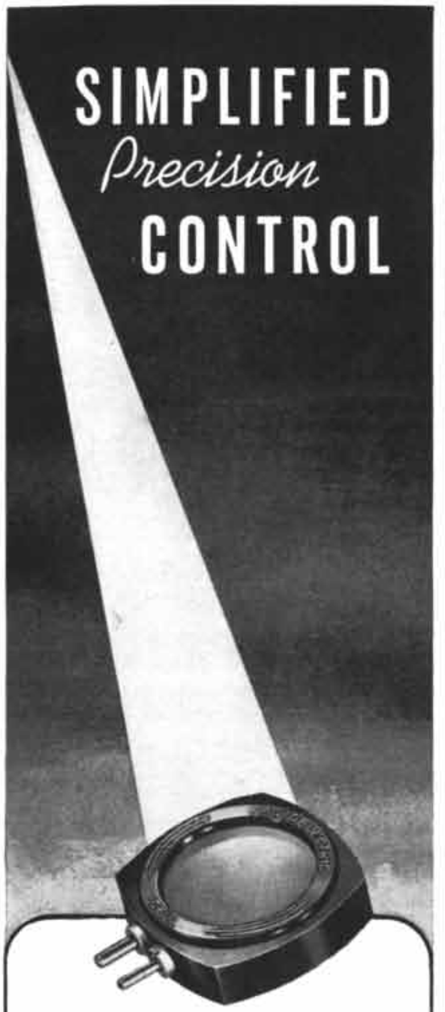

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er or engineer can be aware of all that is pertinent to his problem. In other words, the feedback loop is terribly congested. It is hoped that the new ideas of information theory will help to clear up the congestion and make the needed information more accessible.

We have seen that it is relatively easy to store library information for mechanical handling, say by recording on microfilm. The difficulty arises in locating quickly the information desired. Some progress has been made in this direction by Vannevar Bush and Ralph Shaw, who have developed a machine called the Rapid Selector. Printed matter is photographed on a large reel of microfilm in the order in which it is received. The information content of each frame is described by an abstract consisting of some 12 words. These words, called descriptors, are recorded in binary form as black and white spots on the margin of the frame. The coded words can be recognized by a photocell. When a research worker wants to extract from the microfilm all the material bearing on a certain item of information, he punches the descriptors defining this item on a card and inserts the card in the machine. The photocell searches the microfilm for these words at a speed of 5,000 pages a minute. Whenever the words on the card match the coded words alongside a frame, the machine makes a duplicate of the frame.

The Rapid Selector has not come into widespread use. One reason is that it takes time to assign descriptors to each page as it is microfilmed, and this constitutes a bottleneck. Another is that a mere dozen descriptors is too few to provide an adequate abstract. The recording problem might be made easier by using a reading machine to scan printed pages and translate their information into bits, which would then be recorded on the film. To retrieve information, however, a user would have to think of all the possible words and phrases that might have been used in describing the ideas for which he is searching. To design an efficient automatic library will require a good deal of thought and study.

Information is the most human of all the problems that the exact sciences have yet tackled. We shall need instruments like those of the human body—memory devices like the brain and control devices like the reflex networks in the nervous system—to handle information for automatic control. Progress is being made, and one of the most useful concepts developed so far is the "bit," by which information can be measured, stored, processed and transmitted most efficiently.

Gilbert W. King is a physical chemist associated with Arthur D. Little, Inc.

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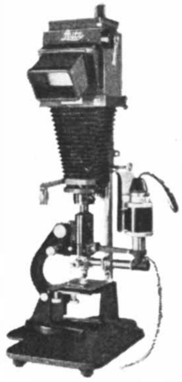

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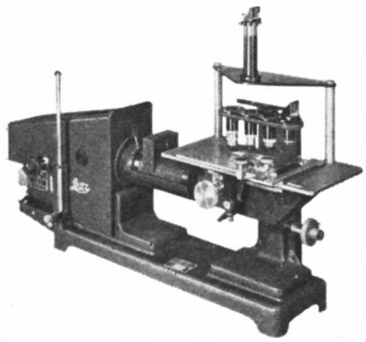

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MACHINES AND MAN

What about the economic and social impact of automatic control systems? Can industry afford to buy them, and will they cause widespread technological unemployment?

by Wassily Leontief

APPROXIMATELY 500 years ago the study of nature ceased to be solely a servant of philosophy and became a patron of applied arts and a source of practical invention. The economic development of the Western world has since proceeded at an ever-increasing pace; waves of technological change, driven by the surge of scientific discoveries, have followed one another in accelerated succession. The developmental lag between pure science and engineering application has progressively shortened. It took nearly 100 years for the steam engine to establish itself as part and parcel of the industrial scene, but electric power took less than 50 years and the internal combustion engine only 30. The vacuum tube was in almost every American home within 15 years of its invention, and the numerous progeny of Dr. Baekeland's synthetic plastics matured before we learned to pronounce "polyisobutylene." At the turn of the 20th century it was said that "applied science is pure science 20 years later"; today the interval is much shorter—often only five years and sometimes but one or two.

From the engineering standpoint the era of automatic control has begun. Some of the fully automatic "factories of the future" are already on paper; they can be described and studied. Engineering, however, is only the first step; what automatic technology will mean to our economic system and our society is still decidedly a thing of the future. In judging its probable impact all we have to go by is tenuous analogy with past experience and theoretical deductions from our very limited information on the new techniques. And it is no help that some of the crucial facts and figures are veiled in secrecy.

Important new inventions are traditionally held to presage the dawn of a new era; they also mark the twilight of an old. For some observers they contain promise; for others, fear. James Hargreaves constructed the first practical multiple spindle machine in 1767, and one year later a mob of spinners invaded his mill and destroyed the new equipment. The economists of the time (the golden age of "classical economics" was about to begin) came to the defense of the machines. They explained to labor that the loss of jobs in spinning would be compensated by new employment in machine-building. And for the next hundred years England did indeed prosper. Its labor force expanded both in textiles and in textile machinery, and wage rates by the end of the 19th century were at least three times as high as at its beginning.

But the men-*v.*-machines controversy blazed on. Karl Marx made of "technological unemployment" the cornerstone of his theory of capitalist exploitation. The conscientious John Stuart Mill came to the conclusion that, while the introduction of machinery might—in most cases would—benefit labor, it would not necessarily do so always. The answer depended on the circumstances of the case. And today that is still the only reasonable point of view one can maintain.

We are hardly in a position to reduce to detailed computation the effects that automatic technology will have on employment, production or our national standard of living. Aside from the paucity of our information on this new development, our understanding of the structural properties of our economic system itself is still incomplete. We must therefore rely on reasonable conjecture.

THE ECONOMY of a modern industrial nation—not unlike the feedback mechanisms discussed throughout this issue—must be visualized as a complicated system of interrelated processes. Each industry, each type of activity, consumes the products and services of other sectors of the economy and at the same time supplies its own products and services to them. Just as the operating properties of a servo-mechanism are determined by the technical characteristics of the measuring, communicating and controlling units of which it is composed, so the operating properties of an economy depend upon the structural characteristics of its component parts and on the way in which they are coupled together. It is not by coincidence that in some advanced phases of his work the modern economist resorts to systems of differential equations similar to those used by the designers of self-regulating machinery.

The services of labor constitute one important set of inputs into the national economy. That it is the largest one is reflected in the fact that labor receives in wages some 73 per cent (in 1950) of the nation's annual net product. But labor is not the only type of input that goes into all other sectors. Certain natural resources, machinery, equipment and other kinds of productive capital feed into almost every branch of agriculture, manufacture, transportation and distribution. In the chart at the top of the opposite page, depicting the growth of our total national product since 1880, is a breakdown of the share going into salaries and wages on the one hand and into non-labor income (profits, interest, rents and so on) on the other. The ratio between these two has been generally stable, but labor's share has steadily gained. Behind these figures lie the intricate processes of our economic development, influenced by such factors as population growth, the discovery of new and the exhaustion of old natural resources, the increase in the stock of productive plant and equipment and, last but not least, a steady technological progress.

A better insight into the nature of that progress is given by the charts on page 154. The number of man-hours required for an average unit of output has gone down steadily since 1880. In the first 30 years of that period the saving of labor seems to have been accompanied by a

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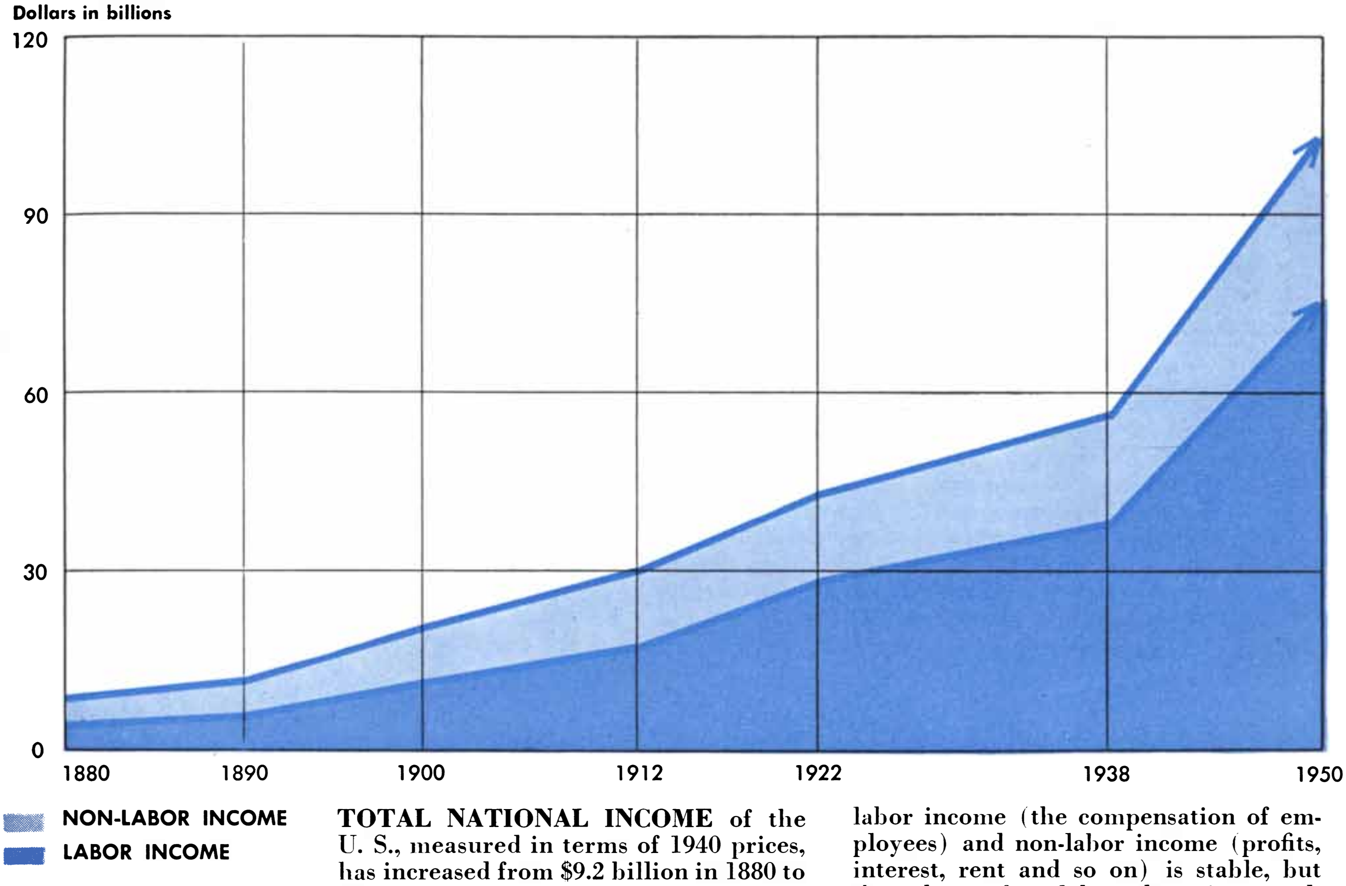
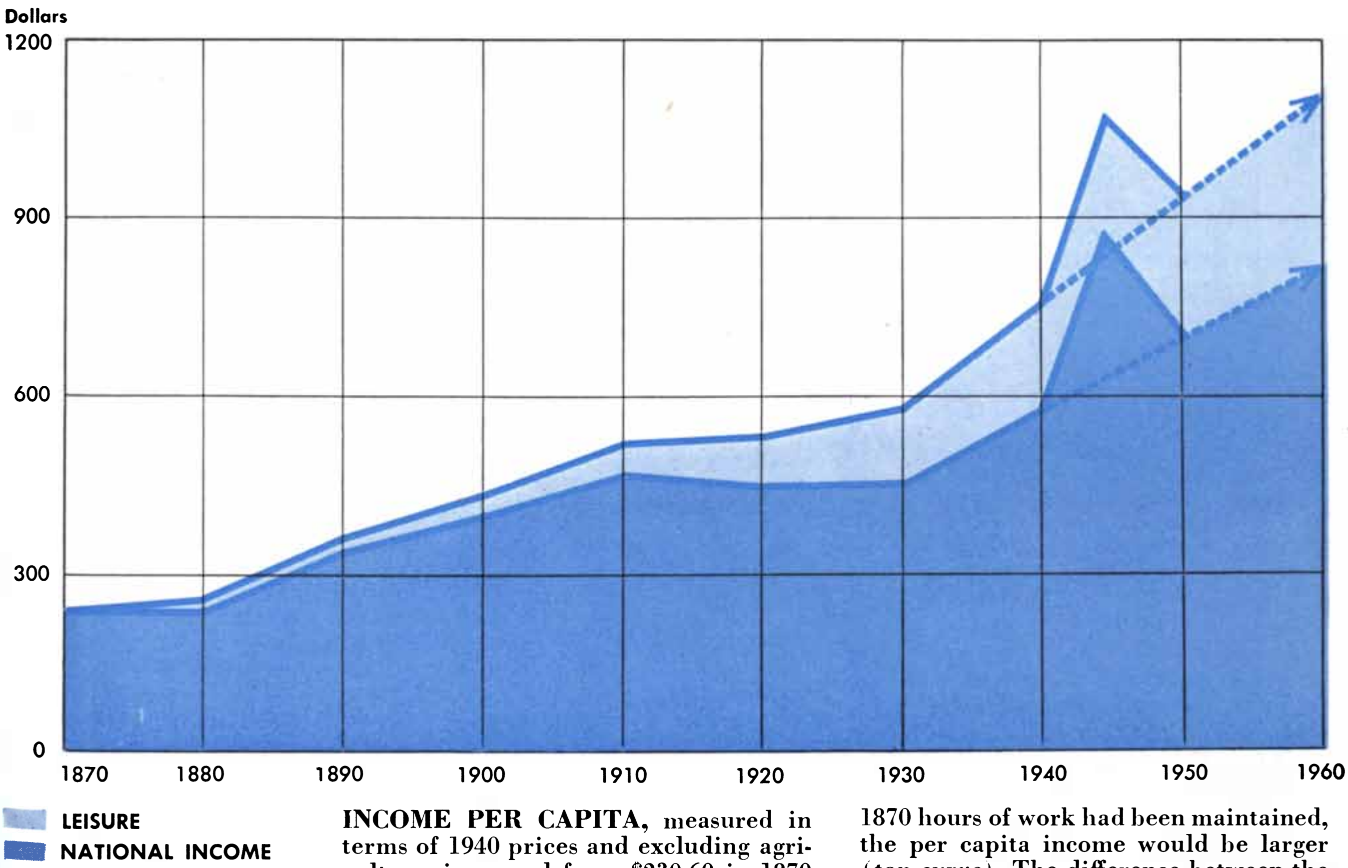


TOTAL NATIONAL INCOME of the U. S., measured in terms of 1940 prices, has increased from $9.2 billion in 1880 to $160 billion in 1950. The ratio between labor income (the compensation of employees) and non-labor income (profits, interest, rent and so on) is stable, but the share for labor has increased.



INCOME PER CAPITA, measured in terms of 1940 prices and excluding agriculture, increased from $230.60 in 1870 to $706.70 in 1950 (*bottom curve*). If 1870 hours of work had been maintained, the per capita income would be larger (*top curve*). The difference between the two curves shows increase in leisure.

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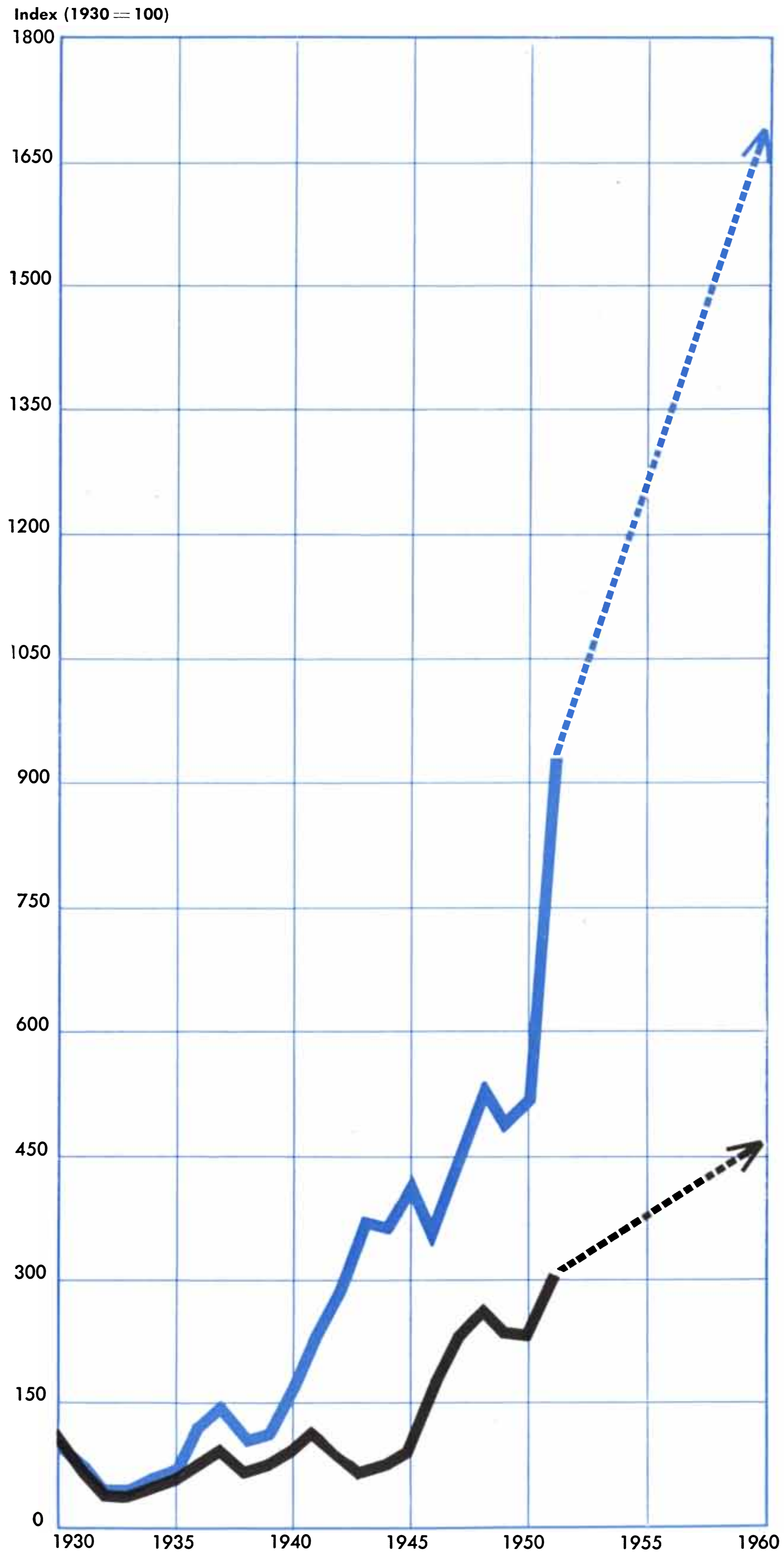

SALES OF INSTRUMENTS for industrial recording and controlling purposes have increased enormously since 1930 (*blue line*) as compared with the total U. S. expenditure for plant and equipment (*black line*).

corresponding increase in capital investment. Between 1880 and 1912 the amount of machinery and of other so-called fixed investment per unit of output rose by 34 per cent, while the man-hour input fell 40 per cent. Then the ratio of investment to output began to drop. We introduced more efficient machinery rather than just a greater quantity of it. That it actually was more efficient can be seen from the fact that labor productivity rose apace. In 1938 a unit of output consumed only about half as many man-hours as would have been spent upon its production in 1918.

SUCH IS the stage which the new technology—the technology of automatic control—has now entered. The best index we have of how far automatization has gone is the annual U. S. production of "measuring and controlling instruments." The trend of this production is outlined in the chart at the left. After hesitation during the depression and the war years, it now rises rapidly. In part this rise mirrors the recent accelerating pace of industrial investment in general, but the chart shows that the instrument production curve is going up more steeply than that of plant investment as a whole. This gain is a measure of the progressive "instrumentation" of the U. S. economy. A breakdown of the relative progress of automatic operation in individual industries appears in the table on page 156. The chemical and machinery industries lead; next come metal processing (mainly in the smelting department) and ceramics. In interpreting this table one must take into account the fact that instrumental control is less costly for some processes than for others (*see table on page 158*).

The estimated cost of complete instrumentation of a new modern plant to automatize it as fully as possible today ranges from 1 to 19 per cent (depending on the industry) of the total investment in process equipment. The average for all industries would be about six per cent. On this basis, if all the new plants built in 1950 had been automatized, some $600 million would have been spent for measuring and control instruments. Actually the production of such instruments in 1950 totaled only $67 million. In other words, to automatize new plants alone, to say nothing of those already built, would require nearly 10 times as great an investment in instruments as we are now making.

Yet six per cent is far from a formidable figure. Furthermore, the investment in instruments would not necessarily mean a net increase in the total plant investment per unit of output. On the contrary, the smoother and better-balanced operation of self-regulating plants has already shown that they can function with less capitalization than a non-automatic plant of identical capac-

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Let Beckman's Years of Leadership in Instrumentation Assist You

*** For many years the Beckman name has been widely recognized throughout industry as typifying major advancements in the field of modern instrumentation. Not so well known, perhaps, is the fact that the Helipot Corporation—originator and leading manufacturer of precision potentiometers and similar components vital to automatic control operations—is a wholly-owned subsidiary of Beckman Instruments, Inc. And the recent acquisition of Berkeley Scientific Corporation by Beckman Instruments adds still another leader in its field to this pool of experienced "know-how" in the design and development of advanced electronic instruments and associated components essential to push-button process and factory operations.**

No matter what *your* problem is in automatic control applications, check with Beckman to determine whether we can supply—possibly already are producing—the very unit or component you need to solve the problem. Typical Beckman products include . . .

ANALYTICAL EQUIPMENT

In the "sensory" phase of automatic control, Beckman provides equipment and instrumentation for quickly detecting and measuring variations in chemical composition, color, acidity and alkalinity (pH), moisture content and other critical functions in chemical analysis and control, including the detection and measurement of extremely small electrical currents (as small as $3x10^{-13}$ amperes).

Also, an extensive range of nuclear instruments—radiation meters, scalers, rate computers, monitors, scintillation detectors, etc.,—is available to meet varied requirements in atomic research and development operations.

PRECISION COMPONENTS

Now widely used in guided missiles, fire control systems, radar, sonar and other advanced electronic applications, such components as precision potentiometers and synchros are vital to virtually *all* types of automatic control systems—industrial as well as military.

The Helipot (the original multi-turn potentiometer) is widely recognized as one of the vital advancements that have made today's precision instrumentation possible. Its helical principle provides a degree of precise control not possible in previously available commercial potentiometers and its ready adaptability to "ganging" and other special construction features make it ideal for automatic control systems.

Incorporating years of experience in mass-producing critical parts to extremely close tolerances, an extensive range of Synchros is also in production. These units—electromagnetic devices for remote transmission of angular data—combine precision workmanship, compact design and exceptional accuracy with mass-production economies.

COUNTERS AND COMPUTERS

This equipment puts the "control" in automatic control systems by adding the coordinating and integrating functions. Beckman and the Berkeley Scientific division have had extensive experience in this field, also, and are now producing analog and digital computers as well as time-interval meters, events-per-unit-time meters, count rate meters and other types of electronic counters and related devices.

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Ultraviolet, Visible and Infrared Spectrophotometers, Colorimeters, pH Meters and Electrodes, Radiation Meters, Aquameters, Computers, Synchros, and a Wide Range of Special Products.

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If you are now planning automatic plant or process operations—why not bring your problems to Beckman—an organization highly skilled in basic fundamentals of such systems? We'll gladly study your requirements and make helpful suggestions without obligation.

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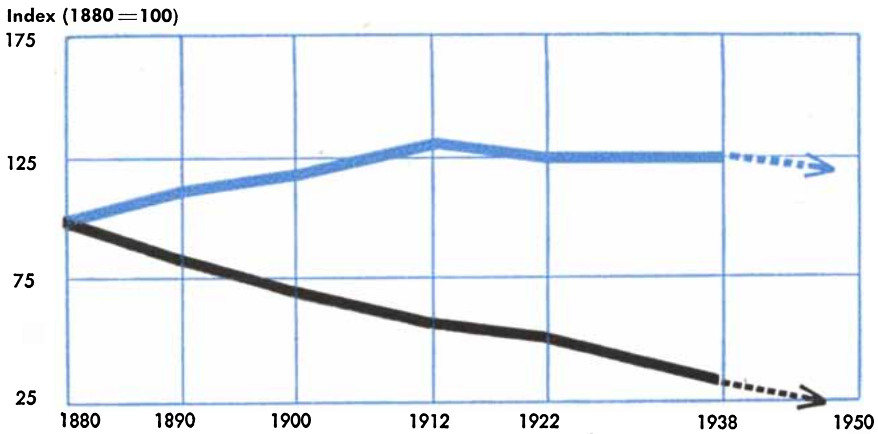
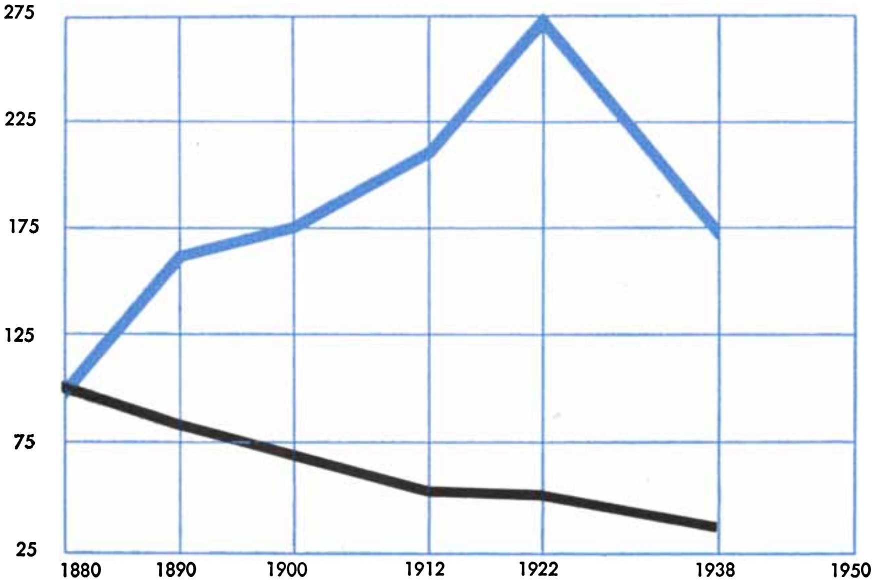
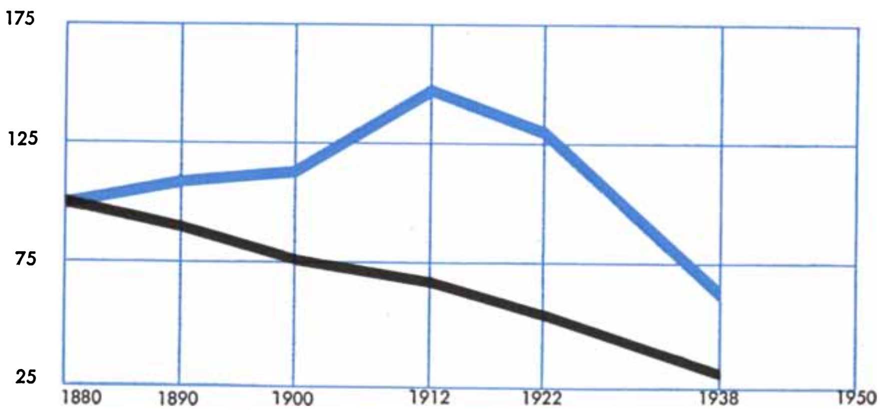


U. S. PRODUCTION has increased in efficiency. The blue line plots the decreasing index of plant and equipment required to produce one unit of output; the black line, the man-hours required to produce one unit.



MINING AND MANUFACTURE similarly increased in productivity. Labor savings have been secured largely by expenditure on plant equipment. Increasing efficiency of plant is now reflected in declining capital cost.



AGRICULTURE shows a similar pattern. Here the index of plant and equipment per unit of output is actually lower in 1938 than in 1880, reflecting the enormous increase in the productivity of agricultural machinery.

ity. And much existing equipment can readily be converted from manual to automatic control. It therefore seems that the automatization of our industries, at least to the extent made possible by present technology, is likely to advance rapidly. The mechanization of the 19th century required heavy capital investment and proceeded slowly; the new technology, unhampered by such vast capital requirements, can be introduced at a much faster pace.

In transportation and agriculture, machines by now have practically eliminated the need for human muscle power. Man has all but ceased to be a lifter and mover and become primarily a starter and stopper, a setter and assembler and repairer. With the introduction of self-controlled machinery, his direct participation in the process of production will be narrowed even further. The starter and stopper will disappear first, the setter and assembler will go next. The trouble-shooter and repairman of course will keep their jobs for a long time to come; the need for them will even increase, for the delicate and complicated equipment of automatic control will require constant expert care. We shall continue to need inventors and designers, but perhaps not many even of them: the chief engineer of a large electronic equipment firm recently expressed to me his apparently well-founded hope that before long he would have circuits designed by an electronic machine, eliminating human errors.

ALL THIS inevitably will change the character of our labor force. The proportion of unskilled labor has already declined greatly in recent decades; it is down to less than 20 per cent. Meanwhile the numbers of the semiskilled have risen, and they now constitute over 22 per cent of the labor force. This trend has slowed down during the past decade, however. Now we shall probably see an accelerated rise in the proportion of skilled workers, clerks and professional personnel, who already make up 42 per cent of our working population.

In a country with a less fluid and more differentiated social structure than ours, these rapid changes in the occupational composition of the population might have brought about considerable strain. But the celebrated, and often criticized, uniformity of American living renders the effects of such transition almost imperceptible. For example, recent studies indicate that the family of a typical $3,000-a-year clerk spends its money in very much the same way as the family, say, of a machine-press operator with a similar income.

Will the machine-press operator be able to earn his $3,000 when an automatic controlling device takes over his job? The answer must depend in part on the speed with which the labor force is

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Positions are available at West Lynn, Mass., and Lockland, Ohio. Do not apply if your best skills are being used for vital defense work. Please send resume to: Technical and Supervisory Personnel, Aircraft Gas Turbine Division, Dept. C.

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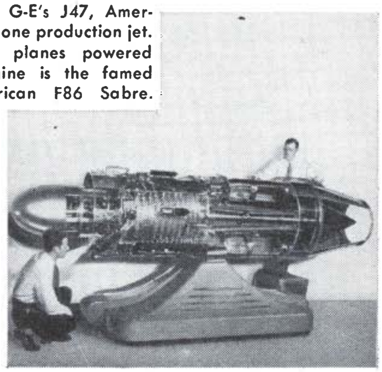
Boeing B47, shown in rocket assisted takeoff. Powered by six G-E jet engines, the B47 is the fastest jet bomber in the world.

Cutaway of G-E's J47, America's number one production jet. Among the planes powered by this engine is the famed North American F86 Sabre.



G-E engineer congratulates Air Force technician on new engine performance record. G-E jet engineers maintain close contact with engine operation in the field

G-E engineers examine model of new turbojet. Group conferences such as this are standard procedure in development of G-E jets.

This modern engineering and administration building is the hub of all activities at G-E's jet center.

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INDUSTRY	1946	1947	1948	1949	1950	1951
Ceramics	110	113	106	70	102	131
Chemicals	125	110	101	62	117	208
Foods	125	107	96	66	103	107
Machinery	107	112	119	61	105	168
Metals	113	98	106	81	134	249
Petroleum	80	90	140	86	98	132
Textiles	106	105	112	75	129	128
Utilities	72	96	122	111	147	222
Total	**100**	**104**	**115**	**82**	**122**	**192**

GROWTH OF INSTRUMENTATION in various industries is shown in this table, which lists the sales of instruments to those industries by years. The index of the table: 1946-1949 average sales of instruments = 100.

able to train and to retrain itself. If such upgrading were to fall behind the demand of the changing technology, semiskilled and unskilled workers certainly would suffer unemployment or at least sharply reduced earning power. The experience of the last 20 years, however, has underlined the flexibility of U. S. workmen. Under the stimulus of the general American striving toward social and economic betterment, they have been quick to take to vocational training for new jobs. There has been no surplus of unskilled and semiskilled labor; indeed, wages in these fields have risen even faster than in skilled and professional work.

But if automatic machines largely take over our production, will there be enough jobs, skilled or otherwise, to go around? Admittedly the possibility of eventual unemployment cannot be excluded on *a priori* grounds. If the capital investment were to increase rapidly while the need for manpower dropped, the resulting rise in capital's share of the national income could cause drastic unemployment. But as we have seen, the amount of capital needed for each unit of output has actually been reduced in recent years, and the installation of automatic machinery will further reduce it. Therefore labor should be able to maintain or improve its relative share of the national income. The danger of technological unemployment should be even smaller in the foreseeable future than it was at the end of the 19th century, when capital requirements were rising.

WHILE THE increase in productivity need not lead to involuntary idleness, it certainly does result in a steady reduction in the number of years and hours that an average American spends at making his living. The average work-week has been shortened from 67.2 hours in 1870 to 42.5 hours in 1950. This reflects a deliberate decision by the American people to enjoy an ever-increasing part of their rising standard of living in the form of leisure. If we had kept to the 67-hour week, we would be turning out a considerably greater amount of goods than we actually are. The difference between this hypothetical per capita output, computed on the basis of the well-known Cobb-Douglas formula, and the actual present output is indicated in the chart at the bottom of page 151. This difference represents the amount of commodities and services which the average American has chosen *not* to produce and consequently not to consume in order to enjoy shorter hours and longer vacations. The spread between the two curves has steadily increased; in other words, we have chosen to spend more and more of our ever-increasing production potential on leisure. The temporary shift to a high output of material goods during the last war

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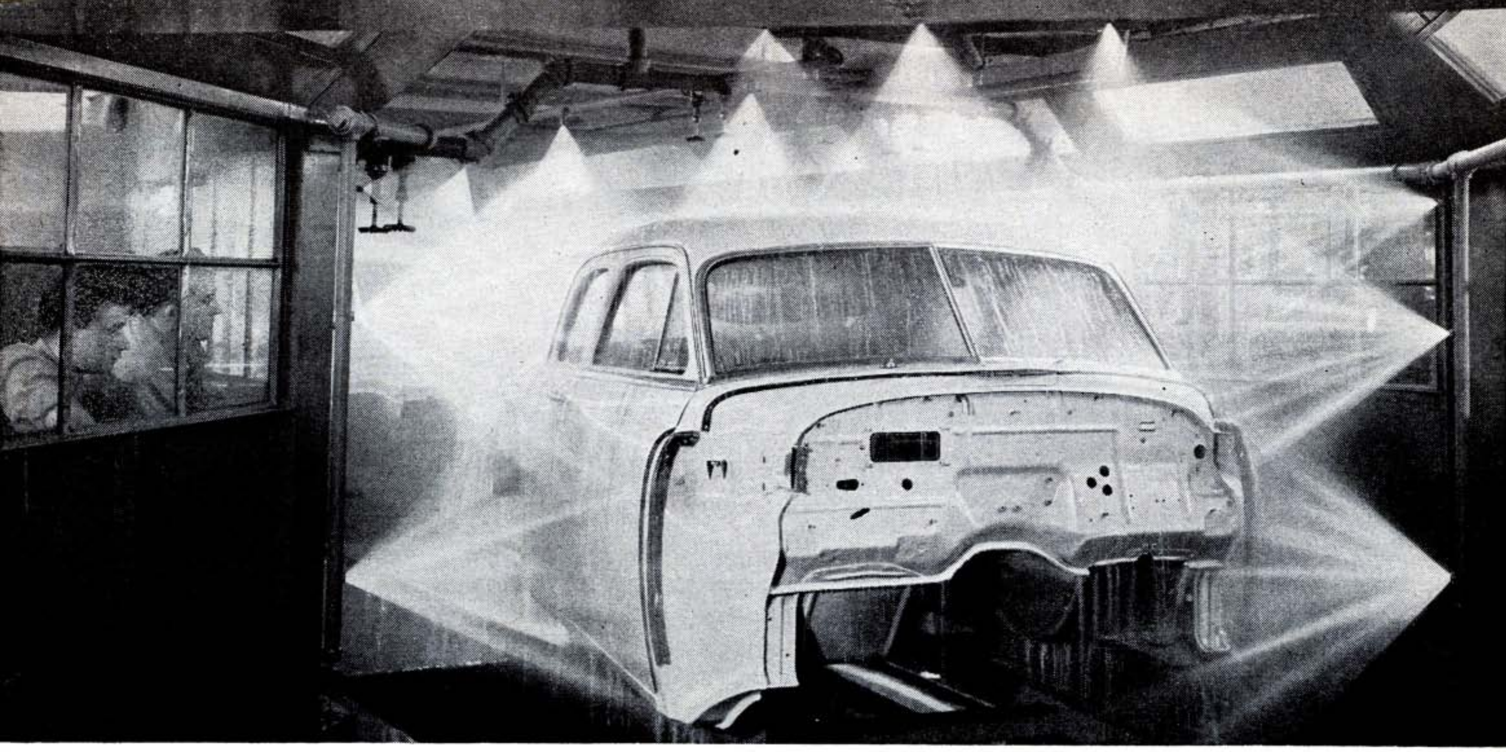

A "CLOUDBURST" in this 100-foot water tunnel proves the effectiveness of Chrysler Corporation's advanced methods of sealing against moisture, dust and drafts. Here complete De Soto bodies move slowly past high-pressure water jets that douse them from every angle. This is typical of the thoroughness with which all Plymouth, Dodge, De Soto and Chrysler cars are built.

A CAR'S BODY TELLS A LOT ABOUT A CAR'S REAL WORTH TO YOU

Chrysler Corporation engineers, stylists, and production men work together, so that body and chassis form a perfectly balanced unit — created from the start for your safety, comfort and *driving and handling ease.*

The way a door latches and holds . . . the amount of head and leg room you get . . . the comfort of the seats . . . breadth of vision . . . ease of getting in and out — all these are easily read guides to the worth of any car.

In a Chrysler-built car, you get a superior body—and a superior chassis — engineered to give you the greatest worth for your money. You can prove this for yourself just by calling your nearby dealer and driving one of these great cars.

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ENGINEERS' EYES ARE EVERYWHERE. Out of their laboratories and on to the production lines go Chrysler Corporation engineers, to follow through each step in body construction. Here an engineer studies the double welding of a Dodge body, one of the many things that mean safer and quieter cars, with windows that work easily, doors and panels that stay solid and free from rattles.

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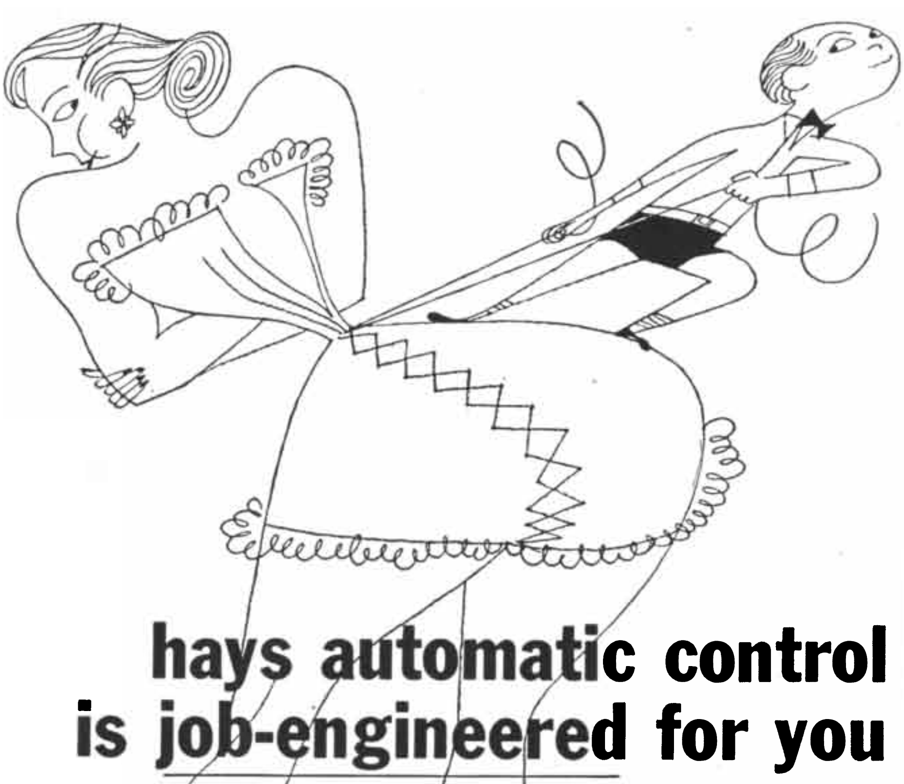
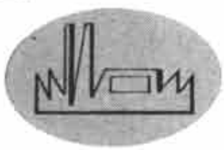
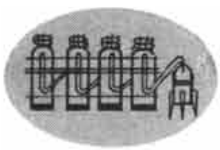


hays automatic control is job-engineered for you



. . . in your boiler plant

complete instrumentation and automatic control in plants of every size for steam generation.



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only emphasizes this tendency, for we returned to the long-run trend immediately after the war. In the future, even more than in the past, the increased productivity of the American economy will be enjoyed as additional leisure.

Looking back, one can see that 1910 marked the real turning point in this country's economic and social development. That was the year when the last wave of immigration reached its crest; the year, also, when our rural population began to decline in absolute terms. Between 1890 and 1910 our national input of human labor had shot up from 28.3 million standard man-years to 42.5 million. Then in 1909 the model-T Ford began to roll off the first continuous production line. This great shift to mass production by machine was immediately reflected in shorter hours. In the next decade our manpower input increased by only one million man-years, and after 1920 it leveled off and remained almost constant until the early 1940s. Even at the peak of the recent war effort our total labor input, with an enormously larger population, was only 10 per cent greater than in 1910. Automatization will accelerate the operation of forces which have already shaped the development of this country for nearly half a century.

THE NEW technology will probably have a much more revolutionary effect on the so-called underdeveloped

INDUSTRY	PER CENT
Meat packing	19
Pharmaceuticals	15
Textile plants	5-12
Soap	3.2-8.6
Dry ice	6.3
Equipment manufacture for the chemical and oil refining industry	.5-6
Paper mill	5
Rubber	5
Petroleum refining	3-5
Packaged foods	3-5
Mining and processing of ores	2-5
Chlor-alkali electrolytic plants	3.25
Sulfuric acid *(contact method)*	3
Pulp mill	3
Carpets	2-3
Rayon and rayon yarn	1-2

RELATIVE COST of instrumental control in various industries is given by per cent of total equipment cost.

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In this room at the Donner Laboratory of the University of California can be seen perhaps the world's greatest concentration of usable, controllable centrifugal force. Eight Spinco Ultracentrifuges: 3 Model E analytical units and 5 Model L preparative units routinely subject research samples of blood protein materials to 260,000 and 144,000 times gravity.

Ultracentrifugation, both by the optical measurement of moving boundaries and through the separation of materials under high centrifugal force, is one of the newer and more rapidly expanding techniques for exploration into the characteristics of matter. Throughout the world, hundreds of Spinco Ultracentrifuges are being used in laboratories for the isolation, purification, and characterization of viruses, enzymes, hormones, and other particulate materials.

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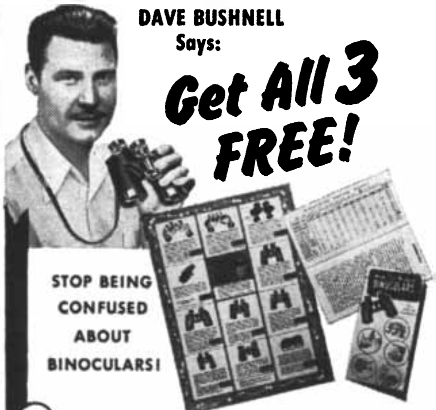

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countries than on the U. S. or other old industrial nations. Shortage of capital and lack of a properly conditioned and educated labor force have been the two major obstacles to rapid industrialization of such backward areas. Now automatic production, with its relatively low capital and labor requirements per unit of output, radically changes their prospects. Instead of trying to lift the whole economy by the slow, painful methods of the past, an industrially backward country may take the dramatic shortcut of building a few large, up-to-date automatic plants. Towering up in the primitive economy like copses of tall trees on a grassy plain, they would propagate a new economic order. The oil refineries of the Near East, the integrated steel plant built after the war in Brazil, the gigantic fertilizer plant recently put into operation in India—these are examples of the new trend in underdeveloped regions of the world. How formidable the application of modern technology in a backward country may become is demonstrated by the U.S.S.R.'s recent great strides in industrialization.

At the outbreak of the First World War the U. S. suddenly lost its source of many indispensable chemicals in Germany. Domestic production had to be organized practically overnight. The newly created U. S. chemical industry had no force of experienced chemical craftsmen such as Germany had. The problem was solved, however, by the introduction of mechanization and automatization to a degree theretofore unknown. The American plants were run with amazingly small staffs of skilled workers. The same thing is now happening, and possibly will continue on a much larger scale, in backward countries. Advanced design, imported mostly from the U. S., will compensate at least in part for their scarcity of high-quality labor.

Naturally automatization, while solving some problems, will everywhere create new and possibly more difficult ones. In Western civilization the liberation from the burdens of making a living has been going on for some time, and we have been able to adjust to the new situation gradually. In the rising new countries economic efficiency may at least temporarily run far ahead of progress toward social maturity and stability. Much of the stimulus for the educational advancement of the Western nations came from economic necessity. Automatization may weaken that powerful connection. It remains to be seen whether the backward countries will find a driving force to help them develop the social, cultural and political advances necessary to help them cope with the new economic emancipation.

Wassily Leontief, professor of economics at Harvard University, is author of The Structure of American Economy.

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MODEL 1121. The Reluctance Amplifier* is a small, lightweight and efficient amplifier designed for use with A.C. servomotors. It operates directly from the A.C. power line. Two A.C. inputs and one D.C. input may be used in any combination. A unique circuit eliminates the necessity for a power transformer. Output 10 watts into 1500 ohms; 18 watts into 735 ohms. Dimensions: 5¾"x3½"x3¼" (for 400 cps model). **Pat. Pending*

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MODEL 2300-A. The Servo Laboratory Analysis and Synthesis Equipment includes a selected list of equipments required in any servo test and development laboratory. These equipments are grouped in a carefully arranged package to permit the designer readily to synthesize a wide variety of systems from standard components and test them with maximum efficiency and time economy. Complete flexibility is provided by standardized interchangeable, plug-in electronic components and efficient and versatile mechanical breadboards. Write for details.

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THE MICROSEN BALANCE

AN UNPARALLELED ADVANCE IN THE APPLICATION OF

ELECTRONIC COMMUNICATION

TO PROCESS CONTROL

THE MICROSEN BALANCE is a compact, modified Kelvin Galvanometer structure—operates automatically on the force balance principle. It transduces mechanical motions into electrical signals and vice versa—is equally effective for the stable amplification of electrical signals.

A calibrated spring converts mechanical motion to force loading of a pivoted beam. The tuning of a high frequency oscillator coil, adjacent to the beam, detects the balance conditions of the beam and varies the current flow in the circuit accordingly. The rectified oscillator output – .5 to 5 milliamperes – serves as the transmission signal. A calibrated portion of this signal is fed back to an actuator coil, attached to the underside of the beam, which operates in a permanent magnetic field. This electrical feedback signal applies a force opposed to the mechanical input force.

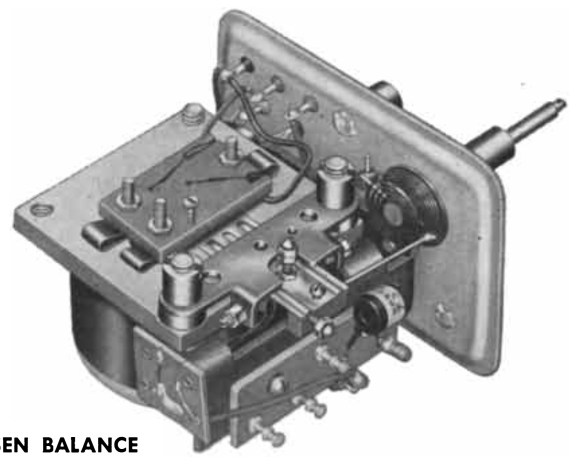
Whenever the two opposing forces become unequal, equilibrium is immediately reestablished by the movement of the beam which either increases or decreases the magnitude of the output current. Output current value is constantly compared with the mechanical input value. Thus, the Microsen Balance insures a linear current signal proportional to the mechanical input and independent of the transmission circuit resistance, up to a maximum of 3,000 ohms.

The Microsen Balance—used in all American Electronic Instruments—*instantly* transmits *pressure, temperature, flow* and *liquid level* information to the panelboard and controller signals to the valve. It provides these advantages of electric communication:

1. Virtually eliminates transmission lags by restricting the use of pneumatic lines to control boards. (The average signal delays over 500 feet of transmission line are 10 seconds for pneumatic, 5 x 10^{-7} seconds for electric).

2. Eliminates all distance considerations.

3. Assures superior performance in process control by high speed response. All changes are detected and corrective measures are initiated



THE MICROSEN BALANCE

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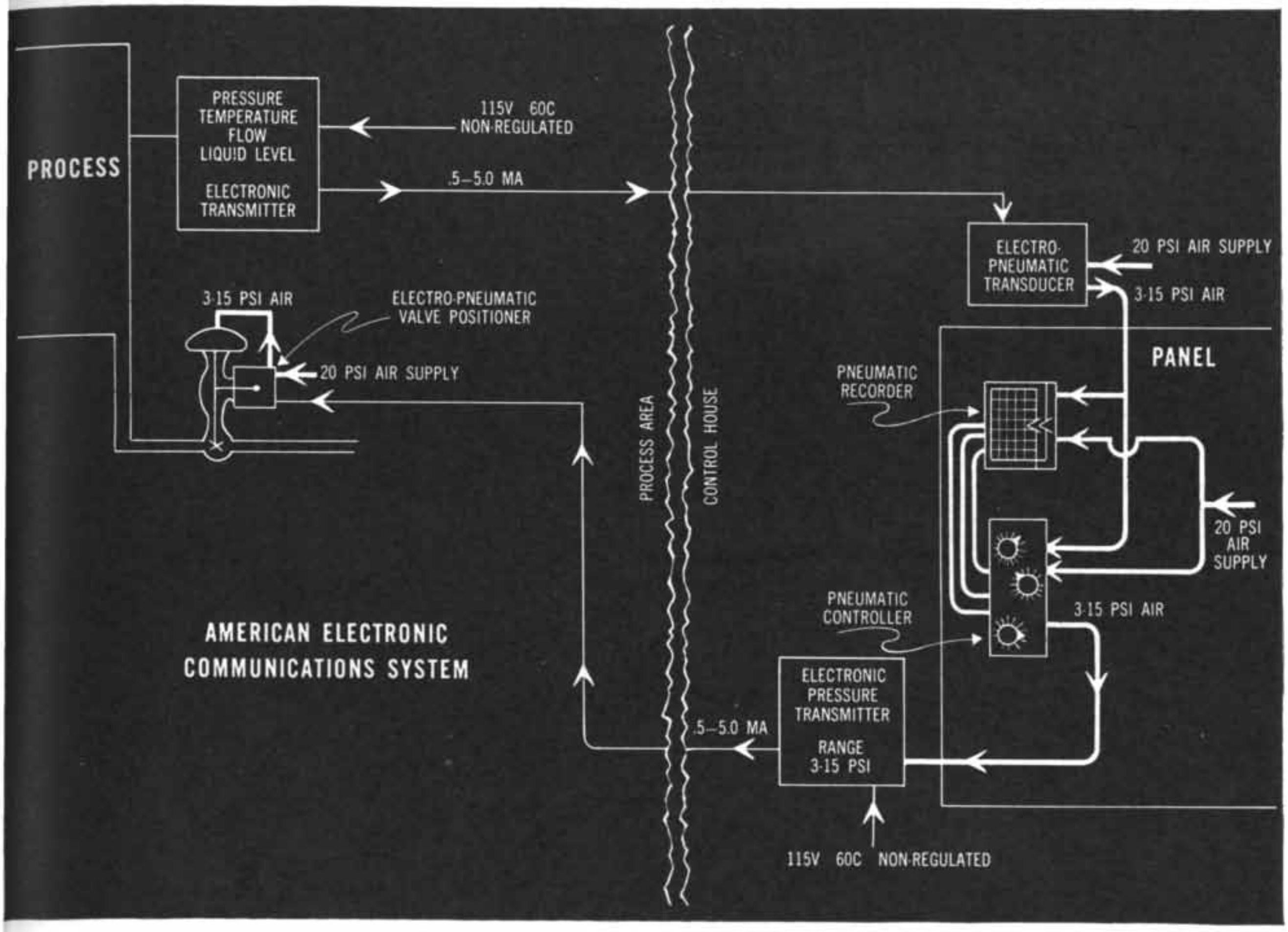

practically instantaneously. This type of "tight" control envisions smaller process equipment for given throughput.

4. Makes all adjustments readily accessible to one operator in the control room.

5. Eliminates freeze-ups of pneumatic lines. Climatic conditions can be completely disregarded.

6. Replaces four pneumatic lines from the panel loading station to the controller at the valve by a simple, two-wire circuit. (Pneumatic controllers must often be located near the valve in order to reduce response delays.)

7. Reduces signal line maintenance.

8. Permits the utmost flexibility through the current type signal. Any number of receiving instruments may be located in a single transmission circuit. Signals are additive for control function computation using two or more input signals.

Elements in the American Electronic Communications System are:

ELECTRONIC TRANSMITTER. Types to transmit pressure, differential pressure, temperature, flow or liquid level. Produce a .5 to 5 milliampere current signal proportional to the magnitude of the variable being measured. Constantly compare electrical output with the magnitude of the measured variables—insure accurate and linear output.

ELECTRO-PNEUMATIC TRANSDUCER. One type utilizes an electronic amplifier and may be used for very low-level signal inputs such as derived from thermocouples. Another type incorporates a mechanical or pneumatic type amplifier — is especially suited for use with the transmission signal of .5 to 5 milliamperes. Both convert electrical input to proportional pneumatic output. They provide the means for utilizing pneumatic recorders and controllers now widely used. Constantly compare the pneumatic output of 3 to 15# of air with the electrical input signal—assure linearity and accuracy.

CONTROLLERS. Pneumatically operated. Widely used with indicators and recorders of the pneumatic type. Some are built integrally with these units or as separate units in the stacked type.

ELECTRONIC PRESSURE TRANSMITTER. Converts air output from controller into an electrical signal.

ELECTRO-PNEUMATIC VALVE POSITIONER. Receives .5 to 5 milliampere signal and compares it to the actual displacement or position of the valve stem—produces a pneumatic signal which mechanically operates the valve.

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What GENERAL ELECTRIC People Are Saying

The three men whose statements appear below are engaged in research and development work on various types of control in General Electric's General Engineering Laboratory at Schenectady, N. Y.

J. G. HUTTON

PLANT CONTROL: The control of processes by remote and automatic means may be said to have had its beginning with the birth of the electron tube and hence the electronics industry. The almost instantaneous receipt of an electric signal, even at a considerable distance from its source, and the ease with which many physical and chemical changes can be converted into electrical impulses, opened the way for automatic control even in the most complicated processes.

In the petroleum and chemical industries many attempts have been made in recent years to provide new and improved methods for determining accurately both qualitatively and quantitatively the composition of mixtures in either gaseous or liquid form.

Perhaps the most versatile, and as a result, the most useful of the methods, is that based on the principle that certain materials selectively absorb infrared radiation. By comparing an unknown mixture against a standard, analyses can be made. In the case of hydrocarbon mixtures the technique cannot be extended beyond those containing six or more carbon atoms, however.

The mass spectrometer in contrast can be used for the analysis of most mixtures whose components are fully vaporized at a pressure of some 40 microns at normal temperature. Its range of usefulness may be extended by heating the sample introduction system, the upper temperature being limited only by the thermal properties of the material of the system. By this relatively simple expedient, hydrocarbon mixtures containing components with 40 carbon atoms, have been analyzed. Except for the high initial cost, delicacy and bulk, the mass spectrometer would be directly useful for process control.

Such objections may be overcome by the use of a mass spectrometer utilizing the cyclotron resonance principle. The tube is positioned in a uniform d-c magnetic field and an rf voltage applied to suitable electrodes to produce a periodically varying electric field whose axis is perpendicular to the magnetic field. Ions are produced in the analyzer region of the tube by bombardment of neutral gas molecules with an electron beam whose axis is coincident with the magnetic field. Under the influence of the combined electric and magnetic fields, the ions are accelerated and have an orbit of increasing radius—an Archimedes spiral. When the natural period of an ion of given mass is equal to the periodicity of the electric field, the particle assumes a resonant condition and acquires sufficient radial displacement to be absorbed or collected by a suitably placed electrode. Particles of different mass, having a different natural period, will not resonate. As a result such particles will be out of phase with the electric field and will not gain sufficient energy to reach the collector. By varying the electric or magnetic fields, or both, ions, representative of all molecules in a gaseous mixture, may be separated and collected.

C. W. CLAPP

QUALITY CONTROL: Only a few years ago, it was common practice for the operator of a steel rolling mill to estimate the amount of tension or stretching force in the strip being rolled by kicking it with his foot. Today, the operator watches the pointer of an instrument called a tensiometer to read the tension in the strip more accurately than was ever possible by the old method.

Tensiometers, X-ray thickness gages, width gages, pin-hole detectors, etc., in the steel industry are examples of a currently well-developed trend to augment or replace the crude sense perceptions of the mill operator with more accurate, more rapid, and more reliable instrumentation.

As machine speeds increase, and higher quality of product becomes essential, it will inevitably become necessary to instrument many of the decision functions of the operator as well. What is needed here is a machine "brain" to receive data from sensory instruments concerning the quality of the product, to interpret this data in the light of known characteristics of the machine, and to arrive at the most effective program of corrective action to restore the quality of the product.

F. E. CREVER

BIT WEIGHT CONTROL: The improvements in control components and techniques of analyzing control systems in the past decade have made precise control of power equipment practical for industry generally. It is no longer considered sufficient to provide power equipment to augment man's efforts; rather, the convenience of automatic and precise control is often desired. Typical of this trend is the General Electric automatic bit weight control for rotary drilling. Not only does the system provide a means of handling the hundreds of thousands of pounds of piping, but also it provides an automatic system to regulate the weight on the bit and to limit the speed of the lowering of the bit. This is provided through two simple settings of the quantities involved on knobs provided for the operator. The system utilizes the regulating properties of the amplidyne generator controlling power equipment to perform these functions. More recently amplistats have been developed so that the advantages of static regulating equipment are being applied to the many control applications necessary to continued progress in industry.

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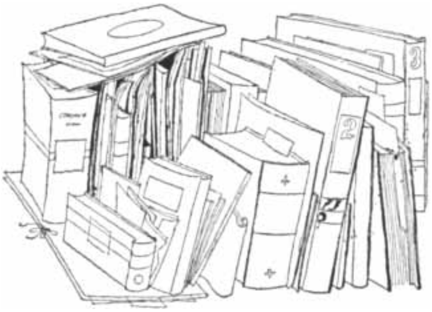

BOOKS

Beyond automatic control: A physicist's statistical examination of man's future

by James R. Newman

The Next Million Years, by Charles Galton Darwin. Rupert Hart-Davis (London).

About 20 years ago William Olaf Stapledon, an imaginative English novelist, published *Last and First Men,* a projected history of mankind from the present to its presumed finish about five trillion years from now. His narrative ended with the earth, inhabited by the 18th species of *Homo sapiens* (reckoning ours as the first), about to be destroyed by a solar convulsion. *Last and First Men* is a book not easily forgotten. I returned to it when reading Sir Charles Darwin's volume and found it as engrossing as on first acquaintance.

Compared to Stapledon's story the best science fiction today is vulgar and paltry. Stapledon's book derived its power not from its speculations as to the marvels of super-science, nor even from its graphic descriptions of the cataclysms periodically engulfing the physical world, but rather from a remarkable treatment of the evolving nature of man himself. The subject is one which only the ablest writers venturing into this sphere of imagination, E. M. Forster and H. G. Wells among them, have been able to treat on a serious level. Stapledon was concerned primarily with the psychological traits of the successive human species. In his story one civilization after another grows up, flourishes and crumbles against a background of climatic changes, geological catastrophes, world epidemics, global wars, Martian invasions and the like. Again and again the human race is all but wiped out; then new species arise, often superior intellectually and physically to the races that have gone before. But the recurrent theme is the comedy of Eden: man is unable to let well enough alone; sooner or later he becomes bored and restless even in Paradise. Envy, curiosity, quarrelsomeness, suspicion, brutishness—sometimes dormant but never absent from his nature—reassert themselves and invariably encompass his downfall.

A similar theme runs through Sir Charles Darwin's *The Next Million Years.* Sir Charles, a distinguished physicist and grandson of the founder of the evolution theory, has not written a book of pure fancy and weird conjectures. His "time machine" is as dependable a vehicle as scientific knowledge can contrive. The million-year journey is conducted under the strict auspices of rational thought. The journey is no less interesting for this discipline. Reason and imagination are blended to provide a remarkably varied and stimulating itinerary.

It would be rash, as Sir Charles acknowledges, to predict the history of the next 10 years. But every insurance company knows that long-range predictions are safer. Indeed, it is easier in some ways to say what will happen than what has happened. Assuming a moderate consistency in nature, it is possible on the basis of present knowledge to make certain fairly reliable forecasts over the next million years.

The classic example of large-scale prediction is Boyle's Law of gases. We know almost nothing about the behavior of this or that gas molecule enclosed in a container before us, yet it is possible to predict the behavior of the whole ensemble of molecules with precision. Sir Charles proposes a Boyle's Law of human behavior over the long run. To this end he avails himself of the same exquisite and paradoxical tool of prophecy, the theory of probability. To derive Boyle's Law it is essential to know something of the internal conditions of the gas (*viz.,* that the molecules constitute a conservative dynamical system, which is to say that "the total energy of two colliding molecules is conserved") and of the external conditions, namely the character of the containing vessel. The analogous law of human behavior, while not determined by statistical mechanics, also rests upon a knowledge of internal and external conditions. For the "wildly varying and violently colliding" gas molecules, Darwin substitutes the more complex human molecules, less varied, perhaps, in their trajectories but no less violent in their collisions. For the container, he takes the earth itself. On this foundation he builds a system of human thermodynamics.

The Next Million Years is not concerned with the trivia of history. The events historians consider important and stirring—wars, crusades, political upheavals, migrations, the crises of civilization, even such phenomena as ice ages—are passed over as of no consequence on this time-scale. What matters is what will be happening "most of the time" on the endless train of summer afternoons. The aim of the book is to "form an estimate of the normal and not the exceptional course of the life of mankind on earth."

For the forecasting historian the crucial question is: who will survive? This must "override all questions as to whether future man will be better or worse than present man, or whether he will rise to heights we cannot conceive or sink to levels we should despise." A species which dies out has by an inexorable principle demonstrated its unworthiness to live, however admirable or noble it may be by moral standards. "The dead shall not breed" is the dictum of natural selection; not the meek, but the survivors shall inherit the earth.

In the long run, says the author, population must always press upon resources. Malthus' law is not mathematically exact and also must be modified by factors he could not have foreseen. Nonetheless it is clear that an unchecked population will outrun its food supplies. Undoubtedly food production can be increased substantially: tenfold, say, by bringing more land into cultivation and by improving agricultural methods; a thousandfold, perhaps, by ingenuities beyond present conception; possibly even a millionfold by intensive cultivation of the vegetation of the sea. Compare these estimates with reasonable expectations as to birth rates. It is plausible to suggest that in a century the world's population will have doubled. Wars are unlikely to arrest this expansion by much or for long. In three and a half centuries the earth's population will have increased by a factor of 10, in 10 centuries by a factor of 1,000, in 20 centuries by a factor of a million. Even with everyone munching on seaweed, chlorella, sawdust and similar goodies, there will be barely enough food to keep the world's inhabitants crawling around. Yet 2,000 years is an insignificant period on the million-year scale. Even if the rate of population increase has been much overestimated, this hardly affects the argument, for assuming it took 1,000 years instead of 100 to double our numbers, we would still attain a millionfold increase in population within 20,000 years. We may take it as axiomatic that men will multiply, that food supply will not keep pace

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with their rate of increase and that a margin of the population must consistently be sloughed off by starvation, disease or other natural agents.

Sir Charles dismisses as unlikely any prospect that the human race will balance population and subsistence by deliberate limitation of its own reproduction. He sees no real chance that individuals will, in numbers sufficient to make a difference, practice birth control so as not to jeopardize the survival of their great-great-grandchildren. The processes which must win out on the long time-scale are those that are spontaneous and stable. The voluntary limitation of population, on the other hand, is a highly unstable process—the term stability roughly signifying that when a dynamic system "gets a little above its average level, by that very fact a force comes into play to pull it back, while if it falls below, a force is evoked to raise it again." Nations cannot be expected to accomplish much more by edict than individuals by voluntary restraint. To be effective, the limitation of the birth rate would have to be world-wide, based on a rational collective policy agreed to by all states. One need not comment on the unlikelihood of such a concordat. Though the majority of men might accept the policy of limitation on "broad rational grounds," one can safely anticipate a good deal of vehement, indeed fanatical, opposition based on creed. The main difficulty lies in enforcement, not only within the separate nations, but among them. A flagrant breach of the pact by a single country must disrupt a system which can maintain itself only by balancing its reciprocal pressures. Once the system collapses, only mass murder can restore the man-food equilibrium upon which survival depends.

We are led to a set of fairly simple and perhaps obvious conclusions, conclusions which the author's grandfather well understood. Men need food to survive; they must compete fiercely to get it. There are groups among them possessed of qualities which are likely to confer an advantage in this competition. These groups will determine the future course of history; their descendants will inhabit the earth a million years from now. It is hardly necessary to point out that the qualities destined to win out in the long run will not necessarily be those we now admire and seek to preserve.

What else can be predicted? The climate of the earth has been roughly the same for a billion years, and there is no reason to expect major changes for many more than a million years to come. A few ice ages might be disagreeable but could scarcely prove decisive. The planets revolve serenely, the sun continues to shine, and it is improbable that this harmony will be disturbed in the period considered. There is a chance,

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Sir Charles concedes, that a dark star may be moving toward our solar system. A collision would unquestionably do us in even if the earth itself were not hit, but the chance is so small that it need not concern us.

The problem of fuel resources is more serious. Our treasury of fossil fuels, accumulated for us over a period of 500 million years, has already been heavily depleted. At present consumption rates, it will be empty in 5 or 10 centuries. Future man must learn to live on income instead of on capital, and the standard of living is bound to fall. Water power will not fail, but it can contribute only a small part of world energy requirements. Atomic energy, from what is now known, offers no long-term solution. However, the potential supply of heavy hydrogen is in effect unlimited and if we could find a way to make it "burn" slowly, the problem would be permanently solved. There is scant reason to believe that ordinary hydrogen can ever be made to yield nuclear energy; if it could be, that, too, would yield a solution—of a kind. A frustrated *fuehrer*, or even a well-meaning lunatic bent on preserving the dignity of man, could set fire to the sea and to the earth's hydrogen envelope, with the result that the earth would for more than 10 years shine "as brightly as the sun does now." Such an event "would make the solar system into a very respectable new star," but plants and animals would be missing. Our descendants must look to other energy sources—sunlight, wind, tides, vegetation, the interior heat of the earth, the cold water at the bottom of the sea—to eke out their needs. The expectation is not, in Sir Charles' opinion, altogether satisfactory, and mankind will probably have to learn to get on with a good deal less energy than our age is accustomed to.

Besides fuel, many other shortages will plague our successors. Stocks of essential metals will run out—some of them very soon. All sorts of ordinary things today regarded as indispensable, not merely to comfort but to existence, will vanish as the raw materials of which they are made gradually disappear. Substitutes will be found, but not for every object we have come to cherish; nor will the substitutes necessarily be of comparable quality. Plastic eating utensils are a devilish invention but supportable; the prospect of plastic surgical instruments and machine tools is disheartening.

The majority of the earth's present inhabitants may be justifiably skeptical of Sir Charles' contention that they are living in a Golden Age. Even the members of Western society may be permitted to doubt that this is the best of times. Yet in the material sense, disregarding certain inequalities of distribution, man is better off than ever before and better off than he is likely to

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be in the long-run future. Our period is marked alike by profligacy and invention; on balance we squander more than we discover, and thus over the centuries the estate diminishes.

I observed earlier that Sir Charles shares Stapledon's views as to man's essential qualities. In fact his book addresses itself primarily to the problem of "internal conditions": namely, whether man can be expected to change his nature markedly in the next million years. For if such changes were to occur, it would follow that several of the major inferences already set forth—notably as to population—would have to be reconsidered. "It was mainly the belief," Sir Charles declares, "that there will be no revolutionary change in human nature, that emboldened me to write this essay."

He argues this proposition strongly. To begin with, he selects his span of prophecy, a million years, with certain geological and biological data in mind. These data force the conclusion that it takes a million years to make a new species. It matters little, apparently, how many generations occur in that period; some species change more quickly, some more slowly, but this "good rough rule" applies with general force to most of the species we know—rats, insects, buffaloes or men. For a million years, then, we shall have to get along with man as he is now.

It will not be denied, of course, that man has done much to improve himself since the species first appeared. How much more can he do? Sir Charles recites the four revolutions that have taken place in the development of humanity: the use of fire, the invention of agriculture, living in cities and the scientific revolution. The "central fact" of this latest revolution, which we are still undergoing, "has been the discovery that nature can be controlled and conditions modified intentionally." The principal limits to such modifications—the constants and the bounds, in other words, of "external conditions"—have been discussed. It remains that the potentialities of science and technology stretch far beyond imagination; in this realm of conjecture the ground on which the prophet stands is certain to be treacherous. My feeling is that in these matters generally Sir Charles is too conservative. But I am delighted to report on his speculations on the use of high-speed computers as soothsayers. He sees the possibility of calculators which could improve on the performance of the Delphic oracle, not to say poll-takers and military intelligence experts. It may come about that such machines in a short space of time could "explore the consequences of alternative policies with a completeness that is far beyond anything that the human mind can aspire to achieve directly." Still, this brings us no closer to altering the drives

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impelling the man behind the machine. One suspects, for example, that a calculator which would reveal the outcome of a projected war would be discredited, if not banned, by sovereign states. So long as men believe what they want to believe, there will be wars.

Granted that no new species, "Homo sapienter," will arise spontaneously, does it lie within our own power to improve the existing breed of men as we have done with cattle and corn? Genetics affords no basis for an optimistic reply. The traits we regard as contributing to social good—tolerance, cooperativeness, rationalism—are "acquired characters" and do not pass through the sieve of inheritance. They are handed on by precept and example, not by genes; such, at least, is the authoritative consensus. It is possible to breed for milk-giving qualities in cows, for rust-resistance in wheat, for learning capacity in dogs. It may be possible to breed men for pole-vaulting ability, for red beards or for aquiline features. But it is utterly beyond comprehension how permanently to build into the inheritance machinery the traits, say, of kindliness or healthy skepticism. Nor, for that matter, is it clear that such traits would necessarily promote the ability to survive. Changes can be brought about in the germ cells by means of X-rays which induce mutations. Startling effects have been achieved in this way with the long-suffering fruit fly, *Drosophila*. But this is no more than a hit or miss method which "simply stirs things up so that an arbitrary change results," usually deleterious. Tampering with the delicate mechanism of chromosomes and genes is like trying to adjust a fine watch by banging it on the floor; the treatment is unlikely to bring about the desired result.

The future, then, is fairly bleak. A million years from now the earth will be poorer, shabbier, more crowded than it is today. Its population, having been held in check by starvation, wars and other Malthusian governors, will be perhaps three to five times what it is now. The human species will not look very different. Its physical characteristics will change, of course, but "not to a great extent, since it is not primarily these qualities that preserve humanity in the struggle for life." We may assert with confidence that men will become "cleverer," for intelligence is a determinative factor in natural selection. Since Sir Charles does not share Socrates' view that wickedness is caused entirely by ignorance, he regards it as uncertain that men will become "morally better" as they become more intelligent. In a highly competitive world, moreover, the "sinner has many advantages over the saint," and whatever advantage promotes survival is its own justification and makes its own way.

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continue to advance. Inquisitive men will strive to know for the sake of knowing; others will build machines and invent practical processes. Sir Charles conceives of the invention of drugs to produce a permanent state of contentment (very useful for dictators), to remove the "urgency of sexual desire" and so bring about in humanity "the status of workers in a beehive," and to control the sex of offspring. None of these marvels, however, promises to add substantially to the sum of human happiness. Happiness, we are reminded, resides not in a state but in a change of state; eternal bliss is so tedious a prospect that one might prefer, given the choice, everlasting torment. Fortunately the dilemma is not thrust upon us. Life will continue to fluctuate between pleasure and pain.

The Next Million Years is a readable and honest book, packed with challenging ideas. The author speaks with authority on many matters, always with an attractive diffidence and in good temper. His explanations are clear, so clear that there is no difficulty in knowing where one disagrees with him and why. It is prudent to reject the notion that man is perfectible, but on the other hand it may not be overoptimistic to hope that he is capable of bettering himself before he vanishes from the earth. The Mendelian laws do not lock men into a groove of predestination; the science of inheritance, moreover, is not immutable. Man cannot be domesticated, says Sir Charles; he is a wild animal. In this wildness is his undoing, but also his glory.

SYMMETRY, by Hermann Weyl. Princeton University Press ($3.75). Dr. Weyl presents a masterful and fascinating survey of the applications of the principle of symmetry in sculpture, painting, architecture, ornament and design; its manifestations in organic and inorganic nature; its philosophical and mathematical significance. In the everyday sense symmetry carries the meaning of balance, proportion, harmony; in geometry it connotes a much more precise concept, that of bilateral symmetry. "A body, a spatial configuration, is symmetric with respect to a given plane E if it is carried into itself by reflection in E." The mathematical concept lends itself to remarkable elaborations. Simple forms, when subjected to translatory and rotational motions, are transformed into marvelously intricate designs; these designs in two and three dimensions are encountered in art, biology, chemistry, astronomy, physics and crystallography. In mathematics the ruling principle of symmetry is applied to forms and processes of every conceivable variety; that is to say, the forms and processes are defined in terms of the combination of motions which gives birth to them. Weyl

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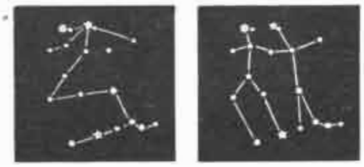

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shows how symmetry establishes a ridiculous and wonderful cousinship between objects, phenomena and theories outwardly unrelated: Greek statues, terrestrial magnetism, women's veils, polarized light, natural selection, group theory, the work habits of bees in the hive, vase designs, quantum physics, cell division in sea urchins, X-ray interference patterns, Romanesque cathedrals, snowflakes, music, the theory of relativity. Many excellent illustrations support the text, and the publishers have done their share by making a handsome volume. But the reader must be warned that this is not an easy book.

ATOMIC POWER: AN ECONOMIC AND SOCIAL ANALYSIS, by Walter Isard and Vincent H. Whitney. The Blakiston Company ($4.75). This comprehensive survey deals with the costs of atomic power, consequences for specific industries, location theory, regional aspects, cultural resistances, indirect effects. The authors, two of the most thoughtful students of the subject, traverse ground partly covered in the pioneer study by the Cowles Commission, but they have made a fresh and independent appraisal which merits careful attention. On balance they are conservative in their expectations. They do not think it likely that the advent of atomic power will revolutionize the present social and economic structure of the world; they offer an impressive array of "technical, human and cultural obstacles in the way of the establishment of commercially feasible atomic power." They concede that limited use of it may come fairly soon in certain industries, glass and aluminum as examples, and in some industrialized areas where hydroelectric power is not available. A case study of Brazil leads to the conclusion that for various reasons atomic power would not bring an industrial renaissance in regions of that type. The authors argue that the nation which has "the most to gain in the long run" from atomic power is the U.S.S.R., with energy resources inferior to ours, a mobile labor force, a rapidly expanding market and considerable technological experience. "It is not merely that Russia can; it is also that the believed necessity to do so is greater." Obviously, as Isard and Whitney point out, the national considerations in Russia's case have far-reaching implications for international control schemes.

THE APOLOGIE AND TREATISE OF AMBROISE PARÉ, edited and with an introduction by Geoffrey Keynes. The University of Chicago Press ($3.50). Ambroise Paré was the greatest surgeon of the 16th century. This selection from his writings portrays successfully the man and his achievements: his "voyages made into divers places" in the role of military surgeon for kings and nobles of France, and case histories of his pa-

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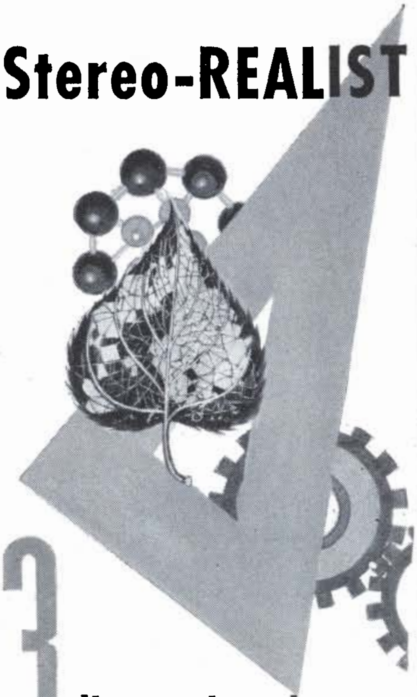

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FACTS FROM FIGURES, by M. J. Monroney. Penguin Books ($1.25). A general reader's introduction to statistics by an English statistician and industrial consultant. Mr. Monroney is a steady and knowledgeable guide in advancing from the simple elements of probability through the mathematics of the distribution of brunettes, floods, soccer goals and horse kicks, the problems of correlation, sampling, goodness of fit, quality control, ranking methods, variation and kindred topics. Numerous exercises are provided—with answers, fortunately. For all Monroney's skill and patience, one soon comes to realize—if this truth was ever forgotten—that gaining an understanding of statistics is not a comfortable downhill glide.

TECHNICAL REPORTING, by Joseph N. Ulman, Jr. Henry Holt and Company ($4.75). A handbook of elementary principles for writing scientific articles and technical reports. It is based on a course in writing for science and engineering students, but the need for such manuals is not limited to students; a glance at any professional journal makes abundantly clear that communication is a neglected art in the scientific community. Mr. Ulman's precepts are sensible and helpful; his examples of how not to write are well chosen. Unfortunately his own writing and his attempts to rewrite the horrible examples fall a good deal short of the goals of clarity and brevity that he sets up.

PSYCHOANALYTIC EXPLORATIONS IN ART, by Ernst Kris. International Universities Press, Inc. ($7.50). This group of essays applies aspects of Freudian theory to the creative process and its results. Dr. Kris has a broad clinical and

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cultural background, and his essays, though somewhat disconnected and of varying quality, are carefully and originally thought out. The art of the insane, an ever intriguing subject, is studied on the hypothesis that creative spells in psychotics are an attempt at restitution. Kris' essays on comic drawings and caricature discuss the history and function of humor and laughter in the Western personality. He develops with brilliance the idea that the comic is only successful when it has become a safe defense against anxiety and when magic concepts no longer operate. His essay on Prince Hal's conflict should take its place with Ernest Jones' study of Hamlet; both are enrichments of literary criticism by psychodynamic insight.

An Introduction to Projective Techniques and Other Devices for Understanding the Dynamics of Human Behavior, edited by Harold H. Anderson and Gladys L. Anderson. Prentice-Hall, Inc. ($6.75). An excellent book for the professional psychologist and for the interested psychiatrist. It is also valuable for the layman who has heard much but knows little about projective techniques. Extreme statements now current about a number of the tests have led people to think that they are the 20th-century substitute for fortunetelling. Actually, although many of the techniques are still in the experimental stage, some of them have already become useful diagnostic tools and even therapeutic devices. The best-known are the Rorschach, the Thematic Apperception and the Wechsler-Bellevue Tests. But projective tests also include finger-painting, drawings, block building, mosaic structures, play activity, classical word association, handwriting and responses to structured and non-structured pictures. This book, intelligently edited, consists of articles by authorities in each of the techniques described.

Psychotherapy with Schizophrenics, edited by Eugene B. Brody and Fredrick C. Redlich; introduction by Robert P. Knight. International Universities Press, Inc. ($4.00). For a long time it was believed that psychotherapy could not deal successfully with psychoses, the severe mental diseases. By now it has been shown that it not only can help but occasionally can cure schizophrenics. This symposium, by a group of clinicians and theoreticians, discusses the various methods of psychotherapy used with these patients. Among the outstanding papers are those of Dr. Frieda Fromm-Reichmann and Ruth and Theodore Lidz.

The Yearbook of Psychoanalysis, Volume VII, edited by Sandor Lorand. International Universities Press, Inc. ($7.50). The 1951 edition of this well-known annual on psychoanalytic

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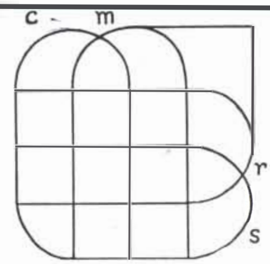
THE FACTS OF LIFE, FROM BIRTH TO DEATH, by Louis I. Dublin, in collaboration with Mortimer Spiegelman. The Macmillan Company ($4.95). Here are questions and answers on vital statistics of interest to the morbid, the curious, the hypochondrial, the amateur, the professional—in short, to almost everyone. Am I too fat (or too thin)? What is my life expectancy, aged 47, with a heart murmur? What is the chance of my dying of cancer if I am a farmer living in Nebraska, or of coronary thrombosis if I am a lawyer practicing in New York? What are the most common occupations of women? Is diabetes inherited? What are the chief defects disclosed by school health examinations? What country has the lowest death rate? What are the chances that a marriage will end in divorce? What is the safest mode of travel? What are the chances of being struck by lightning? How many children were orphaned in both world wars? The answer to the last question, if you should care to hear it, is of the order of 20 million.

THE DESIGN AND ANALYSIS OF EXPERIMENTS, by Oscar Kempthorne. John Wiley & Sons, Inc. ($8.50). The author, professor of statistics at Iowa State College, presents a comprehensive treatment of this important discipline, developed largely by R. A. Fisher and F. Yates. His purpose is to describe the design of experiments and to relate its theory "to the general theory of statistics and to the general problem of experimental inference." For statisticians and biological scientists.

THE ZOOLOGY OF TAPEWORMS, by Robert A. Wardle and James Archie McLeod. University of Minnesota Press ($12.50). A monumental treatise on the tapeworms of the world. It summarizes what is known about their classification, structure, physiology, life cycles, relationship to the host, origin, evolution from "free-living" worms. Profusely illustrated and accompanied by an up-to-date bibliography, this is an indispensable reference work.

COMPENDIUM OF METEOROLOGY, edited by Thomas F. Malone. American Meteorological Society ($12.00). This encyclopedic survey of the current state of meteorology, prepared under the supervision of the American Meteorological Society, contains more than 100 contributions by leading meteorologists and atmospheric physicists from all over



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PREFACE TO EUGENICS, by Frederick Osborn. Harper and Brothers ($4.00). A revised edition of a book well-received on its first appearance in 1940. Osborn explains for the general reader what is known about the effects of heredity and environment, present population trends, efforts (in Europe mainly) to control population, the importance of a rational, world-wide eugenics program. It appears that the U. S. is the only "technically advanced country in the modern world" without an explicit and officially formulated population policy.

INTELLIGENCE AND CULTURAL DIFFERENCES, by Kenneth Eels, Allison Davis, Robert J. Havighurst, Virgil E. Herrick and Ralph W. Tyler. University of Chicago Press ($5.00). One of the major conclusions of this investigation is that conventional intelligence tests unduly penalize children in the lower economic strata. They overemphasize verbal ability and motivations and kinds of knowledge characteristic of the middle class. The writers argue that the tests, developed primarily to predict school success, are inadequate as guides to estimating the ability of children of the lower economic class to solve problems at home, on the street or anywhere else in their culture. Intelligence tests have been criticized on similar grounds for years, but critics have so far been unable to suggest what criteria, other than some aspect of school performance or achievement, could be used to validate an intelligence test. The finding that lower-class children are handicapped by the verbal and abstract character of present tests is a legitimate reason for not using such tests to compare the "intelligence" of class and racial groups. But non-verbal tests will be no better as a measure of intelligence until someone finds a standard for judging the validity of the scores.

ELECTRONIC AND IONIC IMPACT PHENOMENA, by H. S. W. Massey and E. H. S. Burhop. Oxford University Press ($14.00). A survey, in the International Series of Monographs of Physics, of the theoretical and experimental aspects of collision phenomena. Among the topics considered are the passage of electrons through gases, the experimental analysis of the cross sections for impact of electrons with atoms, electron collisions with atoms and molecules,

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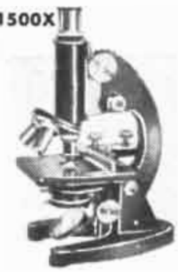

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PROCEEDINGS OF THE SECOND BERKELEY SYMPOSIUM ON MATHEMATICAL STATISTICS AND PROBABILITY, edited by Jerzy Neyman. University of California Press ($11.00). The subjects dealt with at this meeting in 1950 include physics, astronomy, econometrics, probability, mathematical statistics, traffic engineering, biometry, wave analysis.

A PHILOSOPHICAL ESSAY ON PROBABILITIES, by Pierre Simon, Marquis de Laplace; translated by Frederick Wilson Truscott and Frederick Lincoln Emory. Dover Publications, Inc. ($1.25). A reprint of Laplace's famous essay with an introductory note by E. T. Bell. This is one of the great books of semi-popular science, a by-product of Laplace's *Théorie analytique des probabilités* and other researches in probability. It has long been out of print in the English translation and is much sought by students of the subject.

MATTER AND MOTION, by James Clerk Maxwell, with notes and appendices by Sir Joseph Larmor. Dover Publications, Inc. ($1.25). A paper-bound reprint of Maxwell's little classic introducing the subject of physical science in general. The exposition is elegant but austere; not for the average reader.

CONTRIBUTIONS TO THE FOUNDING OF THE THEORY OF TRANSFINITE NUMBERS, by Georg Cantor. Dover Publications, Inc. ($1.25). A reissue of P. E. B. Jourdain's translation of the two pathbreaking memoirs by Cantor on the theory of the alephs. The book has been hard to find, and students of the philosophy and foundations of mathematics will be well pleased to lay hands on it at so moderate a price.

HEGEL'S SCIENCE OF LOGIC, translated by W. H. Johnston and L. G. Struthers. The Macmillan Company ($6.50). A reissue of a noted work in Muirhead's Library of Philosophy. Hegel wrote this massive, and of course turgid, essay at Nürnberg in 1812 and was engaged in revising it at the time of his death in 1831.

THE CLASSIFICATION OF ANIMALS, by W. T. Calman; THE ECOLOGY OF ANIMALS, by Charles Elton; MENDELISM AND EVOLUTION, by E. B. Ford. John Wiley & Sons, Inc. ($1.25 each). First American issue of a group of manuals in the series of Methuen "Monographs on Biological Subjects." Designed for research workers, teachers and students.

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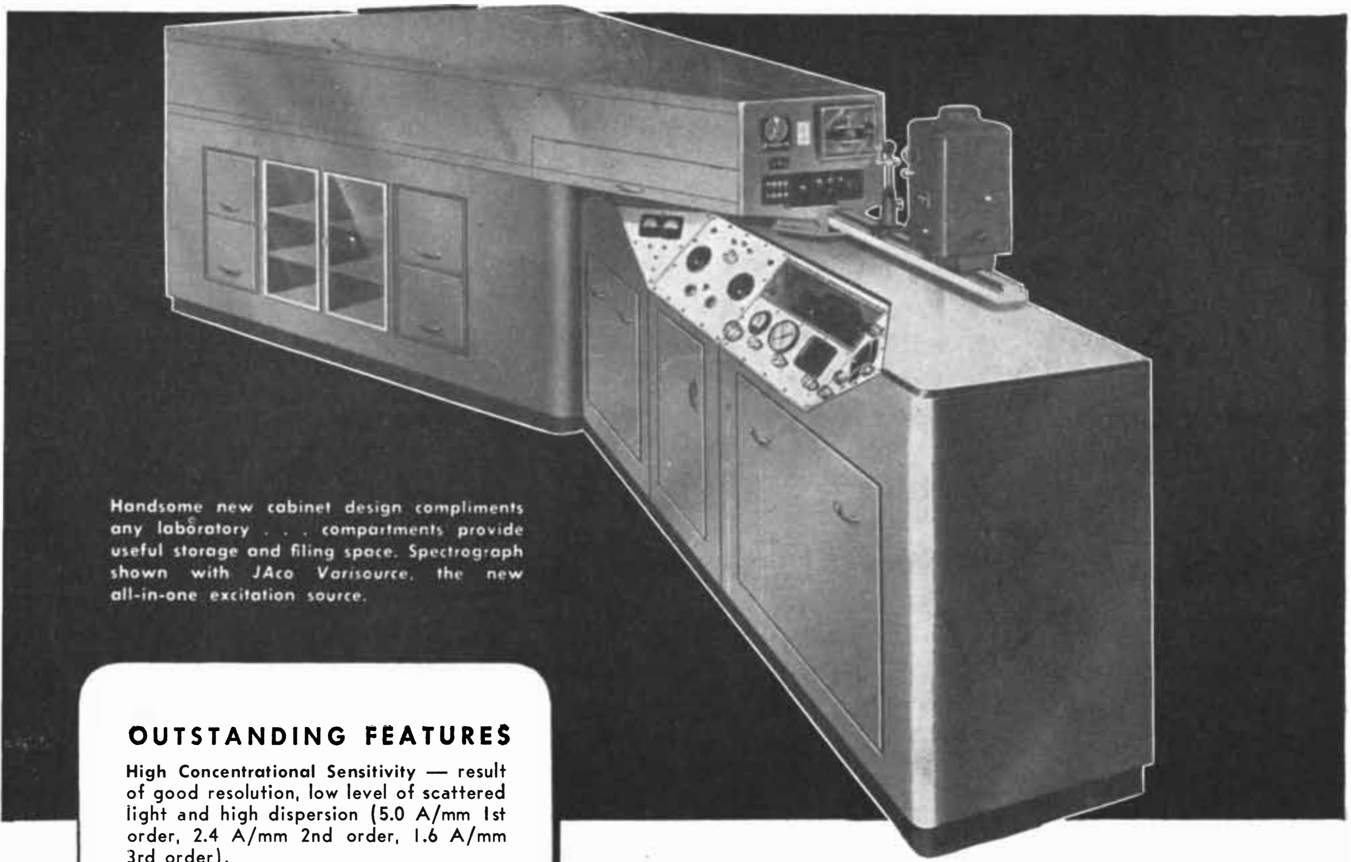

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THE AMATEUR SCIENTIST

About home-made cloud chambers and the fine telescope of a Portuguese navy officer

Conducted by Albert G. Ingalls

SOMEONE once said that all the equipment a scientist really needs is a pencil, a piece of paper—and a brain. James Clerk Maxwell and Albert Einstein managed to push back the frontiers of knowledge without a cosmotron to their name. For experimental research in nuclear physics today a pencil is not quite enough, but a resourceful amateur can put himself in business with a capital investment of less than a dollar. For this sum he can build a cloud chamber to trap atomic particles. The chamber will stage a show more fascinating than a 100-gallon tank of tropical fish, and in a few sessions will display more nuclear tracks than the observer can analyze in a lifetime.

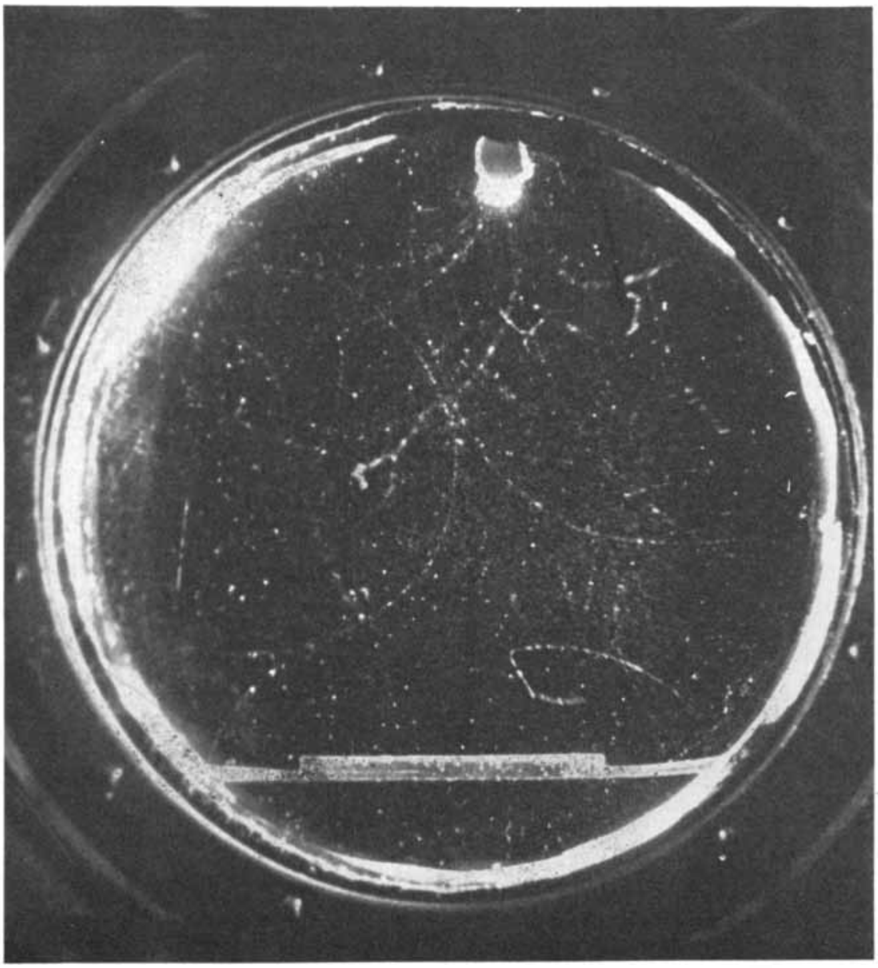
This simple, recently invented workshop version of a basic physicist's tool is called the diffusion, or "continuously sensitive," cloud chamber. It can be built in 10 minutes by anyone with a dime's worth of dry ice, some alcohol, even the rubbing kind, and a glass jar. Within a few minutes it will begin recording tracks, provided it has been set up properly. The project requires care, close attention to the instructions and some knowledge of cloud-chamber principles. The background and instructions are supplied in the following discussion by I. Clyde Cornog of the University of Pennsylvania's Randal Morgan Laboratory of Physics.

"Toward the end of the last century," says Dr. Cornog, "a few persons here and there were studying the condensation of supersaturated vapors. It was known that water vapor could be cooled well below its dew-point without condensation, provided no dust particles were present. In 1896, C. T. R. Wilson of Cambridge University discovered that the ions formed in gases by X-rays could, like dust particles, act as centers of condensation in supersaturated water vapor. Later he showed that ions produced by 'rays' emitted from radioactive substances would likewise cause condensation. In a supersaturated chamber moving particles produced a visible trail of ionization. The apparatus Wilson developed to carry on this work became known as the Wilson expansion cloud-chamber.

"The phenomenon of radioactivity also was discovered in 1896, and the radiations emitted from radioactive substances were soon identified as of three kinds: negative particles (electrons), positive particles (alpha particles) and gamma rays. Wilson and a colleague, P. M. S. Blackett, found that all three kinds of emission caused ionization, and they saw in the cloud chamber a way of investigating the properties of these emissions—their velocity, energy, charge and so on. They published their first expansion-chamber photographs, showing the white trails produced by particles, in 1912.

"The construction and operation of a simple Wilson cloud chamber is shown in the accompanying diagram. The chamber is a glass cylinder with a glass top. Its floor is a movable piston, covered with black velvet as a background against which to see the tracks. The chamber is illuminated by a flat, wide pencil of light. A little water on the velvet serves to keep the water vapor in the chamber saturated (not supersaturated). And a battery is wired to the top and bottom of the chamber; its function is to create an electric field to keep the chamber swept clean of all ions except when it is expanded to show the passage of particles.

"The chamber operates as follows: The piston is pulled down suddenly, increasing the volume of the chamber by about 25 per cent. This cools the vapor and causes it to become supersaturated. Now a particle traveling through the chamber will leave a thin white trail of



The physicist's expansion cloud-chamber, showing particle tracks

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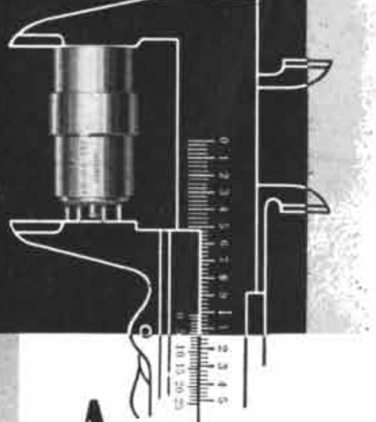
subminiature pressure transducer



A pressure transducer weighing less than 1 ounce provides the accuracy and stability of the familiar unbonded strain gage, unaffected by reduction in size. The design allows flush mounting of the ½ inch diameter diaphragm. Natural frequencies, depending on range, extend to several kilocycles per second, yet the accuracy of ± 1% of full scale holds for static as well as dynamic measurements. The electrical output of the four active arm transducer bridge will operate oscillograph galvanometers directly.

The Model P81 Subminiature Pressure Transducer is described fully in Bulletin No. 3.4, available upon request.

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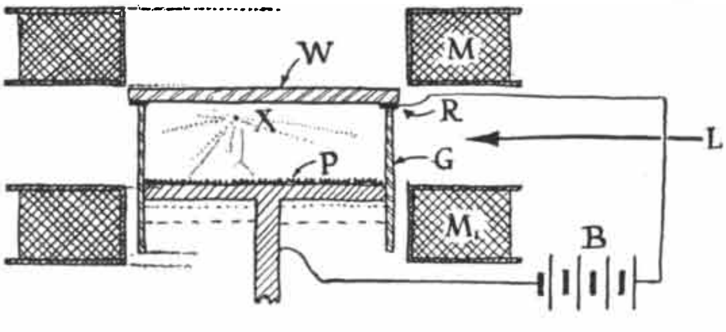

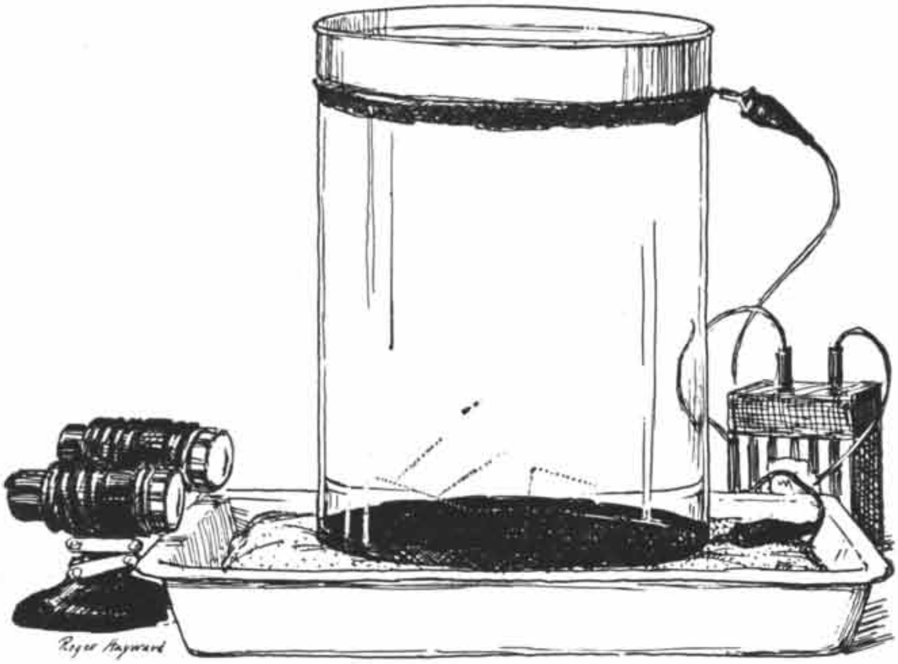

Expansion chamber with magnets (top); diffusion chamber (bottom)

vapor globules, each representing the condensation of an ion. As a source of particles we can use a speck of some radioactive material which continuously emits beta-particles, or electrons. Close examination of the photograph of the track of such a particle will show that numerous pairs of ions have been formed. When an alpha-particle, which is considerably heavier, passes through the chamber, we see that its track is much thicker than that of an electron, indicating that a great many more ions per centimeter of path have been formed. Gamma rays produce numerous short paths throughout the chamber, indicating that the rays have not only ionized gas molecules but have also given the ions sufficient energy to form tracks of their own.

"If a magnetic field is directed vertically through the chamber, the fast-moving charged particles will follow curved paths. By measuring the curvature of these paths it is possible to determine the speed and energy of each particle.

"Wilson cloud chambers have various forms, horizontal or vertical, and range in diameter from 4 to 36 inches. Practically all of them today are automatic, making expansion after expansion (two to four per minute), hour after hour. A photograph of the tracks is usually taken at each expansion. The investigator hunts carefully through thousands of photographs for significant peculiarities in the tracks which may lead to clearer understanding of what has happened.

"As a recorder of events the Wilson expansion chamber is very inefficient. Even taking a photograph every 20 seconds (with an exposure of .001 second), it is operating only one-20,000th of the time. Its efficiency can be improved by having the events one wants to observe trigger the camera. Specially designed Geiger counters, for example, can be coupled to the camera's shutter through a suitable amplifier so that the arrival of particles trips the shutter automatically. The chamber then resets itself in readiness for the next event. But even with this improvement hundreds of events may occur unrecorded between successive expansions.

"Therefore physicists have for some time been working to develop a continuously sensitive cloud chamber. One problem with this modification of Wilson's idea is to devise a way of wiping out old tracks without interfering with the new ones. Great strides have been

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made recently in the design of sweep fields and other accessories that improve the diffusion chamber's operation.

"In its basic form the continuously sensitive chamber is very simple to make and operate. Almost every laboratory now has one or more. Some operate continuously for the benefit of visitors; some are set up by students; some are used in research projects of the highest importance. Any person can set up such a cloud chamber by carefully following the instructions.

"The basic principles are these: Suppose that a closed vessel is arranged so that the top is warm and the bottom quite cold, and so that a vaporizing liquid is at the top, inside the vessel. This produces a sharp change of temperature inside the vessel, the liquid at the top being near room temperature, and that at the bottom about 70 degrees below zero Centigrade. After a time the vapor formed at the top is found to be continuously diffusing downward, becoming colder and more saturated as it moves. Near the bottom of the vessel it becomes supersaturated, and in that zone the path of an ionizing particle will show up just as it does in the expansion chamber. If these conditions are maintained, and if the sensitive region near the bottom is properly illuminated, radiations entering the vessel will be continuously observable.

"The simplest sort of continuous diffusion chamber consists merely of a large glass beaker, about eight inches in diameter and ten inches high. Inside, on the bottom, is a piece of black velveteen to increase the visibility of the tracks. Across the top of the jar is placed a sheet of cardboard, which is kept saturated with alcohol. The jar is set on a cake of 'dry ice.' Tracks appear in the sensitive region near the bottom a short time after the device is placed in operation.

"The diagram on the opposite page shows a somewhat more elaborate setup. The bottom of the glass cylinder here is an aluminum plate 1/8 inch thick. It is covered with black velveteen inside and fixed to the cylinder with electrician's tape. The top is a similar plate, with a sheet of sponge rubber about the same size as the cylinder fixed to the underside with screws. It is saturated with alcohol. A metal pan of warm water sitting on the top plate keeps the alcohol warm. This apparatus is connected to a battery of 100 to 300 volts which supplies a sweep field. Lights illuminate the sensitive section—a region near the bottom from 1/2 to 2 inches deep.

"To operate the chamber you soak the sponge rubber in alcohol, set the chamber on the cake of dry ice and fill the pan on top with water at room temperature. At this point enters the well-known 'first law of research'—sometimes called 'Murphy's law.' The law may be stated roughly as follows: 'If anything can go wrong, it will.' The

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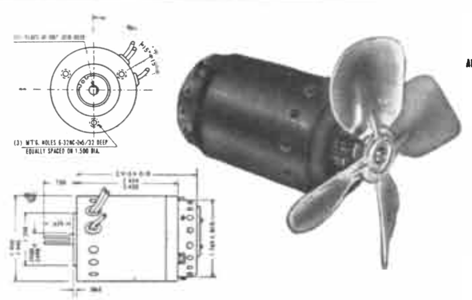

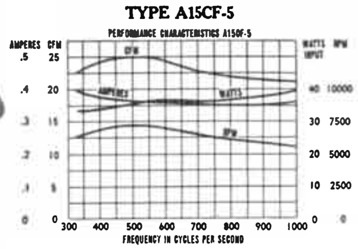

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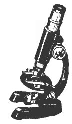

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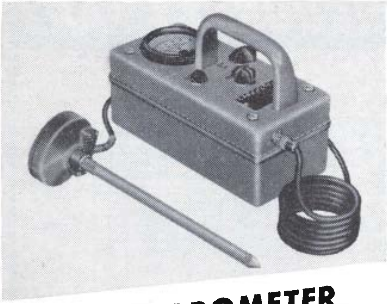

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Development of this instrument has been a joint effort with the John Carroll Seismological Conservatory.

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alcohol bottle will upset, the chamber will crack, or something else will happen. At any rate, you wait and hope for the best. After a time the temperature gradient is established, the dust particles disappear and you begin to see tracks as you look down into the vessel toward the side where the light originates.

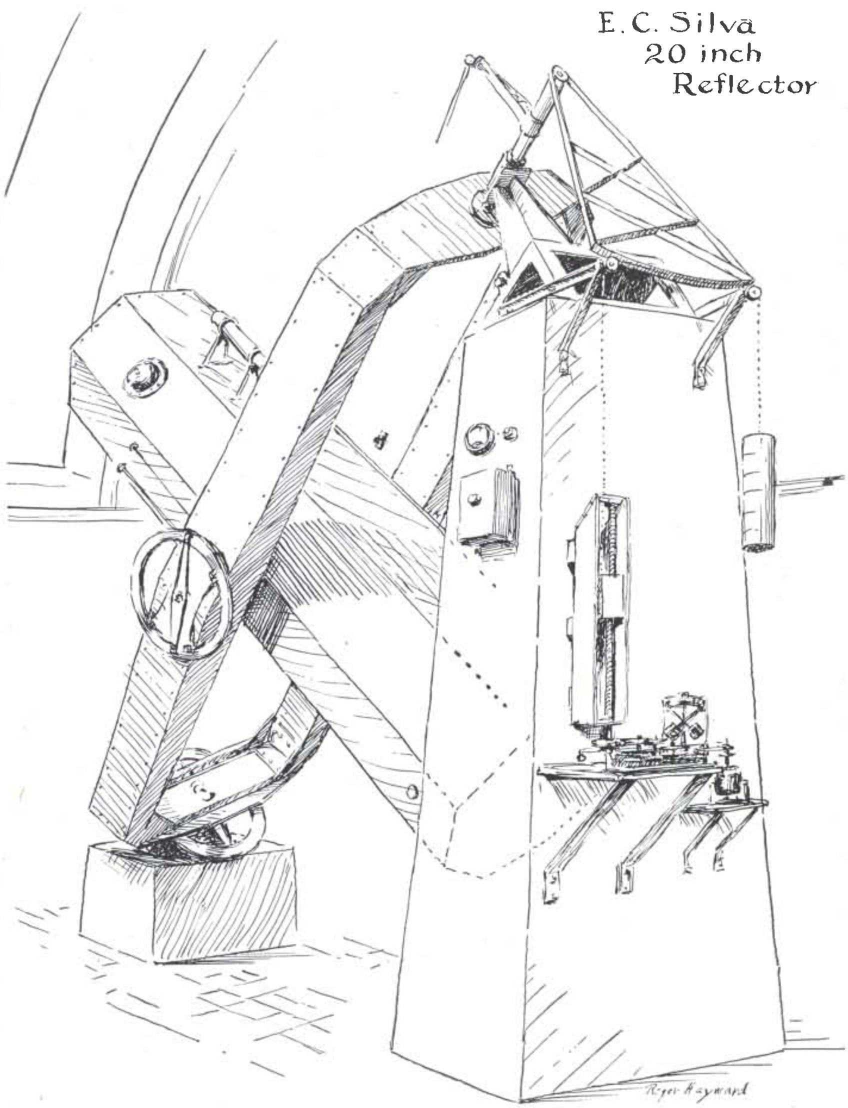
"These tracks are from random nearby radioactivity or from cosmic rays. For a more regular source of radioactivity you may use a little piece of the hand from a luminous watch or clock; the 'Westclox' hands are said to show considerable radioactivity and can be had from watchmaker supply houses. Coat a small piece of hand with a varnish not affected by alcohol and suspend it by a thread in the sensitive region. [Scientific American will supply a speck of radium, suitably mounted, free-of-charge to any reader upon receipt of a self-addressed, stamped envelope.] The alcohol can be either ethyl or methyl; even denatured (wood) alcohol will serve."

This department has built several successful diffusion chambers based on Dr. Cornog's description, but in every case only after some sharp tussles with Murphy's law. Many things can go wrong—and they do. The interval between completing a chamber and the time it starts to work will be shortened considerably if the builder gives some attention to these details:

1. The vessel should be reasonably airtight. A wide-mouthed jar fitted with a screw top of metal and turned upside down works better than one which merely sits on a metal plate. If the latter arrangement is used, wet the metal plate with alcohol to form a liquid seal.

2. The importance of side-lighting cannot be overemphasized. The beam from a home movie or slide projector makes an ideal lighting arrangement. The important point is to light the individual droplets brightly in comparison with their surroundings.

3. The experimenter must learn to recognize the trails of droplets as they



A Portuguese amateur's telescope

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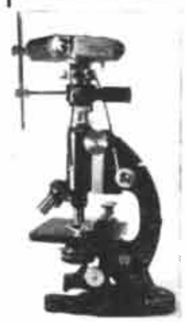

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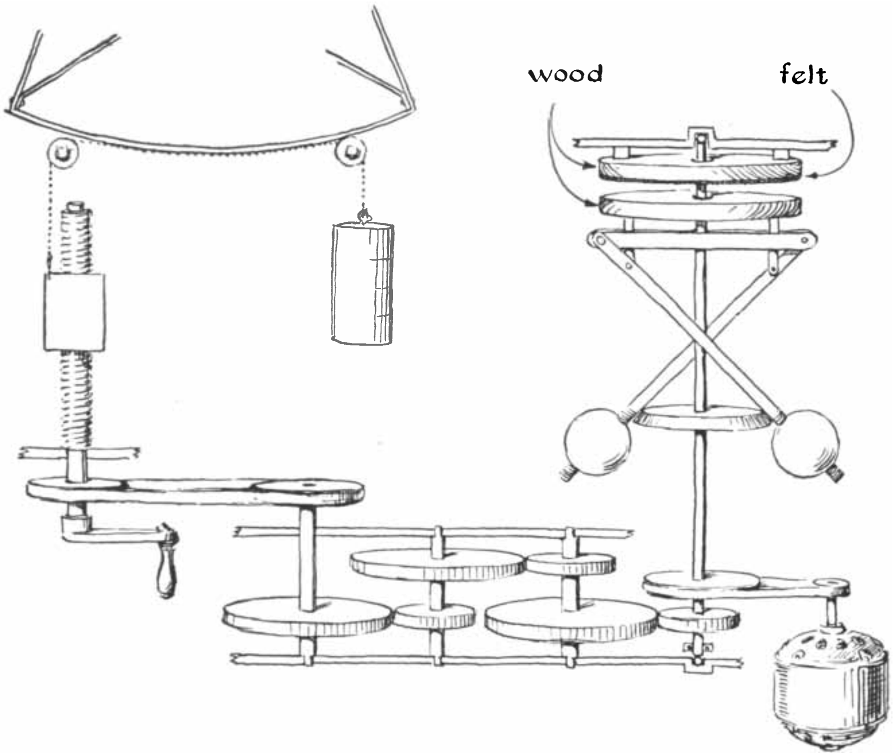

Telescope drive and governor

appear. Soon after the apparatus is set up, clouds will form two or three inches above the bottom of the vessel and "rain" will begin to fall from them. This micrometeorological phenomenon will be enhanced if the velveteen carpeting on the floor of the chamber is moistened with alcohol. The rain is easy to recognize and the tracks appear as thin, silvery threads in its midst. They last for only a split second, then drift away like miniature wisps of smoke.

4. If you use an up-ended jar as the chamber, it is advisable to cement the alcohol pad to the inner surface at the top and the velveteen covering to the inner surface of the metal lid. The cement must be allowed to dry thoroughly, else it may contaminate the alcohol and thus ruin the experiment. Another, and better, way to hold the parts together is to use a wire expansion ring or some similar device.

5. Remember that there must be a sharp difference of temperature between the top and bottom of the chamber. The

Messier 33 photographed by the Silva reflector. Exposure 215 minutes

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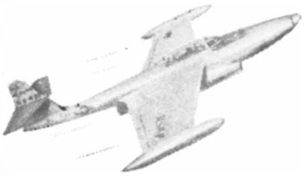

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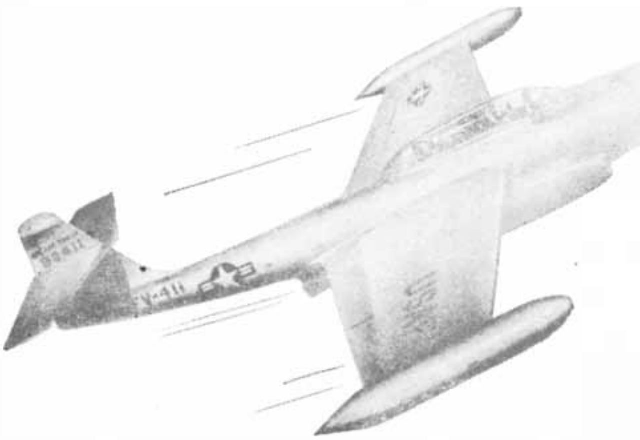

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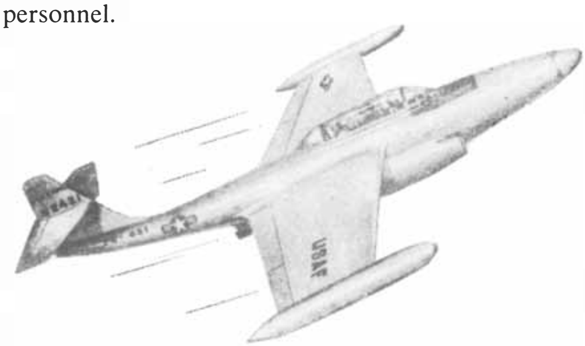

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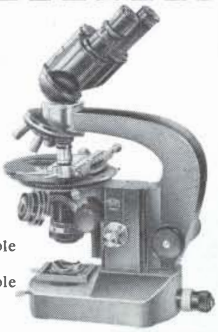

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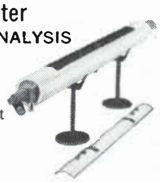

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The Great Nebula in Orion. Exposure 170 minutes

assembly should rest directly on the block of dry ice. A metal bottom, because of its superior heat conductivity, works better than one of glass or plastic. The dry ice should stand on some insulating material such as corrugated cardboard, and the uncovered portion of the top of the ice should be covered with a bit of cloth to prevent frozen vapor rising from it from interfering with observation.

6. A well-soaked pad holds enough alcohol to keep the chamber going for about eight hours. As previously mentioned, the metal plate at the bottom should be moistened, but not flooded, with alcohol, as a thick layer of alcohol tends to reduce the depth of the chamber's sensitive region.

7. It is easy to paralyze the chamber with overly "hot" radioactive material. The amount of luminescent material in the minute hand of a Westclox can stop the chamber's activity at a distance of 18 inches! Use only a tiny chip of it. However, in most localities

The Trifid Nebula. Exposure 180 minutes

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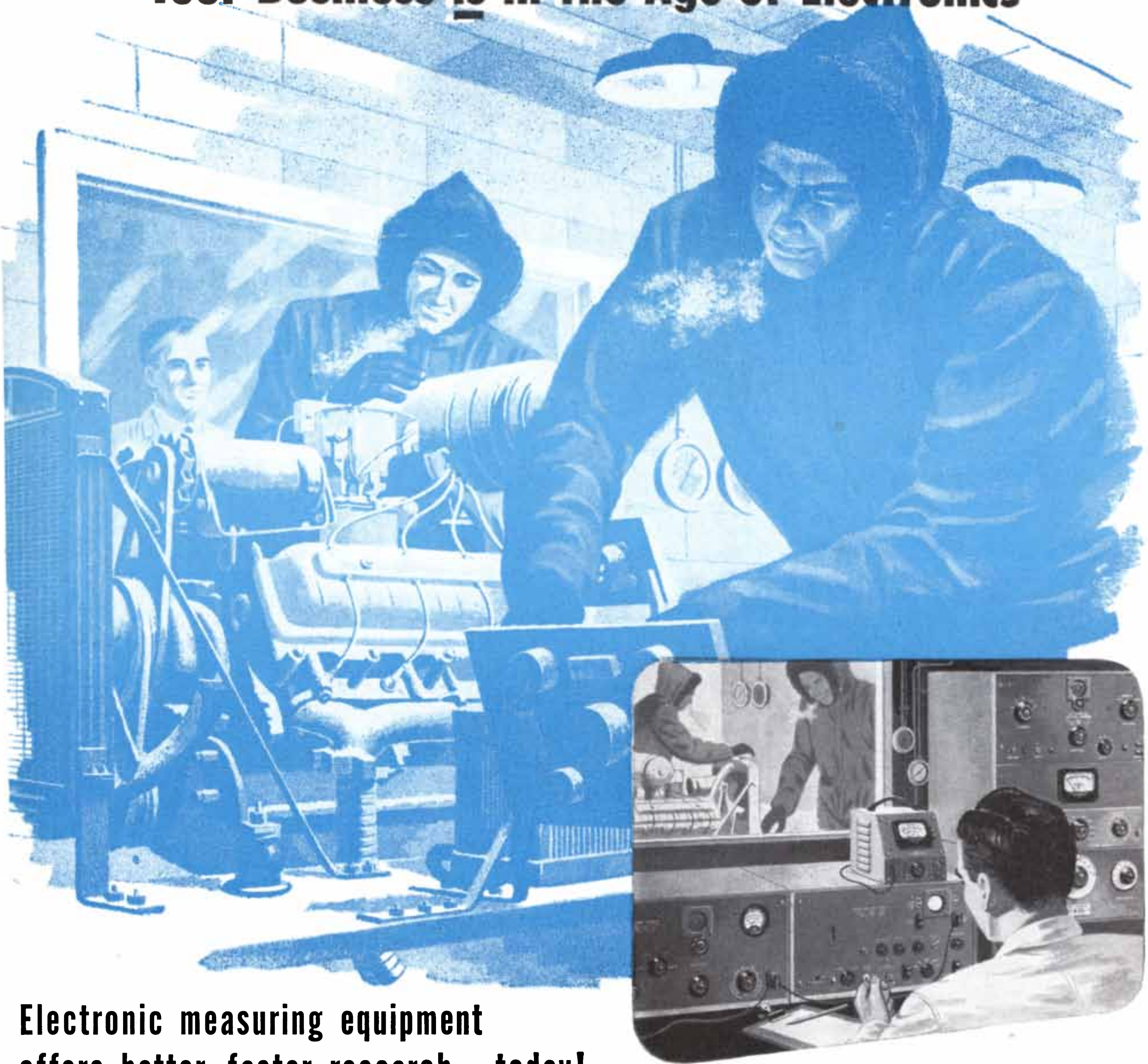

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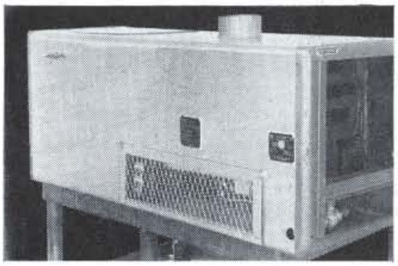

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The Silva housetop observatory

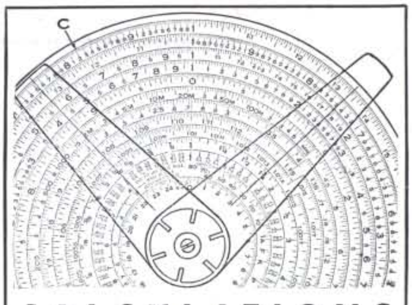
tracks induced by cosmic rays will provide enough excitement to reward the amateur's effort in constructing the device.

In 1946 Lieutenant Commander Eugenio Conceiçao Silva, of the Bairro dos Oficiais, Alfeite, Portugal, wrote to this department that, after building several reflecting telescopes from 4 to 12 inches in diameter with the help of *Amateur Telescope Making,* he wanted to "try his hand and elbow grease" with a 20-inch and needed a glass blank from which to make the concave mirror. Since then we have exchanged numerous letters, and the following account brings Commander Silva's project up to date.

It took him 18 months to obtain a 20-inch blank; he finally purchased one for £36 (about $90) from Chance Brothers, Limited, of Birmingham, England. While awaiting its arrival and, as he writes, "working backward in the good old fashion set up by *ATM,*" he first prepared on the roof of his house an 18-foot, metal-roofed, wood-lined dome turning easily by hand on 13 ball bearings.

Four years later Commander Silva wrote that he had finished his telescope and had it in working order, "ready for star-gazing, variable-star-observing and photography." He sent a collection of photographs made at its Newtonian focus. Three of these are reproduced on pages 184 and 186. That the telescope gives a high-grade optical performance is shown by the small round star images in the corners of the photographs. (Some of the images lose their roundness in the halftone engraving process.)

"I chose the double-yoke English type of mounting," Commander Silva writes in his perfect English, "because of its sturdiness and ease of construction and despite its one limitation, the inaccessibility of the Pole. Yet it can be pointed as far as 75 degrees north declination." The yoke of the telescope is built of half-inch oak plywood. The octagonal tube is built of the same material reinforced by iron ribs. The focal length of the mirror being 10 feet, the focal ratio is $f/6$. A coudé Cassegrainian sec-



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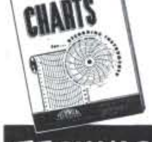

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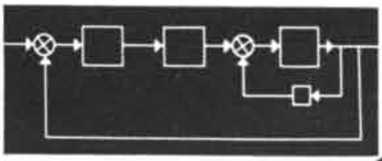
ondary mirror, when used, converts this to $f/18$ for visual observing with powers up to 800. There are identical screw-capped openings on four sides of the tube for insertion of the eyepiece-diagonal unit, and four in addition for the coudé unit.

Commander Silva continues: "The mirror blank, originally 3 by 21½ inches, was worked throughout face up with a 12-inch subdiameter glass tool on which I had previously made two 12-inch mirrors, and thus it was worn down finally to only one-half-inch thick. The strokes used were those described in *Amateur Telescope Making—Advanced.* I found the instructions adequate when supplemented by thought and the usual willingness to experiment, fail, try again and maybe fail again but keep on learning until results are attained. The subdiameter tool method permits a larger element of personal idiosyncrasy than the conventional method. The job was easier than I had expected. The most tedious part was the roughing out, but the grinding went very well with the tool on top. Astigmatism was avoided by walking as regularly or, rather, as irregularly around the mirror as possible. It was always supported on the nine-point equalizing system later installed in the telescope. Polishing and zonal correcting were done with honey-comb foundation, but final figuring was done on a pitch lap since HCF gives bad contact. By the subdiameter lap method the work advances very rapidly, and frequent testing is necessary. Raised zones were treated by pressure on the edge of the lap a little outside of their crest. I used cerium oxide because I was unable to get scratch-free rouge.

"Parabolization with the subdiameter lap proved easier than with full-size laps. By the Foucault test, the mirror was found to be a little undercorrected. I let it stay and called it a job. Having caught chronic 'mirroritis,' I should enjoy making a 30-inch mirror by the subdiameter tool method.

"I am satisfied with the telescope's performance. Visually it easily reaches its theoretical magnitude, 15.5.

"The drive is powered by a fan motor and drives the sector attached to the polar axis through a train of reducing gears and a nut and a screw which may be run back with a hand crank. Here at Alfeite the electric power is not synchronized and the voltage, nominally 220, often changes more than 10 per cent; hence I built an automatic centrifugal regulator or governor to control the drive. The motor is belted directly to the regulator. The belt is not tight and may slip if the motor turns too fast. I had to calculate the position of the points of suspension of the two rotating masses so that for three revolutions per second they would be in equilibrium in any position, but if they turned faster they would suddenly rise and bring the



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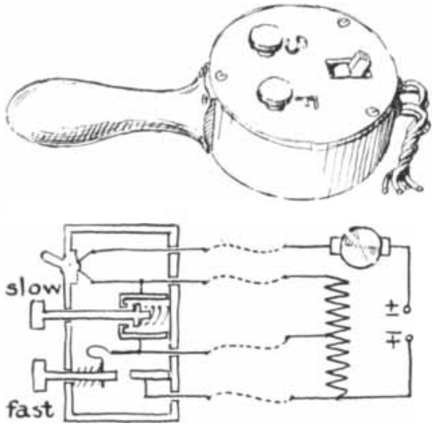

Hand switches and circuit

rotating disk against a fixed disk at the top. To obtain this result accurately they should theoretically rise in a parabola instead of a circle. This being difficult to arrange, the points of suspension of each mass must be made to coincide with the center of a circle tangent to the middle of the parabola.

"It was a pleasure, and perhaps a surprise, after the regulator was built, to test it and, counting the revolutions made in one minute, find the designed 180; for I must confess that I was a little doubtful about the results of my geometrical lucubrations. It is, however, possible to change the critical velocity a little if necessary by screwing the two masses up or down on their rods. This is the Young isochronous governor, not the Silva, and it works very well.

"The flow of current may be controlled by two resistances, which may be either taken out or put in the circuit by two buttons held in the hand during photographic exposures. In this way it is possible to drive the motor faster or slower than its normal speed and, notwithstanding the governor, the driving mechanism obeys."

Commander Silva, whose chapter on a double-star micrometer is included in *Amateur Telescope Making—Advanced,* is a professor of ballistics in the Portuguese Naval Academy and director of the Naval Laboratory of Explosives. He mentions that his hobby resembles his vocation—both consist of aiming hollow cylinders at the sky. "A few months ago," he says, "I wrote some articles on telescope-making in a Portuguese popular science magazine. As a result there are now seven fellows grinding glass disks and hoping to see the moon at arm's length."

Instructions for calculating the design of the isochronous governor, with a worked-out example, which Commander Silva kindly supplied by request, are held over for later publication for lack of space, as are descriptions of his solar eyepiece, his method of making Ramsden eyepieces, and his solar prominence spectroscope with a Thollon (carbon disulfide) prism.

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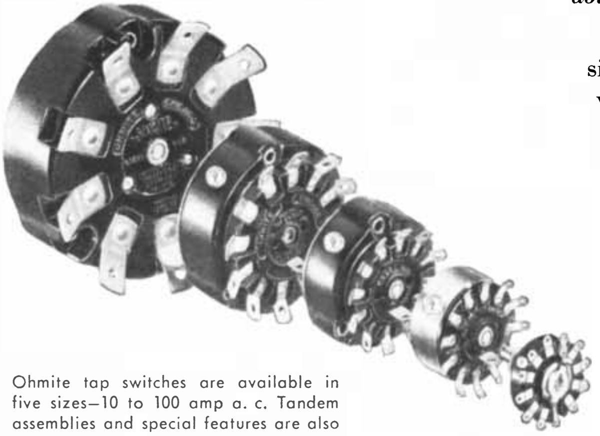

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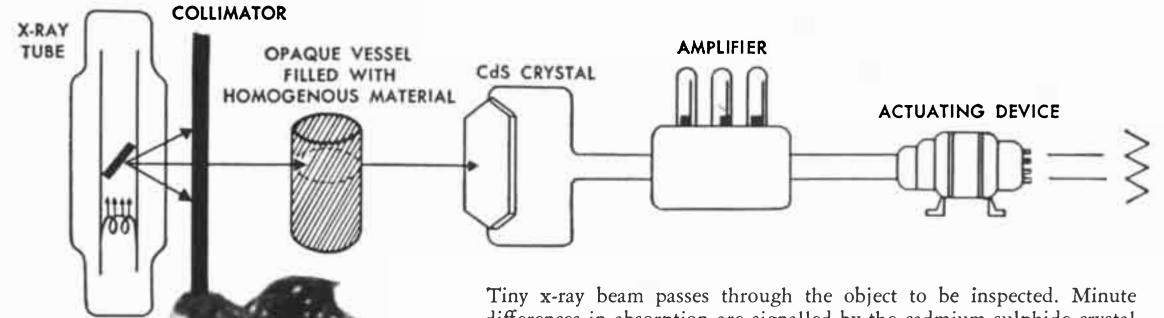

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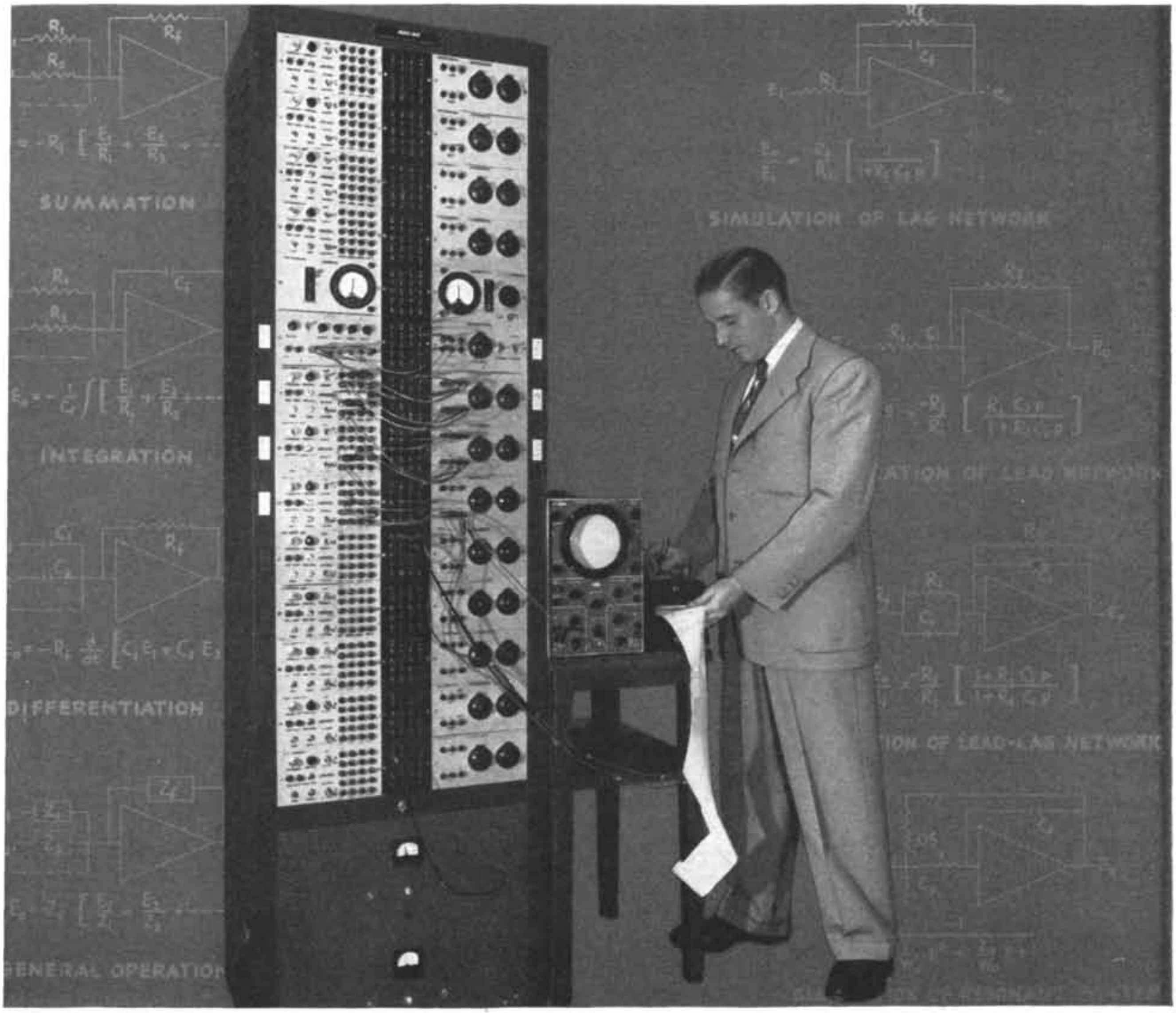

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