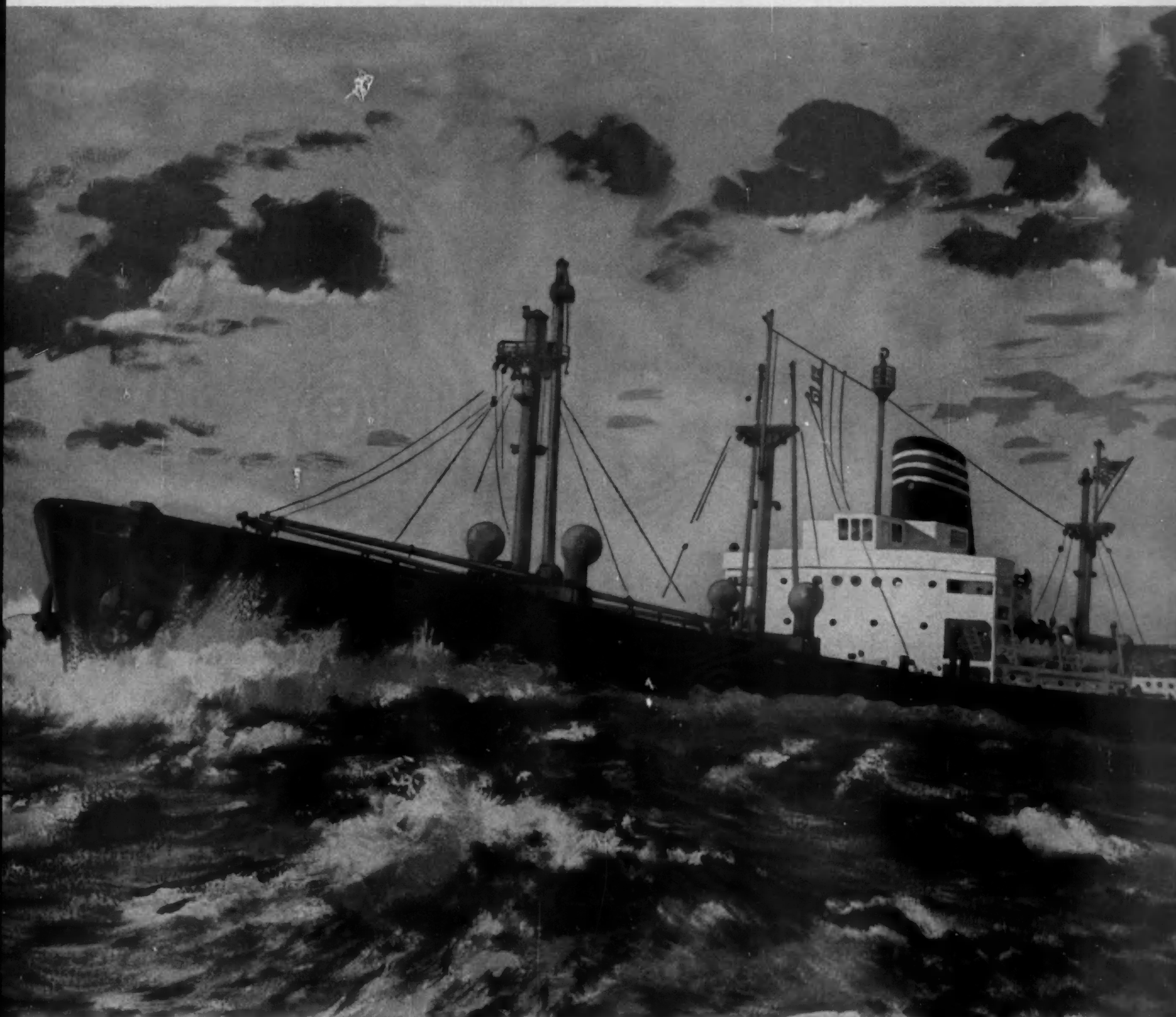
GENERAL ELECTRIC

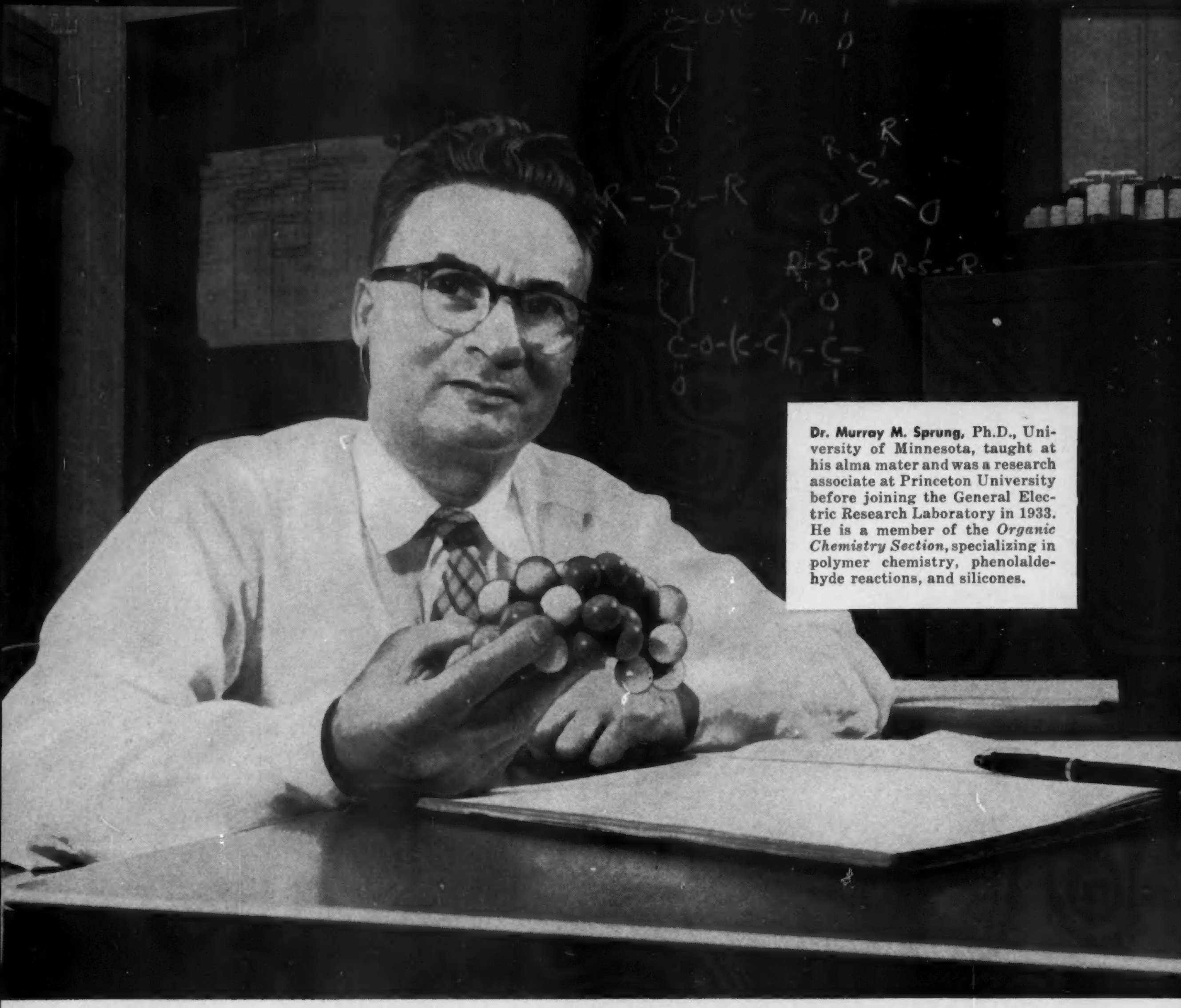
Review

MARCH 1957



SPECIAL REPORT: **SEA TRIALS OF AMERICA'S FIRST GAS-TURBINE SHIP (page 6).**

IN THIS ISSUE



Dr. Murray M. Sprung, Ph.D., University of Minnesota, taught at his alma mater and was a research associate at Princeton University before joining the General Electric Research Laboratory in 1933. He is a member of the *Organic Chemistry Section*, specializing in polymer chemistry, phenolaldehyde reactions, and silicones.

Product progress through creative chemistry

General Electric's Dr. Murray M. Sprung designs polymers

The *creative chemist* seeks knowledge from which he—or others—can build new materials. Among the aims of the creative chemist are the design and synthesis of specific structures in which requirements such as strength, elasticity, heat resistance, and insulating properties are carefully balanced.

Man-made materials—particularly plastics—have come into their own during the past few years, and one of the chemists who have made key contributions is Dr. Murray M. Sprung of the General Electric Research Laboratory.

Dr. Sprung's studies of phenolics, vinyls, and other polymers have been reflected in greatly improved insulating materials for electrical equipment. His early and continuing work in silicones has helped in the creation of entirely new products which today are widely used both in industry and the home.

At General Electric, research is motivated by a belief that providing scientists with the tools, the incentives, and the freedom to seek out new knowledge is the first step toward progress for everyone.

Progress Is Our Most Important Product

GENERAL ELECTRIC

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Review

MARCH 1957 VOLUME 60 NUMBER 2

The GENERAL ELECTRIC REVIEW is issued in January, March, May, July, September, and November by the General Electric Company, Schenectady, NY, and is printed in the U.S.A. by the Maqua Company. It is distributed to scientists and engineers throughout industrial, consulting, educational, professional society, and government groups, both domestic and foreign. . . . . The GENERAL ELECTRIC REVIEW is copyrighted 1957 by the General Electric Company, and permission for reproduction in any form must be obtained in writing from the Publisher. . . . The contents of the GENERAL ELECTRIC REVIEW are analyzed and indexed by the Industrial Arts Index, The Engineering Index, and Science Abstracts. . . . Six weeks' advance notice and old address as well as new are necessary for change of address. . . . Address all communications to Editor, GENERAL ELECTRIC REVIEW, Schenectady 5, NY.

COVER

In a painting by artist Joseph Chenoweth, America's first gas-turbine propelled merchant vessel—the rejuvenated Liberty ship GTS *John Sergeant*—plows through heavy seas in the Atlantic. The *Sergeant* is part of the U.S. Maritime Administration's program to upgrade vast numbers of World War II Liberty ships. For the complete story of the *John Sergeant* and her significance to the future of America's merchant marine, see article on page 6.

Guest Editorial

LIMITS IN RESEARCH

In contemplating the satisfaction of a career in science or engineering, one should be guided by a realistic picture of the present status and the probable future course of technology. If we look back two or three generations, we see a scientific world of limited horizons, one in which the most exciting challenge was the refinement of measurement—the location of the next decimal. How mistaken that concept was has been dramatically demonstrated by the phenomenal scientific and technological progress of the past half century.

Today we are sometimes misled by the equally erroneous misconception of a world in which *all* technological frontiers are boundless. Because of the spectacular progress being made in many technical fields, it is easy to jump to the conclusion that *anything* can be accomplished by the expenditure of enough money and manpower. Although this idea when applied to science has some validity, a more sober view will show that realism requires that we recognize some boundaries and limits.

In industrial research it is important, where possible, to delineate and understand these limits. The process is, of course, attended by some risk. If we are up against a real stone wall, we would like to know it, but it is equally important to be sure that what looks like a permanent obstruction is not merely a temporary roadblock. I would like to consider three examples from current science and technology and to examine the structure of what appear to be limits imposed by nature.

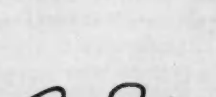
As a first example, consider a class of materials that are basic to the electrical industry—magnetic steels. These materials are being constantly improved in many of their properties and in their methods of processing. However, with respect to one vital property—magnetic saturation—we appear to be up against a stone wall. It is easy to calculate that if we could increase this property, let's say double it, the resulting improvement in magnetic materials would have a great impact on the industry. Hence, we must be sure of our interpretation of this limit, if it is a limit.

Fundamental understanding of magnetism is well advanced, and we can identify the source of the magnetic flux saturation in the alignment of the spin of the electrons that make up the atoms. Iron and cobalt have a particularly favorable atomic arrangement of their spinning electrons and, hence, the highest magnetic saturation of all the elements. Because it is difficult at present to conceive how this basic property of atoms could be altered, we appear to be facing a limit and though not a stone wall it is at least a major roadblock. Further, our best soft magnetic materials are presently at this limit. *Here we see a natural limit, and technology is at that limit.*

Consider a second example, illustrated by perfect crystals and their extraordinary strength. We have in the laboratory a perfect crystal of pure iron in the form of a tiny filament which attains a tensile strength of nearly 2-million psi by actual test. No practical metals or alloys are anywhere near this high strength. These perfect crystals are important because they indicate clearly a natural limit to the strength of materials and show what we have to do to attain that limit. Here then we have an example in which *we see a natural limit, and technology is much below this limit.*

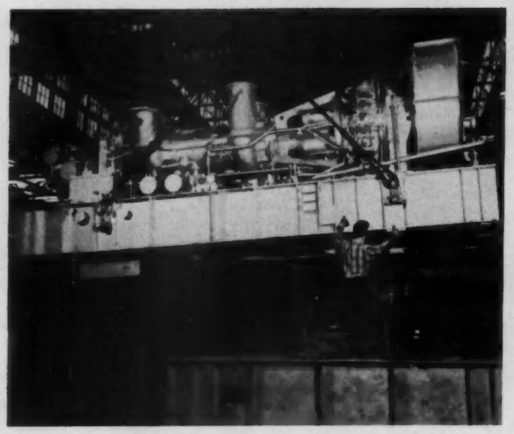
The third example is illustrated by the nuclear fusion reaction; there is substantial hope that this process may eventually be adaptable to power production. Although a good many things are presently known about the conditions required to produce this reaction and some success has attended initial efforts, there is more hope than substance to the venture at present. None of the limits of temperature, pressure, reaction rate, efficiency, or other characteristics of the reaction is known, and a great deal of technical effort will be expended to determine the outlines of this interesting subject. Here we have an example in which *the limits imposed by nature are almost entirely unknown.*

A recognition of the existence of natural limits on physical properties and processes can serve as a guide to expenditure of scientific effort in specific areas. The future course of technology will be determined by our progress toward these seen and unseen limits and by the discovery of new areas, not now recognized.



VICE PRESIDENT AND DIRECTOR OF RESEARCH

World War II Liberty ships moored in New York's Hudson River represent great defense potential. Upgrading them from plodding 11-knot vessels to present-day cargo-ship standards can be realized because . . .



GAS TURBINE plus . . .

NEW BO

Liberty Ship *John Sergeant:* Variations on Aircraft Technology Make Maritime History

***Review* STAFF REPORT**

For the past two decades, a great deal of effort and money has been expended on the development of gas turbines. Especially in the marine field, the results of these efforts have been somewhat disappointing and, in any event, not comparable with the great expectations of 10 years ago. It isn't my intent to discuss the past, but to look to the future and describe what now appears will be the first successful all-gas-turbine ship.

With these words John J. McMullen began his presentation, "The Gas Turbine Installation in Liberty Ship *John Sergeant*," before the annual meeting of the Society of Naval Architects and Marine Engineers (SNAME) convening in New York in November of 1955. He concluded:

> The most important feature of any new development is enthusiasm coupled with sound technical judgment and engineering. Also, you need a certain degree of courage because there is always danger of the unexpected. If you don't achieve the original objectives, there are always persons who 'knew it all the time'.

McMullen, a vigorous marine engineer with the physique and sprightliness of a football quarterback, knew what he was talking about. Chief of the U.S. Maritime Administration's office of ship construction and repair, he had shepherded their program of Liberty ship conversion and improvement since August 1954. In the conversion program, as in similar activities, American industry has proved to be a key factor. Vital contributions to the country's defense are achieved through the cooperative efforts of government and business.

Essential among the Administration's numerous objectives is upgrading the vast numbers of Liberty ships mothballed in the national defense reserve fleets, or boneyards—the merchantmen's term. Equally important is development of new types of propulsion plants to power America's merchant vessels of the future.

For the mass experiment, four ships were chosen from some 1426 Liberty ships lying at anchor in reserve fleets throughout the nation.

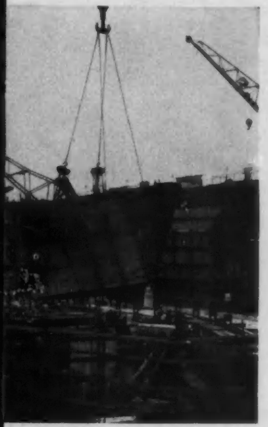
The basic design of the Liberty makes it adaptable to conversion. The idea behind the Maritime Administration's conversion program is not to upgrade her to compete commercially with the modern cargo ship. Instead, it's to have a reserve of efficient cargo carriers on hand in the event of a national emergency.

In 1937, just before World War II exploded in Europe, the United States launched a long-range shipbuilding program that would give the nation the best-equipped, safest, and most suitable vessels in numbers adequate for its trade and defense needs. The program was designed to produce 500 ships at the rate of 50 vessels annually. You know what happened: the United States became embroiled in the war and began its gigantic wartime production of ships. Before the war ended, nearly 6000 vessels went down the ways and to sea, instead of the original 500.

About 3000 of those emergency-built vessels were Liberty ships, the "pack horses" of the World War II fleet. They were designed from the viewpoint of minimum cost, rapid construction, and simple operation. In the fall of 1941 the first Liberty was launched; and during peak production, as many as three a day came down the ways. Each one cost well over a million wartime dollars to build.

Cargo ships are the priority vessels of wartime ocean transportation. And a Liberty can carry 10,000 tons of cargo—aircraft, tanks, trucks, machinery, boxes, crates, or bags—in her holds. A big ship, she measures 442 feet long and 60 feet wide at the beam—comparable with today's general-cargo vessels.

Today the Liberty ships tugging at their anchors in the reserve fleets still have a vast defense potential. Their greatest handicap: lack of speed. Liberties were designed for a sustained sea speed of 11.4 knots. To keep up with modern seagoing convoys, a ship needs a speed of 15 or 16 knots. But in a national emergency, steel becomes a



ECTION plus . . .

CONTROLLABLE PROPELLER equal . . .

. . . a fast and highly maneuverable Liberty ship, the GTS (gas-turbine-ship) *John Sergeant*. She can move along at 17 knots with power to spare.

critical metal; you need it for many other things besides building ships. By modernizing the 1500 ships in the reserve fleets, you save a lot of steel plus precious time.

In carrying out their experimental conversion program, the Maritime Administration had chosen four prime movers—two conventional and two advanced—to determine the feasibility of additional power for Liberty ships. Geared diesels were installed aboard one vessel in a Baltimore shipyard; at a Brooklyn yard, a steam turbine replaced the old engines of another. For a third Liberty, General Motors worked at developing a free-piston gas turbine.

For the Liberty ship *John Sergeant*, General Electric modified its highly successful land gas turbine. This machine, after an expenditure of many research and development dollars, had been designed for industrial applications. At the time of the Maritime Administration's selection, 50 of them were establishing a remarkable record of performance. Some drive compressors for or operate from natural gas in various parts of the country; others pressurize oil fields beneath Lake Maracaibo, Venezuela. Still others are installed in electric power stations. A similarly designed machine powers railroad locomotives.

In the summer of 1955, preceding McMullen's address to the SNAME, the Maritime Administration's contract had been awarded and the land gas turbine's maritime version was set up at General Electric's Schenectady plant. On hand to gain experience with this new form of propulsion were the *Sergeant's* chief engineer and his principal assistants. All handpicked, they were employees of the U.S. Lines—the shipping firm that was to operate the *Sergeant*. In Schenectady, with the help of General Electric's design engineers, they acquainted themselves fully with operation, construction, and maintenance of the marine gas turbine.

In February 1956 the marine gas turbine—mounted on an integral base and shimmering in a coat of silvery paint—was sent off to the Newport News Shipbuilding and Dry Dock Company in Virginia. There the *John Sergeant* was undergoing some fairly extensive alterations (photo sequence).

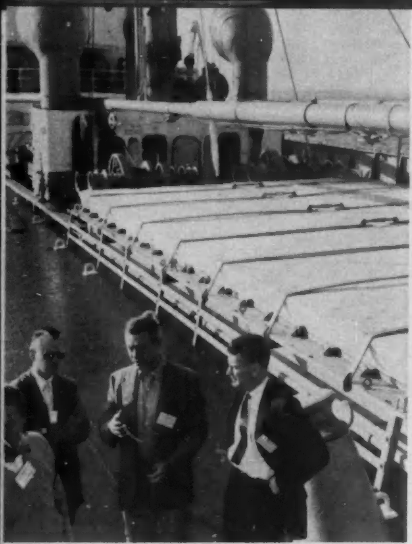
To increase her seakeeping abilities at the expected higher speed, the *Sergeant* got a new bow section—slimmer and some 25 feet longer than the original. This operation, called *waterlining* in nautical terms, is akin to streamlining an aircraft. McMullen believed this alteration would add a knot to the ship's speed.

The *Sergeant's* propeller is an important part of her developmental propulsion system. Manufactured by the S. Morgan Smith Co., York, Pa., its pitch is controllable and varied entirely by hydraulic means. Not unique to marine propulsion, the propeller is, however, notable for its size—17½ feet in diameter, the largest of this type yet built for a merchant ship—and its compatibility with the gas turbine.

The gas turbine's inherent unidirectional operation makes the controllable pitch propeller a natural component. To slow down, stop, or back off, you simply reverse the propeller's pitch. In principle it's almost identical to the reversible-pitch propeller of an aircraft. There's a big difference, though, between braking an aircraft that's landing and stopping a vessel at sea. Water is an incompressible fluid. Consequently, the torques exerted on a reverse-pitched propeller by a ship of the *Sergeant's* momentum—she weighs more than 17,000 tons loaded—are tremendous.

The controllable-pitch propeller, as McMullen later pointed out, shows an outstanding engineering achievement. For maneuvers that require up to half speed—in and out of port, for example—the ship would be entirely controlled by changing propeller pitch. During emergency crash-astern maneuvers, the propeller could be reversed by a single-lever control in eight seconds.

This single-lever control presents another unique feature of the *Sergeant's* propulsion system. It integrates power output of the gas turbine with the propeller's pitch, much like the single-lever thrust control of an aircraft jet engine. Thus the ship's skipper can



J. J. McMullen (no tie) briefs journalists on emergency crash-astern maneuver about to occur from ship's speed of 17 knots when bridge officer throws unique single-lever control (above) to crash-astern position.

From 17 Knots to Cras

operate his vessel directly from the bridge, if necessary. You'll readily recognize the advantage of this.

Normally the skipper of a merchant vessel relays his directions to the engine room via a voice tube or the engine telegraph. All this takes precious time, particularly if he is forced to maneuver his ship through a harbor in a thick fog at night. When this happens, he can depend only on whistle signals—rather deceiving in a thick fog—or on radar, if he has it. If other ships get too close, whistle signals and radar may become useless or, at best, confusing; the skipper must rely on his own vision. With visibility down to 100 or 150 yards, quick control of the propulsion plant can mean the difference between collision and safe passage.

By moving the single-lever control from its midpoint with a simple hand motion, the bridge officer changes the propeller's pitch while the gas turbine's power output is automatically held to a minimum. Speed of the vessel then becomes a function of propeller pitch and the gas turbine's rpm. If he moves the hand lever beyond the full propeller pitch position, the gas turbine's power output increases and the ship gradually moves faster.

A similar single-lever control located in the *Sergeant's* engine room enables the engineer on watch there to operate the power plant during normal runs at sea. Additionally, a separate lever permits him to control the propeller independently, if he chooses.

The *Sergeant's* conversion at the shipyard in Virginia continued throughout the summer, with the date of her sea trials drawing nearer. How would the *Sergeant* perform? Only the sea trials would tell.

A ship is a complex economic body: warehouse, hotel, and power station. When that power station is an advanced yet untried form of propulsion installed in a ship built hurriedly during wartime, anything could happen.

Installation of the marine gas turbine went along well, considering the small engine-room space aboard a Liberty—a compartment below the deckhouse roughly 57 feet wide and 50 feet long. Sufficient for a Liberty's conventional power plant, it was cramped even for as compact a unit as the gas turbine with its relatively few accessories.

This isn't a criticism. For history has borne out the wisdom of those who selected the Liberty's original power plant. Her remarkable war record is in no small way attributable to it.

One thing the *John Sergeant's* old power plant has in common with its sleek gas-turbine successor: both burn Bunker-C fuel.

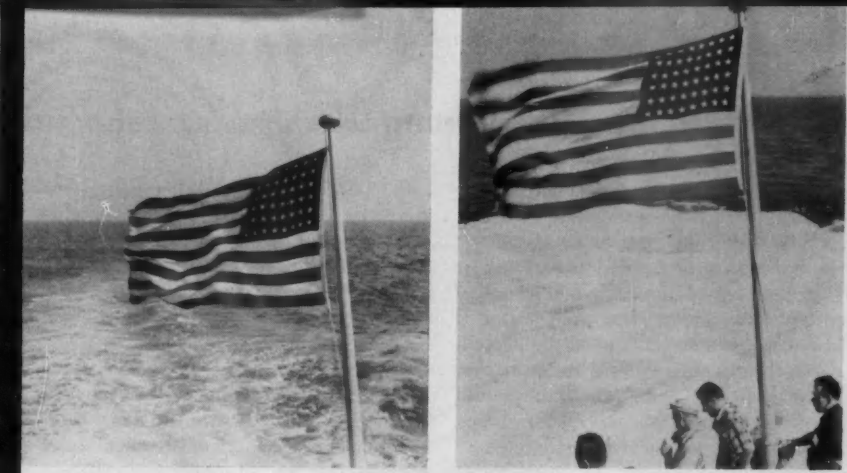
Bunker C, sometimes called black fuel, is the residue from refined crude oil. About as cheap an oil as you can get, it supplies fuel for most steam-propelled merchant and naval vessels. Naturally, certain disadvantages accompany its low price. Viscosity, for example. Bunker C is so viscous that it has to be heated to flow through a pipe. A more serious handicap for the gas turbine, however, are two elements in the crude oil: sodium and vanadium. These can corrode and form deposits on the turbine's hot nozzles and buckets. (How research and engineering helped solve this problem: July 1955 REVIEW, page 14.)

By adding an inhibitor—a commercial grade of Epsom salts—to Bunker C, you can neutralize the effect of vanadium corrosion. But unfortunately, fuel technologists haven't yet found an economical additive that will neutralize the effects of sodium. It literally must be washed out. Fresh water plus Epsom salts and a de-emulsifying agent are mixed with the heated oil; the water plus dissolved sodium is then removed by centrifuging.

Such a fuel-washing system is aboard the *John Sergeant*. Enough Bunker C is washed and stored so that in the event the washing system is out of service the ship could proceed under way at full power for 24 hours. The ship also carries a tank of diesel oil for an additional 72-hour run at full power. Finally, should the fuel-washing system be inoperative, the gas turbine in an emergency can operate on untreated Bunker C. In this instance, the temperature of the combustion gases entering the turbine have to be sharply reduced. Because a gas turbine's efficiency closely relates to gas-inlet temperature, the ship could proceed to port only under reduced power and speed.

Latitude in the choice of fuel is an advantage peculiar to all gas turbines because they derive their power from hot gases expanding through a turbine. How you go about heating those gases makes no difference. About as simple a rotating machine as you'll find anywhere, the gas turbine has just three basic parts: compressor, combustion chamber, and turbine. Any variations from these represent engineering refinements.

The *Sergeant's* power plant contains two turbines, instead of one, mounted in tandem on separate shafts. It also has a regenerator, or heat exchanger. Rated 6600 hp, the unit is appropriately described as a two-shaft regenerative open-cycle gas turbine.



Astern maneuver accomplished without vibration, would take a conventional ship of the *Sergeant's* displacement, four to five minutes.

Astern: 2 Min 47 Sec

Its high-pressure turbine drives a compressor that in turn supplies compressed air to the combustion chambers. Essentially then, this turbine-compressor-combustion combination is a hot-gas generator. For practical purposes the low-pressure turbine mounted on the power shaft does the useful work. It drives the propeller through a double-reduction gear, precision-made of a hard nickel-chrome-molybdenum alloyed steel.

Speed and torque of the power turbine can be controlled independently by varying the fuel input and the angle of the second-stage nozzles that feed the low-pressure, or load, turbine. The more closed the nozzles—the more constricted the passageway—the greater the pressure drop and velocity of the hot expanding gases entering the load turbine and the greater the power output.

Gases leave the combustion chambers at 1450 F. When they exit through the power turbine, they're still plenty hot. To recover some of their energy and increase the plant's over-all efficiency, the gases are ducted to a regenerator. On the way, they flow over coils that superheat steam for a small turbine generator set for ship services. In the regenerator, they give up much of their heat to the compressed air flowing from compressor to combustors.

Finally, to wring out some more of their energy, the gases are carried through a waste-heat boiler for generating the ship's service steam, before being exhausted out the ship's stack. Because the gases are exhausted into the atmosphere, the power plant is termed *open cycle*.

By August 1956, transformation of the GTS (gas-turbine ship) *John Sergeant* completed, shipbuilder's trials got under way at Newport News. Deckhouse and bow lengthened and her hull sporting a coat of glossy gray paint, the *Sergeant* bore little resemblance to her drab-colored sisters of a decade ago. She looked sleek, acted sleek.

As the ship slipped through the waters of Hampton Roads, Va., no smoke showed from her single stack. To observers in the engine room, her gas-turbine power plant—barely audible on deck—sounded like the whir of a large electric fan. The builders, satisfied that their yard had done a good job on the conversion, considered the *John Sergeant* ready for acceptance tests by the Maritime Administration.

Four days of official sea trials were scheduled during the second week in September: The *Sergeant* would leave the shipyard at seven o'clock each morning—Tuesday, Wednesday, Thursday, and Friday—returning each evening at seven.

Never again would the *Sergeant* receive such loving care at the hands of so large and select a crew as she had during the week of the trials. Normally, a Liberty carries a crew of 40. But for the sea trials, 122 trained employees of the Newport News shipyard manned the *Sergeant*. Her master was Captain E. D. (Kid) Edwards, a veteran Virginian pilot. In charge of her all-important engine room—center of everyone's interest—was G. M. MacDonald, superintendent of the yard's machinery division. And the shipyard's vice president and works manager personally directed operations on the *Sergeant*.

An international flavor prevailed on Thursday—day of the *Sergeant's* public debut. Maritime nations throughout the world, with their economies more dependent on profitable ocean commerce than this country's, were watching to see how the "clever Yankees" would make out. And so the two previous days had been devoted to exhaustive sea trials. Central figure in them was McMullen, chief protagonist of the gas-turbine vessel.

After an epicurean buffet dinner Wednesday evening, a group gathered in the Common Room of the James River Country Club. They represented the elite of the shipping industry: professional mariners, military men, naval officers, maritime officials, engineers, shipbuilders, and shipping executives—all from the top echelon. On hand, too, were observers from several maritime nations, advocates of the free-piston gas turbine, plus a few dozen newspapermen and magazine journalists as well as representatives of all the companies that had contributed to the *Sergeant's* rejuvenation. The general manager of General Electric's gas turbine department, John P. Keller, came with several of his associates, including the engineers who had contributed much to the marine gas turbine's design.

McMullen had arrived breathless but exuberant as usual. He and Clarence G. Morse, who is the Chairman of the Federal Maritime Board and the Maritime Administrator, were quickly cornered by maritime newsmen and writers. Perched in bamboo chairs to one side of the Common Room, they answered questions fired by the journalists.

The *Sergeant's* power plant, McMullen told them, was the most revolutionary thing in the marine field since the diesel engine. The ship's captain had characterized the *Sergeant* as the most maneuverable vessel he'd ever been aboard. For what McMullen termed "shoestring" operations—$3.4 million—her performance had given the best research and development returns per dollar spent of any shipbuilding program.

An executive of one of the shipping companies sauntered by, and chuckling, shouted above the barrage of questions, "Say, Mac, did you take off your life preserver yet?" McMullen looked up good-naturedly, recognizing an old friend.

"I'm just a new bride," he replied. "I can't do without it!"

McMullen might literally have been the bride and the gathering that evening the bridegroom. Shortly he would make the principal address. Guests shuffled around in the large room as they took their seats. Brief introductory remarks and acknowledgments were made by several officials, including the maritime administrator. And then McMullen took the floor.

Forthright in manner, McMullen sometimes puts aside the usual engineering reticence. Greatly respected for his ability, when the occasion arises, he exercises firmness in getting a job done. Remarkably rugged, he will be 40 years old in May. His background and experience are extensive.

From a Bachelor's degree in electrical engineering via the U.S. Naval Academy, he went on to obtain, over a period of years, a Master's degree in naval architecture and engineering from the Massachusetts Institute of Technology and a doctorate in mechanical engineering from the Swiss Federal Institute of Technology in Zurich. During the war, he served as engineering officer on naval vessels and, in postwar years, as project officer in the machinery design branch of the Navy's Bureau of Ships.

His maritime career came as no accident. Immediately prior to his appointment as chief of ship construction and repair for the Maritime Administration in 1954, McMullen was vice president and chief engineer of the Hudson Engineering Company of Hoboken, NJ. This firm, founded by his father, specializes in ship repair and maintenance on the Hudson River waterfront.

When McMullen took the floor, you could sense the anticipation. Without notes or any other ostensible preparation, he proceeded to explain, in typical engineering fashion, the workings of the *Sergeant's* revolutionary propulsion system.

The formal part of his talk ended, McMullen launched into a series of impromptu remarks, and the guests moved forward a bit on their seats. He was no mincer of words:

> This ship is the finest thing any of us have seen in a long time, McMullen confided. The greatest thing about it is its tremendous overload capacity. We ran it at more than 7500 hp, 18.043 knots, unloaded. Some people thought the gas turbine would be noisy. So we measured the noise with a meter. The gas-turbine installation had a noise level of 96 decibels. A small diesel generator nearby had a noise level of 116 decibels—it was the noisiest piece of equipment in the engine room!

This was what the audience had gathered to hear. And they listened attentively as McMullen candidly compared the gas turbine with other marine power plants. Opinions that would affect maritime history were being formed in the minds of many.

Finally, after some 15 minutes of impromptu speaking, McMullen exclaimed, "It's just fantastic. But tomorrow, you'll see for yourself."

At six the next morning, buses pulled up in front of a large hotel in Fort Monroe, Va. Officialdom of the maritime industry boarded them for the trek to the Newport News Shipbuilding and Drydock Company. Through the morning stillness of the Virginia peninsula, the buses sped along rural roads and across bridges that spanned long trainloads of West Virginia coal traveling six abreast.

Within a half hour the buses deposited their passengers at a long steel pier. At the far end, tied to one side, lay the GTS *John Sergeant*, a tugboat nudging her bow. Looking at her in the brilliance of a cloudless morning sky, you understood the reason for McMullen's exuberance. With her lengthened bow, she bore little resemblance to the tubby Liberty she had once been, Her superstructure painted a gleaming white and her stubby funnel bearing the red, white, and blue markings of the U.S. Lines, she looked like a fast, powerful, and maneuverable ship.

Promptly at seven, her decks crowded with several hundred observers and camera-toting journalists, the *Sergeant* backed off from the pier under her own power, swung in an easterly direction, and headed toward the Atlantic.

Passengers had been assigned boat stations and berths when they first came aboard. Now, after a light catch-as-catch-can breakfast of coffee and doughnuts, they roamed the *Sergeant's* decks from stem to stern. Off limits, except to only very important persons, were the bridge and engine room. A formal tour of these places, in groups, took place at 11 o'clock.

It was an excellent day for the sea trial. The sky was bright and clear, the breeze slight, and the ocean tranquil. Aside from special demonstrations for the invited guests, scheduled throughout the day were tests of propeller pitch versus rpm—not very exciting but important design information.

Most of the morning the *Sergeant* moved along at various speeds from slow to swift, circling, zig-zagging, and leaving crooked wakes in the water behind. After all the guests had been served a lunch of fried chicken and steamed vegetables—some ate in the wardrooms, others simply perched on deckhouse railings or sat on cargo hatches—the *John Sergeant* began perceptibly to pick up speed. She was being run under full power and normal propeller pitch. She cut through the water with remarkable ease and silence. No smoke belched from her stack; it was difficult even to detect fumes.

As the *Sergeant* moved effortlessly through the water—silently and without a pitch, roll, or heave—her speed was announced officially at 18.03 knots. One of the observers leaning against a lifeboat davit on the boat deck looked down at the water swishing by and, shaking his head, remarked aloud, "She's quite a ship."

People began to gather in small groups, expressing their astonishment too. Soon a story began circulating about an incident that happened the day before: the *Sergeant*, through no fault of her own, had almost run down a tugboat hauling a string of barges. The tug's skipper, sizing up the *Sergeant* from the distance as an old 10-knot Liberty with a new paint job, moved into her path. He was surprised when the *Sergeant*, moving along at 18 knots, bore down on him.

But the big thrill of the day came late in the afternoon. McMullen announced that a crash-astern test would take place. He urged people to move to the fantail for the best show and, smiling affably, proceeded there himself. Soon a small circle of journalists gathered around him, seeking his comments on the *Sergeant's* present and future performance. He answered them as candidly as he could. Then, as though expressing a long-pent-up wish, he said, "We'd like to run this ship to its point of destruction—if we had enough money. That way we'd find out which part would fail first!"

Urging the group once again to keep

...do much to advance maritime technology."

their eyes on the ship's wake, McMullen turned and made his way back to the midship deckhouse.

Though the *Sergeant* began to pick up speed, you could sense it only by the increasing stiffness of the breeze or, perhaps, the swoosh of water past her hull. From the horizon, three Navy bombers flew in, swooping down inquisitively for a look at the unfamiliar ship, then disappeared.

For the next 5 or 10 minutes the *Sergeant* maintained her fast clip. Word passed along that she was moving at a steady 17 knots. Then the foghorn let out one long blast—the signal for crash astern (photo sequence, pages 8 and 9). Immediately, everyone braced himself, grabbing on to a hand railing or some other fixed object nearby.

This turned out to be an unnecessary effort. The *Sergeant* did slow down. But try as you might, you couldn't perceive any deceleration whatever—no jarring or jerking motion, no grinding sound of gears under strain.

Gradually, as the big ship approached what mariners call "dead in the water," her wake began to take on a pale green color, with thousands of little bubbles rising to the surface. The only way you could detect the slowing down was to visually compare the ocean's movements. This sensation, or lack of it, McMullen had exuberantly pointed out the evening before and reiterated again that day. But the majority aboard were skeptical of his claim until that moment.

Quickly now, the smooth greenish wake began to froth and turn white. Growing thicker, it fanned out from the *Sergeant's* stern a distance of 50 yards as she came to a full stop—a beautiful thing to see. Cameras clicked!

The period of time from the moment the *Sergeant's* foghorn shrilled crash astern till she stopped dead in the water was officially announced later as 2 minutes 47 seconds. From a speed of 17 knots, her forward motion was arrested until she became dead in the water and began to move aft—all with hardly a perceptible vibration. Compared with vessels having a fixed-blade propeller, her performance was phenomenal. Conventional ships the *Sergeant's* size normally take four to five minutes to complete crash astern. What's more, the whole maneuver was accomplished by one man on the bridge throwing a lever.

Living up to her advanced billing and establishing her reputation in the presence of several hundred witnesses, the *Sergeant* headed west for Hampton Roads and her dockside berth at Newport News. Truly she had fulfilled McMullen's prophecy made nearly a year before—the first successful all-gas-turbine ship.

The GTS *John Sergeant* is now back at a familiar job: running cargoes under the flag of the U.S. Lines. She rates as one of the world's most instrumented ships; with her specially trained crew, she will do much to advance maritime technology. But just what the future of her marine gas turbine will be, no one can say for sure at this time.

McMullen told the November 1955 SNAME meeting unequivocally that the *Sergeant's* gas turbine, if successful, *wasn't* expected to replace all other forms of marine propulsion. Nothing has happened since that time to change the basic truth of his statement. A writer in the National Maritime Union's newspaper, *Pilot*, mentioned the possibility that maritime officials would recommend gas-turbine power plants for the new Freedom-class prototype ships being developed to replace the Liberty. Only time will tell, however.

Many engineers view the marine gas turbine as presently limited to a certain horsepower range. Beyond certain power outputs, they say the gas turbine begins to lose out to the steam turbine. With technology's present fast pace, though, you never can tell what might happen.

Generally speaking, the crux of the gas-turbine design problem centers around thermal efficiency; this in turn relates to gas-inlet temperature. The objective in a nutshell: raise this temperature substantially above today's figure. And so the marine gas turbine's future depends heavily on new materials and, accordingly, falls into the metallurgist's bailiwick.

The U.S. government holds more than passing interest in the idea of pairing a closed-cycle gas turbine with a gas-cooled nuclear reactor. Under auspices of the Atomic Energy Commission, one company is already studying the feasibility of such a marriage. Clarence G. Morse has said of the Liberty ship conversion program, "The primary reason for a program in this field . . . is the higher inherent adaptability of closed-cycle gas-turbine plants to the utilization of nuclear energy."

However, maritime technology moves in many directions today. And a new form of propulsion, though highly important, is only one of them. You lose the advantage of a fast cargo ship if loading or discharging takes too long.

Ship architecture and marine hydrodynamics represent other areas of interest. Naval engineers have managed to damp much of a ship's roll. But the pitching—the vertical swing of the bow and stern—and heaving—the rise of the ship's center of gravity—don't lend themselves to such correction.

Dr. Kenneth S. M. Davidson of Stevens Institute of Technology in Hoboken, NJ, a mechanical engineer renowned for his experiments in hydrodynamics, may have a way out of this dilemma. By blending the hydrodynamic slipperiness of advanced submarines with the boundless power of nuclear propulsion, Dr. Davidson thinks that one day heavy cargo may be submarined at 80 knots from New York to London, in about 35 hours.

But even then it's doubtful that the pioneering efforts of the GTS *John Sergeant* will have been forgotten. —JJR

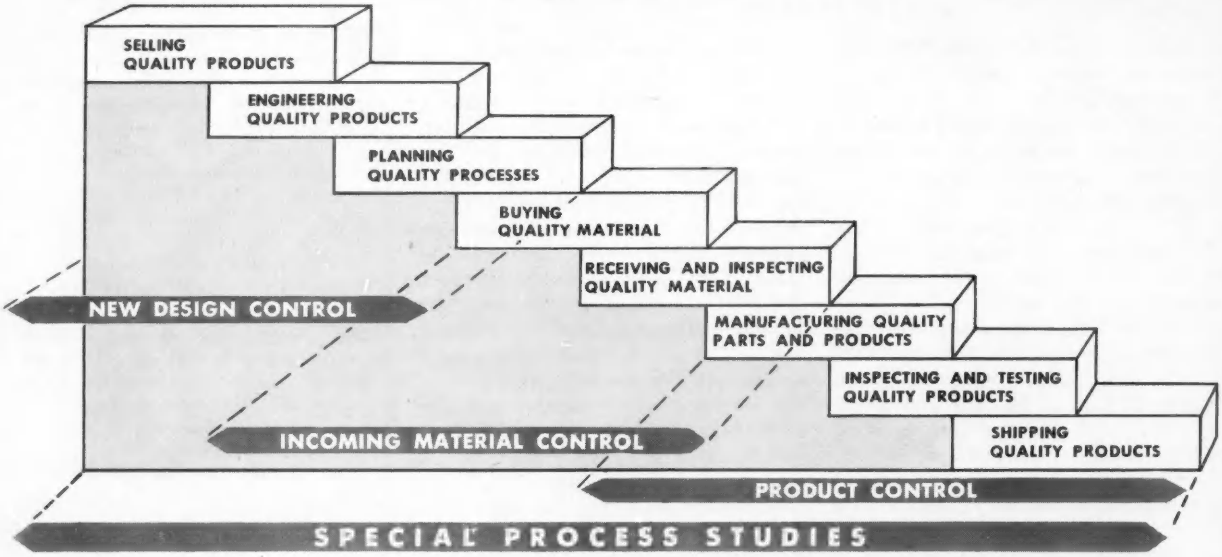
THE PROGRAM'S HISTORY

The idea for the gas turbine's application came into being in 1952 when the U.S. Maritime Administration's Program Planning Office was under jurisdiction of Admiral Walter C. Ford (USN, retired). Packaged and taken to the then Maritime Administrator and chairman of the Federal Maritime Board, Louis S. Rothschild, the program was in turn accepted by Sinclair Weeks, Secretary of Commerce.

Legislation drawn up to provide necessary appropriations, the Liberty Ship Engine Improvement Program was presented to Congress. Both the Senate's Interstate Commerce Committee and the House of Representatives' Merchant Marine and Fisheries Committee wisely supported it.

In June of 1954, Admiral Ford procured the services of John J. McMullen as Chief of the Office of Ship Construction and Repair. McMullen subsequently directed the work within the Maritime Administration and between the Administration and private industry. In this role he had the full support and encouragement of Clarence G. Morse, present Maritime Administrator and former General Counsel of the Federal Maritime Board.

QUALITY CONTROL ACTIVITIES DURING THE PRODUCTION CYCLE



Total Quality Control: A Program that Pays Off

As a major management activity, this new concept provides industry with professional effort to meet product quality at optimum quality costs.

By Dr. A. V. Feigenbaum

Products bought and used today by most American consumers, whether housewives or large corporations, are of a generally higher level of quality than ever before made available in this country. Factoring out inflationary elements by considering real prices in terms of real wages, the technical evidence leads to one clean-cut conclusion: Our refrigerators, our turbine-generators, our washers and dryers provide us year after year with better, more consistent day-in day-out value per price dollar—a practical definition of quality.

The present era of competition in the American market place has become as much an era of quality competition as one of price competition. Few businessmen today question the principle that although price or delivery or promotional stunts may sell a product the first time, it is quality that keeps the customer returning the second, third, and fifteenth time. No reputable manufacturer today would knowingly consider offering an inferior quality product.

Trend Toward Higher Quality

The trend of customer demand toward higher and higher quality levels is likely to intensify rather than diminish in the next few years. Certainly, the electrical industry typifies this trend. Quality levels for motors and generators tighten appreciably year by year. Consumers are progressively more minute in their examination of the finish of appliances or in their judgment of the fidelity of radio and television sets. Even for those most critical products on which human safety already depends—jet engines, airborne electronics, naval ordnance—military quality requirements are being made progressively more sensitive.

Obsolescence of Practices

A key result of this increased customer demand for higher quality products has been a rapid and dramatic obsolescence of in-plant practices and techniques for controlling the quality of the products being manufactured.

For example, the machined part that could once be checked with a pocket scale or with precision micrometers must now be carefully measured with an air gage. Material that could once be visually accepted if it were "reddish brown and shiny" must now be carefully analyzed both chemically and physically to assure that it is beryllium copper instead of phosphor bronze.

Performance testing requirements call for more and more complex testing equipment. Intangibles like dust in the air and humidity have become both extremely tangible quality problems and the objective of elaborate safeguards. Automation, in which rapid quality evaluation is a pivotal point, has magnified the need for mechanization of inspection and test equipment—now largely in the hand-tool stage.

High Level of Quality Costs

As a major consequence of this obsolescence, quality costs (inspection,

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test, laboratory checks, scrap, rework, customer complaints and others) have —usually without fanfare—crept up to become a multimillion-dollar expenditure item.

The total of these quality costs for many American businesses compares today with their total direct labor dollars, with distribution dollars, and with material purchase dollars. Although there are no formal nationwide studies on the subject, evidence suggests strongly that many businesses have quality-cost expenditures representing 7, 8, and 10 percent and much more as a proportion of their cost of sales. In some instances, this means 80, 90, and 100 percent and even more as related to total direct labor dollars.

The breadth of these quality dollars and their sharp upward trend over the last decade is only now becoming recognized. A major reason for this curious head-in-the-sand view toward such a major expenditure item has been the inadequacy in some forms of historical cost-reporting methods. In these methods, there has been piecemeal identification of a few individual quality-cost elements like scrap and spoilage or field complaint expenses. More typically, quality cost has been presented as merely the cost of a company's inspection activity.

Actually each of these elements is only a fraction of the total quality sum. The full magnitude of quality cost—and the breadth of the need for its control—has been obscured by the fragmentary character of the older costing systems.

The Twin-Edged Quality Problem

Collectively, these three current trends—higher quality demands by customers, the obsolescence of company quality practices, and the resulting high quality costs—confront American business with a twin-edged quality problem . . .

- Much improvement must be effected in the quality of many products and in many quality practices.
- The quality results must be accomplished simultaneously with substantial reductions in over-all quality cost.

Business management in the United States has been actively and aggressively turning to better ways and means for meeting this double-edged problem. Let's review the direction of this effort.

It has started by accepting the principle that *quality control*—the task of controlling product quality—is far more than a matter of what we have historically known as inspection work. For the quality of a product—an electric relay, for example—has been affected at many more stages of the production cycle than those susceptible to inspection activity. It has been influenced by the *Marketing* function, which had evaluated the level of relay quality that customers wanted and for which they were willing to pay. It has been influenced to a major degree by *Engineering*, which reduced this marketing evaluation to exact drawing specifications.

It was influenced by *Purchasing* in choosing, contracting with, and retaining vendors for parts and materials. It was influenced by *Manufacturing Engineering* in its selection of the jigs, tools, and processes for relay production.

Manufacturing supervision and *shop operators* have had a major quality influence during parts-making, subassembly, and final assembly. Also the important effect of *mechanical inspection* and *functional tests* in checking conformance to specifications should not be overlooked. *Shipping* has its influence in the caliber of the packaging and transportation.

Thus the determination of quality and, consequently, of quality cost takes place throughout the entire production cycle. The twin objectives of better product quality and lower quality cost cannot be achieved by concentrating upon any one phase of the cycle alone—inspection, design engineering, reject troubleshooting, operator education, or statistical analysis—important as each phase is in its own right. Doing the job adequately requires instead a program of *total* quality control.

Total-Quality-Control Approach

Such a program approaches quality control as a new and important business management function directly related to product quality throughout the entire cycle from design through shipment. This contrasts sharply with the older inspection concept in which coverage was essentially confined to the shop floor and remained this way even though in recent years the inspection function may have been made more efficient and more modern by the addition of certain statistical methods like sampling tables and control charts.

The theme of this traditional inspection activity was "They [bad parts] shall not pass." In contrast, the theme of the total-quality-control concept is "Make the parts right the first time." Emphasis is on defect prevention so that routine after-the-fact inspection can be substantially reduced.

In the shop-floor phase of the total-quality-control activity, for example, the burden of quality proof rests not with inspection but with the makers of the part: machinist, assembly operator, or foreman. Preproduction quality planning provides them with the tools needed to meet their quality responsibility. In-process quality auditing and analysis makes the new quality-control inspection a positive assist to this good quality performance rather than a policeman of this performance.

Like traditional inspection, the quality-control function is responsible for assurance of the quality of the products shipped; but its much broader scope adds a major management qualification to this responsibility. Quality control becomes responsible for "quality assurance at optimum quality costs," thus formally and directly coming to grips with both sides of modern business's twin-edged quality problem.

This view of total quality control does not see the typical quality-control man as an industrial statistician exclusively, nor necessarily as a well-grounded inspection specialist who has had training in useful statistical methods. Instead, it sees him as a quality-control engineer with an adequate background in the business's product technology and with training in inspection and test technique, in statistical methods, and in other major tools useful in improving the control of product quality.

Program in Operation

Now let's see specifically how this total-quality-control program has been organized to work for those companies which use it. The wide scope of its quality activities breaks down into four classifications—the major elements of the total-quality-control program. . .

New Design Control—control of new or modified products prior to the start of production

Incoming Material Control—control of incoming purchased parts and materials

Product Control—shop-floor control of materials, parts and batches from machines, processes, and assembly lines

Special Process Studies—conducting of special analyses of factory and processing problems.

These elements in the total-quality-control program have a relationship to the over-all production cycle (illustra-

PLANNING AND ANALYSIS ACTIVITIES IN THE MAJOR QUALITY-CONTROL ELEMENTS

The major phases of quality-control engineering's planning and analysis work in the four quality-control elements:

In New Design Control

Provide preproduction service to design engineering and manufacturing engineering in analyzing the quality ability of new products and production processes and in the related quality debugging.

This assures a product that will be as defect-free as possible *prior* to the start of production. Among the new technical tools that the quality-control engineer brings to this effort are process-quality capability studies, tolerance-analysis technique, pilot-run practice, and a wide variety of statistical methods.

Assure the quality planning of the inspections and tests to be carried on when production is under way. This establishes continuous control of in-process quality. It involves determining and documenting . . .

> Dimensions and characteristics of the parts to be checked;
>
> Degree to which they are to be checked;
>
> In-process and final production points at which checks are required;
>
> Methods and procedures—including statistical sampling plans, control charts, and other aids—to be used;
>
> Personnel who will make checks: that is, which shall be done by production operators and which by the quality-control inspection and test subfunctions.

Design genuinely modern inspection and testing equipment which, to the fullest possible extent, is physically integrated with manufacturing equipment to permit the machine to check its own work. The emphasis of this activity is on economical investment expenditures, maximum equipment utilization, and fullest practical mechanization and automation both of operations and quality-control paperwork.

In Incoming Material Control

Establish and maintain good quality relationships with vendors and suppliers by . . .

- Planning the periodic rating of the quality performance of present suppliers, to provide facts which assist the purchasing function in quickly bringing satisfactory or unsatisfactory quality performance to the attention of vendors.
- Evaluating the quality capability of potential suppliers, to provide facts which assist purchasing to select good quality vendors.
- Assisting the vendors to understand the quality-control requirements of the purchase contracts they have won.
- Establishing quality certification programs, which place the burden of quality proof upon the vendor rather than upon an extensive, expansive in-plant incoming inspection effort.

In Product Control

Carry on the cost measurement and quality-cost-reduction project activity required for over-all quality-cost control and reduction.

Perform process-quality capability studies to determine the quality limits within which a machine or process can be expected to operate so that parts can be routed to these equipments which are economically capable of maintaining engineering specifications.

In Special Process Studies

Analyze complex in-processing quality problems, which have been fed back by inspection and test. These studies are directed both to the elimination of defects and to the development of possible improvements in present quality levels.

tion, page 12). Each of them is supported by definite methods and procedures that are as integral a part of basic shop practice as production-control or cost-control routines.

Organizational Principles

Fundamental to business management's development of these methods and procedures are two quality-control organizational principles: 1) quality is everybody's job in a business; and 2) because quality is everybody's job, it may become nobody's job.

In defiance of the first principle, many business experiments over the years have attempted to centralize all quality responsibility in a company by organizing a function in which the job has been handsomely described as "responsibility for all factors affecting product quality." These experiments have had a life span of as long as six to nine months—that is, when the job incumbent had the advantage of a strong stomach, a rhinoceros hide, and a well-spent and sober boyhood. Others not similarly endowed did not last the six months.

The facts are simply that the marketing man can best evaluate the customer's quality preferences; the design engineer is the only man who can effectively establish specification quality levels; and the shop supervisor is the individual who can best concentrate upon the building of quality.

Total-quality-control programs thus require an initial step: top management re-emphasizing the respective quality responsibilities and accountabilities of all company employees in new design control, in incoming material control, in product control, and in special process studies.

In turn the second organizational principle leads to the second major top-management step required for organizing total quality control: the many individual responsibilities for quality should be buttressed and serviced by the establishment and operation of a recognized well-organized genuinely modern management function, with product quality as its only area of specialization and the four quality-control elements as its only area of operation.

Responsibilities of Quality Control

The two basic responsibilities of the quality-control function . . .

- Provide *quality assurance* for the business's products: that is, be sure that the products shipped are right.
- Assist in assuring *optimum quality costs* for those products: that is, be sure that the good quality products are shipped at the right quality cost.

The quality-control function fulfills these responsibilities through its three subfunctions: quality-control engineering; inspection; and test. They operate three activities which form a continuous feedback cycle . . .

- *Quality planning* done by quality-control engineering; this establishes the basic framework of the quality-control system for the business's products.

• *Quality measuring* performed by quality-control inspection and test; this determines, in accordance with the quality plan, the conformance and performance of parts and products with engineering specifications.

• *Quality analysis* that results from rapid feedback to quality-control engineering; this fosters new planning, thus completing the cycle. This analysis also fosters corrective action for product quality deviations.

Planning Leads to Quality Measuring

Careful quality planning and quality analysis (see box) make a positive type of quality measuring possible as well as necessary. During incoming material control and product control, the quality-control inspection and test subfunctions not only fully establish that the materials received and the products shipped are of the specified quality but also thoroughly and promptly feed back facts for preventing the purchase and production of poor-quality material in the future.

This positive quality measuring requires only a minimum of routine, hand-sorting inspection, and test. In product control, for example, a continuous four-step sequence makes this result possible.

The first step involves quality-control engineering work to assure that production operators can—with the facilities provided—make parts right the first time and, as the second step, that the operators know they can.

The third step requires additional quality-control engineering work so that the necessary equipment and gages are available to permit operators to check their own work. The operator spends much more time at the work place than the inspector, and it seems the very essence of common sense that the operators should, to the maximum extent possible, do the bulk of the routine inspection required. This then makes the fourth step in the sequence possible: inspection and test are freed to do genuine quality-control work.

They provide positive assistance in the production of the right quality by . . .

• Becoming auditors of the good quality practices that have been established

• Providing as much on-the-spot shop-floor analysis of defects as possible

• Feeding back facts about these defects for corrective analysis and action elsewhere.

Such quality-control effort inevitably upgrades the traditional inspection and test activities. Compared with this older activity, the quality-control type of inspection and test requires fewer but more highly qualified and more specialized people—men and women who have genuine ability to be helpful in making the right quality. As an example, let's take the arc-welding inspector who not only knows when a weld penetration on a part is satisfactory but who also can counsel the shop on why the penetration of defective welds has been unsatisfactory.

Quality-Control Engineer

Certain elements of the quality-control engineering work, which is so basic to the new total quality control, had been previously performed on a sporadic basis. But the quality-control engineer himself has been something new under the sun. We are now recognizing that quality-control engineering is not merely a new label for the inspection-planning package, nor a fresh designation for the test-equipment engineer, nor yet a technologically flavored title for the industrial statistician.

It is, instead, a specialized technical activity characterized by a unique combination of skills in the appropriate phases of product and process technology, as well as in quality-control technique itself. Quality-control engineering work is the product of the cross-fertilization of modern developments in several fields: statistical methodology, fast-response high-precision inspection and testing equipment, and management-engineering progress in understanding the nature of the control function in modern business. Its attributes form a genuinely new sector of the engineering profession.

In experience, education, aptitude, and attitude, the man entering quality-control engineering work today is, in fact, not much different from the man entering other longer established major technical fields: for example, product engineering or manufacturing engineering. He possesses, or has the capacity to acquire, the necessary product and process background; the personal characteristics to work effectively in a dynamic atmosphere with people of diverse interests; a technical background which enables him to acquire, if he does not already have it, the growing body of quality-control engineering knowledge; and the analytical ability to use this knowledge in solving new and different quality problems.

Tangible Results of the Program

Experience in an increasing number of companies shows that operation of the total-quality-control program has paid off handsomely. For one example, a midwestern company manufacturing motors installed a total-quality-control activity, which in 15 months: 1) improved product quality substantially, 2) reduced field complaints several fold, and 3) reduced the going level of quality costs from an annual rate of about a million dollars a year to a new annual rate of something over $650,000—a total saving of $350,000. And during this period, output increased about 10 percent.

More broadly, total quality control in the United States has resulted in six important improvements . . .

Better product quality

Reduction of scrap, complaint, inspection, and other quality costs (Improvements of one third or more in over-all quality costs are not unusual)

Better product design

Elimination of many production bottlenecks

Improved processing methods

Development of a better spirit of quality-mindedness on the production shop floor.

Thus in its actual practice, total quality control successfully meets business's twin-sided quality problem of better quality at lower quality costs. The reason for the satisfactory better quality can be clearly understood from the very nature of the prevention-centered step-by-step technically thorough program. But the explanation for the accompanying by-product of lower over-all quality cost may not be nearly so obvious.

Costs of Quality

The reason for the favorable cost result of total quality control is that it cuts the two major cost segments of quality—which might be called failure and appraisal costs—by means of much smaller increases in the third and smallest segment—prevention costs. Why this is possible can be seen as soon as the character of these three categories is considered . . .

- Failure costs are caused by defective materials and products that do not meet company quality specifications. They include such loss elements as scrap, spoilage, rework, and field complaints.
- Appraisal costs include the expenses for maintaining company quality levels by means of formal evaluations of product quality. This involves such cost elements as inspection, test, quality audits, laboratory acceptance examinations, and outside endorsements.
- Prevention costs are for the purpose of keeping defects from occurring in the first place. These include such costs as quality-control engineering, employee quality training, and the quality maintenance of patterns and tools.

In the absence of formal nationwide studies of quality costs in various businesses, it is impossible to generalize with any authority about the relative magnitude of these three elements of quality cost. However, it would probably not be far wrong to suggest that failure costs may represent from one half to three quarters of total quality costs, while appraisal costs probably range in the neighborhood of one quarter of this total. In many businesses, however, prevention costs probably do not exceed one tenth of the quality-cost total. Out of this 10 percent, usually 8 to 9 percent is directed into such traditional channels as pattern and tool maintenance and the specification changing or interpreting work of product engineering. This leaves only 1 or 2 percent for elements of quality-control engineering work.

It is a significant fact that, historically, under the traditional inspection function, failure and appraisal costs have tended to move upward together, and it has been difficult to pull them down once they have started to rise. The reason for this relationship is that as defects increase, thus pushing up failure costs, the number of inspectors has been increased to maintain the "they shall not pass" screen to protect the customer. This has pushed up appraisal costs.

For the reasons mentioned earlier, screening inspection does not have much effect in eliminating the defects nor can it completely prevent some of the defective products from leaving the plant and going into the hands of customers who would complain. Appraisal costs thus stay up as long as failure costs remain high. The higher these failure and appraisal costs go, the higher they are likely to go without successful preventive activity.

Once these two main elements of quality cost have started to rise—as they seem to have throughout industry generally today—the one best hope for pulling them to earth again seems to be spending more on the third and smallest element—prevention cost. The 10 percent now spent may well need to be doubled, much of the increase going for quality-control engineering as well as for improved methods of inspection and test equipment automation.

At first glance, such increases in prevention costs may not seem to be in the interest of quality-cost improvement, but this objection is rapidly dispelled as soon as results are considered. Translated into quality-cost terms, the operation of total quality control has the following sequence of results . . .

- A substantial cut in failure costs—which has the highest cost-reduction potential of all quality-cost elements—occurs because of the reduced number of defects and the improvements in product quality brought about by modern quality-control practice.
- Fewer defects mean somewhat less need for routine inspection and test, causing a reduction in appraisal costs.
- Better inspection and test equipment and practices, and the replacement of many routine operators by less numerous but more effective quality-control inspectors and testers bring about additional reductions in appraisal costs.
- Because the new quality-control inspection and test is effective in preventing defects, appraisal dollars for the first time begin to exercise a positive downward pull on failure costs.

The ultimate end result is that total quality control brings about a sizable reduction in over-all quality costs, and a major alteration in the proportions of the three cost segments. No large long-term increase in the size of the quality-control function is required as a necessary condition for quality-cost improvement. Instead, quality-control expense, as a proportion of total company expense, will be down in the long run.

The personnel mix of the quality-control function will, however, change to include a much higher proportion of professional and specialist-type people.

Quality Dollar Budgeting

It is worth noting that the identification and analysis of quality costs permit a major forward step in the business budgeting process. They make feasible establishing the dollars needed for quality control, not on the basis of historical inspection cost experience but on the basis of current company objectives in product quality and quality costs.

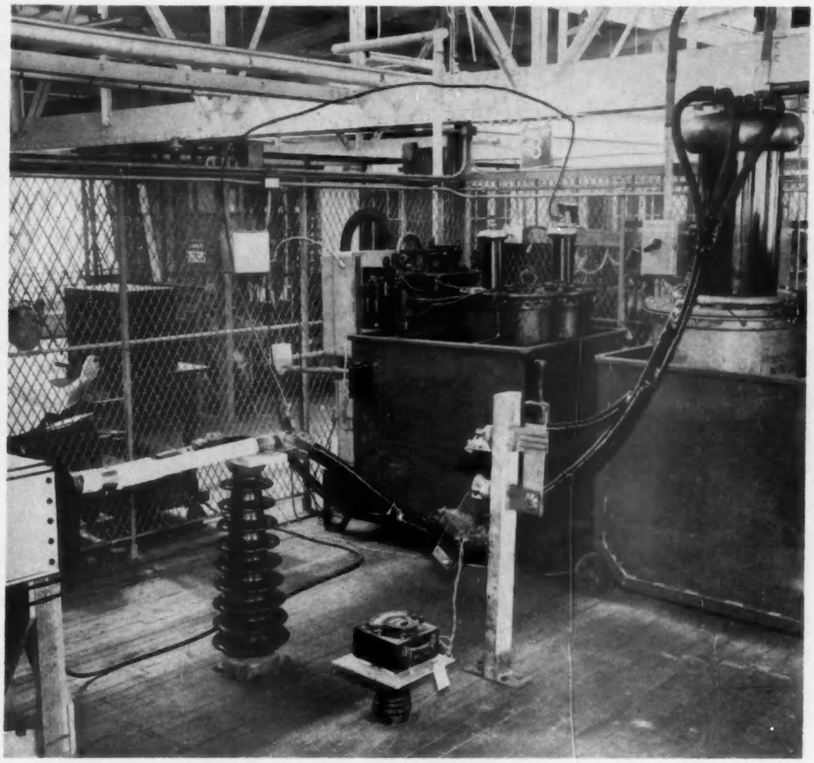
Looking to the Business Future

The problem of meeting customer quality requirements is becoming so complex technically and so costly financially that a major breakthrough in scientific management practices has had to take place to come to grips with the problem. This breakthrough is the new concept of total quality control.

This concept's design-through-shipment integration of the many quality elements in the production cycle makes today's quality control far more than merely a more efficient inspection function or merely a statistical analysis effort. The concept's new quality-control function, a major modern business-management activity, provides company top management with professional effort in meeting the objectives both of assuring product quality and at the same time of fostering optimum quality costs.

This broad approach welds the new technology of quality control into a strong organization structure that is sufficiently broad to come to grips successfully with the three major quality problems that modern business must face and solve: the upward customer pressure on quality levels; the resulting rapid obsolescence of quality practices; and the very high level of quality costs.

Helping realistically to meet these problems is the way the new total quality control will, in the years ahead, serve American companies and the American economy's goal of progressively better goods at progressively lower real cost. In this business future, it is only too evident that the right product quality and the right kind of quality-control program to assure it will be among the major factors in any company's survival, health, and progress. Ω



HIGH-CURRENT HIGH-VOLTAGE load cycle test on 15,000-volt silicone-glass insulated lead cable shows no sign of cable breakdown after 1½ years' continuous test operation. Field conditions are simulated in heat chamber (white box, left).

New Trends in High-Temperature Cables

By B. J. Mulvey

Many special wire and cable applications involve high-temperature operation, such as the wiring of electric apparatus, switchboards, and equipment in power stations and industrial plants that contain boilers, furnaces, or other heat sources. Additionally, the wiring of cranes, boilers, controllers, and motors for steel mills and locomotives for mine use require special materials. In general, this means that for normal cable life, a heat-resistant cable insulation must be used in any industrial application where ambient temperatures run higher than about 50 C (122 F).

For many years the standard cable construction for high-temperature use consisted of a conductor, a covering of felted asbestos or asbestos roving, and an asbestos braid or lead sheath. Depending on the construction and application details, asbestos-insulated cables can be used at conductor temperatures up to 200 C. But such cables are vulnerable to moisture absorption, which can occur during either light-load or shutdown periods. Varnished cloth tapes inserted between layers of asbestos furnish some moisture resistance. However, a lead sheath over asbestos-varnished cambric insulation offers the most reliable moisture resistance but limits cable use to a maximum conductor temperature of 110 C.

Besides poor moisture resistance, the electrical properties of asbestos also severely limit its use. Its insulation resistance is extremely low compared with almost any other insulation. And the very high power factor and dielectric constant lead to excessive internal losses in the insulation wall on high-voltage applications. For this reason, the material has been generally limited to use in 600-volt applications, with some at 5000 volts.

Glass yarns have been used in high-temperature cable design but principally as outer braids for mechanical protection of the primary insulation. The type of impregnant or varnish treatment given glass yarns primarily determines their insulating properties. Glass itself is generally regarded as a spacer rather than an electric insulant.

In the late 1930's a mineral-insulated cable—Pyrotenax—was developed in France. Called Type MI in the United States, it consists of one or more solid-copper conductors embedded in closely packed magnesium-oxide insulation and enclosed within a solid-copper tube. Its excellent heat and flame resistance and the inert properties of the refractory magnesium-oxide insulation have made this cable useful in areas subject to severe nuclear radiation. This cable presents three main problems: the hygroscopic nature of the magnesium oxide requires special moisture-seal terminal fittings, the limited length of cable and number of conductors per cable that can be made, and its restriction for use on 600-volt circuits or less.

Insulation Requirements

The ideal insulation for high-temperature use should be . . .

- Suitable for high-temperature use and flexible at low temperatures
- Stable electrically over a wide temperature range
- Low in power factor and specific inductive capacity
- Physically strong enough for fabrication and installation use
- Weather, fungus, moisture, and corona resistant.

During the 1930's many attempts were made to improve the heat resistance of natural rubbers by special compounding. Thus the operating temperature of rubber was increased from 50 C for code rubber to 75 C for heat-resistant rubber, but this still did not allow rubber to replace asbestos.

About this time the General Electric Research Laboratory became interested in silicones—a laboratory curiosity since 1892—for use in heat-stable insulating materials. The Corning Glass Company also followed this interest and ultimately formed the Dow-Corning Corporation to manufacture these ma-

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terials. Now in this field are three manufacturers: General Electric, Dow-Corning, and Linde Air Products.

After World War II the development of silicone rubber as a cable insulation received tremendous impetus when the U.S. Navy began specifying it for the insulation on Navy cables. Up to that time, silicone-rubber compounds had been extremely weak and difficult to handle during both cable manufacture and installation. The effort expended to meet the Navy specifications led to a great improvement in physical properties, and now silicone rubber most closely approaches the ideal for a high-temperature cable insulation.

Called a polyorganosiloxane by the chemist, silicone-rubber gum compounded with certain inorganic fillers and cured with a peroxide-type catalyst gives a rubber-like product. This is but one member of the silicone family that ranges from light liquids through viscous greases to solids. The chemical compositions of the gum vary for specific applications.

Insulation Properties

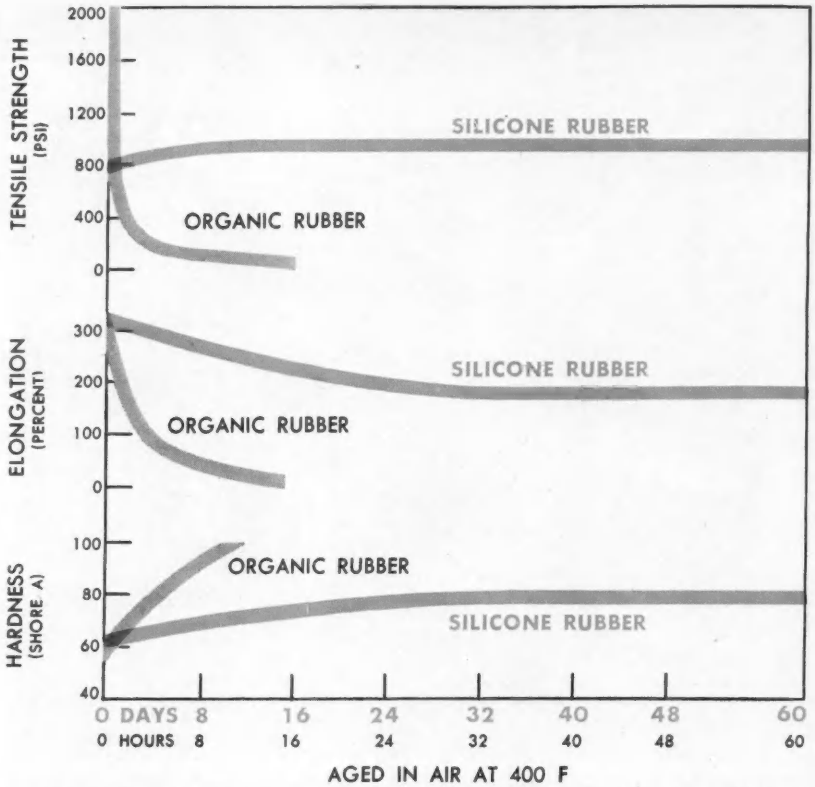
Some silicone-rubber compounds can, with sufficient care, be extruded on copper conductors. However, in comparing the physical and electrical properties of extruded silicone rubber with commonly used rubber-like insulations, silicone rubber has low tensile strength (Table). This makes it difficult to extrude heavy walls and limits the cables to a maximum conductor size of 500,000 circular mils (MCM) and a maximum wall thickness of eleven sixty-fourths of an inch for 5000-volt cable.

Of course, the main attraction in silicone rubber is its heat resistance. In one test of silicone rubber versus organic rubber at 400 F in air, organic rubber practically disintegrated after 8 hours' exposure (illustration, top). On the other hand, silicone rubber after 60 days' exposure had stabilized, with its physical properties only slightly below their original values.

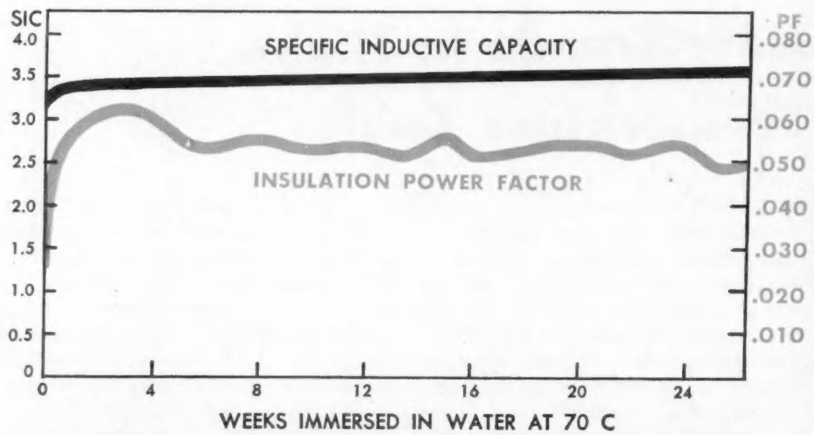
Moisture resistance is an important consideration in choosing a cable insulation. Compared with an acceptable value of up to 20 mg, the Underwriters' Laboratory report on silicone-rubber appliance wire shows a test value of 4.5-mg water absorption per square inch of exposed surface. The effects of long immersion on the power factor and the specific inductive capacity (SIC) of a silicone rubber cable sample immersed in 70 C water show the stability of electrical properties in water (illustration, lower).

On the basis of these properties, a fairly complete line of extruded silicone-rubber cables for voltages up to 5000 volts is now being used as appliance wires, aircraft cables, power wiring, and heating cables. For mechanical protection during handling, either a glass or asbestos braid usually covers the silicone rubber. Significant production economies brought about through improved manufacturing techniques have reduced prices of these cables to practically the same as those for similar asbestos-insulated cables, thus increasing acceptance of silicone rubber throughout industry.

Extrusion methods for heavy insulation walls necessary at voltages above 5000 volts have not been worked out.



SILICONE RUBBER retains stabilized physical properties after 60 days' exposure at high temperatures. Abscissa for organic rubber appears in hours, silicone rubber in days.



LOW MOISTURE ABSORPTION of extruded silicone rubber cable and stability of electrical properties in water insure long cable life in exposed, wet locations.

PROPERTIES OF ELECTRIC INSULATION MATERIALS

Properties	Silicone Rubber	Natural Rubber	GR-S	Neoprene	Butyl	Polyvinyl Chloride	Poly-ethylene
Maximum operating temperature	150–200 C	75 C	75 C	90 C	90 C	80–105 C	75 C
PHYSICAL							
Elongation (percent)	100–300	500	500	750	550	150	500
Tensile strength (psi)	500–1000	2000	1000	1800	700	2500	1500
Low temperature flexibility	Excellent	Very Good	Good	Good	Very Good	Fair-Very Good	Excellent
Abrasion resistance	Poor	Fair	Fair	Good	Fair	Very Good	Good
Ozone resistance	Excellent	Poor	Poor	Very Good	Very Good	Very Good	Good
Tear resistance	Poor	Fair	Fair	Fair	Fair	Very Good	Very Good
Flammability	Burns (leaves nonconducting ash)	Burns	Burns	Nonflammable	Burns	Nonflammable	Burns
Specific gravity	1.20	1.60	1.40	1.60	1.40	1.35	0.92
ELECTRICAL							
Insulation resistance (K)	5000	20,000	2000	100	75,000	2000	75,000
Dielectric strength (V/Mil)	450	450	450	400	450	750	1000
Power factor	0.0050	0.0400	0.0350	High	0.0100	0.1000	0.00050
Dielectric constant	3.1	5.0	4.2	High	4.0	6.0	2.3
CHEMICAL RESISTANCE							
General	Good	Fair	Fair	Good	Good	Very Good	Very Good
Strong bases	Good	Fair	Fair	Good	Good	Very Good	Very Good
Strong acids	Poor-Fair	Fair	Fair	Good	Very Good	Very Good	Very Good
Oil and gasoline	Poor-Good	Poor	Poor	Good	Fair	Very Good	Very Good
Moisture absorption	Very Good	Fair-Good	Excellent	Fair	Very Good	Very Good	Excellent

But an insulation is available that can be used on cables rated up to 35,000 volts. In 1953 a glass tape coated with a General Electric silicone rubber became available for commercial use. Consisting of a 4-mil base glass-fabric tape coated on both sides with silicone rubber to a total thickness of 10 mils, this material maintains excellent electrical properties at 125 C. In 14-day aging tests at 250 C, these properties not only are retained but also actually improve to some extent. Additionally, the material has excellent dielectric strength and corona resistance, low moisture pickup, and good physical properties.

Made in 1954 by a large eastern electric utility, the first high-voltage installation of cable insulated with silicone-rubber glass tapes was made on a 15-kv generator unit that carried thermal bottlenecks and inadequate cables. The cables were single-conductor 2500-MCM copper conductors conservatively rated at 125 C copper-operating temperature—an ampere rating of about 40 percent more than conventional cable.

In progress since its manufacture, long-time laboratory tests on this cable indicate general improvement of its electrical properties with age. They also point up the value of reducing wall thickness on future cables.

High-Temperature Application

Silicone extruded-rubber insulated cables are increasingly used in hot locations where conventional rubber or asbestos cables have given trouble: for instance, on power and control cables of electrically driven ladle cars at the Hanna Nickel Smelting Company plant at Riddle, Oregon. These ladle cars transport large ladles, filled with molten material. Formerly, the conventional heat-resistant cables had to be replaced every three or four weeks because of insulation failures. In the past year or so, the use of silicone cables indicates that the new insulation can readily withstand the heat involved. The failures that did occur were caused by mechanical rather than temperature limitations. It is hoped that improved mechanical design such as flexible conductors and flexible stainless-steel outer braids will in the future eliminate practically all cable failures.

As the cost of silicone rubber decreases, its use will increase to the extent that it will probably replace asbestos-varnished cambric as a general-purpose high-temperature cable insulation. Allowing equipment operation at higher temperatures than previously possible, silicone-rubber insulated cable fits the trend toward Class H equipment for use in prolonged high temperatures or occasional overloading. It offers a new standard-cable insulating material for the heat-plagued glass and metals industries. Ω

Credits

Page	Source
6 (photo, left)	Maritime Administration
6, 7 (photo, center)	Newport News Shipbuilding and Drydock Company
7 (photo, center)	S. Morgan Smith Co.
20-22 (all photos except the lead)	C. Emmett Calvey Taunton, Mass.
34	American Society for Testing Metals
42, 43	Agar Portrait Marshalltown, Iowa

Precision molding the plastics case of a detachable exposure meter for the new Keystone movie camera needs careful planning and strict adherence to the product's design. Picture sequence shows steps in production that began with consultations in custom molder's engineering office . . .

1 Customer, drafting supervisor, and cus tom-molding engineer study product draw

What Is Custom Molding?

In an era where lack of materials has hampered new product development, molded plastics are attracting attention because of their unusual properties.

***Review* STAFF REPORT**

Today the plastics industry constitutes a well-established segment of the American economy. Still, the majority of engineers look upon plastics as a substitute material.

When implying this to J. E. Faloon, a friendly, competent, and persuasive engineer who supervises manufacturing operations at General Electric's Plastics Department custom-molding plant in Taunton, Mass., he literally bristled. "In the first place," he retorted, "we all have to be careful that we don't think of plastics as a substitute for anything."

"Not even for metal?"

"Not for metal or anything else. If the plastics material can't stand on its own feet and do a better job everything considered, then we aren't interested. It would be like some items that appeared during the war—simply substitution, no lasting value!"

A process engineer at the same plant followed up this comment by predicting that the much-talked-about spaceship to the moon would carry some plastics material with it.

That's probably a safe bet. For the growth of plastics since World War II has increased phenomenally. You get some idea from last year's automobiles: the average car from head lamps to tail lamps utilizes 30 pounds of plastics. By comparison, the previous year's models contained only 12 pounds.

Despite this relatively recent growth, the plastics industry is by no means young. In fact, many people in the field think of it as an old industry.

Plastics got its start at Basel, Switzerland, in 1846 when the German chemist Christian Friedrich Schoenbein discovered nitrocellulose. But for 22 years it remained more or less a laboratory curiosity. Then, in 1868, America's John Wesley Hyatt—famous for his development of roller bearings—began the first commercial production of nitrocellulose, marketing it under the trade name of Celluloid.

A Belgian-American, Leo Hendrik Baekeland, is generally credited with the subsequent growth of the plastics industry. A chemical engineer teaching at New York's Columbia University, Baekeland in 1909 formulated a plastics that, because of its peculiar properties, stimulated the imagination of manufacturers. He called it Bakelite—a forerunner of present-day phenolic molding compounds.

Today you come up against a continually growing spectrum of tongue-twisting names: furfural formaldehyde, polytetrafluorethylene, and coumarone-indene. Yet, ironically enough, most "new" plastics have lived in the laboratories for years. Even the word *plastics* originated as far back as 1920. And the field itself represents an industry within an industry. Restricted to materials synthesized chemically, it usually excludes synthetic rubber and the natural products of plants and animals, typified by shellac.

Plastics to Order

One of the larger and perhaps oldest subdivisions within the many divisions of the plastics industry is custom molding (photo sequence). To understand custom molding in its proper industry-wide perspective, you should compare it with two other major molding operations.

One method requires the services of the proprietary molder who completely controls his end products. These might include the plastics dishes, utensils, or lampshades you see in the dime stores and the colorful Santa Clauses that decorate the doors of American homes

us ing to decide how best to mold
aw plastics exposure-meter case.

2 With tool drawing of master mold, engineer explains design feature to skilled moldmaker.

3 In check of accuracy and workmanship, moldmaker removes spots from female mold member.

at Christmastime. The proprietary molder has a mass market, limited only by people's willingness to buy his products. In essence, he mass produces.

Now take the so-called captive molder who also mass produces. Unlike his proprietary counterpart, he exerts an influence on design. A specialist, he mass molds a component that will be marketed as only a part of a piece of equipment.

The custom molder differs from the proprietary and captive molders in one respect: he molds to order a limited quantity of diversified products. If he mass produces, then it's in the same sense as a person who turns out tailor-made suits.

A custom molder doesn't design the part, nor does he market that part to its ultimate consumer.

You may, for example, want 1-million, 10,000, or only 500 plastics bases for a piece of equipment you've designed. The custom molder has no part in deciding the quantity. His job: mold to your specifications.

Highly representative of this work is the General Electric plant at Taunton, Mass. Information released in 1955 credits it as being the country's largest custom-molding plant. There you'll find complete engineering, drafting, molding, and mold-manufacturing facilities.

At Taunton, consultations with the engineering customer usually begin at an early stage in the product's design. At least, the custom molder prefers it this way for he has an opportunity to lend his influence. Both he and the customer stand to benefit. Otherwise the design might call for some special feature in the part that would be impractical or even impossible to mold.

Ideally, a male and female member form a mold—it has no side members, called undercuts in the trade. The custom molder looks for a straight up-and-down action to produce the molded product. Deviations from this ideal mold cost proportionately more.

Accordingly, an engineer with no background in plastics molding might design a product that would run the price of its molded counterpart up 4 to 10 times what it should be.

Usually, a middle ground can be reached. The custom molder knows the engineer must consider the attributes that make the product marketable. And so, rather than take an impossible stand on simplicity, he tries to lead him toward the least expensive and most serviceable design.

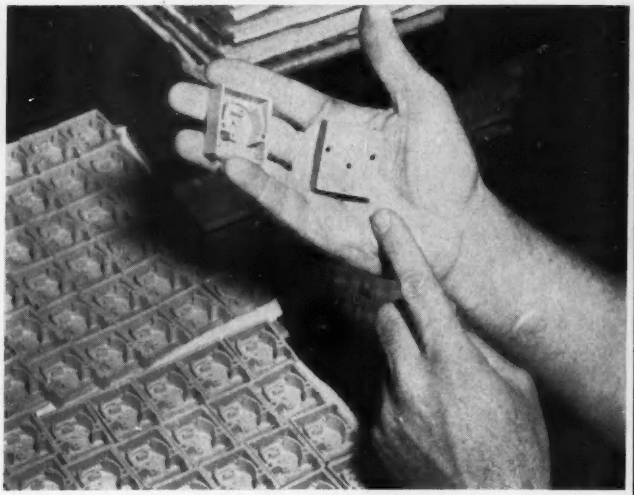
Master Craftsmen

In a sense the word *custom* derives from the moldmakers. Sculptors in steel, they work from a tool drawing of the product and interpret the never-too-graphic markings. From a cold block of steel, they create the master mold that forms the plastics parts.

No one more keenly appreciates their importance than R. H. Sharland, leader of tool design at the Taunton plant. A smiling, perceptive fellow, Sharland described his moldmakers as highly skilled craftsmen without whom the

4 Mold in open position preparatory to injection molding operation gets final tightening as press is readied for production (inset: male member close-up).

5 Automatic molding cycle completed, operator raises safety gate and reaches in to remove plastics part from open mold.



6 Prior to shipping, custom-mold exposure-meter cases receive a quick visual inspection and final packaging directly at the press.

custom-molding business wouldn't be competitive.

"They must not only work from a tool drawing and read blueprints," Sharland said, "but also see ways to improve the mold's design. Besides working closely to dimensions given in the drawing, they've got to know the capability of each machine in our shop." Sharland explained that the moldmaker produces the mold as quickly and accurately as humanly possible.

Generically speaking, these highly skilled craftsmen are toolmakers, fully qualified to operate machine tools of the metal-trades industry. For they've had the special training of 3½ years on the job plus night school—the minimum requirement to qualify them as moldmakers.

Picking and Choosing

Long before the tool drawing reaches the moldmaker's skilled hands, however, the engineering designer and custom molder must agree on the plastics material and its properties. At this point engineering judgment tempered with common-sense economics comes into play. For ultimately, the type of plastics determines the molding process. Both items—the plastics material and the molding process—influence the product's final cost.

An important property usually settled on at the outset is dimensional stability. Some plastics have it, some do not. In other words, plastics parts that are molded under heat and pressure to given dimensions may contract slightly in a normal environment. Whether this shrinkage, even though slight, can be tolerated depends on the product's application.

As a rule, products handled by the custom molder must be held to close tolerances. Suppose, for example, you design a telephone headset—a typical product of the custom molder—that must be threaded onto a metal base. A dimensional change in the molded part of even a few thousandths of an inch could be intolerable. The threaded parts might not mate properly.

When it comes to dimensional stability, most manufacturers of plastics toys have a decided edge over the custom molder. If a toy is 1/16-inch larger or smaller than its design, the product doesn't suffer. It is still a marketable item. But the custom molder exercises stringent quality control. When a part doesn't meet dimensional specifications, he scraps it.

In the toy industry, certain exceptions occur, however. Some products adhere strictly to design specifications. Their molds may even cost more than those of custom-molded products. Plastics parts of the toy locomotives that your neighbors' or your children play with are a good example. Some reveal fine detail; every little rivet stands out.

The electric insulating characteristic of plastics is something that may or may not be needed in the product. Yet, like the prize in a box of Crackerjacks, it's a dividend. And rather than detracting from the value, it's a definite attribute.

Radio manufacturers don't exactly depend on the plastics radio cabinet as an insulator. Yet, the fact that the cabinet is an electric insulator makes their design problem that much easier.

Thermal-insulating properties provide another plastics dividend. Plastics, as you know from experiencing the sensation, feel warm to the touch. Metals feel cold. Being an insulator, plastics can't conduct heat from your fingers as rapidly as metal—an important property for many applications.

Probably, when you open the door of your refrigerator at home, you see what the industry calls a breaker strip—a framework of plastics lining the door or the cabinet itself. A white plastics material for years, more recently it's apt to be a soft pastel in keeping with the trend toward colorful kitchens. Your wife may think the breaker strip is there for beauty. But basically it provides a thermal barrier against heat entering the refrigerator.

Of the many attributes of plastics, perhaps color makes the biggest impression on the average person. Vivid and varied, the color permeates the product; it can't wear off. Neither do scratches stand out conspicuously.

Along with this valued attribute, you can't overlook another fact: it's usually cheaper to formulate color into a plastics material than to apply several coats of paint to the product. Of course, for a plastics part going inside a device, color won't matter. But color becomes a real advantage when it helps sell your product.

In making a choice, you must remember that plastics—just one more form of construction material—like any material, has certain limitations.

7 Ultimate service: houses handy exposure meter to augment your camera.

It's always a matter of proper application.

Faloon, the manufacturing supervisor at Taunton, puts it this way: "If you apply the wrong kind of paint in your bathroom and it peels off the walls, don't think the paint industry is all wrong. You just didn't apply the right type of paint.

"Take that telephone. Now the material that encloses it has some shrinkage. Yet it's designed so that shrinkage doesn't work against it in any way. At the same time, designers have taken advantage of the electric insulating properties.

"And the toughness? You can knock that phone off the desk and I'll guarantee that something inside will break before the case will!"

Materials in Control

For all their variety and tongue-twisting names, most plastics fall into one of two categories: thermoplastics or thermosets.

Thermoplastics plasticize beyond certain maximum temperatures. That is, they change their physical state from a solid to a soft plastic mass. Take, for example, acrylonitrile—the thermoplastics used for the exposure meter cases shown in photo sequence. At sufficiently high temperatures, acrylonitrile begins to soften and flow under its own weight. In this respect it's not unlike ice cubes. Molded over again, it will cool to a new shape.

Not so with thermosets. At elevated temperatures, thermoset plastics don't melt: they char or burn. In the higher temperature spectrum, their range of application is greatly extended over thermoplastics.

Thermosets also contain a higher proportion of fillers—another distinguishing characteristic.

Just as different ingredients lend variety to the gelatin desserts your wife molds, filler materials impart different properties to plastics. For instance, fillers like rag fiber or cord give the plastics greater strength; asbestos adds high-heat resistance; mica imparts good electrical properties; and so on down the long list of filler materials and their effects.

However, some people in the plastics industry think thermosetting materials have reached their maximum usefulness. And in the future, emphasis may shift to thermoplastics as more new materials appear.

The trouble arises in the basic nature of thermosets. While thermoplastics materials can be molded or remolded like ice cubes, thermosets must undergo a chemical change more akin to making waffles with an electric grill. Accordingly, a certain amount of cooking, or curing, time is needed for molecular cross-linkage to take place. The result: a longer molding cycle. Productivity per man-hour and per machine decreases and costs increase.

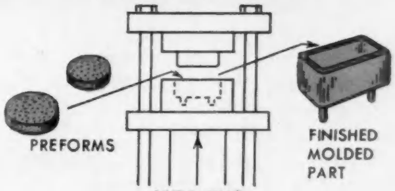
Other reasons are involved, too. But to fully appreciate them, you need to know something of the two major molding processes: compression and injection.

In the compression-molding process thermosetting materials are preformed into an easily handled, accurately weighed shape (illustration, top). The preform is then manually inserted into the female half of a steel mold, heated to about 330 F. The mold closes. Then subjected to both heat and pressure, the material flows to conform to the mold's shape. After a curing period to allow the material to cross-link and set chemically, the molded part is ejected.

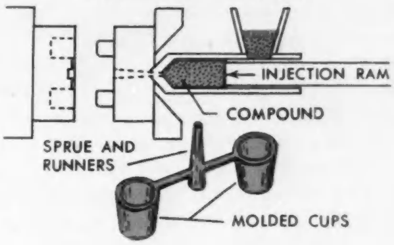
In an effort to somewhat offset the time consumed during the curing cycle, process engineers resort to preheating. It works this way: At each station, where an operator may be running three presses, there is an electric oven. When not feeding the presses, the operator inserts preforms into the oven where they quickly heat to nearly molding temperature.

This saves time. But unfortunately, the compression-molding process labors under still another handicap: The molded parts may have flash or rough edges that have to be smoothed off—a problem not usually encountered with injection-molded thermoplastics.

COMPRESSION MOLDING



INJECTION MOLDING



With injection molding (illustration, lower), pellets of thermoplastics material pass through a heating cylinder—an integral part of the press—and are plasticized to a liquid or semifluid state. Then a plunger forces the material into the relatively cool confines of the mold's cavities where it solidifies.

In short, only the shape of the material has changed. You could remelt and mold the same material over again or, for that matter, mold it by the compression-molding process provided you made certain changes in the cycle. But it would take three to five times longer than producing the same part by simple injection molding.

Almost 99 times out of 100, compression-molded parts require finishing, while injection-molded parts mold free of flash or rough edges. The latter can be packed at and shipped right from the press in a more or less continuous process.

Over-All View

Neither the engineer who specializes in thermoplastics nor the one whose forte is thermosets will concede any ground. Each material's attributes and limitations, depending on the application, offset differences in cost.

In a given application, a plastics part of either material may cost even more than a metal one. But because the plastics has certain essential proper-

". . . plastics and custom molding . . . something to . . . cheer about."

ties—say, electric and thermal-insulating features—the cost when viewed from the over-all design may be less. And this, in the final analysis, forms the basis for choosing between a thermoplastics or thermoset material.

Let's use the molded base of a watthour meter as a classic example of end use determining the material. Very likely this meter—as intricate as any business machine—will be located outside the house, thus exposed to all weather. People expect it to operate in this fashion, without maintenance, for periods as long as 30 years.

The base of that watthour meter, if it's a General Electric product, is made of a general-purpose phenolic thermoset —a woodflour-filled plastics. Over the years, chemists have refined and improved this material so that the base has a service life equal to the meter's other rugged components.

Another example—this time a thermoplastics material that softens and becomes more and more pliable as temperature increases—is a polyethylene coil-form that slips over the neck of a color television tube, insulating two copper focusing coils.

Though polyethylene softens at high enough temperatures, the heat generated in the back of a TV set does not affect it. In such an application, designers welcome polyethylene's pliability. For the assembler can easily work the coil-form over the neck of the tube and around the coils.

Point of Agreement

Those within the industry may mildly disagree on the merits of thermoplastics versus thermoset materials. But they all take an optimistic view: they're sure that the future of plastics and custom molding is something to stand up and cheer about.

Why the optimism? For one reason, they look to new materials. Every day new ones are being formulated and older ones upgraded in laboratories throughout the nation. These promise to remove some of the shortcomings that plastics now labor under—perhaps, one day, all of them.

The engineer specializing in thermoplastics eagerly looks to the time when high-temperature limitations will no longer handicap him. Right now, for instance, only nylon withstands sterilizing, or boiling, temperature. One problem: nylon costs roughly three times as much as standard thermoplastics.

In a class of its own so far as thermoplastics are concerned, nylon molds at higher temperatures than most other materials. This coupled with certain other characteristics makes nylon a little trickier to mold. But nylon has provided some remarkable applications, opening new fields that other thermoplastics couldn't touch.

Frequently, nylon turns up in the form of gears for relatively light loads—household fans and electric mixers, for example. These gears aren't molded to the tolerances of their metal counterparts. Yet in any significant production, the combination of the two factors—light loadings and not-too-close tolerances—make for a more economical gear.

Besides having all the characteristics you'd normally expect in operation, nylon gears have several other attributes. For one, they possess simplified lubrication requirements. And in many instances water alone makes a good lubricant; sometimes, a coat of petroleum jelly will do.

When you come to the question of operating life for nylon gears, people in the custom-molding industry don't make any sweeping claims. The situation is too complex. Properly applied and designed, they will give equal or perhaps better life than other materials. And they do have a great advantage over metal gears in this respect: when metal gears wear, they become noisy; but when nylon gears wear, they retain their sound-dampening characteristics.

Thermoplastics that, like nylon, will stand up to higher temperatures are certainly needed. But the custom molder's aspirations do not end there. Among other things, he desires physically stronger plastics. Also he looks for materials with greater resistance to abrasion that look better when molded, yet cost less in the raw form. Then too, he needs thermoplastics that will mold easier in shorter and shorter cycles.

New machinery will also play its part. The ultimate goal: automation. With a view to greater productivity in the near future, plastics-molding engineers are working closely with machinery manufacturers who design equipment custom-built to their needs.

A new injection-molding machine with a 90-ounce capacity, a recent acquisition of the Taunton plant, suggests a good example of such cooperation. In one cycle this machine can mold 90 ounces of a certain kind of plastics. The new press turns out radio cabinets in 45 to 50 seconds each; previous machinery required 70 seconds per cycle. What's more, it does away with an annealing process formerly used to relieve strains in the molded cabinets.

Thermoset materials present almost identical machinery needs: shorter cycles and greater productivity. One engineer at Taunton envisions the day when molding of thermosets will be completely automatic. And one automatic machine will be equivalent to three of today's manually operated presses. (Even today, parts are molded, cleaned, and packaged right at the press.) For success in this field, he awaits the newer fast-cure thermosets that loom promisingly across the horizon.

No Holds Barred

Custom molding, like other segments of American industry, has its problems, hopes, and ambitions. Its future depends on materials development.

In strength, ductility, and flexibility, plastics don't always compare with metallic elements. But this is today. Who can say about tomorrow?

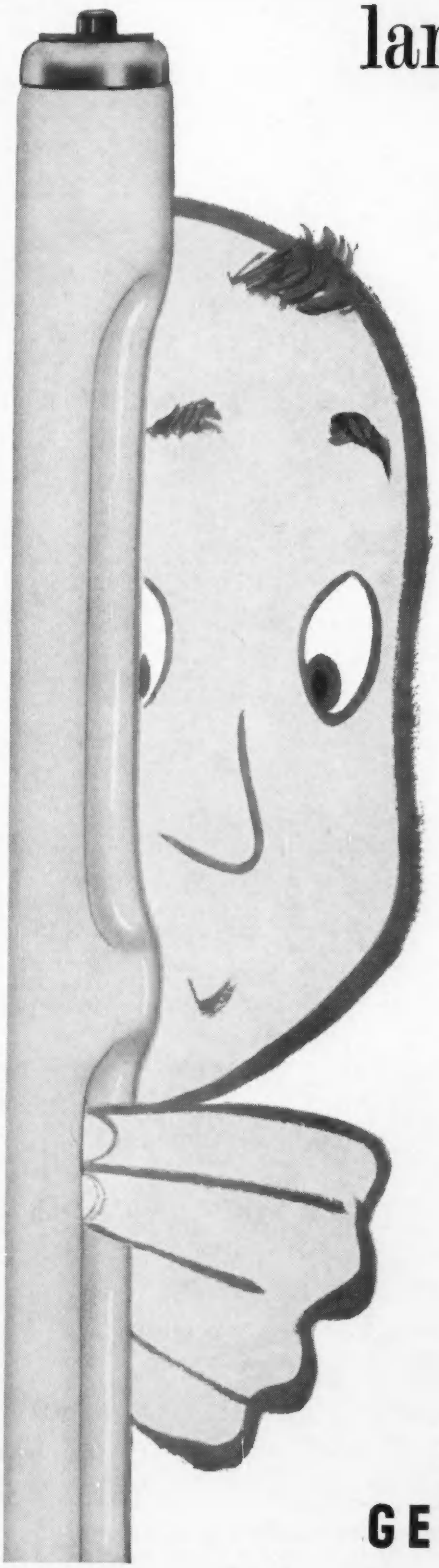
The outlook for plastics promises to be exciting. The structural field is wide open: one day lamp bulbs, even telephone poles, may be made of plastics.

In an effort to stimulate thinking on this subject, the Massachusetts Institute of Technology recently published a report, *Plastics in Housing*, sponsored by Monsanto Chemical Company. For the application of plastics, they considered everything from the foundation of a house to its roof. They came up with brightly colored, highly finished, weather-resistant columns of reinforced concrete, fabricated by simply pouring concrete into a framework of durable plastics pipe.

While this application appeals greatly to the technical mind, another suggestion in the report might seem a bit fanciful to you—stabilized-earth housing. Using synthetic resins, structures could be constructed of chemically stabilized earth.

And the many imaginative plastics applications yet to come will be as familiar to you as the hundreds of plastics articles we now use every day.—JJR.

The shape of fluorescent lamps to come



New General Electric "Power-Groove" discovery means more light for you . . . at less cost

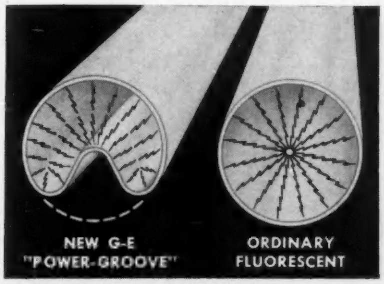
Look at this new kind of fluorescent lamp. It's the General Electric "Power-Groove"—a revolutionary new development created by G-E engineers. It not only gives more than 2½ times as much light as the 8-foot slimline (most widely used 8-foot fluorescent), and lets you save more than 20% on your initial cost, and has fewer parts to maintain . . . but it even *looks* different—for a reason.

It's the grooves in General Electric "Power-Groove" Lamps that make possible a greater increase in light-per-foot than all the combined increases made since General Electric introduced fluorescents in 1938!

The new G-E "Power-Groove" Lamps are the popular 8-foot length (200-watts) with 4-foot sizes also available and 6-foot sizes later. They are Rapid Start lamps that need no starters — and are to be used in fixtures and circuits designed especially for them.

IF YOU'RE PLANNING a new lighting installation—you'll want to investigate G-E "Power-Groove". New G-E "Power-Groove" lamps are going into some installations right now! You'll be able to buy them . . . and the fixtures . . . in quantity by midsummer, so get the whole story now. Call your local G-E Lamp Supplier or write: General Electric Co., Large Lamp Dept., Nela Park, Cleveland 12, Ohio.

COMPARE! The new G-E "Power-Groove" construction (left) works 3 ways to give more light. One: it places some of the light-producing phosphors closer to the energizing area in the center of the lamp. Two: it presents a greater surface area which permits the generation of more ultraviolet rays to activate the phosphor. And three: it makes the lamp run cooler—which permits a higher current design and gives you more light per watt.



Progress Is Our Most Important Product

GENERAL ELECTRIC

The trend is to METALLIC RECTIFIERS

INDUSTRY DISCOVERS A THRIFTIER WAY TO GET LARGE BLOCKS OF DC POWER

Today, more than 30,000 kilowatts of General Electric Germanium rectifier power supplies are pouring out a vast amount of direct current to U.S. industries, and a greater amount are on order and in production. This mounting number of applications includes electro-chemical processing, steel mill cleaning and tinning lines, aluminum anodizing, aluminum pot lines and electro-plating. Three years ago, there were none!

Just as you'd suspect, the major reason behind this trend is increased economy . . . in first cost, installation cost, power cost, and maintenance.

Metallic rectifiers are mechanically static, comparatively light in weight, and require no special foundation. They are constructed in basic cubicles . . . building blocks of power. Thus, they can be easily installed anywhere, on balconies, in basements, or right at the utilization equipment.

First cost is frequently lower than other methods of conversion, and when installation savings, power savings, and maintenance savings are factored in, the total cost reduction is impressive.

Practically no maintenance is needed with metallic rectifiers because of their static nature. The only moving parts are either a small cooling fan or small water pump. Extensive life tests indicate no loss in efficiency, no aging, and consequently no apparent limit to the life of a rectifier cell.

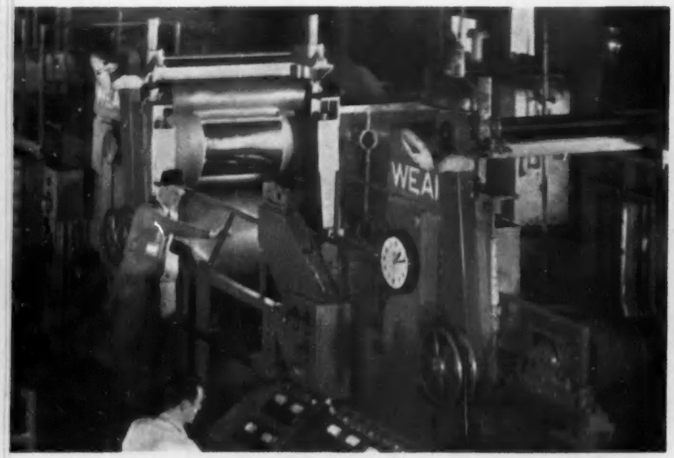
These combined advantages are the basis for the trend to metallic rectifiers. If you would like additional information, please contact your nearby G-E Apparatus Sales Office, or write to Section 464-1 General Electric Company, Schenectady 5, N. Y.

464-1

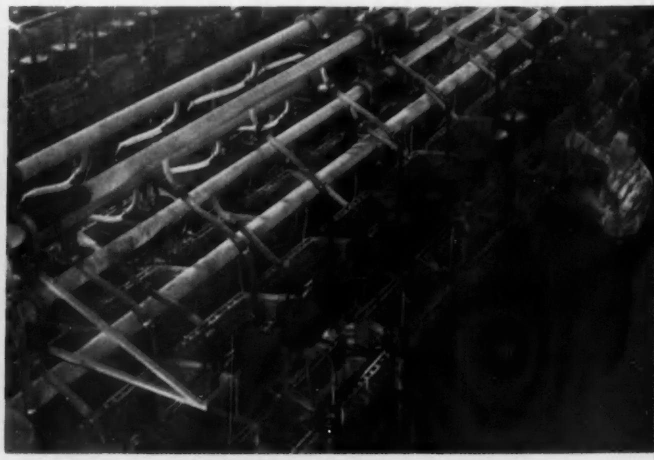
Progress Is Our Most Important Product

GENERAL ELECTRIC

RECTIFIER DEPARTMENT



DC POWER FOR STEEL MILLS—General Electric Germanium rectifiers are now being used for electrolytic cleaning and tinning lines, and for the economical production of hydrogen. Tinning lines like the one shown here are exhibiting power savings of up to 17%. Metallic rectifiers are sturdy and compact; and hence, easier to install. They need no oiling or periodic shutdown for cleaning and rebuilding.



DC POWER FOR ELECTRO-CHEMICAL PROCESSES—Here electrolytic cells produce hydrogen and oxygen by electrolysis. DC power—30,000 amperes at 65 volts—is supplied by G-E Germanium rectifiers. Metallic rectifiers are finding increased use in the electro-chemical industry due to their high efficiency, lower first cost, and continuity of service.

DC POWER FOR ALUMINUM ANODIZING—The G-E Germanium rectifier installation shown in the background supplies d-c power for anodizing the aluminum evaporators used in home refrigerators. The gold colored unit on the left has passed through the anodizing operation; the unit at the right has not yet been anodized. Seven cubicles provide 40,000 amperes at 24 volts d-c.

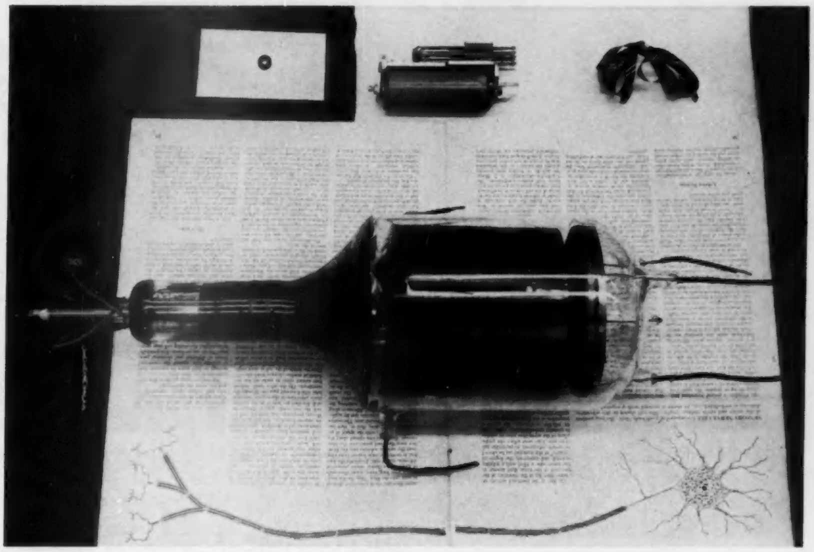
DC POWER FOR AUTOMOTIVE PLATING—This automobile grille has just been removed from the chromium plating tank shown at the right. Behind the inspector is a G-E Germanium rectifier installation of eight cubicles which delivers 48,000 amperes at 12 volts d-c. The plating industry has been quick to realize the increased economy and reliable service offered by Germanium rectifiers.

NEW DESIGN—Smaller size, greater dependability, and lower cost are the features of this new cubicle design. Dotted outline shows the former size. New design is 44% smaller, yet delivers 20% more power output.

SILICON RECTIFIER here supplies power for producing hydrogen. Because of its higher operating temperature and voltage, silicon will soon join the G-E rectifier line.


ENGINEERING LEADERSHIP
KEY TO ATOMIC PROGRESS

Sensory nerve cell shown at the bottom of the photo functions in much the same way as the memory devices above it. These devices are capable of storing varying amounts of information: tube, up to 2500 bits; magnetic core, 1 bit; relay, 1 bit; and tape, 600 bits per inch.



Memory in Man and Machines

From the beginning, man supplemented his memory with various devices. Now he has electronic memories—closely resembling their human counterpart.

By B. H. Geyer and C. W. Johnson

The storage of information—a process as fundamental as life itself—occurs in the brain of all living creatures. And in man this activity realizes its highest state of development. Yet, he has always had to devise artificial aids to supplement his memory.

In prehistoric times, pictures on cave walls carved by stone chisels afforded man his only recording medium. Today we use the printed word, phonograph records, punched tapes and cards, and a host of new components with important scientific and industrial applications. But even in these new media—many still uncommon in everyday life—the basic process of information storage itself remains a fundamental and commonplace occurrence: The boy scout who blazes a trail through a forest stores information in a manner closely paralleling that used in many advanced information-recording systems.

Mr. Geyer came with General Electric in 1949. He has worked on the design and development of digital computers and is presently doing numerical analysis work for the Heavy Military Electronic Equipment Department, Syracuse, NY. Mr. Johnson, who joined the Company in 1947, is located at the Electronics Park Laboratory, Computer Subsection, Syracuse. Prior to this, he was concerned with radio sonde receivers and airborne radar indicators.

The Bit

Information is a quantity much like force or mass or electric current. And it can be measured just as precisely, though sometimes not so easily. The *bit*—the most commonly used unit of information—represents the amount of information involved in choosing one of two equally probable alternatives.

For example, a traveler coming upon a fork in the road has no idea which of two branches to take; a sign telling the correct choice would give him one bit of information. Had there been four possible routes and the traveler had no idea which was correct, the sign would have given him two bits of information. However, if there had been four routes, and he knew that two were incorrect, the sign would then have supplied only one bit of new information. The information that the traveler receives is a function not only of the sign's contents but also of his own prior knowledge. In general, the amount of information required to select one of a number (N) of equally probable alternatives is just $\log_2 N$ bits.

The capacity of any information-storage device can be measured in bits. But generally the usage of this term is restricted to storage devices that need a precisely defined capacity. If you wished to compare the storage capacity of a phonograph record to that of a book, you would measure both in bits. However, because books are usually compared with other books, the number of words or pages normally provides a satisfactory measure of the storage capacity. With a phonograph record, minutes of playing time give a satisfactory index of the amount of information for most purposes.

Were books and records the only storage devices, the need for the bit as a precise unit of information-storage capacity might be questionable. However, in recent years a whole new class of high-speed information-storage devices has grown up as a necessary part of the new electronic computing and data-processing systems. In describing and evaluating these and other systems and devices, the use of the bit as a unit of information-storage capacity lends mathematical precision.

METAL CYLINDER, possessing an over-all capacity as high as 3-million bits, supplies computer with information needed to solve problems.

MAGNETIC CORE (impaled on a needle) is capable of storing one bit of information.

SHORT-TIME STORAGE MEDIA

Magnetic Principle

In theory, magnetic tape is an example of a short-term storage medium of the magnetic type because of its high-speed record and erasing characteristics plus its magnetic properties. However, to maintain the fast access times required for most short-term storage applications, the tape would have to be moved past the record and playback heads at an impractical rate probably causing it to tear and break. Using a solid metal cylinder or drum as the backing for the ferromagnetic material will avoid these difficulties.

In these storage systems such a cylinder commonly rotates at constant speeds in the range of 1200 to 15,000 rpm. Thus the maximum time required to locate a specific item of information will be the time required to complete one rotation—access times may be as low as 0.005 second. Information is frequently recorded in drums in parallel multiple tracks permitting storage densities of 1000 pulses, or bits, per square inch. This can result in an over-all capacity as high as 3-million bits of information per drum.

As an alternative to magnetizing a small area of iron oxide, some recently developed storage systems depend on the magnetization of small ring-shaped ferromagnetic cores formed in a rectangular array. Because these toroids are less than 1/16 inch in diameter, it is possible to build an array containing 10,000 of these elements in a 10x10-inch area. This reduces to an information density of 100 bits per square inch, excluding input-output circuitry. On an area basis this is not comparable with drum recording systems but offers better potentialities on a volume basis. In addition, these rectangular arrays lend themselves to fast access times. Specific information items can be located in a few millionths of a second.

Electrostatic Principle

A large class of media can be grouped in the general electrostatic classification. In the simplest form, such a memory system may consist of an array of ordinary mica capacitors commonly used in radio circuit applications. Because an open-circuit capacitor with low internal leakage will hold a charge for a relatively long period of time, this component can be used as the basic memory element for the storage of one bit of information.

In most systems, charging the capacitors through switch-type elements—such as diodes or neon bulbs—obtains the open-circuit condition needed for storage. As an alternative to storage of a small amount of electrostatic charge in an individual condenser, other systems—in use for several years—depend on the storage of small spots of charge on a dielectric. The dielectric material is mounted in a special cathode-ray tube similar to those used in oscilloscopes. It is common for such a memory tube to store an array of 1000 or more spots of charge on a dielectric a few inches in diameter. Seventy or more of these tubes have been used in some data-processing systems.

Memory Function in the Human Brain

The process of information storage occurring in some modern large-scale data-processing systems sometimes parallels on a functional level the operation of the human memory. A study of how one operates may thus throw a little light on the other's performance.

With this in mind, let's examine some of the similarities in the memory functions of the human brain and contrast them—as presently understood—with the corresponding functions of modern large-scale electronic equipment.

In some respects, human memory operates far more efficiently and effectively than any presently conceivable electronic storage system. But in a few instances the performance of electronic or storage systems surpasses its human counterpart by a significant margin.

Consider the elemental building blocks that comprise the brain's structure. Most theories of human memory and brain function find their bases in these blocks—the nerve cells, or neurons, some 10 billion in number. Intensive studies made during the past several years show that in many respects these cells act as switches. In this capacity, they transfer or interrupt the flow of electric impulses that originate in the sense organs or travel to the muscles or other parts of the body. A close functional relationship exists between these cells and components presently used in electronic systems.

Any type of on-off device, whether an electric switch or a neuron, can serve as a storage element in a memory system. Thus you may frequently find that the theories describing the human memory process correspond to present machine-storage systems.

For example, storage components in electronic systems tend to fall into two classifications: dynamic, or circulating, and static. The dynamic category refers to systems where stored information takes the form of electric or mechanical impulses circulating around closed loops. At any point in the loop, the pattern of the pulses will carry the stored information. In a corresponding theory designed to describe a portion of the human memory process, the electric loops might easily take the form of closed chains of neurons.

In contrast, the stored information in a static system has the form of various spatial patterns of binary data that are unchanging in time. The patterns can again consist of connecting networks of neurons; but think of the stored information in the form of neuron pattern connections rather than pulses that circulate through the patterns.

Those who have carried out extensive studies of the brain function have reason to suppose that its memory mechanism combines both of these schemes: the circulating concept accounts for the recording of recent memories, and a form of static system provides for storage of older information. Some electronic systems use a somewhat analogous scheme: a circulating system for storing temporary information; a static system for permanent data.

How does the over-all storage capacity compare in the human memory and present electronic storage systems? Exact figures can easily be given for electronic systems, but accurate data for the human brain is difficult to obtain.

Evidence indicates that the figure for the brain falls somewhere in the range of 10^8 to 10^{15} bits (100-million to 1-million-billion bits). Either value represents a far higher density of information than attainable in any electronic storage media now in use.

Were a machine to be constructed having a total capacity in the range suggested, a serious fundamental problem would arise in addition to the obvious ones that pertain to size and power requirements: As yet, no adequate methods have been developed for searching through such a magnitude of storage for specific data in a reasonable time. The access time would be too high. The brain possesses phenomenal capabilities in this respect—at least under some conditions. In fact, its extreme variability in this area of performance is surprising.

Access times for the human memory range from fractions of seconds to hours or even months. For example, you sometimes experience a temporary inability to recall a name or some other isolated piece of information. Yet if this name were suggested, you would recognize it almost instantly. This implies very high speed recall or recognition capabilities. It would be exceedingly difficult to match these capabilities in any electronic storage system having a capacity approaching that of the brain. However, the relatively small-scale information stores presently employed in electronic systems permit access times as short as a few millionths of a second.

A distinction must be made between the performance of the memory portion of a system—whether human or machine—and the performance of the associated input and output functions. The momentary failure to recall a name does not mean that it has been forgotten but that the scanning, or output, circuits are operating improperly or at too slow a rate.

Studies repeatedly point up one interesting area of dissimilarity: specific items of information in the human brain have no definite localization. Memory traces seem to diffuse throughout sizable portions of the brain. Thus the inactivation of a few neurons here and there results in no noticeable impairment of memory functions. Unfortunately, no presently conceived machine can afford this luxury. Information must always be specifically localized, and reliability of performance must stem from reliability of components rather than spare parts wired in parallel.

Electronic Storage Components

The definition of the basic unit of information, or bit, suggests at once the form of an elemental means for its storage. Since a bit is the amount of information required to decide between two equally probable alternatives, such a piece of information can be readily stored in any kind of mechanical or electric device having two stable states. You need only understand that alternative *A* is represented by the existence of state *A* and alternative *B* by state *B*.

Almost all storage elements in present electronic systems take some sort of on-off, or binary, form. Any medium that in some sense possesses two stable states would be a potential candidate for a storage component.

Paper—one of the oldest information storage media—meets the requirement if you consider the presence of a standardized symbol or marking as one of the stable states and the absence of marking as the other state. When preparing paper for use in automatic machines, punched holes rather than information put in the form of a marking usually prove more convenient; but the principle remains the same. Punched cards controlled automatic weaving machinery as early as the 18th century. And today cards or paper tape still control some forms of digital data-processing machinery.

The information storage density of cards or tape runs from 25 to 100 holes, or bits, per square inch—not an impressively high figure. Replacing tape with photographic film gives much better results. The normal method of recording the binary information exposes small areas of film to light or other radiation. The presence or absence of a dark spot at a designated area in the developed film carries the information.

This approach permits a density as high as 5-billion bits per square inch, representing a density better than that given as a lower estimate for the human brain. However, present electronic equipment cannot accommodate such a large figure: the medium is better than the present input and output equipment can conveniently handle. It would require x-ray diffraction methods to record the information and an electron microscope to search it out. If you can settle for a lower information density, film serves as a perfectly satisfactory medium for many applications.

Magnetic tape, also frequently used for storage of binary data, will normally be similar or identical to the tape used in recording systems—popular in recent years for recording music for radio broadcast and home use. The record and playback portions of the system operate on the same principles as a home tape recorder but with a speed about 10 times faster. Besides the relative simplicity of the record and playback mechanism of a tape system, the advantage of tape reusability makes this a popular storage medium.

Cards, paper, magnetic tape, and film exemplify media for relatively permanent data storage. Information requiring frequent reuse is normally recorded in this form. Most computer applications

STORAGE DEVICES FOR . . .

. . . Digital Computers

All digital computers make use of information storage devices in a variety of ways. The arithmetic and control sections of a computer use single-bit storage elements for several functions: a typical computer might utilize hundreds of single-bit storage elements. Additionally, the arithmetic registers of a computer are storage devices having capacities of 15 to perhaps 50 bits. While the computation progresses, however, the computer section called the memory, or store, accumulates the largest amount of information. This section stores the input data, intermediate results, output data, and usually the instructions that determine the sequence of computations for periods of time varying from a few microseconds to almost indefinitely in some computers.

The various computer memories do not all necessarily function in any one computer. These memories can be divided into four types . . .

- *High-speed working store:* This usually consists of electrostatic or magnetic-core storage characterized by very short access time, say less than 20 microseconds, and total capacities of a few hundred to as high as 1-million bits.
- *Medium-speed working store:* Magnetic drums find extensive application in this area with a few mercury tanks also being used. Either type can be combined with a high-speed store of limited capacity, or used as the sole working storage of a medium-size computer. Both ways, the capacity ranges from a few thousand to a few million bits, and the access time ranges from ¼ to perhaps 50 milliseconds.
- *Slow-speed working storage:* Storage of information in the million-bits class utilizes magnetic tapes. One 10-inch reel of ½-inch-wide tape stores 10- to 30-million bits. The access time may well be a major fraction of a minute in a very large tape memory.
- *Input-output storage:* A computer's input and output must be recorded on some form of storage medium. The output may be in the form of a printed page, punched cards, punched-paper tape, or magnetic tape. The input can take any of these forms except the printed page. Only the amount of real estate available to store the records limits the amount of storage. Normally you would not consider access time for input-output storage.

These four types of storage appear in various combinations and amounts in different types of computers. A large general-purpose scientific computer probably contains generous amounts of each. A more modest instrument would probably omit one or more of the first three. In particular, many medium-speed computers use working storage of the second type only and one or more of the input-output storage media.

In business computers, storage capacity is frequently the most important characteristic. For example, in many business applications the computer will contain an enormous amount of storage of the second or third types. Inventory control systems, reservation systems, and filing systems in general exemplify this type of computer.

Another business application requires the computer to process large amounts of input and output data. Billing operations and, to a lesser extent, payroll computations are examples. Input-output storage facilities constitute the dominant element in a computer for these applications.

. . . Communication Systems

As an example of using communication-systems storage devices to store redundant information, consider the problem of reducing the bandwidth required to transmit a television picture. The picture consists of 525 scanning lines. Think of each line as an array of approximately 600 dots. These dots may in turn be assumed to have one of 16 possible values of brightness. If you assume that each dot may take on any of the 16 brightness values with equal probability, 4 bits ($\log_2 16$) of information must be transmitted for each dot—a total of 1,260,000 bits per picture. At 30 pictures per second, this totals 37,800,000 bits per second. Transmitting a television picture using present techniques thus requires a transmission channel capable of handling this rate of information.

However, each dot in the picture does not take on any of the 16 assumed brightness values with equal probability. In fact, with a knowledge of the brightness value of any particular dot in the previous picture, or frame, and the brightness value of adjacent dots in the current frame, the brightness value of that particular dot in the frame can be predicted. Information theory tells that each dot in a TV picture represents much less information than the 4 bits calculated on the foregoing assumption. Actually, a TV picture can be transmitted over a channel having a capacity much less than 37,800,000 bits per second. One method makes use of the fact that a given dot in the picture will probably have the same brightness value it had in the previous frame. A storage device capable of storing the entire picture is required at both the sending and receiving end of the channel. Each frame generated at the sending end is compared with the contents of the storage device; the new information is transmitted only if it differs from that in the storage device. At the receiving end, a similar storage device "remembers" those parts of the picture which have not changed and corrects those parts which have changed according to the received information. Thus a complete up-to-date picture is present at all times. In this system, the storage device stores the redundant part of the picture. Only the changes in the picture are transmitted over a channel in which the capacity may be much lower than that required by conventional TV transmission.

Besides television, other communication links are known to be inefficient for required channel capacity. Almost any system designed to increase channel efficiency needs some form of storage.

need another type of storage: short-term storage that preserves data for only seconds or fractions of seconds. Punched cards or film have serious disadvantages for this operation: neither is suitable for rapid erasure and reuse. However, a wide variety of other components have been specially designed for use in short-time storage systems. Most of these find their bases either in the principle of temporarily changing the magnetic state of ferromagnetic material—such as iron oxide—or in the storage of electrostatic charges on the surface of a dielectric (Box, page 30).

These memory schemes are of the static type. The specific bits of information in static systems are stationary with respect to some physical frame of reference such as a card, drum, or matrix of wires. Nonstatic circulating systems can be found in electronic systems, particularly computers. Binary information in a state of continual flow around a closed electric circuit characterizes circulating systems. This information is usually in the form of a voltage pulse or a mechanical vibration.

Such circuits will always need delay devices: For example, a column of mercury or quartz slows the flow rate of the stored pulse information. The longer the interval of time required for such a pulse to travel the length of the column, the greater the system's storage capacity. Some mercury tank systems, about two feet long, have obtained a capacity of about 1000 bits per channel. Normally, information in transit through the delay medium will not be accessible for use in the system; thus the time required for propagation down the channel represents the maximum access time —commonly 200 or 300 millionths of a second.

Most of these components are of the two-state, or binary, variety; and data-processing equipment is usually designed to handle this type of information only. However, some storage components —such as magnetic tape—can record multiple-state information. This property permits a higher storage density. Programs under way at some research centers are designed to develop systems that operate efficiently with information of a higher order than binary.

Present Applications

During the past 10 years, a vast new industry devoted to the development and production of electronic devices for automatic data processing has appeared. Such systems almost invariably require some form of memory—thus storage becomes an important factor in data processing.

EXPERIMENTAL STORAGE TUBE is examined by authors Johnson (left) and Geyer.

Modern electronic information-processing systems fall into many classes: scientific and business computers, communication systems, and automatic control systems. These, among others, require some type of information-storage devices. The storage may serve as a connecting link between devices that produce or accept information at nonuniform rates. Such a storage device is called a *buffer store*.

In a computer, storage devices may be called upon to store intermediate results of the computation, input and output data, and the instructions for performing the calculations, as well as the many small but fast storage devices included in the control and arithmetic circuits of the machine. Communication-systems storage devices are frequently used to store the redundant component of the information to be transmitted. Further discussion on storage devices appears in box on opposite page.

Future Requirements

Storage devices of the future will have to meet many conflicting requirements—as yet, no single type can. If such a device were to exist, it should be able to store up to a billion bits with random access time of about a microsecond, at a cost of less than \$0.0001 per bit. But such an element is not yet in sight.

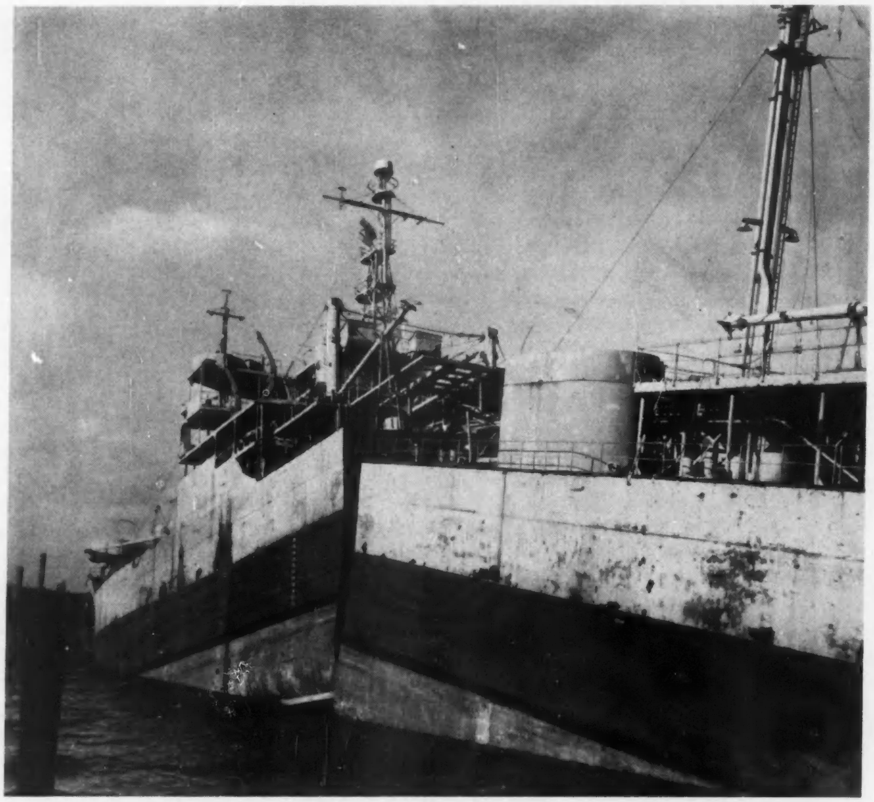
However, the future will show improvement in existing devices. And new devices, now in the laboratories, may lead to perhaps 10-million-bit high-speed random access memories at costs of perhaps \$0.001 per bit.

The large random access memory of moderate access time presents another area where significant improvement will probably appear. You can expect to see the development of billion-bit stores with random access times of a second or less at a cost of less than \$0.001 per bit—filling a need in the field.

In information transmission, storage must play a major part in the design of an efficient television system. Commercial realization of this and other efficient systems depends in part on development of storage systems that combine fast access and capacity, presently difficult to obtain.

Storage plays an essential role in almost any data-processing or efficient communication system. Data-processing systems perform certain tasks at a higher speed or more economically than is practical for the human brain. And just as the human brain in the course of its performance of these tasks makes use of its memory capabilities, you find that an electronic system relies on an electronic memory to carry out the same operation.

On a functional level, the electronic memory sometimes bears a striking resemblance to its human counterpart. Speculatively, this resemblance might increase as machines are designed to duplicate more and more the functions of the brain. While most of this similarity will probably be superficial, some of it may prove to be of sufficient significance to provide a guide for both the system designer and the student of the human mind. Ω



Metal failure in the *Ponaganset* resulted from a strange quirk in the behavior of structural steel that has contributed to many similar casualties.

Research Explores Brittle Fracture Problem

In seeking significant answers to why structural metals fail under stress, scientists are focusing their studies on the complex origin of fracture.

***Review* STAFF REPORT**

In December 1947, a T-2 tanker, the *Ponaganset*, was lying quietly at her pier in Boston harbor. Suddenly, with a sharp noise that was heard for at least a mile, she broke cleanly in two (photo).

The destructive agent, although not an enemy in the military sense, inflicted a heavy toll on Allied shipping during World War II: 6 total losses plus 964 casualties out of the 4700 ships built by the Maritime Commission. The *Ponaganset* and her unfortunate sisters had been destroyed by a strange kind of fracture. Metals cracked apart like dropped milk bottles. And by engineering rules, these metals were supposed to be ductile and fail under excessive overload only after a warning period in which they gradually became elongated. The casualties occurred under various loading conditions, usually at low temperatures.

In April 1943 the Secretary of the Navy established a board of investigation to study the catastrophic fracture problem. After three years of analyzing the technical and statistical aspects of the casualties, the board traced the failures to the brittle nature of steel below certain temperatures and under different conditions of stress. Also they established a permanent group to sponsor a continued research program for improving the design, materials, and methods of fabrication of ship structures.

Although ship fractures received widespread publicity and initiated the first intensive scientific investigation, the phenomenon was by no means confined to ships. Bridges, storage tanks, pipe lines, pressure vessels, turbines, power shovels, and smoke stacks—all had been affected.

Two Modes of Failure

At the time when the *Ponaganset* failed, the general characteristics of brittle fracture were fairly well-known. The source of failure was traced to a faulty fillet weld attaching a small clip to the main deck. Notches or other discontinuities in the metal seemed to share joint responsibility with low temperature for causing the change from ductile to brittle.

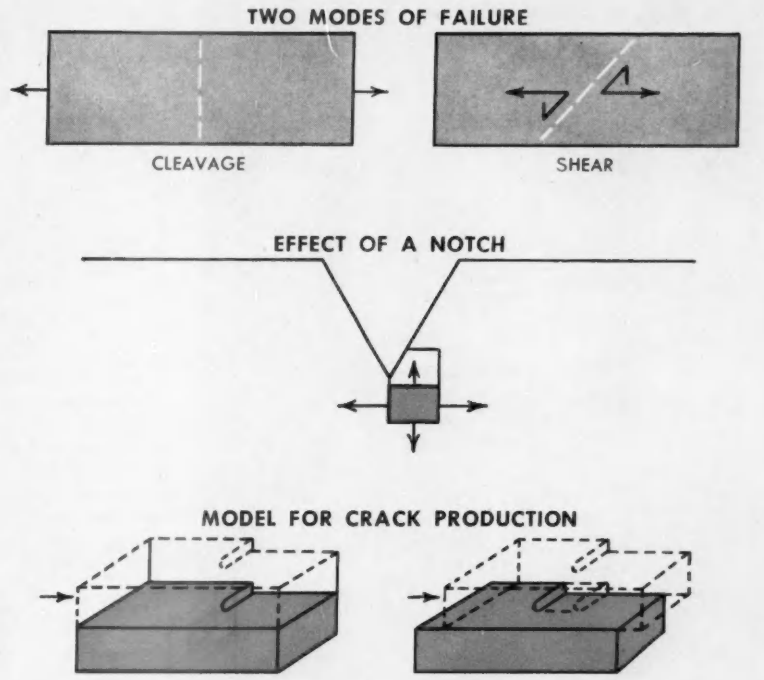
The phenomenon can best be explained by considering the two ways in which metals fail. One is cleavage—the actual pulling apart of the material within the crystals or along the grain boundaries. When this causes a structure to fail, the metal first deforms elastically until the forces holding the material together are overcome; then it snaps sharply in two, leaving a rough fracture surface.

Another method of failure is shear—a slipping of one crystalline plane over another within the grain. The material deforms plastically; that is, it becomes elongated and fails to regain its normal shape with the relief of stress.

Let's consider a bar of metal in simple tension (illustration, top, left). The maximum stress tending to cause the bar to fail by cleavage is resisted by the cross-sectional area that is perpendicular to the load. When a break occurs, the fracture follows this 90-degree plane.

Though in simple tension, components of the load act to produce shear on other planes (illustration, top, right). It can be shown mathematically that maximum shear stress occurs on planes at 45 degrees to the load and that the ratio of maximum tensile stress to maximum shear stress is always 2 to 1 in a simple tension test.

This ratio has a basic significance to brittle behavior. A material at least twice as strong in resisting the cleavage forces as it is in resisting shear will fail by the shear mechanism; it deforms plastically and is said to be ductile. On the other hand, if its strength to resist cleavage is less than twice its shear strength, the material is brittle and will fail by cleavage before the shear mechanism can come into play.



WHEN A CRYSTAL CONTAINS A SCREW DISLOCATION AND HAS A PARTICULAR ORIENTATION TO THE SHEARING FORCES, A SLOT CAN FORM AS A RESULT OF THE SLIP MECHANISM.

Effects of a Notch . . .

When a notch is introduced in the bar, it has the immediate effect of increasing the ratio of tensile stress to shear stress above 2 to 1 in a small area at its root (illustration, center). The tiny colored element at the root of the notch is under load; the area immediately above is not. When the colored element tries to decrease in cross section under load, the other exerts a restraining force and thus sets up another tensile stress perpendicular to the main stress. The shear stress thus decreases. If the metal was on the borderline between ductile and brittle, the shift in the stress ratio might be enough to cause the little element to fail in cleavage. If it did fracture, the notch would become slightly deeper, a new element at the root would become brittle and crack, and the process might continue—at rates as high as a mile per second—until the bar breaks in two. Thus a whole structure can fail in cleavage even though all the metal with the exception of one particle is ductile.

. . . and Temperature

When the temperature of a structure falls, another effect contributes to brittle fracture. Both the cleavage strength and the shear strength of the structure increase but not at the same rate—the shear strength increases more rapidly with lower temperatures. When the ratio reaches the critical value, the structure becomes subject to brittle fracture. However, the effect is not a simple one. The size and shape of the notch and local defects in the metal largely determine at what temperature the structure begins to become brittle. Metals normally considered to be ductile at temperatures above liquid nitrogen (−320 F or −195 C) may become brittle under the influence of a notch at service temperatures (perhaps 40 F).

The scientist who undertakes the study of brittle fracture confronts a complex problem. He finds the behavior of tiny defects in the metal to be as important as the nature of the metal itself. Notches and other discontinuities are known to produce complex stress patterns that contribute to brittle fracture. He knows the importance of temperature. But the many variables do not permit assigning the definite transition temperature where a given steel changes from ductile to brittle. Laboratories lack facilities to simulate the service conditions of a large structure under a complex load.

In facing this predicament, some scientists have chosen to abandon, at least temporarily, the effort to correlate brittleness with such physical variables as load and temperature. Instead they center their attention on the crack itself and try to determine how it begins and propagates.

Early Studies of Cracks

The first productive experiments of this kind were performed in the early 1920's by a British scientist, Griffith, who developed a theory for the breaking of glass. He prepared smooth glass samples, introduced cracks of known size, and measured the force necessary to cause fracture. From his results he reasoned: in order for a crack to grow, enough energy must be supplied to create the new surfaces that must be formed. At first the energy had to be supplied externally. But as the crack

MICROCRACKS supply Dr. J. R. Low, Jr. with the first evidence of fracture in the surfaces of metal samples after stress.

THE MOLASSES FLOOD

A real catastrophe occurred at Boston in 1919 when a storage tank holding 2,300,000 gallons of molasses burst. Besides great property damage, the fracture caused the death of 12 persons who either drowned in molasses or died of injuries; 40 others were injured and many horses drowned. An extensive lawsuit culminated after years of scientific testimony in a decision handed down by a court-appointed auditor stating that the tank failed by overstress, not by explosion. The auditor's statement fairly well summarizes the amount of knowledge concerning brittle fracture current among practicing engineers at that time.

". . . I have listened to a demonstration that piece *A* could have been carried into the playground only by the force of a high explosive. I have thereafter heard an equally forcible demonstration that the same results could be and in this case were produced by . . . the weight of the molasses alone. I have heard that the presence of Neumann bands in the steel . . . proved an explosion. I have heard the Neumann bands proved nothing. I have listened to men, upon the faith of whose judgment any capitalist might well rely in the expenditure of millions in structural steel, swear that the secondary stresses in a structure of this kind were negligible; and I have heard from equally authoritative sources that these same secondary stresses were undoubtedly the cause of the accident. Amid this swirl of polemical scientific waters, it is not strange that the auditor has at times felt that the only rock to which he could safely cling was the obvious fact that at least one half of the scientists must be wrong . . . ."

became larger, this energy would be supplied from an internal source and at that point the crack would propagate spontaneously. The release of elastic strain energy in the volume of material just above and below the crack, as the crack spreads, furnishes the internal source.

Griffith determined the tensile stress required to propagate a crack through glass. However, the same criteria applied to metals predicted that cracks too small to be seen with a microscope would propagate spontaneously. Actually, much larger cracks had been observed and found to be noncritical. Therefore, Griffith's work was unapplied for a number of years.

About 1945, Orowan made an observation that reconciled the huge gap between theory and practical observations in metals. In analyzing fracture surfaces by x-ray diffraction, he found that the crystals lining the fracture area had undergone a small amount of plastic deformation before snapping. After calculating the energy necessary to produce this slip, he found that it was on the order of a thousand times greater than the surface energy used in Griffith's calculations. Moreover, when values were substituted for plastic energy of surfaces, his calculations produced crack diameters that correlated well with those that fractured metals. In iron, for example, the critical diameter works out to be approximately one millimeter.

Laboratory Research

The research of Griffith and Orowan concerned the propagation of intentional cracks. But how did cracks start in metals without a helping hand?

Several scientists at General Electric's Research Laboratory have employed a rather obvious but at the same time an unusual technique in searching for fracture origin. Dr. J. C. Fisher, manager of the Laboratory's physical metallurgy section, explains it this way:

"A lot of our work is done by just watching cracks form and travel through materials or examining the fracture surfaces. Sometimes we use a microscope and other times just our eyes." The Laboratory made a major contribution to the knowledge of brittle fracture in this manner.

Dr. J. R. Low, Jr. (photo) of the alloy studies section microscopically examined the surfaces of metal samples after stress for the first evidence of fracture. To make sure that the metal was stressed while brittle, he immersed the samples in liquid nitrogen, lowering their temperature to about −195 C.

In some instances when the sample was composed of large grains, nothing was visible until the stress became large enough to produce complete fracture. But in small-grained material, tiny microcracks appeared at lower stresses and always seemed to be the same—cracked grains.

Microcracks

From these observations, Dr. Low proposed that these microcracks were the nucleus of fracture and equal in size to the average grain diameter—a value that could be measured for any given material. Now calculations of the stress required to produce fracture could utilize a practical term for crack diameter. Thus Dr. Low's testing and theory of microcracks infer that the reduction of grain size can make metals more resistant to brittle fracture.

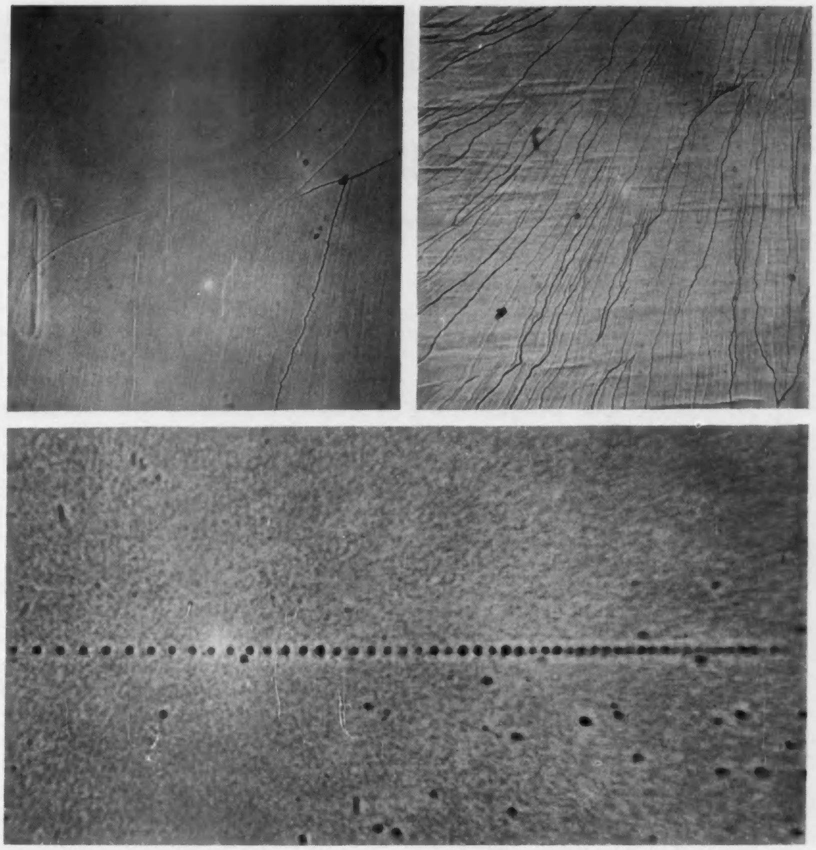
He found that as soon as the stress on a fine-grained material was raised to the yield point, it underwent a small amount of slip and simultaneously a few grains would break. As the stress was increased, more grains broke and some microcracks grew until the stress became large enough to bring on complete fracture.

Fracture Requirements

Dr. Low pointed out two requirements for fracture: microcracks must be present and the stress high enough to propagate the cracks from grain to grain throughout the material. The fine-grained material had microcracks but lacked the required stress; the coarse-grained iron had sufficient stress, but no microcracks. The former material underwent a degree of plastic deformation before it fractured and thus might be considered somewhat ductile. The other broke with the first slip and therefore acted in a brittle manner. In both materials, however, plastic deformation was required to produce brittle fracture.

Dr. Low's work deals with the way that brittle fracture occurs in an aggregate of crystals; other work at the Research Laboratory concentrates upon finding how the grains break to produce the first microcracks. In studying the cleaved surfaces of single crystals, Dr. J. J. Gilman of the physical metallurgy section has found markings that resemble a network of rivers and tributaries (photos, top). He attributes this pattern to the fact that crystals are not orderly stacks of atoms as they are sometimes pictured. Instead they contain many irregularities or dislocations that cause faults in the planes of atoms. As a crack tries to progress across one of the planes, these dislocation sites cause the crack to drop to a lower plane or rise to a higher one, tearing out the intervening material in the regions where cracks on different planes overlap. Dr. Gilman has shown that the energy expended in this tearing process accounts for some of the cleavage strength of the crystal. By varying the number of dislocations and concentrating them in preferred sites, he learns more about their behavior.

He can introduce dislocations by bending or straining the crystal or by causing it to fracture at a temperature high enough to permit some accompanying plastic deformation. Such techniques as denting the surface with a punch and forming a subgrain boundary by disorienting one plane with respect to another concentrate the flaws in localized areas.



CLEAVED SURFACES of single crystals display river-like markings (left). Network becomes more dense after prestraining crystal (right)—a pattern attributed to dislocations. Etching technique is used to show piling of dislocations along a subgrain boundary (lower).

Grain Breakdown

It is suspected that the first crack opens at a highly stressed site in the crystal. Dr. Gilman's studies of dislocations help to explain how the stresses might become concentrated to produce this effect.

A laboratory photomicrograph shows an array of dislocations lying along a subgrain boundary (photo, lower). As a crystal undergoes plastic deformation, the dislocations have a tendency to pile against barriers to the slip process—in this metal, probably, a grain boundary. The effect shows as a closer spacing of the etch pits near the right end of the line. Such piling of dislocations, Dr. Gilman suggests, might account for the stress concentrations necessary to open a crack.

Dr. Fisher recently proposed a model (illustration, page 35, lower) showing how the slip process can open a crack in a crystal that contains a special kind of dislocation—a theory now being tested at the Research Laboratory and in other laboratories.

Mechanical Variables

Determining the proper criteria for using available materials probably presents the most pressing concern in thwarting brittle fracture. The Research Laboratory and other General Electric laboratories have been working out correlations between ductility and such factors as temperature, state of stress, size, and loading rate for representative materials.

Brittle fracture studies at General Electric and throughout the world are not only producing knowledge to alleviate a serious engineering problem but also furnishing a better understanding of why some materials are brittle and others ductile. Armed with this knowledge, science hopes to modify some of the brittle materials so that they can bend to the needs of our rapidly advancing technology. And as brittle fracture possibilities are further recognized, higher safety factors can be built directly into materials, thus helping industry design better products for use in today's living. —THS

American Society of Heating and Air-Conditioning Engineers

By John W. James

People everywhere expect, sometimes even demand, a healthful, comfortable indoor climate at the flick of a switch—at home and in the office, factory, or public building. For a century the heating, ventilating, and air-conditioning engineer has contributed many changes to this particular phase in the standard of living.

The professional status of this form of engineering today can be largely attributed to the American Society of Heating and Air-Conditioning Engineers (ASHAE). Founded in 1894 by a handful of men determined to elevate the dignity of their profession and provide the public with more than perfunctory service, the Society represents an organization of more than 10,000 engineers. It includes 67 chapters throughout the United States and Canada plus members in many foreign countries.

For about 60 years before the Society's organization, the business of heating and ventilating was generally based on an accepted ancient rule of thumb. Despite a good understanding of the principles of steam and hot-water heating, the lack of equipment restricted the operations of the engineer: it was necessary to both design and make the equipment needed for heating installations. Ventilation and the use of fans or blowers, called fanners, were also quite well understood, but difficulty in obtaining power restricted their use.

With the formation of the Master Steam and Hot Water Fitters National Association in America in 1889, a number of men attempted to disseminate engineering information about heating by encouraging presentation of technical papers at their annual conventions. But after about six years it became obvious that the commercial side of the heating business largely concerned the majority of the membership.

On August 2, 1894, Hugh J. Barron, the acknowledged founder of the American Society of Heating and Ventilating Engineers (ASHVE), L. H. Hart, William M. Mackay, and 15 other interested men met in Mr. Hart's office in the World Building, New York City, to discuss the need for developing and disseminating technical advancements to heating and ventilating engineers. These men stimulated sufficient interest to obtain 75 charter members who met on September 10, 1894, in the Broadway Central Hotel, New York City, and adopted a name, bylaws, and constitution for the new Society.

The following January the first ASHVE annual meeting was held in the hall of the American Society of Mechanical Engineers, New York City. At that time the founders established the primary objective of the Society: "For the promotion of the arts and sciences connected with heating and ventilating; the improvement in the mechanical construction of the various apparatus used for heating and ventilating; the reading, discussion, and publication of professional papers; and the interchange of knowledge and experience among its members."

Expansion of Industry and ASHAE

Progress of the heating and ventilating engineering profession was consistent with advancements made in the industry. The year 1906 marked the formation of the first ASHVE chapter in Chicago and the introduction of the squirrel-cage-type blower as a substantial aid in ventilation systems. Air purification also contributed immeasurably to the advancement of ventilation and developments in interior cooling methods.

In 1911 with a membership of 405, the Society established a permanent headquarters in the Engineering Societies Building, New York City.

The year 1914 saw the advancement of automatically controlled heating and the use of gas, oil, and electricity as fuels. And air-conditioning now known throughout the world, but then a new and nameless industry, started about that time. Some early methods of cooling: use of ice in 1880, ammonia refrigeration in 1887 to cool a rajah's palace in India, and mechanical refrigeration in 1898.

Prior to 1911, at least three American concerns were organized, wholly or in part, in the field of air conditioning. Credit for this new term went to S. W. Cramer in 1906 when he presented a paper on humidification and humidity controls for textile mills before the National Cotton Manufacturers' Association. Personnel in textile mills knew measurement and control of moisture content as conditioning. Cramer thus proposed the name *air conditioning* for the means that would maintain a desired humidity in a room where textiles were processed. This terminology, adopted about 1908 by Carrier, covered a broader application than just humidity control; it included air cooling, heating, cleaning, and general ventilation control.

Until 1921, air conditioning's almost exclusive application was in industry. Although the public didn't recognize it as being essential to human comfort until 1936, the basic data was developed by the Society in 1923.

Consistent with the increasing amount of activity by members in designing air-conditioning systems, in 1954 the Society changed its name to American Society of Heating and Air-Conditioning Engineers.

Publications

At the Society's first annual meeting, members approved an annual publication of all proceedings and papers. Known as *Transactions*, this service of ASHAE has been published every year since 1895, providing a valuable record of the developments. By 1904, the Society had presented and published 81 original papers—76 by members.

At this time the profession showed the great need for technical knowledge. Prior to 1900, installations of hot-blast systems of heating could be based only on manufacturers' catalog data. During this nine-year period the Society presented 22 papers on all branches of such heating systems.

Recorded proportions for planning and computing heating systems for large

During 1956, Mr. James served as President, American Society of Heating and Air-Conditioning Engineers.

buildings were also unavailable. The design of a steam-producing plant involved the study of previously recorded weather conditions and a consideration of average temperature and average heat use. Yet, in this area, America excelled all other nations in the early 1900's. Heating and ventilating engineers used simple and effective design procedure, manufacturing was improving, and construction costs were reduced at the same time operating quality increased.

Another publication was initiated in 1915 to better inform the members. Established as a quarterly and later published monthly, the Society *Journal* contains advance publication of technical papers, reports of Society and chapter meetings, and items of general interest. Since May 1929, the *Journal* has been published as a section of the *Heating, Piping, and Air Conditioning* magazine.

Increased research activity necessitated a means of reporting the results to an ever-increasing membership and others in the profession and industry. In 1922 the first issue of the *Heating, Ventilating, Air Conditioning Guide* was published. For many years now this book has proved to be an invaluable aid to engineers, architects, educators, and contractors.

Research

From the day of its inception, a primary purpose of ASHAE was and still is research. For the first 25 years such research activity had been confined to individuals or committees utilizing available equipment or facilities.

In January 1919 the Society celebrated its 25th anniversary at an annual meeting in New York City and approved the establishment of a permanent research laboratory located in the U.S. Bureau of Mines, Pittsburgh, Pa.—fulfilling one of the Society's earliest ambitions. J. J. Wilson of Troy, NY, had proposed a sinking fund for the purpose of maintaining such a laboratory.

A synthetic air chart prepared in 1920 by Society member Dr. E. Vernon Hill of Chicago was one of the first attempts to catalog and understand the importance of the several physical and chemical properties of man's atmospheric environment. Emphasizing the need for greater information, it served to direct attention to the need for more research.

Society research at this time undertook developing standards of atmospheric conditions for the comfort of man. Various phases of this study continued from 1920 to 1943 including work on the well-known ASHVE Comfort Chart. In 1923 the U.S. Bureau of Mines' and the U.S. Public Health Service's interest in men's physical reaction to temperature and humidity in deep mines instituted the study. Men stripped to the waist in still air furnished data for a basic chart.

The Society also developed the Comfort Zone in the same year. This indicates the temperature range in which most people are comfortable; essentially winter-heated space.

By the following year the effects of air velocity on the feeling of warmth in different atmospheres of temperature and humidity had been studied. Later additions to the basic chart included persons normally clothed and seated at rest.

Made available about 1925, the Comfort Chart has received international acclaim and acceptance—a significant tribute to the value of this fundamental research. Although studies continued between 1925 and 1944, no sufficiently conclusive data justified revising the Comfort Chart. Further study since 1944 has provided additional information.

The application of summer cooling and air conditioning in the mid-1920's indicated the need for accurate data on the rate of heat dissipation from the human body to the atmosphere. Between 1929 and 1931 the Society presented four papers that represented a great contribution of physiological information accepted and extensively used by physiologists and air-conditioning engineers.

From 1936 to 1940, 11 papers were presented by the Society dealing with optimum effective temperature for summer cooling and air conditioning.

In 1930 the First International Heating and Ventilating Exposition was held in Philadelphia under the auspices of the Society and consisted of 280 exhibits. In January 1955, Philadelphia was the site of the 12th International Heating and Air-Conditioning Exposition with its 472 exhibits; attendance totaled 34,758. Last year Chicago was the site of the exposition—the largest of its kind ever held in the world.

The year 1930 also saw completion of the first 10 years' activity by the research laboratory of the Society. Its basic work had produced standardization in heating and ventilating processes, developed codes for determining equipment efficiency, and laid the groundwork for future advancement. The Society is justly proud of the fact that it is the only professional engineering society that maintains and operates its own research laboratory. In 1944 the laboratory was moved to limited quarters in Cleveland, Ohio. In 1946 the Society acquired its present large, permanent quarters in Cleveland.

Covering a wide range of subjects, laboratory research has paralleled the work of the Committee on Research, the many technical advisory committees, and work at a large number of cooperating institutions.

Society Growth and Membership

In 1944 the Society celebrated its 50th Anniversary and the 25th Anniversary of the Research Laboratory. The meeting—held in New York with President M. F. Blankin presiding—witnessed an outstanding attainment: more than 1200 papers had been published by the Society since 1895 plus 22 editions of the *Heating, Ventilating, Air Conditioning Guide*. In addition, committee reports and other valuable information for the guidance of heating, ventilating, and air-conditioning engineers had been made available.

What started as an idea in 1894 developed in 50 years to an organization of more than 3000 members with 30 chapters throughout the United States and Canada.

Today with 67 chapters and a membership exceeding 10,000, the Society presents a picture of a vigorous organization dedicated to the basic philosophy of its charter members.

ASHAE research now consists of 22 active projects and an annual research budget of nearly $250,000. Since the inception of the laboratory, the Society has spent more than $2 million on research, but this does not represent the actual expenditure of time and money.

In 100 years the profession and the industry have made tremendous strides forward to provide humanity with standards of year-round comfort far beyond the imagination of the engineers of the 1800's.

And in 62 years ASHAE has produced a record of achievement in advancing the arts and sciences of heating, ventilating, air conditioning and cooling, and the allied arts and sciences for the benefit of the general public. Much of the credit for this dedication must go to the founders of ASHVE, now the American Society of Heating and Air-Conditioning Engineers—engineers of human comfort. Ω

Baling The tractor-mounted generator provides the electric power required to drive the components of trail-behind machinery while the tractor is in motion.

Sawing Supplying the power for field [...] eration of versatile and porta[...]

Mobile Power Packaged for the Farm

By A. F. Lukens

Perhaps the idea of mounting a generator on a farm tractor or a truck doesn't strike you as particularly radical or startling. But such a development—seven years in the making—is now being released on the farm-implement and light-truck markets. However, the introduction of an especially designed unit represents the real advance. This unit can be used for myriad purposes by anyone capable of plugging the cord of an electric toaster into a wall socket. And you'll find it economical enough to be within the means of the ordinary farmer.

The generator—sometimes called a mobile wall socket—represents a powerhouse in itself. A single unit, driven by the main engine, incorporates all the necessary functions of the usual power systems: generation, excitation, regulation overload protection, and distribution.

Let's consider what this new mobile unit will mean.

Machinery on the Farm

Until the middle of the last century, methods of agriculture and the use of agricultural tools had hardly changed. Pictures from Egyptian pyramids show sickles, scythes, hoes, and plows of apparently the same type used in this country during the early 19th century. In the 1850's new tools such as the metal plow, mowing machine, thresher, and combine began a kind of agricultural revolution—one that lagged behind the industrial revolution by about 100 years.

For 20 years, particularly during the last 10, the machine's advance on the farm has been rapid. At first the tractor—the key of farm mechanization—merely replaced animal power as a source of traction, dragging the same old machines across the field at the same old horse-drawn speeds. The capability of the trailing machine, not the tractor, limited these speeds.

Today, with a better source of motive power available, farm-implement engineers redesign old machines as well as invent and design entirely new ones for jobs never before accomplished mechanically. The cotton picker, the prime example of this trend, has not only revolutionized the actual field work but also helped to extend the cotton-growing center by half a continent.

Nearly all these new machines require both operative and tractive power. The power source comes from either the tractor engine or an auxiliary internal-combustion engine mounted on the trailing machine. Shafts, belts, gears, and other mechanical devices transmit this power to the points of use in the machine.

A comparison between a farm machine and a modern tool—complete with multiple electric motors, solenoids, switches, and safety devices—will convince you that electric transmission of energy belongs on farm equipment.

And to accomplish this transition, the generator—the source of energy—must be mobile and must be driven by the excess power of the tractor engine.

Now the farmer, like everyone else, has available to him a great many general-purpose electric hand tools such as drills, saws, and welders. But because of the limited area covered by electric wiring, these prove useful only within

Mr. Lukens—Engineering Section, Small A-C Motor and Generator Department, Schenectady—started on General Electric's Test Course 28 years ago. He has worked on single-phase motor design and has been an application engineer and a product planner for specialty and synchronous motor products.

...er tools is only one of the great many farm ...s afforded by the new generating system.

Growing Mobile generator supplies power to operate 1000-watt lamps that produce artificial light periods causing certain plants to grow more rapidly.

the immediate area of the farm buildings. The ability to use these tools anywhere on the farm or range would multiply their effectiveness for him. For instance, a damaged machine requiring only a few moments of welding would normally have to be taken at a speed of 5 or 10 mph to a repair shop; but if the job could be done in the field (photo, page 42), it might well prevent the loss of a whole day's harvest. With a proper and adequate source of power, uses of electricity for this type of service would be unlimited and unpredictable.

Also present-day farms and ranches depend so much on electric power that its failure completely incapacitates them. Electricity pumps the water, milks the cows, loads the silo, cleans the barn, dries the hay, and hatches chicks plus a thousand other jobs. In the house it cooks the food, washes the clothes, and operates the TV set—only a few of its functions. In short, the farmer depends more on continuous power than the city dweller. Thus a source of stand-by power becomes almost a necessity.

The design of a unit to fill all these electric power needs of the farmer involved a series of problems concerning such things as high output, large-motor starting ability, small size, reliability, simple operation, convenience, safety, and low cost. These requirements led to the development of the mobile unit (photos) now being produced by General Electric for the International Harvester Company (IH).

This generator, sold by IH under the registered trademark of Electrall, has three purposes . . .

- Motive power—to drive the components of trail-behind machines while the tractor is in motion
- Transportable power—to provide a sizable source of power beyond the range of power lines
- Emergency stand-by power—to supply power for installations during periods of power outage.

The Mobile Generator

The generator—fundamentally a 12½-kw 208-volt 3-phase 60-cycle 2-pole 3600-rpm 4-wire revolving field alternator—has a voltage regulator, overload protection, a distribution system, and an exciter, all integrally mounted. Thus it incorporates the functions of a generating station and distribution system into a single unit that can be lifted by one eyebolt.

For ease in manufacturing and quick servicing, all the components of the control system including the functions of a voltage regulator, overload protection, and the distribution sockets are assembled on a chassis.

Three distribution sockets are supplied: one connects for the three-phase operation, the other two for single-phase power. Socket selection depends on the appliance or tool that might be powered by the generator. Types are limited to those designed to accept the four most common plugs supplied with appliances.

One experience emphasized the importance of design details: a tractor equipped with an experimental generator and an electric drill was thought to be a wonderful setup for the practical demonstration of drilling a hole. But soon it was discovered that the plug on the drill would not fit the generator socket. The nearest electrical shop was 70 miles away!

Selecting the Power System

Much cogitation went into the type of power (a-c or d-c, volts, frequency, and number of phases) that the generator should be designed to deliver. The generator must be able to drive ordinary household devices and appliances as well as the farm motors and tools—almost all of which operate on 60-cycle lines of either 115 or 230 volts, single phase or 220 volts, 3 phase. Thus 60-cycle alternating current became mandatory.

To power the devices, the voltages of the network distribution systems used in large cities were chosen. This is a 120/208-volt 4-wire 3-phase system. By using various lines from the generator, 120 volts, single phase; 208 volts,

Welding Damaged equipment that normally would have to be taken to town for repairs can, with the aid of the mobile generator, be fixed in the field.

Conveying Electric conveyor system erated by generator loads b

single phase; or 208 volts, 3 phase can be obtained without switching or reconnecting.

Safeguarding Personnel

A grounded neutral system used throughout the unit minimizes the danger from electric shock. The generator and motor frames are grounded as well as both the neutral points of the generator and of the motor Y-connected windings. The frames and neutral points of the windings are solidly connected by a fourth wire in the cable. This protects the user because the maximum voltage between the metal of the tractor and any wire does not exceed 120 volts, or ordinary household voltage, regardless of any conditions caused by insulation failure.

Actually to even approach this condition, you must assume a nearly complete breakdown of the insulation on the cable, perhaps from mechanical abuse, *without* a short circuit and a heedless touching of bare copper. Any failure of machine windings would be contained in the machine enclosure and would cause no shock. The control switch and all the wiring on the steering column are in the low-voltage d-c circuit.

Increasing the safety of trailing machines by running a control wire with safety interlock switches at various parts of the machine has yet to be fully investigated. But circuits can be easily arranged electrically to shut down the generator if the user opens any door or cover on the machine, minimizing the chance of physical injury.

Standard Life

Early thinking on this project soon led to the conviction that industrial-electrical life standards were far too long and would lead to apparatus too large to mount on farm machines. The operating life of the tractor—15 years, long compared with the ordinary automobile, and most farm machines—becomes short when compared with industrial-electrical usage. Accordingly, a generator design criterion was set up: 15 years' total life under rather adverse conditions of moisture and dirt, 4000 hours' rotating life, and 1000 hours at rated load.

This estimates out to be the equivalent of 2000 to 3000 hours' actual *loaded* operation and 4000 hours' total use.

Motor operating life on the trailing machine runs much shorter—probably about 500 hours at rated load, a figure estimated to multiply several times in actual operating life. This differs radically from such estimates as 40,000 to 60,000 hours at 105 C hot spot for Class A insulation and 20-year life for motors, often expected by users of electric apparatus.

In the design of the generator, the new idea on life expectancy has virtually eliminated temperature rise as a design specification. Actual rises of 120 C for short periods of time on mixed insulation, Class A and B, have proved entirely practicable, as compared with the conventional 40 C rise. And the same considerations are used in the selection of bearings and cables, all working at relatively high stresses.

Ways and Means

Many different types and sizes of motors can be driven by the farm-tractor generator. But the one used on the hay baler must be of special design to obtain the maximum possible output from the combination generator and motor. This motor has a totally enclosed fan-cooled construction, because it operates in a relatively dirty place and usually stands outside for long periods. The design incorporates special electrical characteristics. When operated from the generator, it has a maximum momentary output of 19 hp.

The use of the generators on small trucks offers all the advantages of tractor operation except actual field operation. Everyone who has occasion to do the myriad jobs away from the home shop, such as the light-construction worker and maintenance worker, find these advantages of tremendous importance.

hay onto a truck in the field. Generator also has
ue as a source of emergency stand-by power.

COMMON LOADS HANDLED BY TRUCK AND TRACTOR GENERATOR

Type of Load	Rating	Volts	Phase	Uses and Limitations
Special motors	———	208	3	Farm machines
Standard motors	3 hp	220	3	All loads
	5 hp	220	3	Most loads (except compressors)
	10 hp	220	3	Centrifugal pumps (fans and saws)
	2 hp	230	1	All loads
	5 hp	230	1	Most loads (except compressors)
	7½ hp	230	1	Very light loads
	2 hp	115	1	All loads
	3 hp	115	1	Very light loads
Electric heaters	3½ kw	115	1	
	6½ kw	230	1	
Electric range		115/230	1	Four top burners or one top and oven
Transformer welders	200 amp	230	1	Up to ¾ capacity
Electric lights	7500 watt	115	1	Balanced on three phases (switch few at a time)
Radio and television		115	1	

Greater Latitude in Design

The rating of the generator now in production accommodates present-day jobs. Larger and smaller ratings will undoubtedly be required in the future. The larger ratings will require more powerful prime movers than those now commercially available. Tractor-engine horsepower has always increased with each new model. Because this will probably continue, it will not limit the design of larger generators. Many common loads can now be carried (Table).

The substitution of an electric motor for an auxiliary engine offers immediate benefits to the user: ease of operation, lower maintenance (a continuous financial drain for a small engine), elimination of fuel stops, extra quietness for judging machine operation, and more efficient over-all operation. But it has not yet revolutionized farm operation. Machines still travel at the same horse-drawn speed, perhaps a little faster, but far from automobile speeds.

Probably a greater degree of freedom for the trailing-machine designer will be the most important result achieved. He will undoubtedly find advantageous ways to utilize the new source of power. Completely new concepts and designs of trailing machines to help speed operation of farm machinery may be forthcoming.

In this respect an analogy can be drawn from the experience of machine-tool builders in the transition from line shafts to individual motor drives. The first step in motorizing machine tools merely involved placing a large motor on the floor near the machine and driving through the same pulley used with the line shaft. Similarly, in motorizing trailing machines, a gasoline engine has been removed and a single electric motor substituted. Current practice in machine tools involves locating a number of small motors, each driving a particular component, at various places on the machine. This reduces the number of mechanical paths through which the energy flows—gears, transverse shafting within the machine, belts, and pulleys. Also this practice has been a contributing factor in the increase in operation speed accomplished by machine-tool designers in recent years.

In addition to using motors to better advantage, the possibility exists for incorporating other electric devices—solenoids, welders, sterilization lamps, and spot heating—on the trailing machines.

Laboratory Studies

Other feasible uses of electricity in agriculture being investigated in various laboratories include . . .

Artificial Photoperiodism—Certain crops grow only as a result of photoperiodism—a change from darkness to a period of light. Normally, this would be day and night; however, if a short period of light artificially interrupts the dark period (photo, page 41), the plant becomes fooled into "thinking" that another day has passed and grows accordingly.

Weed Extermination—Weeds die near an electric fence; but why and under what conditions, science does not fully understand. Experiments now being conducted may determine the possibility of effectively killing weeds in row crops with suitably designed electrodes drawn by the tractor and electrified by the generator.

Insecticide Control—That insecticide dusting powders can be concentrated on the leaves of a plant by electrostatic charging of the dust with proper polarity control—similar to electrostatic paint spraying—has already been demonstrated in a limited manner. If successfully developed, this process would prevent the dust from falling to the ground and would probably achieve better plant coverage.

Everyone intimately associated with the development and promotion of the mobile unit—electrical and farm-machine engineers, power-company officials, agricultural engineers, researchers, practical farmers, and repair men—believes it to be the genesis of extended electrical benefits, a new and nearly limitless field. Ω

To a youngster the gyroscope is a fascinating scientific toy. But in the hands of engineers, its governing principles underlie the relatively simple demonstration gyro and complex stable reference platform. The stable platform system (on test, photo, far right) may represent the ultimate in navigational instruments.

The Gyroscope: A Proved Instrument Take

By P. H. Wilson and L. T. Seaman

There's a lesson to be drawn from the photo sequence. The fundamental laws that underlie the boy's toy gyroscope are used in advanced motor-driven gyros and, finally, in a complete navigation system. Moral: you'll usually find any complex engineering device or system built around a few basic principles.

As a navigation system, the gyro is basic — essential to modern aircraft flight. With it, a pilot flies safely, efficiently, and confidently in all weather to all places on earth. And with the development of newer high-performance aircraft and with missiles speeding farther and faster through the atmosphere or space, you can look for even more extensive use of the gyro in systems of increasing complexity.

How They Work

Two principles are fundamental to the gyroscope: rigidity and precession.

Rigidity is the tendency of any spinning mass to maintain its axis of rotation angularly fixed in space. Our own planet earth, perhaps, best illustrates this tendency—a huge gyroscope with a peripheral speed at the equator of about 1035 mph. Disregarding wobble at the poles, the earth's axis remains fixed in space at an angle of 23.5 degrees from the axis of its orbit about the sun, regardless of the day, week, or season.

The explanation of precession presents more of a problem. If you apply a torque to a spinning mass, its gyroscopic action causes the mass to turn on an axis at right angles to the applied torque and to the axis of spin.

This phenomenon is easier to grasp physically: As a youngster you probably took pride in being able to ride a bicycle with "no hands." To go right, you leaned your body to the right; to go left, you leaned to the left. Whichever direction you leaned, the gyroscopic action of the front wheel spinning about a *horizontal* axis caused the wheel to turn in that direction—but about a *vertical* axis. This is precession.

Fascinating Toy

The gyro began its life in a leisurely fashion 105 years ago.

In 1852 the French physicist J. B. L. Foucault demonstrated the earth's rotation by means of a rapidly spinning wheel, universally mounted in gimbals. He called it a *gyroscope*.

But even the flood of papers and public demonstrations that followed Foucault's invention of the gyroscope failed to elevate it from the category of a fascinating scientific toy. For nearly 50 years it remained in that category and for sound reasons: 1) the high degree of mechanical accuracy needed to make the gyro a practical, useful device was not easily attained; 2) there wasn't a suitable driving force to spin the gyro's rotor at a constant speed.

With development of the aircraft shortly after the turn of the century, the situation changed a great deal. New machining and manufacturing techniques made it possible to reduce the gyro's size to the point where its use in aircraft became practical.

Credit for the first application of the gyro belongs to Elmer A. Sperry who, in 1911, developed the marine gyrocompass. Quickly accepted by the U. S. Navy, it served as a master directional reference for navigation and gunfire control. In 1913, Sperry demonstrated for the Navy the first gyroscopic stabilizer, or autopilot, for aircraft. For this work, he received the Collier Trophy Award.

From here on, the use of the gyro advanced by leaps and bounds. In 1918 the gyro turn indicator was introduced, followed two years later by the aircraft

Mr. Wilson—Manager, Aircraft Instrument Engineering Administrative Practices, Instrument Department, West Lynn, Mass.—came with General Electric on the Test Course in 1942. Mr. Seaman, also a graduate of the Test Course, joined the Company in 1948. He is presently a functional engineer, Guidance and Fire Control Engineering, Ordnance Systems Project Operation, Missile and Ordnance Systems Department, Philadelphia. Mr. Wilson and Mr. Seaman appear in that order in center photo.

e on New Significance

gyrocompass. The artificial horizon and directional gyro came in 1930.

For many years, aircraft gyros were driven by streams of air directed against a series of buckets, similar to an air turbine. But as aircraft began to fly higher and higher, the reduced air density at these higher altitudes necessitated a new means for driving the gyro. Thus during World War II, engineers developed an all-electric aircraft gyro. At its heart was an "inside-out" electric motor. Because of the unique design, a high degree of angular momentum was provided in a small motor. This same principle is utilized universally today.

The many types of gyroscopic systems range from the relatively simple to the greatly complex. More will be said about these later in the article.

Why the Gyro?

For the accuracy and stability needed in an aircraft, any gyroscope must have...

- The largest possible rotating mass for a specified weight and size.
- A rotor speed as high as would be practicable to obtain.
- An extremely low gimbal-bearing friction.

For aircraft gyros powered from a 400-cycle a-c power supply, speeds of 12- and 24-thousand rpm are common.

You might wonder why the gyro is preferred to something more simple. Although the gyro, a fascinating device, comes in a small lightweight package, it does require a great deal of engineering and precision manufacturing.

Actually two other instruments, the ball level and the magnetic compass, have been used to determine an aircraft's attitude—that is, its bank and climb or dive—and direction of flight. However, they prove inaccurate when subjected to acceleration forces, or Gs.

The ball level, a form of pendulum, indicates the total effect of both gravity and acceleration because their effects are equivalent. In a coordinated turn the bank angle, air speed, and rate of turn produce a force perpendicular to the plane's lateral axis. In other words, if you were blindfolded in the airplane, you'd be unable to differentiate straight-and-level flight from a coordinated turn; if you were standing, you'd feel no tendency to tip over. Thus while the ball level helps in monitoring a coordinated turn, it can't determine actual attitude of an aircraft that's accelerating, decelerating, flying through turbulent air, or executing a coordinated turn.

A magnetic compass is subject to errors caused by G forces. And, its oscillatory nature in flight makes it difficult for the pilot to read its markings.

Unlike either of these instruments, G forces leave the gyro unaffected. It's ideally suited to accurately indicate attitude, direction, and rate of turn. Additionally it provides a stable indication that the pilot can easily read or, if need be, one that can be converted to electric signals for operating autopilots, radar, fire-control systems, and the like.

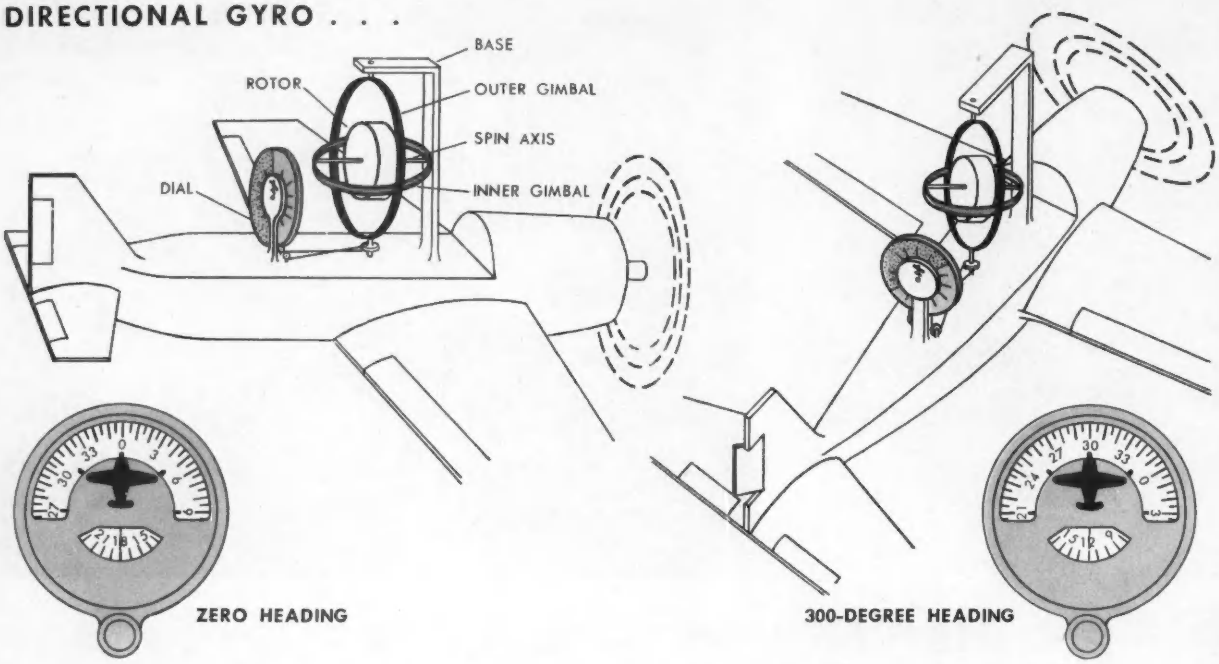
Thus the gyro provides a *stable* reference direction—the distinguishing characteristic—and, as pointed out, it possesses *inertial stability:* by its nature it tends to maintain its spin axis in a fixed direction similar to the way the earth is stablized with its spin axis pointed toward the North Star. With the gyro as a stable reference, you can readily ascertain an aircraft's angular position, its attitude and its direction, or its angular rate of turn.

Simple Direction

A directional gyro mounted in an aircraft (illustration, page 46) gives a direct indication of heading. Here the gyro consists essentially of a rotor supported by two gimbals; each pivots about an axis perpendicular to the other — an arrangement called universal mounting. With it, the gyro's rotor can assume any angular position relative to the base of the instrument.

In operation, the directional gyro's rotor is set spinning with its axis in a horizontal plane. Resisting any change in direction of motion, the rotor re-

DIRECTIONAL GYRO . . .



TWO-AXIS FREE DIRECTIONAL GYRO, with two degrees of freedom besides rotation about the spin axis, gives pilot a direct indication of aircraft's heading. Angle swept out by instrument's base as it rotates around the outer gimbal is a measure of change.

mains fixed in its original plane of rotation; and the spin axis, in its original direction. The gyro's base is rigidly attached to the airframe. As the aircraft changes heading, the angle—swept out by the base as it rotates around the outer gimbal—becomes a direct measure of the change. By mechanically coupling the gyro's outer gimbal to a dial, you can read the aircraft's heading angle.

Such a directional gyro is called a "two-axis free directional gyro." Its two gimbals allow the rotor two degrees of freedom in addition to rotation about the spin axis. And because it isn't controlled or slaved to any earth reference, the heading information depends entirely upon the gyroscopic rigidity.

Artificial Horizons

Pilots refer to a highly important instrument on their panel as an artificial horizon—known to the engineer as a vertical gyro (illustration, opposite page). Free to rotate about two axes, this device detects and indicates changes in an aircraft's attitude. Except for its rotor spin axis being vertically aligned, it bears a similarity to the directional gyro.

When the aircraft changes attitude, the spin axis remains vertical. From the angle thus formed between inner and outer gimbals, you can measure the aircraft's dive or climb. Also, the angle made by the outer gimbal with an index on the gyro's case gives you a measure of bank.

The pilot receives such information visually via the artificial horizon on his instrument panel. In the instrument's window, a horizon bar mechanically coupled to inner and outer gimbals reproduces the maneuvers of bank and climb or dive.

As mentioned earlier, the gyro establishes a fixed-in-space reference direction. But an aircraft flies around a *spherical* earth. Thus you must provide a means for continually aligning the vertical gyro so that its spin axis is always perpendicular to the earth's surface.

Engineers accomplish continuous alignment by taking advantage of the gyro's precessional property—its tendency to rotate about an axis perpendicular to the axes of spin and applied torque.

One method of controlling a vertical gyro's precession: a pendulous erection device (illustration, page 48). During unaccelerated flight, a permanent magnet mounted pendulously aligns itself with the vertical. Then, by means of eddy currents induced in a rotating conducting disk attached to the gyro, it produces torques. These cause the gyro's spin axis to line up with the magnet, thereby indicting a true vertical to the earth.

When the aircraft is maneuvering, of course, the pendulous magnet indicates a false vertical because of accelerative forces acting on it. But design minimizes such errors. Precession torques deliberately made small enable the gyro's spin axis to follow the magnet at a rate of only a few degrees a minute.

Measuring Turn

To measure an aircraft's rate of turn, you use a single-axis device called a rate gyro (illustration, page 49). Its construction differs from the two-axis gyro: only one gimbal supports its rotor; it is restrained; and its gimbal rotates against the action of a spring.

The rate gyro senses a rate of turn about its input axis that is perpendicular to both the spin and output axes. Through the property of precession, a rate of turn about the input axis produces a torque about the output axis. Accordingly, the gimbal rotates against the spring until the two opposing torques become equal. The angle assumed by the gimbal then indicates the aircraft's rate of turn on the face of a panel-mounted instrument.

Sometimes a ball level is included to monitor coordinated turns. You commonly hear this primary flight instrument called a bank-and-turn indicator.

Autopilots

The gyroscopic devices discussed thus far—the directional gyro, the vertical gyro, and the rate gyro—all present their information on panel-mounted instruments.

Such visual transmission of information to the pilot was quite satisfactory in the days of relatively slow and stable airplanes. But in modern aircraft, traveling at high speeds and relatively unstable, reaction time of a human pilot has become a limiting factor in the mechanics of modern flight. The pilot simply can't interpret flight information, make decisions, and apply corrections to the plane's controls with the split-second timing required.

Some form of automatic flight control, or stabilization, had to come. It did, in the form of an autopilot that employs gyroscopes as the sensing elements. The directional, vertical, and rate gyros supply flight information—usually in the form of electric signals—to the autopilot which in turn operates the plane's controls for automatic flight.

Today's autopilots give you straight and level flight. And they control aircraft on takeoffs and landings—and through tactical maneuvers—more effectively and safely than the human pilot.

Many of today's high-performance aircraft—besides being inherently unstable—exhibit another disturbing characteristic that, without the gyro, would prevent satisfactory flight. Technically, you can think of this as an oscillation or buffeting of the fuselage. Stated more simply, the plane tends to flap its tail section.

A gyroscope known as a yaw damper prevents this buffeting in flight. Sensing each oscillation just as it begins to happen, the yaw damper instantaneously sends an electric signal to the autopilot which takes corrective action. Actually the unwanted motion is anticipated, resulting in smooth flight.

Controlling Armament

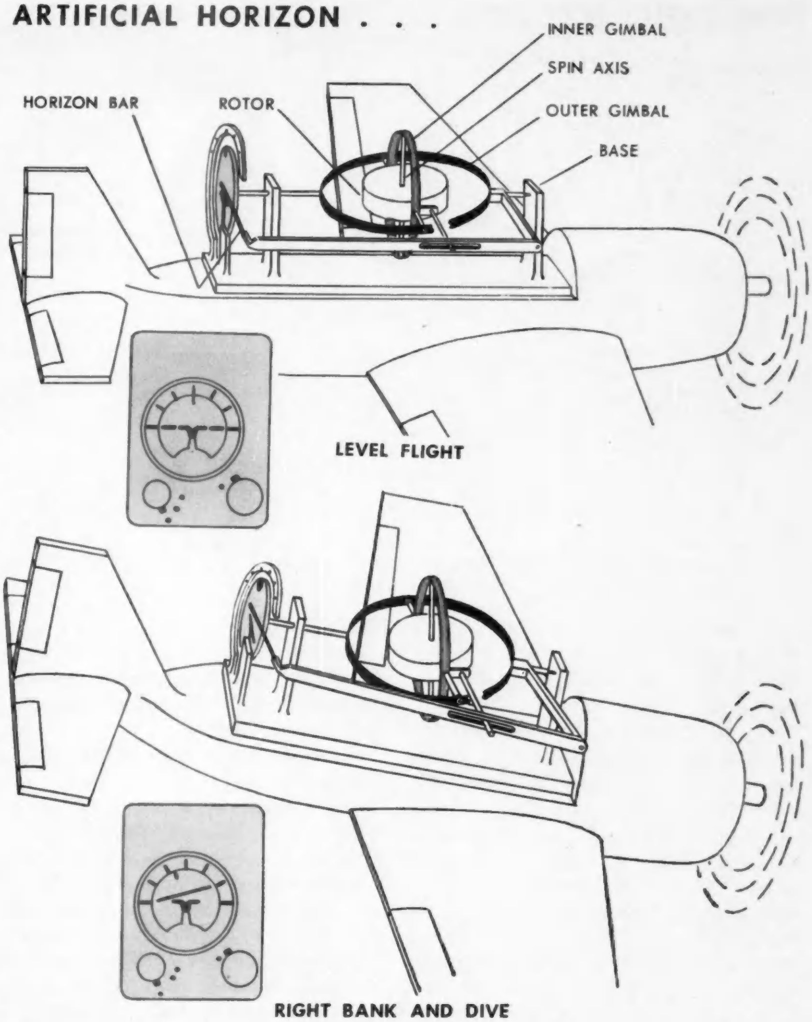
While automatic flight control constitutes a major application of gyroscopes, they are also employed to control weapons.

When bombing from great heights, it's vital for the bombardier to know the vertical—or, in more concrete terms, which way is down. Otherwise bombing from high altitudes would not be accurate. Accordingly, a vertical gyro feeds precise information on the vertical to the bombing computer.

Those familiar with hunting realize the importance of aiming a gun at a point ahead of—or leading—a moving target. This way, both the bullet and your target arrive at the same place at the same time. Similarly, at the high speeds that may be encountered between two aircraft—particularly if they're flying in opposite directions—the proper lead angle is essential to assure a hit. To determine this accurately and automatically is the job of the rate gyro.

In modern weapons systems, the aircraft gunner merely tracks the target in his sights. A rate gyro, mounted in the gun-sight mechanism, provides automatically an electric lead signal that's proportional to the relative speeds and distance between the planes; supplied to the fire-control computer, the proper lead angle is then calculated electronically. The effects of wind velocity, gravity, and the like are considered; and the gun turret rotates to its proper firing position.

ARTIFICIAL HORIZON . . .



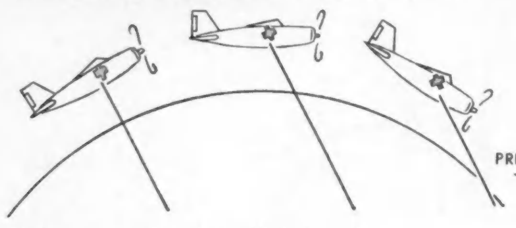
VERTICAL GYRO, also free to rotate about two axes, detects changes in attitude. Major difference between it and directional gyro is vertical alignment of its spin axis.

Manual Navigation

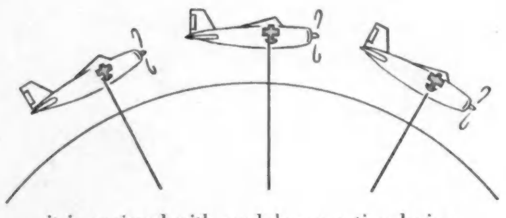
Problems that confront the pilot navigating his aircraft through the skies aren't present in land or sea travel for several reasons . . .

- Celestial fixes—navigation by the sun or stars—are difficult to make normally and impossible to make in bad weather.
- Important landmarks of value to the pilot often become obscured. His magnetic compass offers little help because of its oscillations in all but the smoothest flight. To complicate matters, magnetic disturbances are set up by the aircraft's engines and other contributing sources.

PENDULOUS ERECTION . . .

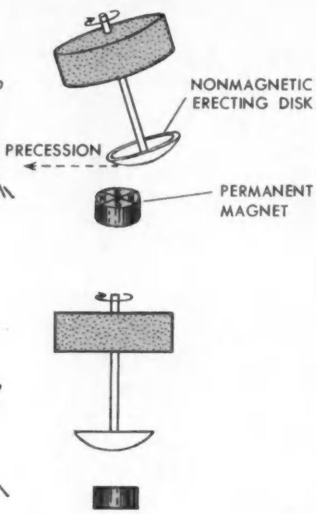


To keep gyro spin axis vertical to earth . . .



. . . it is equipped with pendulous erecting device.

ERECTING FORCE



• The human factor must be considered, too. A pilot has little time to devote to navigational calculations—many other things occupy his time while flying today's complex aircraft. Continually increasing speeds allow him even less time to determine his position before the aircraft is somewhere else.

The gyroscope—a vital navigational instrument—enables the pilot to ascertain his position relative to the earth rapidly and accurately. Almost all of today's aircraft use a compass-controlled directional gyro as a basic heading reference.

This system provides accurate and stabilized heading information to the pilot on panel-mounted indicators. Technically speaking, its directional gyro is continuously slaved to the correct magnetic heading, automatically compensating for any errors. Thus the compass-controlled directional gyro combines the advantages of both the magnetic compass and gyroscope, while remaining unaffected by instantaneous accelerations.

Over the polar regions, the earth's magnetic field can't be used to indicate direction. By flipping a switch the pilot cuts out the magnetic compass, utilizing the system as a free directional gyro. Dialing the correct latitude on his controller automatically precesses the directional gyro and compensates for the effect of the earth's rotation. Even during this operation as a free gyro, the system maintains a high degree of accuracy.

Radio Aids

Heading reference established by a compass-controlled directional gyro is used with many radio aids. One is called the *Omnirange* system.

Through radio stations on the ground and special receivers in the aircraft, Omni indicates the plane's bearing relative to a selected ground station. Knowing this bearing and the aircraft's heading, a pilot can fly along a selected ground course toward the station. By successively tuning in different stations, he can navigate across the country with ease and assurance; with proper equipment, he can determine the aircraft's distance between stations.

Of course, you can't always use radio navigation, and certainly not over hostile territory. Other navigational means therefore continue to be of major importance. These range from simple dead reckoning to the inertial navigation systems you frequently hear mentioned in reference to ballistic missiles and long-range bombers.

Dead Reckoning

When navigating by dead reckoning, the pilot knows accurately only his aircraft's exact heading and air speed. The problem: to determine the aircraft's actual velocity and the course traveled—both of which depend greatly on wind velocity.

Dead reckoning, therefore, involves three operations: 1) estimating wind direction and velocity, 2) measuring the aircraft's air speed and heading, and 3) calculating course and distance traveled from the starting point. This process, inaccurate and time consuming, often is the only way a pilot can determine his position.

Automatic dead-reckoning computers now perform these time-consuming calculations. Radar measures the aircraft's ground speed; a compass system measures its heading. Fed as inputs to the navigational computer, distance and course traveled by the aircraft are automatically determined. Some computers even indicate the aircraft's position in terms of longitude and latitude.

With the advent of navigational computers comes a demand for a compass system having better heading accuracy. But the earth's magnetic field places inherent limits on any improvements that might be made: the North and South Poles of the earth aren't fixed in position but shift slowly with time. The magnitude and direction of the earth's magnetic field change yearly, even daily, at any point on earth. Thus it's doubtful that any compass-slaved navigational system can indicate true direction to an accuracy much better than a half degree.

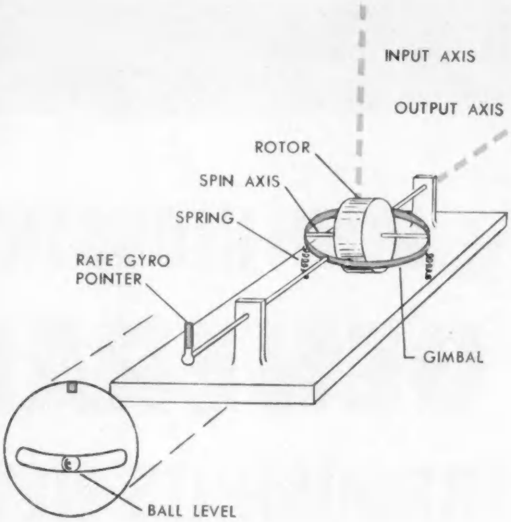
Ultimate: Inertial Navigation

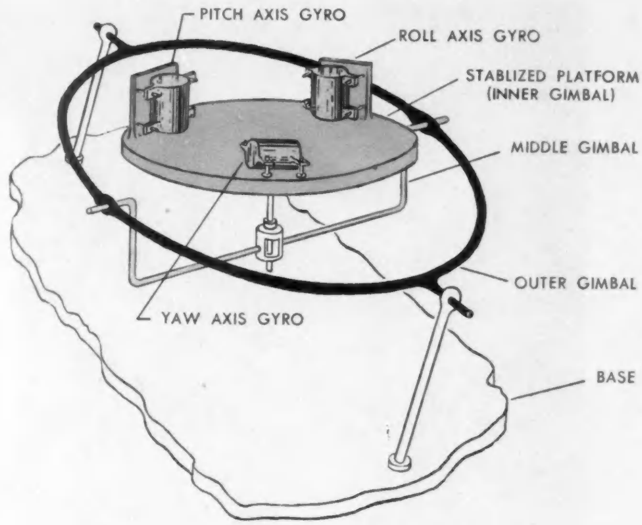
More and more, inertial navigation systems enter the picture. Without depending on a compass, radio, or radar, they accurately indicate an aircraft's or missile's position over the earth.

An inertial navigation system is passive—no information external to the flight vehicle is necessary for its operation. Accordingly, the system can't be detected or jammed by hostile countermeasures.

Though still in the development stage, inertial systems will be used on high-performance aircraft and missiles within a few years. In broad terms, their principles of operation are fairly straightforward. They sense the acceleration of an aircraft or missile in flight by means of devices called accelerometers. Data on acceleration are fed to a computer that—by a process of successive integration—derives the vehicle's velocity and distance from its starting point.

A gyro reference system known as a stable platform (illustration, page 49)—something you'll be hearing more about in the future—comprises a vital part of an inertial system. Mounted on this stable platform are the accelerometers, isolated from the vehicle's angular motions. Reference directions along





RATE GYRO senses an aircraft's rate of turn. This instrument is sometimes called a bank-and-turn indicator.

STABLE PLATFORM reference system, a form of inertial guidance, will control satellite launchings and, ultimately, guide vehicles in space.

which accelerations are measured are thus established. When the vehicle is an aircraft, the stable platform maintains the accelerometers' horizontal; consequently, the equivalent effect of gravity isn't confused with linear acceleration. Additionally, the stable platform determines the flight vehicle's heading and attitude.

It may be apparent to you that inertial devices are perhaps the ultimate in a self-contained aircraft or missile navigational system. Quite so. They supply accurate information of a flight vehicle's heading and attitude plus its geographical position relative to the earth. If you employ additional accelerometers sensitive to vertical accelerations, inertial systems will also indicate altitude. With the flight vehicle's original position known, inertial systems indicate complete linear and angular position of your vehicle relative to the earth or any arbitrary reference system.

Guiding Missiles

The intensive work going on today in pilotless aircraft and missiles gives you an indication of the many new jobs the gyroscope must do. Needed are instruments and other devices to perform the human functions of flight control, weapons delivery, and navigation.

Navigation represents, perhaps, the most important of these functions: the system must determine the missile's position geographically and deliver it to a preselected location. In this application not only does the system need a high order of accuracy but it must also be extremely reliable with high resistance to shock and vibration.

Cruise-type missiles flying at constant altitudes depend on short, stubby wings for aerodynamic lift and an air-breathing engine for propulsion. Their guidance or inertial navigation systems may be similar to those used in aircraft. In addition to an inertial system, they may utilize radio or radar—even star-tracking equipment

Long-range missiles that follow a ballistic trajectory, such as the intercontinental ballistic missile (ICBM), require a somewhat different guidance system—necessitated by the nature of a ballistic flight path.

You can compare the flight of a ballistic missile to throwing a rock in the air. If you know the rock's direction and velocity the instant it leaves your hand, you can determine—neglecting air resistance—the spot where it will land. The tremendous height at which ICBM travels makes the effect of air resistance on its trajectory negligible. Thus by suitably controlling the ballistic missile's velocity, direction, attitude, and position at the last instant of powered flight, you can hit any selected target.

Velocity—one of the most critical quantities in guiding the missile—may be determined by a combination of an accelerometer, a stable platform, and an integrator similar to that used in an aircraft's inertial navigation system.

Future Outlook

As engineers improve the design and manufacturing of gyroscopes, their accuracy will naturally increase. You can look for wider application of the gyro in the more accurate and more useful systems dictated by technological progress. Additionally, engineers recently developed entirely new gyro components and design techniques that promise to open up new fields of application.

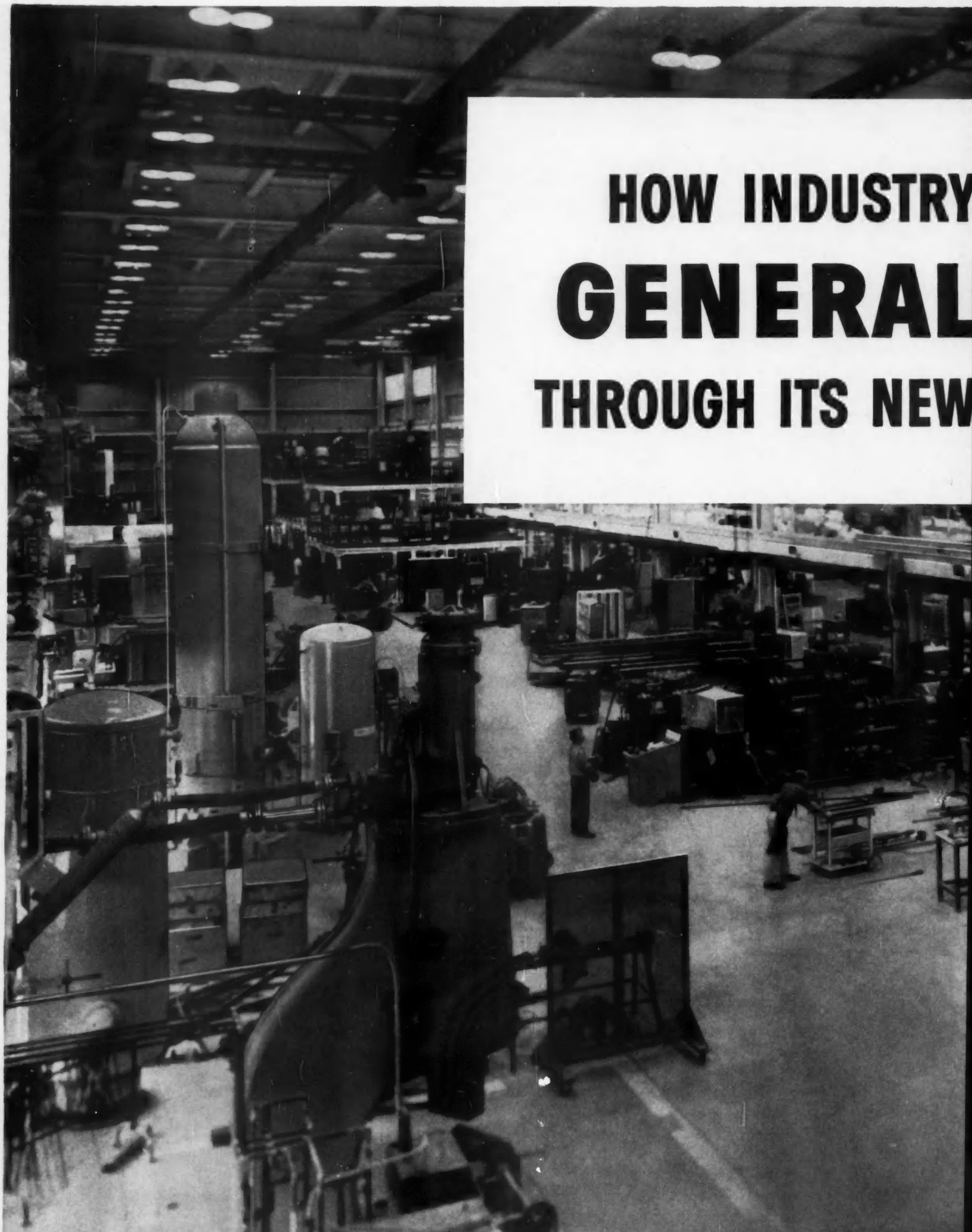
In the immediate future, watch for the stable platform to satisfy demands of both accuracy and minimum weight.

One major advantage to the stable platform: it maintains heading accuracy even though an aircraft isn't flying straight and level—something a two-axis directional gyro does not do well if the aircraft banks greater than 20 degrees. Aircraft employed in antisubmarine warfare demand this kind of performance because they must circle continuously at a steep angle of bank to maintain contact with a submerged enemy vessel. To maintain contact with the submarine, their radar requires an accurate heading signal.

And so, the gyroscope has had a long history—and, since the turn of this century, a rather intensive one. Conceived by Foucault as a laboratory instrument to demonstrate the earth's rotation, it subsequently became a reference device for ocean-going ships and aircraft. Its future is largely tied up with missiles and, ultimately, space craft.

Certainly, during the International Geophysical Year, the gyroscope will be the fundamental reference controlling the Project Vanguard launchings and the earth satellites' flights. Ω

HOW INDUSTRY
GENERAL
THROUGH ITS NEW



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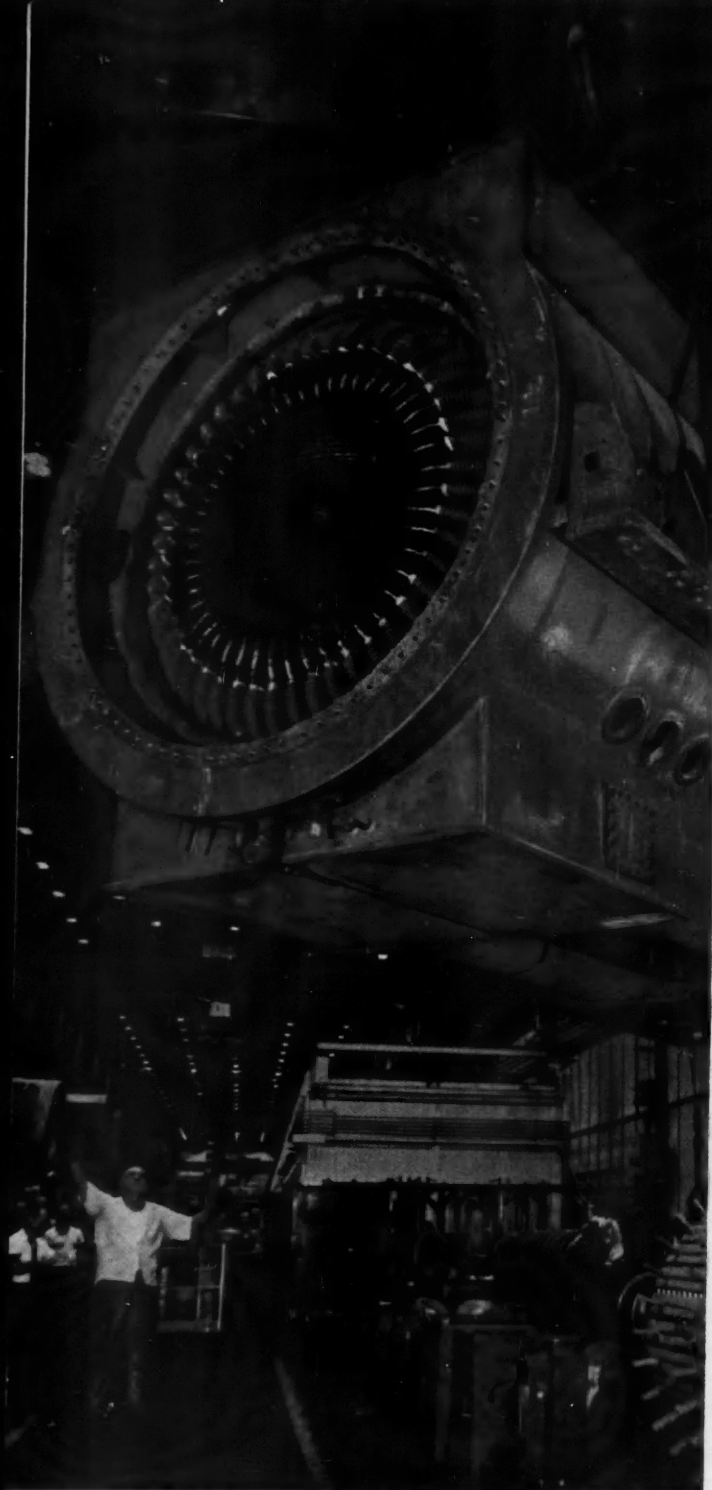
Progress Is Our Most Important Product

GENERAL ELECTRIC



World's first large generator with liquid-cooled stator windings shown prior to shipment to The Cleveland Electric Illuminating Company's Eastlake Plant.

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