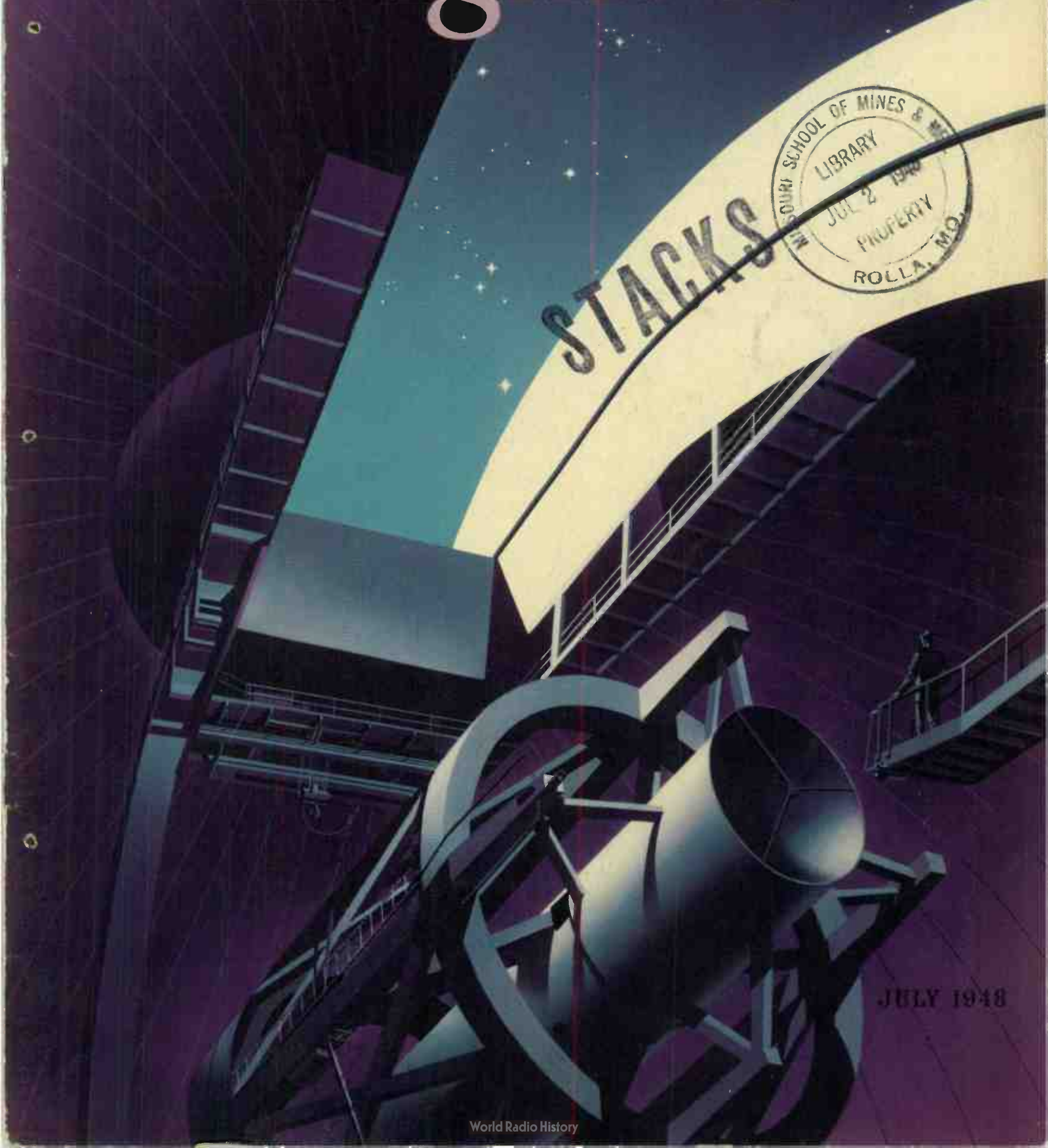
WESTINGHOUSE

Engineer



JULY 1948

Electric Power Load—In the Years Ahead

The following paragraphs essentially are extracts from an address by Gwilym A. Price, President, Westinghouse Electric Corporation, at the convention of the Edison Electric Institute, Atlantic City, June 2, 1948.

The annual load on power systems in this country will grow at the rate of 30 000 kwhrs per minute for each of the five and a quarter million minutes that comprise the next ten years. This is the gist of the predictions that have resulted from a power-load survey for the coming decade made by Westinghouse. Furthermore, to meet this rising load will require an increase of 80 percent in the nation's installed generating capacity. With concomitant increases in other facilities, electric utilities will be required to match in ten years all their investment to date.

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The estimates are based, insofar as possible, on fact; they are not mere extensions of curves of past performance. However, large as these charted increases are, there are good reasons for thinking that these prognostications are on the conservative side. This is because of numerous intangible but inexorable trends that are difficult to reduce to concrete figures.

Some conspicuous major changes are occurring in the industrial scene. Some of these will add up to new or essentially new industries, all of which will build power-system load either directly or indirectly or both. Some, at first glance, seem to be of little consequence to the electric utilities. All, however, are important because they entail large amounts of steel, fabrications, apparatus of many kinds—all of which contain in their creation a large amount of electric power. That's one nice thing about the electric-power business. It stands to gain two ways from every new apparatus, every new gimmick. The new product requires power to make it or power to run it—generally both.

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Consider the synthetic-fuel program. The threat of declining petroleum resources and the uncertain world stability make it appear inevitable that we are to see a new industry of gigantic proportions created for the conversion of solid coal into liquid and gas fuels and into chemicals. The first production stages of this announced program, sponsored by both government and industry and encouraged by the military authorities, call for plants to provide two million barrels of liquid fuel a day. This initial construction program will be five to ten times the size of the synthetic-rubber program. It will call for many millions of tons of steel, fabrication facilities, and equipment of every description—pipe, pressure vessels, pumps, compressors, motors, control—and thousands of technically trained men.

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With the rapidly declining reserves of high-grade, easily worked iron ore, steel companies are faced with an enormous program to enrich or beneficiate the lower grade ores before shipment to mills. This venture is only barely starting so that its requirements are but dimly seen. However, in addition to apparatus it will require large quantities of electric power. In fact, ore beneficiation may raise the energy content of a ton of iron ore from the present 5 to 70 kilowatthours.

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Under the spur of rising labor costs and the general desire to increase productivity from given facilities, many industries are increasing the speed of their processing lines. For example, the new steel strip mills are operating at speeds better than 5000 feet per minute—sixty miles an hour. Only ten years ago, 1500 feet per minute was something to brag about. Tinning-line speeds in some mills are being doubled. Kraft paper as wide as a two-lane highway is being made at rates of 2000 feet per minute. One new mill, within a few days of its initial operation recently, turned out a sheet of heavy kraft paper 19 feet wide at the rate of nearly a thousand feet per minute for 36 hours without a break. That's enough paper (390 miles) to cover a road from Pittsburgh to New York. Textile makers, glass makers, and many others are likewise increasing the speeds of their processing lines.

While these speed records are interesting in themselves, they are doubly significant because they entail additional electrical equipment and electric-power consumption far more than the proportionate increases in speed. To double the speed of a processing line frequently triples or quadruples the power required.

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While attention must be given to the new industries and to expanded industries, the big possibilities with the more prosaic job of modernization of old plants should not be overlooked. One would naturally think that Westinghouse plants would be pretty completely electrified. However, the plant-planning department recently made a survey of all the Company's operations and found that if new processes and new machines were added, which are actually justified by present production, its electric-power consumption would increase by 35 percent.

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The home, power-wise, appears as a bottomless pit, which there is no chance to fill to the brim with kilowatthours. There are many well-appreciated domestic-load builders such as improved lighting, home freezers, air conditioners, dishwashers, electric bed coverings, radio, and television, and the changed "power habits" that have resulted from the automatic cycle washer and its companion, the drier. There are many less common ones, which, while modest in their wattage consumption, are important in the aggregate. Consider the bactericidal lamp, such as the Sterilamp. These have very obvious and large potentialities to aid in the prevention and control of communicable diseases such as colds, measles, etc. Units installed in the bathroom, perhaps within the medicine cabinet itself, and mounted in the bedrooms should cut down appreciably the illnesses that run through a family.

Sterilamps as load builders! Modest in their power uses to be sure. But, if, by 1957, only one such germicidal lamp were installed in each wired home of the country they would add 500 000 kw of load, one fourth the electric power produced at Niagara Falls. And this is a 24-hour a day load.

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Also within this period we are likely to observe how other uncommon devices take their place in the home, each adding its significant bit to turn the disc of the watthour meter. There is the wire recorder, that may become a preferred method of "letter writing." Books may be borrowed from the libraries on film, to be read on microfilm enlargers which will become as common as telephones, placed conveniently about the house—and each equivalent in wattage to a console-model radio. Facsimile machines may become an accepted household necessity—either as separate units or as adjuncts to television sets—operating while the family is at the movies or asleep, recording news, local advertising, or other information.

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Assuming this nation manages to stay at peace, all the signs point to prosperous, busy days for the electric-power industry.

WESTINGHOUSE
Engineer

VOLUME EIGHT JULY, 1948 NUMBER FOUR

On the Side

The Cover—"Searcher of the Heavens Extraordinary" could well be the title of the telescope at Mount Palomar. The giant instrument, which extends man's range of vision by 500 million light years or 3 x 10^{21} miles, will bring new horizons of knowledge into view.

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During July the first complete commercial installation of the All-Weather Approach Lighting System will go into operation at New York City's Idlewild Airport. The system employs the man-made lightning of the krypton lamp to give an airplane pilot a visual indication of the runway during conditions of fog so thick that he literally cannot see his (plane's) nose in front of his face. The equipment will soon undergo further rigid testing at the Landing Aids Experimental Station, Arcata, California, which is reputed to have the poorest weather for air operations in the world. Fog and rain prevail almost constantly and the field is closed to landings for some period of each day during six months of the year. Instead of being used only occasionally, as is normal, the All-Weather System will be required almost daily.

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New York City commuters are now riding their first radar-guided ferry. This is made possible by the installation of navigational radar on a diesel-electric ferry, *The Tides*, which runs between Brooklyn and Staten Island. The vessel crosses two large ship anchorages and The Narrows, through which all ocean-going boats enter and leave the harbor. Because the ferry runs either backward or forward, the radar must indicate ships and other obstructions in its path from either end. Radar is expected to help the ferry in maintaining its schedule even during the most adverse weather.

In This Issue

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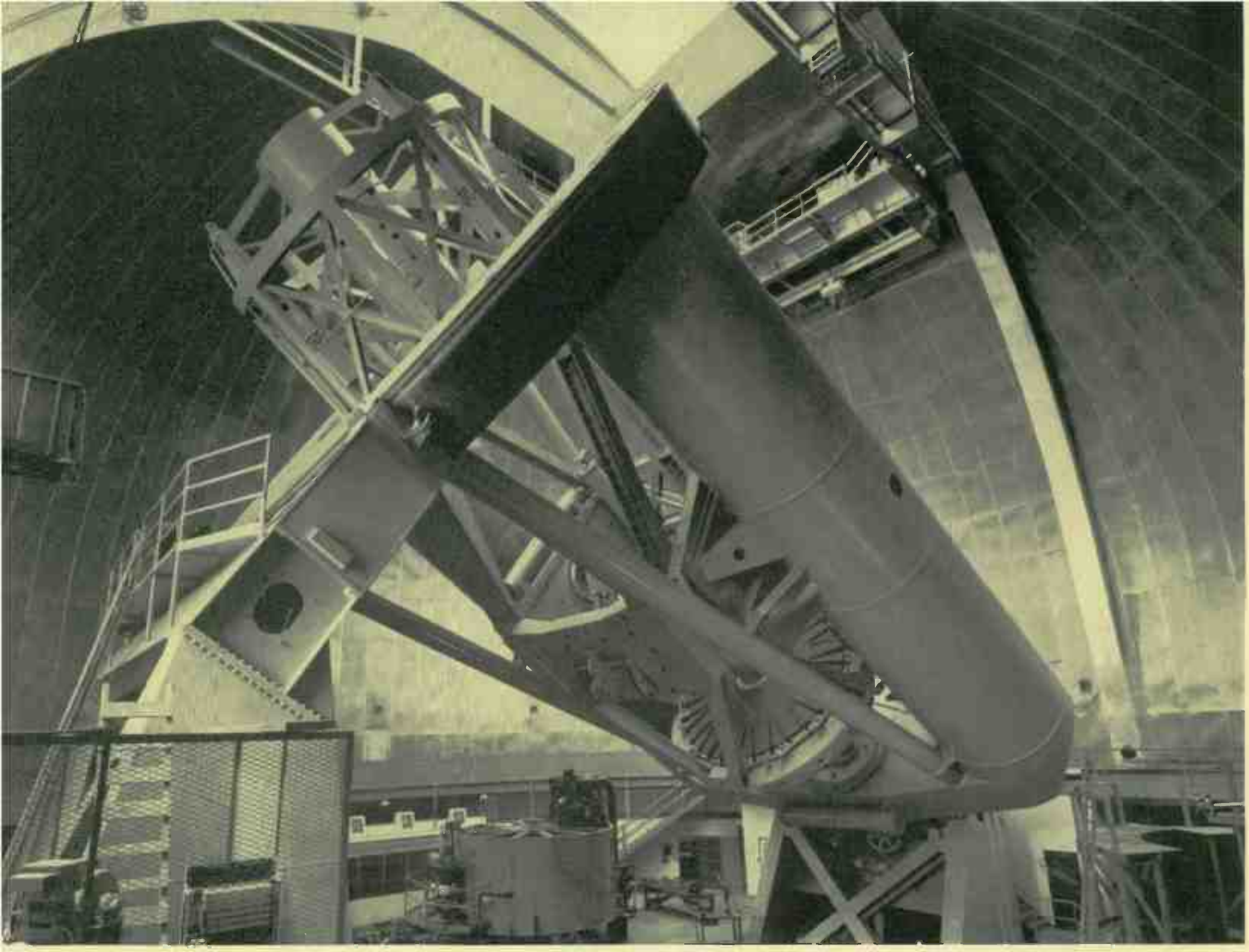
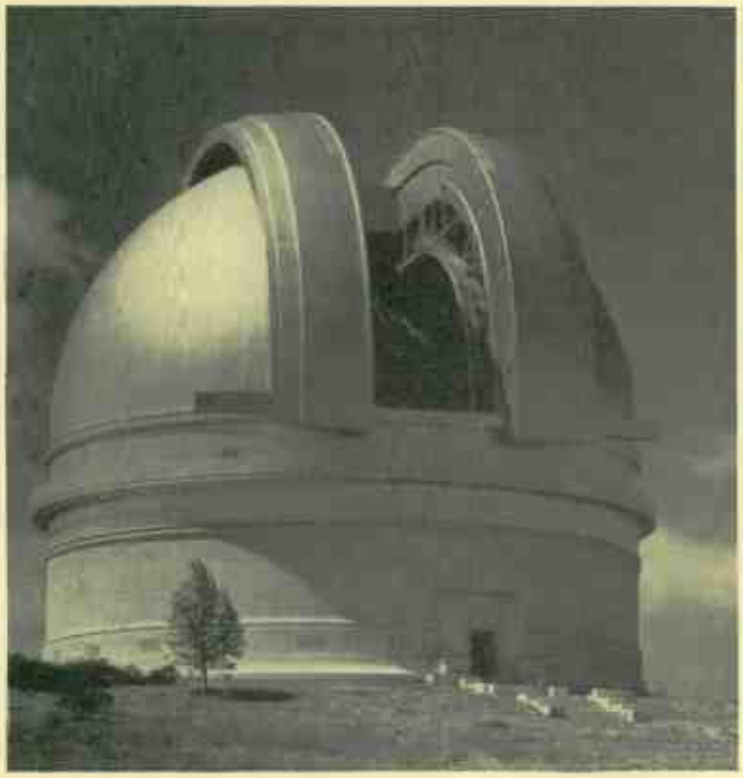


The dome enclosing the telescope belies its size. Actually it is 135 feet across and rises above the plateau atop Palomar mountain as high as a 12-story building. The view above shows the giant being prepared for its dedication early in June.



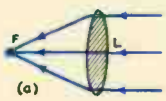
This summer the explorable volume of the universe is being extended about eightfold by that widely heralded new tool of astronomy, the 200-inch Palomar telescope. Few instruments of science have so captured and held public interest over so long a period as this telescope now being readied for service. To the engineer the giant telescope is as interesting for what it is as for what it will do. It is the product of the best of many cooperating technical skills: mathematical, optical, structural, and electrical.

How High Is the Sky!

ENGINEERS and astronomers have much in common. They are all possessed of claustrophobia; they dislike confining boundaries and are forever pushing them back. With engineers it is the restless fervor to make larger machines, or smaller; faster devices or slower ones. With the astronomer it is the desire to extend his depth of vision into space. Early last month was dedicated that most spectacular of all boundary-extending tools—the 200-inch telescope.

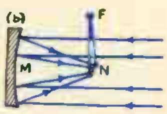
The 200-Inch Is a Combination of Reflecting Telescopes

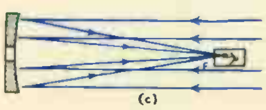
The Palomar giant, for all its size, is, in one sense, the simplest of all telescopes. It is of the reflecting type, consisting of an enormous parabolic mirror that collects light from a distant stellar body and by a single reflection brings it to a focus where the image is recorded on a photographic plate. The instrument is, in short, a giant camera. Thus the telescope has none of the glass lenses that characterize refracting telescopes (*a*). (The largest refracting telescope is 40 inches in diameter. Bigger lenses would be too heavy, would become so thick as to soak up too much of the feeble light, and would distort too much in different positions because it is supported only at the edge.)



The 200-inch disk has a remarkably small ratio of diameter to focal length, $f = 3.3$, whereas most big reflectors have ratios of $f = 5$ or 6. Among other things this has an enormously important structural advantage. The telescope tube is 55 feet long, which is not much more than the 45 feet for the 100-inch at Mt. Wilson. This keeps within bounds not only the mount stresses and weights but also the size of the dome.

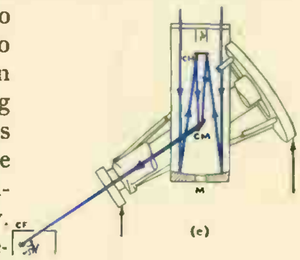
Palomar is simpler than previous reflecting telescopes, which require near the prime focus a second or Newtonian mirror (*N* in *b*) to reflect the image to the photographic or observing position outside the light-collecting path of the main mirror. Elimination of the Newtonian mirror is made possible by the very size of the 200-inch mirror. The mirror's immensity permits locating at the prime focus a tube large enough to hold both film mechanism and observer (*c*) without blocking a significant part of the light from the faint object under observation. For the first time an observer actually rides with the telescope. Absence of the Newtonian mirror has the obvious advantage of eliminating the inevitable error a mirror introduces and the small but important premium of light absorption charged by every mirror for its reflecting services.





But Palomar is more than a single mirror combination; it is provided with supplemental mirror systems for special functions. The simple, single-reflection form will be used when the maximum light-gathering power is required for a small but bright image recorded by long exposure—perhaps extending over more than a single night. For much stellar work, well defined images are required, and for analysis of the light of the stars—which provides clues to their composition—the light must be stretched out into long spectral bands in the spectroscopes. These require supplemental mirrors—of which there are two combinations, the Cassegrain and coudé. In the Cassegrain combination (*d*) a hyperbolic mirror interposed ahead of the film at the prime focus reverses the light beam, sending it back along a path through a 40-inch hole in the center of the 200-inch mirror to the Cassegrain focus below. This gives the telescope a large ratio of focal length to mirror diameter ($f = 16$) desirable for obtaining large-scale images. This follows because in general the greater the focal length the larger the scale or magnification.

The coudé focus has the important characteristic that the light is brought to a fixed, stationary focal point regardless of motion or position of the telescope itself. This coudé focus ($f = 30$), spectrographs, and cameras are maintained in an air-conditioned, constant-temperature room beneath the telescope (*e*). The light is brought to the coudé focus slit by one of two systems of mirrors, depending on the portion of the heavens being observed. All these coudé mirrors and the Cassegrain mirror can be swung into position by remote control as desired. Simultaneously, compensating weights are correspondingly moved to prevent the shifting masses from causing unbalance or distortions in the telescope mount.



The Mirror

The main, commanding element of the sky giant is the big mirror itself. It is a disk cast of special Pyrex glass 200 inches in diameter with a hole 40 inches in diameter at the center through which the Cassegrain hyperboloid mirror reflects light to the Cassegrain focus. (This 40-inch hole in the 200-inch disk is, incidentally, the same size as the world's largest refracting disc.) The upper reflecting surface has been ground and polished to a paraboloid accurate to about one tenth of a wavelength of light. The greatest deviation from the perfect paraboloid is less than two millionths of an inch. The reverse or support side has a pattern of indentations somewhat resembling a waffle. The particular Pyrex has an extremely low expansion coefficient (about one fourth that of plate glass). This is to minimize the distortion that results in the mirror surface as the temperature changes, even by a few degrees.

The ribbed back does three things. It cuts the weight substantially in half, greatly simplifying the problem of the supporting structure. The completed, polished disk weighs 14½ tons. A solid disk would have weighed 25 tons.

The ribbed construction also reduces the amount of mass that must continually seek equilibrium with changing temperatures. The ribbed sections are four inches thick and the surface itself is four and one-half inches thick maximum. Hence no portion of the glass is more than about two

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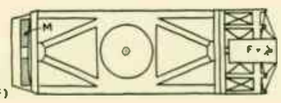
The 200-inch telescope project was conceived and fathered by the great astronomer, George Ellery Hale; financed by a grant to California Institute of Technology of six and a half million dollars by the Rockefeller Foundation. It is an example of cooperation in the grand manner of scores of individuals and many organizations that contributed ideas, technical skills, and the tens of thousands of physical components. Segregation of individual contributions would be fruitless, even were it possible. Westinghouse is proud to have had a major part not only in fabricating the supporting structure but also in assisting with many electrical details and in providing numerous electrical elements. This account, prepared by Charles A. Scarlott, based on information provided by members of the Astrophysics staff of California Institute of Technology, the Allegheny Observatory of the University of Pittsburgh, and engineers of Westinghouse, is not limited to the efforts of a single organization but is an attempt to describe the project as a whole with particular emphasis on representative engineering features.

and one-quarter inches distant from the surrounding air.

The back construction makes possible a new type of support. Between the ribs are cells in which are fitted 36 gravity-compensating supporting mechanisms. Each is composed of 1100 parts, and is designed to prevent sagging or deflection of the 17-foot mirror.

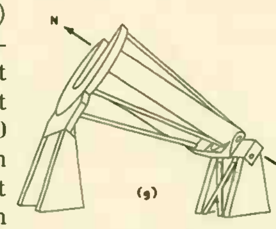
The Telescope Structure

The mirror is held in the lower end of the tube, (*f*) which is a cage-like structure, 55 feet long, and 22 feet across, made up of 20-inch I-beams welded together. An extension to the upper end of this cage is an open-frame ring 22 feet in diameter and 13 feet long that supports in its center 2 steel cylinders or tubes 72 inches in diameter. The lower one provides the setting for the Cassegrain and coudé mirrors when they are required. The observer "rides the telescope" in the uppermost cage. With him are the photographic plate holders at the prime focus, the switches by which he remotely controls all motion of the giant eye, an intercommunication system, and other accessories needed by him as he spends a full night tracking and photographing some celestial object.


(f)

This huge telescope tube, with the 200-inch mirror at the lower end, the prime-focus and observer's cage at the upper end, the Cassegrain and coudé mirrors and compensating weights fastened to it, is supported by large ball-bearing trunnions near its midsection. These trunnions permit the telescope tube to swing in declination, i.e., through an arc in the heavens in the plane of the earth's poles. Thus the telescope tube can move in any north-south plane from the southern horizon to slightly beyond Polaris, the north star.

The supporting structure (*g*) for the telescope tube offered serious mechanical problems in that it must be rigid enough to support its 140-ton load and itself (500 tons in all) in all its positions with almost no distortion and it must allow the telescope to swing in the wide arc of declination just described. Small reflecting telescopes are held between the tines of a fork (*h*). But the mass of the 200-inch mirror tube was much too great to be overhung so far. In fact, this problem had presented itself when the telescope with the 100-inch (solid disk) reflector was designed for Mt. Wilson (*i*). To obtain the necessary rigidity the 100-inch mount was made as a double yoke closed and supported at both ends. But this construction causes the telescope to interfere with itself. The Mt. Wilson telescope is blind to the heavens within about 25 degrees of the north polar axis.



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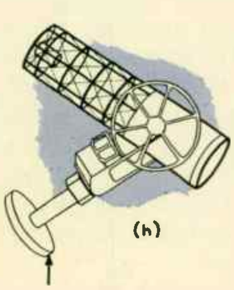
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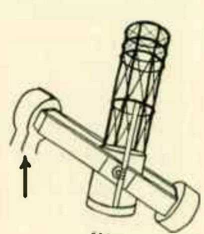
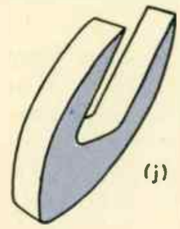

(i)

The 200-inch mount achieves both good rigidity and the ability to "see" any star visible on Palomar mountain. It consists (*h*) of a yoke terminating in an enormous horseshoe-shaped bearing surface at the upper end (north) and a bearing carrying and driving cross-member at the lower end (south). Each side of the yoke is a welded steel cylinder shown in photograph 2 on page 101.

The Bearings

The horseshoe is really a circle 46 feet in diameter with a U-shaped section removed (*j*). It is this U-section that gives the 200-inch mirror the desired universal freedom. For a far northerly look, the telescope tube swings back into the U.


(j)

While every portion of this telescope and its housing presented unusual engineering difficulties, those encountered in machining the horseshoe are representative. The horseshoe is a bearing and, as it turns, its center must be absolutely fixed to achieve an unchanging focal point. It must be a perfect circle when in service, i.e., when carrying its share of the 500-ton load. Unloaded (as during machining after its fabrication) it would be slightly elliptical—not much (only a few thousandths of an inch) but enough not to be the true circle astronomers require of so precise an instrument. To insure its accuracy when installed it was deliberately distorted during machining. Men accustomed to calculating turbine stresses figured that by drawing in the "toes" of the horseshoe with a force of 260 000 pounds and pressing outward near the base of the opening with a force of 450 000 pounds it would be machined as a circle, so that when in service it would have the correct shape.

Friction forces at the horseshoe bearing also presented a serious problem. The telescope is turned in right ascension, to follow some object in the sky as the earth rotates, by a drive located at the opposite end of the yoke (the lower or south end). If the friction at the horseshoe bearing, 55 feet away, were large the resulting twisting moments would inevitably cause serious deflections in the telescope tube. Use of the best "anti-friction" ball or roller-bearing type would induce turning moments of 22 000 pound-feet. Much too much! The solution was found in an oil-pad bearing, similar in fundamental principle to that used to support a waterwheel turbine generator. An extremely thin film of oil (0.003 to 0.005 inch) is maintained between the moving surfaces and the stationary pads. The speed in the case of the telescope is too slow—one revolution per day—for the bearing to create its own oil film as the shoe or runner-type bearings in waterwheel generators do. Instead, oil is forced at pressures of about 375 psi through channels in the four north stationary pads, each of which is 28 inches square. This lifts the slowly turning horseshoe (1.2 inches per minute) sufficiently to avoid metal-to-metal contact. The resulting friction is only 35 pound-feet (instead of 22 000). In the seven-foot circular bearing at the south and driving end, three spherical oil pads similar in principle are employed.

The driving motor that rotates the telescope through a 14½-foot worm gear at the creeping speed of 15 seconds of arc per second of time is rated at only 1/12 hp—about the size of a household fan motor. The gears were cut by C. I. T. engineers to extraordinary precision. Errors in spacing of the teeth were kept to less than one half-thousandth of an inch. This means that the angular error from tooth to tooth is less than one second of arc or four parts per million. To save wear on the operating gear a second worm gear of identical size is used to bring the telescope quickly to a new position. This requires a three-hp motor to drive the telescope at speeds up to 45 degrees per minute.

The 200-inch telescope, as do most large telescopes, employs the so-called equatorial mounting (*k*). The axis of the horseshoe and yoke structure is made parallel to the earth's axis. After the telescope tube has been set to the proper

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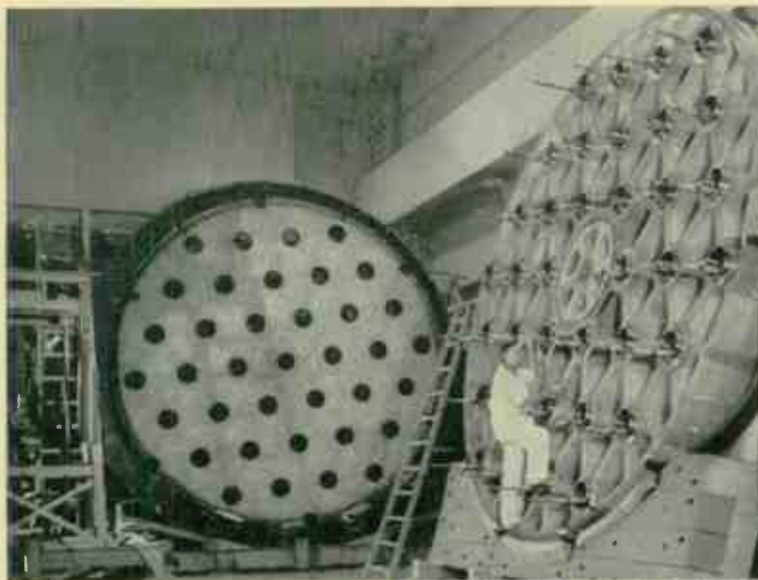
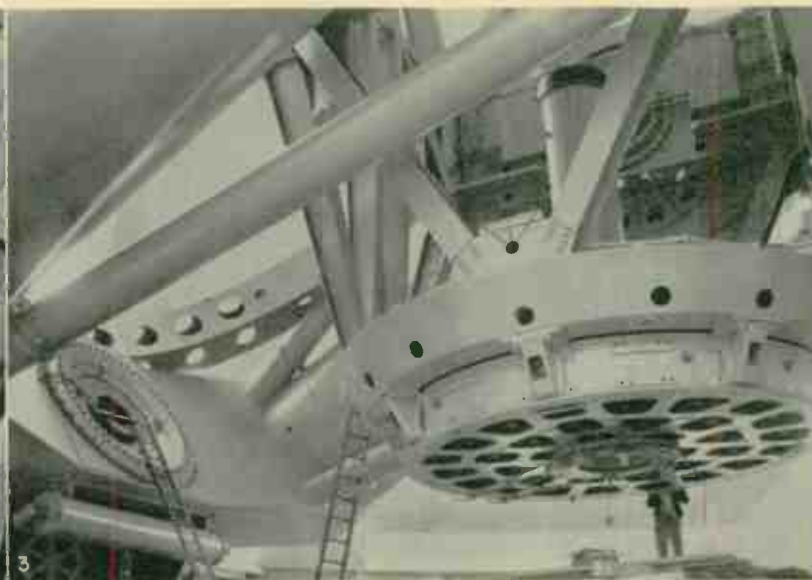
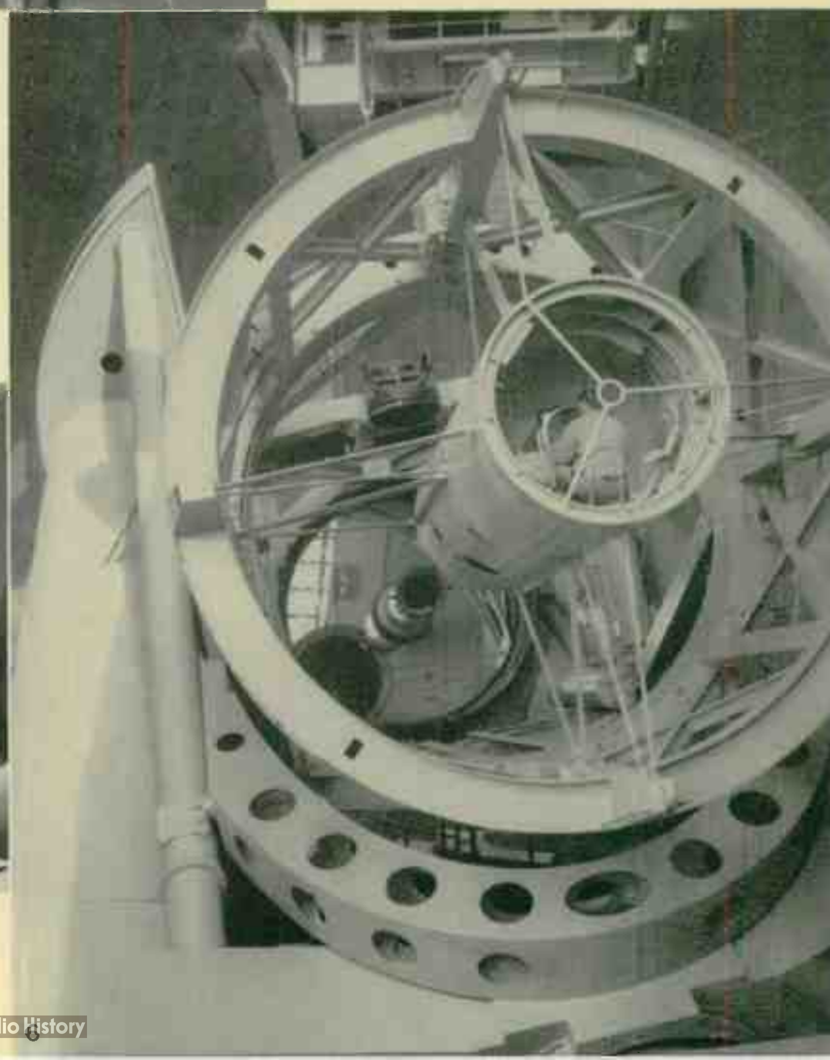




THE 17-foot mirror (1) has been removed from its cell in the optical shop at Pasadena. Resting in its inclined cradle, the ribbed construction of the back surface and the 37 weight-compensating parts are clearly shown. The view in (2) was taken of the support for the telescope tube as it was assembled at Westinghouse, and shows its great size. Each tube is 10½ feet through, big enough for spectrographs and observers.

THE telescope tube with mirror at the bottom is seen in (3). It is suspended on trunnions between the 10½-foot diameter yoke members shown in (2). The south or driving end (declination) is at the left. As one looks down the "muzzle" of the telescope one sees the view in (6). The observer has his normal operating position before the photographic plates at the prime focus, while the tube in which he rides is reflected in the big mirror itself, 55 feet below.

THE control desk for the telescope is shown in (4). The view in (5) shows the elevator that climbs the inwardly curving dome to carry the observer to a point where he can step into the observing tube (see 6).



declination angle, for the mirror to maintain focus on a star requires only that the horseshoe be rotated from east to west (right ascension) at the same speed the earth turns from west to east. This simplifies the drives and their controls.

Electrical Control and Engineering Features

The speed of the right-ascension motor is controlled by adjusting the frequency of the a-c power supplied to it. This basic frequency is generated by the time standard. A new type of clock is used employing the principle of a temperature-compensated vibrating wire developed for power-frequency control. The output of this vibrating-wire time-standard oscillator is modified either by hand or automatically by a mechanical computer that corrects for the small but inevitable errors in the giant structure, and for other variables such as the changes in refraction of the earth's atmosphere as the mirror rotates and "looks" obliquely through changing thicknesses of air. The frequency of the current delivered to the driving motor is the integration of these several factors. The result is automatic tracking of a body within almost infinitesimal limits. But not infinitesimal enough.

The observer who has the lonesome night ride in the prime-focus tube must make the final, tiny adjustments to hold the image, which may be as small as 1/1000 inch, exactly behind the intersection of cross-hairs of his viewing piece during the long exposure. For example, due to air currents, the index of refraction changes, causing tiny shifts in image position.

These changes call, as yet, for human correction. The Palomar scientists, and others, have longingly studied the possibilities of fully automatic tracking using light-sensitive detectors. Although remarkable strides have been made in sensitivity of photoelectric tubes of the electron-multiplier type, they are yet inadequate to operate on the scant light that reaches the earth from some nearby star.

The giant of Palomar embodies other new and novel engineering features, too many even to enumerate, much less describe at length. Among these is the system of remote electrical control, new to telescope operations, by which the observer at any of the several focal points (prime, Cassegrain, or coudé) is kept advised of such data as focus position, zenith angle of telescope, rates of motion in right ascension and declination, sidereal time, Pacific Standard Time, etc. An elaborate system of 68 high-precision Selsyn transmitters and receivers at various points makes this possible.

All operations must be performed reliably. Provisions are made for manual control where automatic equipment may fail. Important auxiliaries are provided in duplicate to minimize loss of observing time caused by outages or maintenance work. Alarms and indicator lights warn of unusual or dangerous positions of mechanisms, and controls are interlocked to allow only the correct sequence of operations. A total of 60 motors, most of them of fractional horsepower, is required for the various telescope functions.

Then there is an enormously valuable new method of applying the reflecting surface that makes the glass disk a mirror. A film of vaporized aluminum under vacuum is applied to the glass. The reflecting surface obtained is far superior to the silver formerly used. It is more permanent, lasting years. Silvered mirrors must be resurfaced every few months. Also, the reflecting power of the aluminum is 100 percent better in the violet and ultraviolet region, a matter of great importance in photographing faint objects of great distance, as well as permitting study of star radiation beyond the violet.

The 200-inch telescope is not just one with double the mirror diameter of the 100-inch. It is the summation of the best that science and engineering can provide—including scores of things impossible when the telescope at Mt. Wilson was assembled two decades ago. Palomar can "see" more than twice as far and can see better—and with the greatest economy of seeing time. The telescope is an expensive seeing machine—costing millions of dollars. One objective that dominated the design of electrical controls and the scores of accessories is that no precious seconds of observing time be lost in the mechanics of the task. A push of a button causes the enormous structure to swing automatically to within five seconds of arc of a preselected star. This is achieved in a few seconds' time. No machine in industry works to a more rigid production schedule.

What Palomar Will Do

The kinds and amount of astronomical exploration that await this new giant are themselves astronomical, much of it being too abstruse for clear understanding by the layman. The 200-inch telescope is, it should be remembered, essentially an enormous, long-range camera. Direct observation, while possible, will be uncommon. Photographic records are permanent, subject to measurement, can be studied by many, and, because of light integration over long exposure times, can "see" things the human eye cannot see. Primarily the telescope is intended, by its more than fourfold light-gathering power, to produce brighter images instead of larger ones and thus see objects much too far away to be recorded by exposures of practical duration with smaller telescopes.

The 200-inch may, however, help solve one particular close-range matter that intrigues layman and scientist alike—the "canals" of Mars. Because the Palomar telescope is "faster" (by four times) than the 100-inch, Mars can be photographed with correspondingly shorter exposures. Hence there should be considerably less blurring of the "canal" markings, if they exist, perhaps recording them with sufficient sharpness to prove whether or not they are artificial.

High on the priority list will be the attempt to resolve the debate as to the expanding universe. Astronomer Edwin P. Hubble, using the Mt. Wilson telescope, obtained evidence (a shift in the light spectra of the farthest nebula toward the red) that led to the startling suggestion that the universe is flying apart at terrific speed. But with the 100-inch, astronomers can't see quite far enough to be positive. With range doubled by the 200-inch, astronomers hope to find conclusive evidence—for or against the notion.

Also astronomers hope to see far enough to bring new data bearing on Einstein's theory that space is curved, which implies that the universe does have finite although grand limits. On this basis light would return eventually (perhaps in 300 billion years) to its starting point.

Not as spectacular but as valuable to science will be the ability of the Palomar giant to probe the secrets of the structure of the universe. With its more powerful spectroscopes the composition of remote stars and their atmospheres can be more accurately known. The relative abundance of chemical elements in the stars can be investigated. Such information bears directly on two fundamental problems, the source of stellar energy and the origin of the chemical elements. The stars are, in fact, a vast laboratory where conditions of both extremely high and very low pressures and high temperature prevail, far exceeding anything attainable on earth. From a study of matter in the "laboratory" of the heavens will come much information leading to an understanding of nature's fundamentals. The 200-inch telescope, by its ability to see distances of one billion light years, will bring men closer to the secrets of the smallest thing in the universe—the atom.

Thermal Protection of Power Transformers

Power transformers should be allowed to carry whatever overloads exist for as long as possible without injury to their insulation. Relays to permit this, operating on the basis of copper temperature, have been in successful service for several years. Now a new relay appears, adhering to the same basic principle, but improved as to accessibility, maintenance, and degree of protection it secures to the transformer. Also it possesses some entirely new features.

C. L. DENAULT, *Transformer Development Engineer, Westinghouse Electric Corporation*

ABILITY to overload a transformer to the fullest extent compatible with safety means dollars to the utility and continuity of service to customers. Many substation operators have learned through experience how to obtain usable overload service from their favorite transformers through varying conditions of load, season and weather. But operators are human. They cannot take care of heavy, short-time overloads and their actions involve human judgment of several variables. Further, many transformers do not have operators. So an electro-mechanical device, such as a thermal relay of the TRO type, steps in to do the job and do it better.

While there were probably many who felt sure that the nameplate values on a transformer did not tell the whole story, it was not until 1930 that the idea was presented in published form.[1,2] In two papers it was pointed out that ambient temperature, previous condition of loading, design characteristics of the transformer and duration of overload—all were factors in determining the amount of overload that could be carried safely. Whether or not the overload would affect the life of the transformer, and if so, how much, were questions that received many contributions in succeeding years.[3,4] The eight-degree rule states that the rate of deterioration of cellulose insulation doubles for each eight-degree C rise in temperature. Coupled with practical experience, this rule formed the basis for early recommendations on short-time overloading. Perhaps the most important contribution was made in 1939 when tests were described[5] showing that repeated heavy overloads did not weaken a transformer of modern design nor cause serious deterioration of the oil. In addition, a new theory was presented for safely overloading transformers by copper temperature and thermal relays. This marked the beginning of safe, scientific overloading of transmission and distribution transformers.

In the years since, much experience has been obtained in controlled overloading of transformers by thermal relays. This experience served as a background in compiling the latest guides and standards sponsored by the American Institute of Electrical Engineers[6] and the American Standards Association.[7] In these publications a relation between hot-spot copper temperature and transformer loss of life is given; but, as stated in the AIEE subcommittee report, "Transformer life expectancy at various operating temperatures is not accurately known, but the information given . . . is considered to be conservative. . . ." In other parts of the AIEE report, relations are given that allow standard calculations to be made for the transient heating of oil-immersed transformers. Here again, these standardized procedures are believed to produce conservative results.

The short-time overload capacity of a transformer depends upon four factors:

1—Time constant of the transformer, or its initial rate of rise in temperature.

2—Temperature differential or gradient between copper and oil.

3—Ambient air temperature.

4—Temperature limit allowed after the transformer has carried a given overload for a given time.

If a thermal relay is to be effective in allowing the safe utilization of the latent capacity of a power transformer, it must automatically recognize all of these factors.

A thermal relay that has been conspicuously successful in the protection of power transformers by copper temperature on the above basis is the TRC.[8] It is a bimetal-actuated device mounted inside the transformer in the top oil zone, that is, in the oil above the core-and-coil assembly. The bimetal receives heat to actuate the contacts from two sources, (1) directly from the oil in which it is immersed, and (2) from the passage of current proportional to the load current through the bimetal itself. When the bimetal is heated sufficiently, as is the case when the safe overload limit of the transformer is approached, movement of the bimetal releases a latch that closes a warning contact. When the safe overload limit is reached, continued movement of the bimetal releases a second latch that closes the trip or alarm contacts. In this relay, resetting the switches and latches is accomplished by a special reset solenoid.

In the course of development leading to an improved relay (TRO), studies were made of various types of heat-responsive systems, that is, systems that produce a usable, reproducible movement or pressure upon application of heat. Model relays were made that used vaporizing liquids, expanding fluids, and bimetal system. These studies, plus results of manufacturing experience and the wartime need for extreme reliability, showed the bimetal system to be outstanding. The bimetal actuator in the new relay is in the form of a helix that rotates a shaft to which contact operating arms are fastened. The shaft, with the bimetal helix at the end, extends a short distance from the back of the relay and is protected and supported by a stainless-steel tube.

The relay contacts, of which there are three sets, are pro-

**Editor's Note: As we prepared this article for publication we asked the author several questions, among them one about the "time constant" referred to. Mr. Denault's answer—written obviously without intention of its publication—we believe is interesting enough to quote in full.*

The TRO relay responds to top oil temperature (top oil temperature rise over ambient plus ambient temperature) and heat that the bimetal adds to it (an amount of heat proportional to load) so that the final temperature of the bimetal is a result of oil temperature and load. By making the increment of heat added to the bimetal by the load current some designed proportion of the winding hot-spot temperature rise over top oil, we arrive at the factor that differentiates the thermal relay (which is responsive to time) and the ordinary hot-spot indicator. The manner by which we arrive at the proper proportion of the hot-spot temperature rise, which is the extra amount of heat added to the relay bimetal, is complex. The calculation procedures and charts require several design manual pages. It is the time factor of the relay that allows heavier overloads to be carried for short times of an hour or two and the lighter to be carried for many hours (up to 24 hours). The relay recognizes this factor of time in determining the amount of safe overload.

The relay and its background sound complex. It is simply a device that follows the AIEE recommendation as to the safe temperature that can be withstood by the hottest part of the transformer winding where time is also a factor. The rules say that a hot-spot temperature of 150 degrees C for one hour, or 115 degrees C for 24 hours, (and other values for intermediate times) will not result in a loss of life of over one percent for the transformer (cellulose insulation—class A).

You see, in a transformer, we have the winding, which is just the copper and associated insulation, as one item which has a time constant of its own—usually from 5 to 15 minutes. The balance of the transformer, mostly oil, but also frame, tank, etc., has another time constant which is a matter of from one to many hours. For all but very unusual conditions, the oil time constant dominates, that is, to reach a dangerous hot-spot temperature, the oil must just have an appreciable temperature rise—which takes time. Thus we can place a relay bimetal in the oil, and add to it the extra amount of heat needed—either directly as with the TRC or by a heater as with the TRO, and we have a device which can protect the winding—provided the time constant of the relay is sufficiently less than the time constant of the transformer as a whole. Just as long as the relay can keep up with—and not lag—the oil temperature rise, it will give protection.

By now things are probably as clear as mud. Let's make it worse. In the TRO heater, the heat input, the heat losses, and the thermal mass of the parts, were carefully related to allow the relay bimetal to follow the oil temperature. Since the relay is not intended to operate under short-circuit conditions, it was not desirable to have the heater thermal relation such that the load-produced heat would raise the bimetal temperature too fast. So the time constant of the relay heater and associated bimetal was made as long as possible to coordinate with the protective relays for short circuits, and yet give protection to the windings for normal overloads.

Now—how can we answer your question! Referring to the four factors:

1—The relay follows the oil temperature of the transformer—and since the oil temperature is determined by the time constant of the transformer, then it can be said that the relay recognizes the transformer time constant whether it be one hour or 15 hours.

2—The heater adds to the oil temperature an amount of heat which makes the bimetal temperature take on the proper value as per application calculations.

3—Ambient temperatures plus oil rise equal oil temperature. Since we are concerned with winding temperature, and the relay is responsive to temperature, the ambient factor is taken care of.

4—The temperature limits are as recommended in the AIEE guides, and are used in the application calculations.

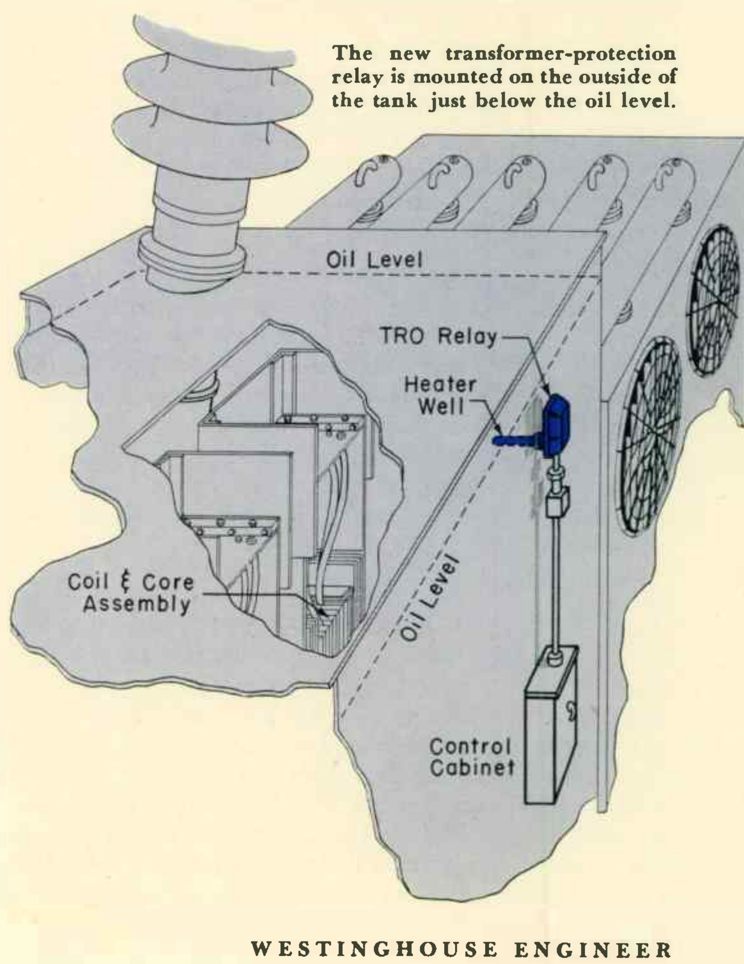
vided by snap action, self-resetting switches. As the transformer temperature increases, the switches are tripped progressively; the first, then the second, then the third. As load increases, the contacts (a) operate fans, (b) give a warning, and (c) trip a breaker or give an alarm as the overload limit is reached. The switches can be easily adjusted to operate at any desired bimetal temperature.

Because the method of heating the bimetal is the key to the success of the relay, many methods and forms of heating have been investigated. In its final form the heater is made as a separate unit in the shape of a hollow cylinder into which the tube-encased bimetal is placed. The time constant* is designed to give proper response of the relay to overloads; yet allows coordination with other relays in the system under short-circuit conditions.

The relay is mounted in a heavy-section aluminum-alloy case on the outside of the tank wall at a point just below the oil level. The bimetal and heater are in an oil-tight cylindrical tube that extends into the oil. This method of mounting places all electrical connections to the relay on the outside of the transformer and makes the relay accessible for inspection and removable for meter-room test without the necessity of opening the transformer, or even taking it out of service. The relay can be applied to existing transformers by cutting a hole in the tank wall and welding on the boss for the well.

The relay requires no additional device to provide ambient compensation. One could have been provided but tests and calculations indicated it is unnecessary. Hot-spot temperature is the sum of (1) ambient temperature, (2) temperature rise over ambient of the top oil, and (3) the hot-spot copper temperature rise over top oil. The relay responds to the top oil temperature, i.e., the sum of the ambient temperature and the top oil rise over ambient, which takes care of the largest part of the correction. The small remaining compensation

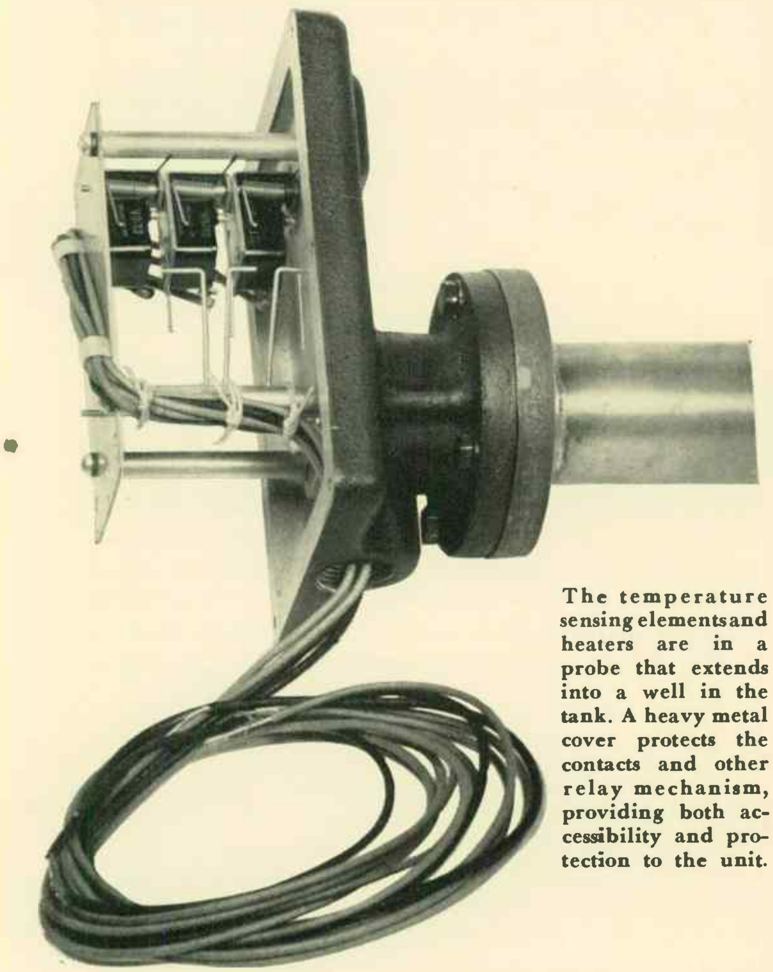
The new transformer-protection relay is mounted on the outside of the tank just below the oil level.



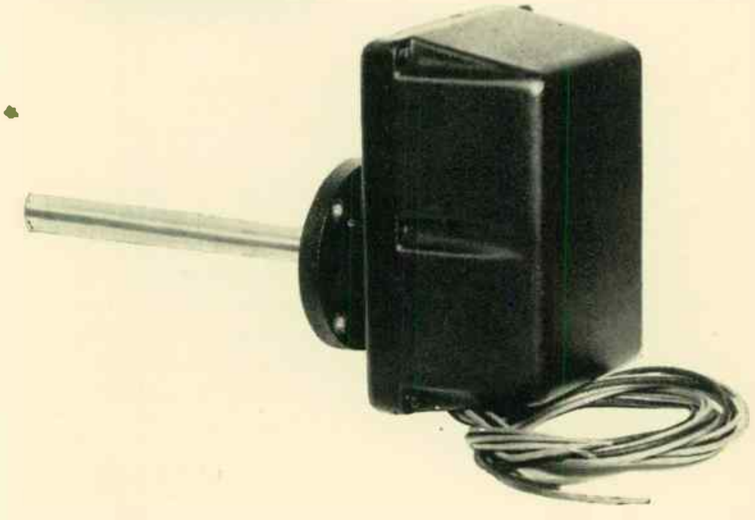
(or possible source of error) depends upon how the load responsive heater is designed. In the heater used, the thermal elements were chosen to follow ambient changes as accurately as possible, thereby doing away with the need for a correction to average conditions provided by a specific "ambient-correcting" device in the relay.

Operating Characteristics

The contacts are self-resetting. However, a seal-in feature for any of the controlled circuits, requiring manual operation of a switch or pushbutton to reset the equipment (usually the warning indicator and circuit breaker), can be provided. Self-resetting is done by small auxiliary relays placed in the circuits between relay contacts and the controlled load. In arranging for self-resetting contacts, the switch differential, that is, difference in relay bimetal temperatures between switch closing and opening points, was carefully chosen. The contacts controlling the fans must not open and close too frequently lest "hunting" result; nor must the fans operate excessively. Also the trip contacts must not remove the transformer from service for too long before the relay cools sufficiently for the breaker to be reclosed. For these reasons, the fan and warning contacts are designed to have a differential of eight degrees ± three degrees C. The trip, or alarm, contact has a differential of ten degrees ± five degrees C.



The temperature sensing elements and heaters are in a probe that extends into a well in the tank. A heavy metal cover protects the contacts and other relay mechanism, providing both accessibility and protection to the unit.



Because the thermal relay is intended to protect the transformer from overloads of the operational type and since other protective relays are available for overloads of the short-circuit class, the relay will not operate on short circuits unless the other protective relays have failed to function. The relay does not operate falsely on overloads of 500-percent, 40-second duration nor on those of 2000-percent and 5-second duration; thus, premature warnings are prevented.

With the TRO separate-heater construction, a single thermal relay can be used to protect a single winding; or, by use of a three-element heater, a single relay can protect all three windings of a three-phase transformer provided the unbalance between phases does not exceed ten percent. The combination of the three-element heater with a single relay gives the windings greater protection than a single-element heater in one of the phase circuits. At the same time, the space required for the three-phase protection is no greater than that needed for single-phase protection.

The convenient location of the TRO relay outside the tank, ease of removal without taking transformer out of service and the added set of contacts for controlling the transformer fans, represent the chief points of improvement of the new relay over the old. The principle of operation, however, tested successfully for over ten years, remains the same.

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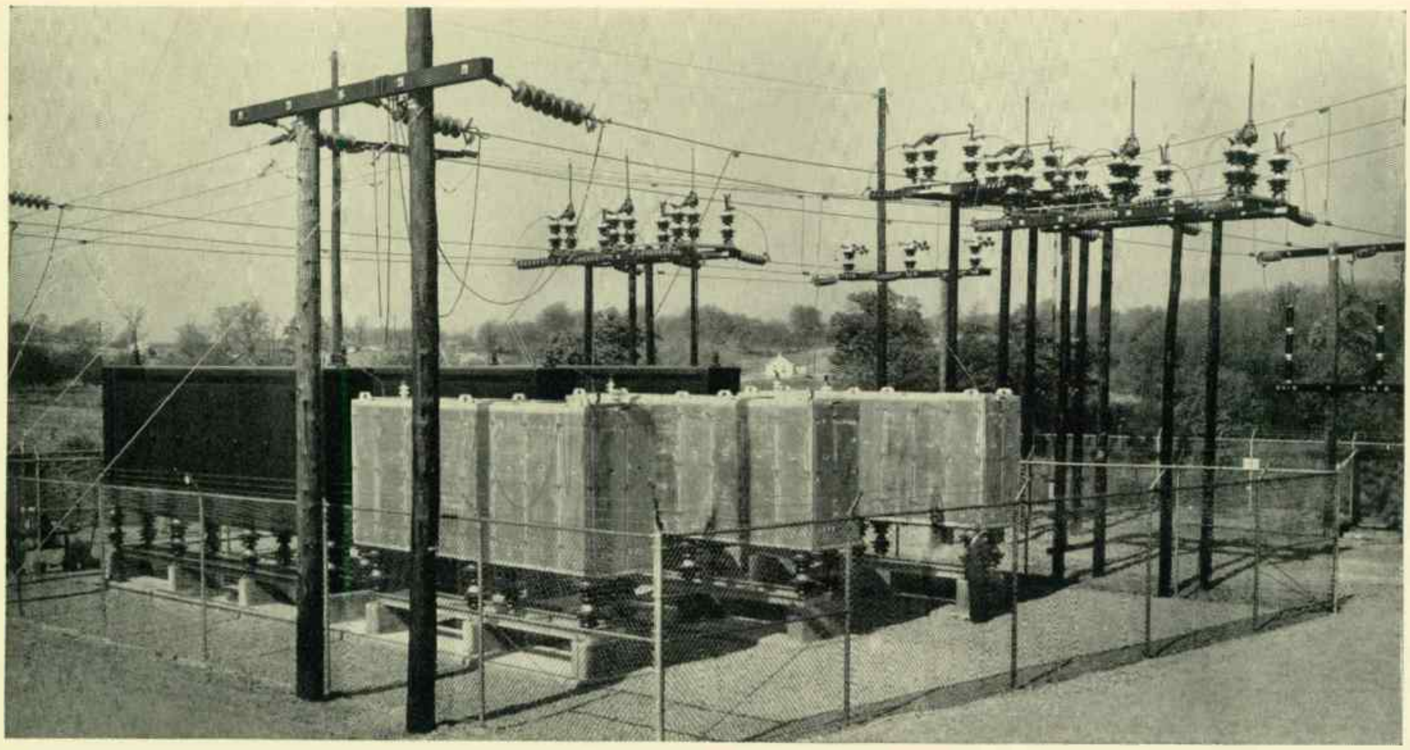
Trends in Vertical Transportation

Vertical transportation is taking two steps forward—as well as traveling up and down. The first consists of a new type of department-store elevator, equipped with a separate "cockpit" for the operator, elevated to give her an unobstructed view of the entrance. Other novel features are a special loud-speaker to broadcast wire-recorded announcements of merchandise and other store activities, an electric-eye safety system that prevents doors from closing on a passenger, uniform-flow ventilation, and high-level, and soft indirect fluorescent lighting.

The second consists of an electric stairway that moves at the rate of 125 feet per minute, almost 40 percent faster than the fastest heretofore in general use in this country. Two such stairways are in operation in Rockefeller Center.



The 10 000-kvar series-capacitor installation on a 66-kv line of the Duquesne Light Company.

Series Capacitors Approach Maturity

The series capacitor, which neutralizes part of the line reactance, is a direct means of reducing voltage drop and minimizing severe voltage fluctuations. Such applications are not new, but they entail many variables not yet fully analyzed. However, sufficient progress has been made to permit certain application principles to be laid down.

A. A. Johnson, *Central Station Engineer, Westinghouse Electric Corporation*

The reputation of the series capacitor is improving rapidly. Until recently, the suggestion to a transmission engineer that he consider its installation to correct voltage conditions usually resulted in a skeptical raising of eyebrows. Yet, despite difficulties, the series capacitor is forging its way ahead in power systems. Like the shunt capacitor,* the series unit spells better transmission and distribution of electrical energy. Behavior of the shunt capacitor is generally well understood and can be accurately predicted—but the same is not true of the series type. Many questions are still unanswered and many problems** are still unsolved. However, the developments and experience of recent years are bringing new knowledge and maturity to the science of applying series capacitors to improve conditions on power lines.

Constructionwise, shunt and series capacitors are identical. In fact, should the need for a series capacitor disappear, it can be removed and reinstalled as a shunt unit. The two types differ primarily in their method of connection. The shunt unit is connected in parallel across full line voltage. The series unit is connected in series in the circuit and hence conducts full line current. While the voltage on a shunt installation remains substantially constant, the drop across the series bank changes instantaneously with load, as with any series device. It is this characteristic, which produces an effect dependent on load, that makes the series capacitor extremely valuable in certain applications. Yet it is this same characteristic that sometimes makes it difficult to apply.

Fundamental Effects of Series Capacitors

A series capacitor in an a-c circuit introduces negative or leading reactance. A current through this negative reactance causes a voltage drop that leads the current by 90 degrees. This drop is opposite from that across an inductive reactance. Thus a series capacitor at rated frequency compensates for the drop, or part of the drop, through the inductive reactance of a feeder. The effects of this compensation are valuable in two classes of applications: one, on radial feeders to reduce voltage drop and light flicker; and, two, on tie feeders to increase the ability of the feeder to transfer power and the stability of the system.

*"Use of Capacitors in Industrial Plants," by R. E. Marbury, *Westinghouse* ENGINEER, May, 1948, p. 84.

**Difficulties encountered in the application of series capacitors will be discussed in the September, 1948 issue of the *Westinghouse* ENGINEER.

Effects on Radial Feeders

The action of a series capacitor to reduce voltage drop and light flicker is illustrated in Fig. 1. The voltage drop through a feeder is approximately

$$IR\cos\theta + IX_L\sin\theta \qquad (1)$$

where R is feeder resistance, X_L feeder reactance, and θ the power-factor angle. If the second term is equal to or greater than the voltage improvement desired, a series capacitor may be applicable. The magnitude of the second term is a relatively larger part of the total voltage drop where power factor is low and where the ratio of feeder resistance to reactance is small. With a series capacitor inserted, Fig. 1 (b), the voltage drop becomes

$$IR\cos\theta + I\,(X_L - X_C)\sin\theta \qquad (2)$$

or simply $IR\cos\theta$ when X_C equals X_L. In most applications the capacitive reactance is made smaller than feeder reactance. Should the reverse be true, a condition of overcompensation exists. Overcompensation is employed where feeder resistance is relatively high to make $I\,(X_L - X_C)\cos\theta$ negative. However, overcompensation is not a healthy condition if the amount of capacitance is selected for normal load, because during motor starting the high lagging current may cause an excessive voltage rise, as shown by Fig. 2. This is harmful to lights and introduces light flicker.

The power factor of the load current through a circuit must be lagging for a series capacitor to decrease the voltage drop between the sending and receiving ends. If power factor is leading, the receiving-end voltage is decreased by the addition of a series capacitor, as indicated by Fig. 3. If the power factor is near unity, $\sin\theta$ and consequently the second term of eq (2), are near zero. In such cases, series capacitors have comparatively little effect.

When properly applied, a series capacitor reduces the impedance of a line and thereby raises the delivered voltage. This increases the kva capacity of a radial feeder and, for the same delivered load kva, reduces line current. However, a series capacitor is not a substitute for line copper.

Series capacitors are suited particularly to radial circuits where light flicker is encountered due to rapid and repetitive load fluctuations, such as frequent motor starting, varying motor loads, electric welders, and electric furnaces. A transient voltage drop, which causes light flicker, is reduced almost instantaneously in the same manner as voltage drop due to a slowly increased load. To predict accurately the reduction in voltage by series capacitors, the current and power factor of the load increment must be known.

Effects on Tie Feeders

Series capacitors can be applied to tie feeders to increase power-transfer ability and improve system stability rather than to improve voltage regulation as on radial feeders. The vector diagrams and eqs (1) and (2) still apply but the emphasis is now on power transfer and stability. For simplicity, assume the feeder impedance consists only of inductive reactance. Since the effect of resistance is small in most tie-feeder circuits, it can be neglected without materially affecting the results. Referring to Fig. 4, the equation for the amount of power transferred through a tie feeder is derived as follows:

$$P = E_R\,I\cos\theta \qquad IX_L\cos\theta = E_S\sin\beta$$

$$I = \frac{E_S\sin\beta}{X_L\cos\theta}$$

$$P = E_R\,\frac{E_S\sin\beta}{X_L\cos\theta}\cos\theta = \frac{E_R\,E_S}{X_L}\sin\beta \qquad (3)$$

where β is the angle between the sending (E_S) and receiving

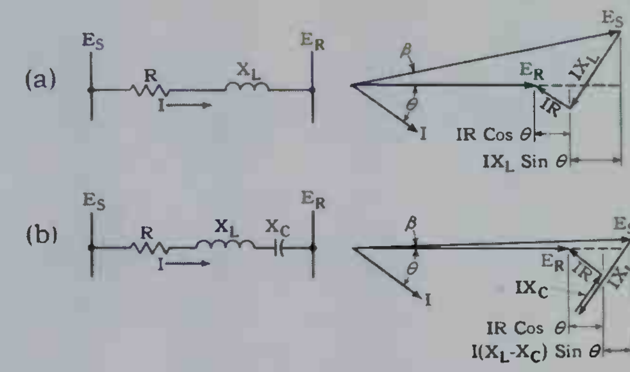


Fig. 1—Voltage vector diagrams for a circuit of lagging power factor (a) without and (b) with a series capacitor. The capacitor increases the receiving-end voltage, thus reducing voltage drop.

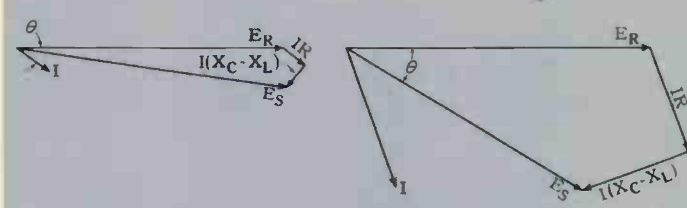


Fig. 2—The high lagging current due to motor starting rapidly raises the receiving-end voltage of an overcompensated circuit causing light flicker.

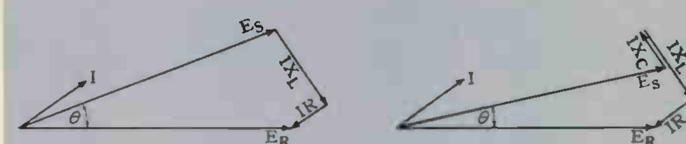


Fig. 3—When the load power factor is leading, a series capacitor is undesirable because it decreases the receiving-end voltage.

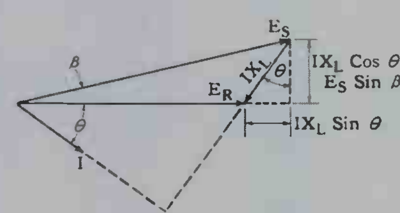


Fig. 4—Vector diagram for a tie feeder in which resistance effects are neglected.

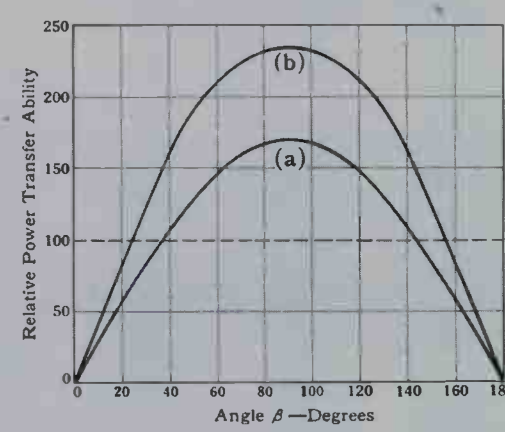


Fig. 5—The power-transfer ability and maximum power transfer of a tie feeder can be increased by a series capacitor.

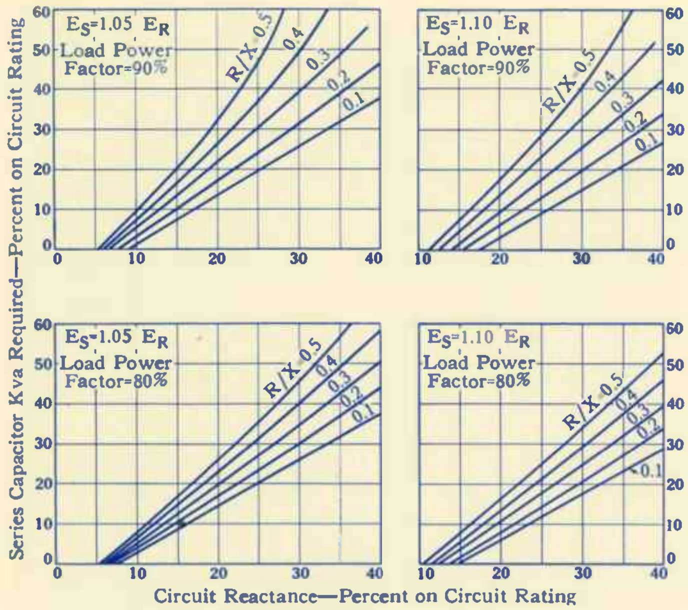


Fig. 6—Kilovar and voltage ratings of a series capacitor for a radial feeder are calculated from these curves.

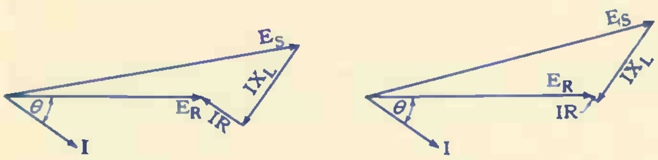
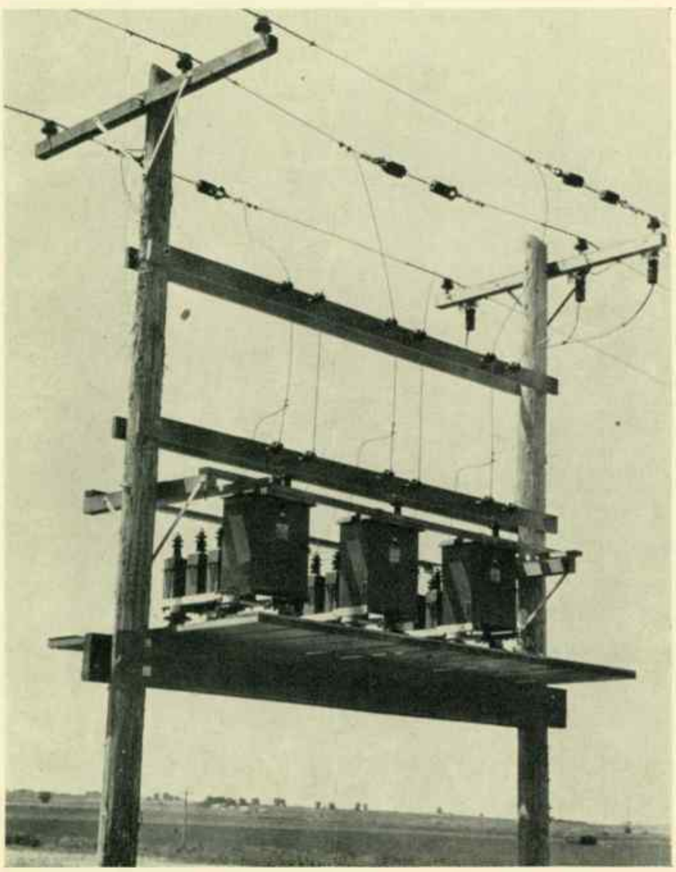


Fig. 7—Feeders having a higher rate of resistance to reactance (for identical percent reactance) necessitate more capacitors.

This 135-kvar series capacitor bank improves voltage conditions on a low-voltage radial feeder.



(E_R) voltages. With a series capacitor, the expression for power transfer is

$$P=\frac{E_S\,E_R}{X_L-X_C}\ \sin\beta \qquad (4)$$

Therefore, for a given phase-angle difference between the voltages, the power transfer is greater with a series capacitor. Thus by making possible a greater interchange of power, the normal load transfer and the synchronizing power flowing during transient conditions are increased, thereby helping stability. This is illustrated in Fig. 5, which shows that for the same angle, a series capacitor effects a 40-percent increase in power-transfer ability—and also the maximum power that can be transferred. Furthermore, to transfer the same amount of power through the tie feeder, angle β is smaller, which aids stability of the circuit.

A series capacitor on a radial feeder is ineffectual unless the load power factor is lagging. This is not as important in most tie feeders as can be seen from eqs (3) and (4). Power transfer is affected primarily by the angle between the sending and receiving voltages and not as much by power factor (which cancels when resistance is neglected). Neither is the difference in voltage magnitudes as important since a small change in this difference may cause a large change in the angle between the voltages.

System Power Factor Improved

The lagging kilovars supplied by a series capacitor improve system power factor, just as a shunt capacitor or an over-excited synchronous machine, but to a much smaller extent. In effect, the capacitor compensates for the I^2X_L "lost" in the feeder reactance. The amount of compensation varies, of course, as the square of the current since the kilovars supplied equal I^2X_C. At half load, for example, only one-quarter rated kilovars is provided.

Application of Series Capacitors

In general, series capacitors are applicable to radial circuits supplying loads of about 70 to 95 percent lagging power factor. Below 70 percent, shunt capacitors are more advantageous. Above 95 percent, the small value of sin θ limits the beneficial effect. Applications to loads of 80 to 90 percent power factor are most likely to be successful.

The application of series capacitors differs materially from that of shunt capacitors. Where power-factor correction is the primary function of shunt capacitors, the only data needed are power factor, magnitude of load, and the desired power factor. On the other hand, the use of series capacitors for voltage correction requires an accurate picture of many other elements of the circuit.

Determination of Capacitor Ratings

A circuit containing a series capacitor is in effect an equivalent circuit consisting of line resistance, line reactance, the series capacitor, and the load. The kva ratings of these components are I^2R, I^2X_L, I^2X_C, and I^2Z, where Z is the equivalent impedance of the load. These ratings, as a percent of the total circuit kva, are useful in calculations concerning series capacitors. The percent rating is obtained simply by dividing the kva rating of each element times 100 by the total circuit kva rating (E_SI). The percent rating of the capacitor, for example, equals 100 I^2X_C/E_SI or 100 IX_C/E_S. The vector sum of the component ratings (as either kva or percent) is equal to the kva rating of the circuit or 100 percent. But because of vector relationships the algebraic sum of the ratings is greater.

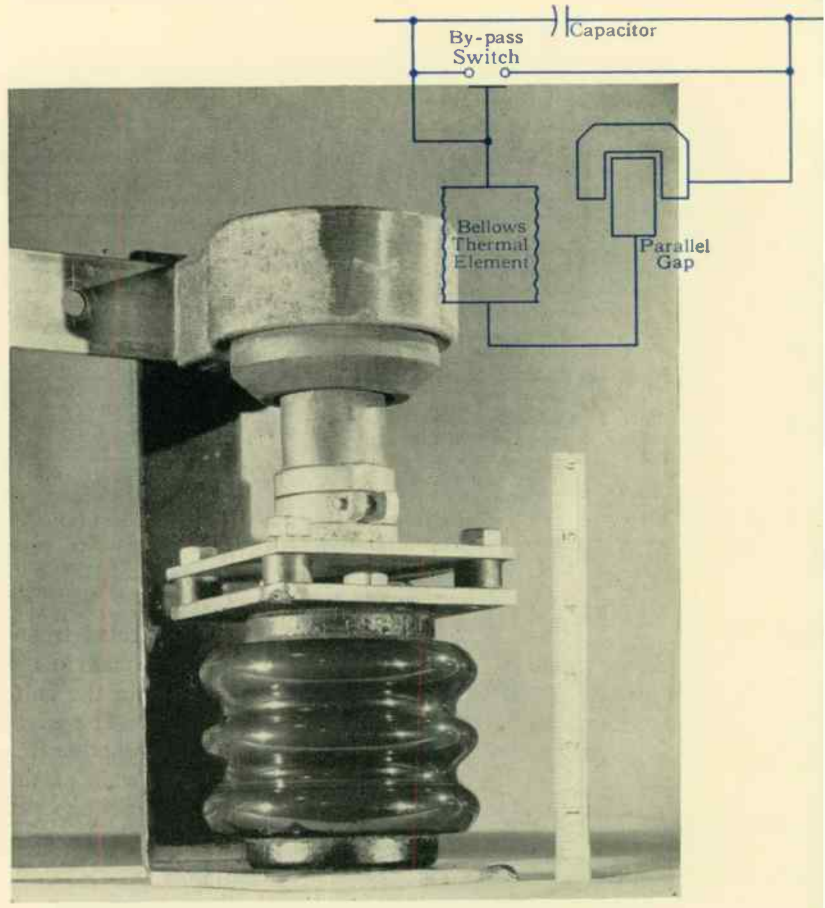


Fig. 8—When the parallel gap breaks down, current flows through the thermal element, which heats and causes the by-pass switch to close, short circuiting the gap. After a time interval the thermal element cools, opening the switch and restoring the capacitor to service.

Calculation of kva ratings as a percent of circuit rating can be extended to voltage. The voltage drops, IR, IX_L, IX_C, and IZ times 100, are divided by the circuit voltage rating (E_S). The percent of the capacitor again equals 100 IX_C/E_S. Consequently, the percent ratings of each component on a kva base and on a voltage base are identical. Therefore, a series capacitor rated 20 percent on the base of circuit kva is also rated 20 percent on the base of circuit voltage. These ratings mean that at full load, the capacitor "consumes" 20 percent of rated circuit kva and the voltage drop across its terminals is 20 percent of rated circuit voltage.

The rating of a series capacitor (kilovars, voltage, and current) for a radial feeder depends on the desired voltage regulation, the load power factor, and the amount of resistance and reactance in the feeder relative to each other and to the circuit rating. The capacitor kilovar rating is calculated from data given in the curves of Fig. 6. To use this data, the feeder rating is taken as 100 percent kva and all other figures are calculated in percent on this base. For example, assume a 10 000-kva feeder having an inductive reactance of 20 percent and a ratio of resistance to reactance of 0.3 supplying a load whose power factor is 80 percent. From Fig. 6, to limit the voltage drop to 5 percent at full load, the series capacitor must be rated 20 percent of the circuit rating. This is 20 percent of 10 000 kva or 2000 kilovars. The capacitor voltage rating is also 20 percent of the rated circuit voltage. Thus if the circuit is rated 20 000 volts, phase to neutral, the capacitor is rated 4000 volts. If a voltage regulation of 10 percent is permissible, only 1100 kilovars (at 2200 volts) are required. Had load power factor been 90 percent, 2200 kilovars (at 4400 volts) would be necessary for 5 percent regulation and 900 kilovars (at 1800 volts) for 10 percent regulation.

Other factors being equal, the ratio of R/X_L has a large effect on capacitor rating, as Fig. 6 indicates. Higher ratios require more capacitors; this is seen vectorially in Fig. 7.

The kilovar and voltage ratings of the capacitor bank have been calculated. Only the current rating remains to be determined. The current rating of the capacitor equals that of the circuit because the bank must be able to carry rated circuit current continuously. In addition, when circuits supply relatively large motors, the capacitor must be able to carry temporarily the starting current of the largest motor plus the current of other loads already in service. The total of the transient and steady-state currents through the bank should not exceed 1.5 times rated.

The rating of a series capacitor applied to a tie feeder is determined from a study of the power-transfer and stability requirements. No definite rules can be stated, but in general, the capacitive impedance of a series capacitor will be less than (probably not more than 70 percent) the inductive impedance of the tie line. If the maximum transient current during a system disturbance is greater than about 1.5 times rated current, stability requirements rather than load transfer may dictate the capacitor rating for a tie-feeder application.

Arrangement of Capacitor Units

When the kilovar, voltage, and current ratings of the bank are known, capacitor units are arranged in series-parallel connections to obtain the desired values. Series connection builds up the voltage rating and parallel connections the current rating. Each bank must be "tailored" to fulfill the requirements of that specific application.

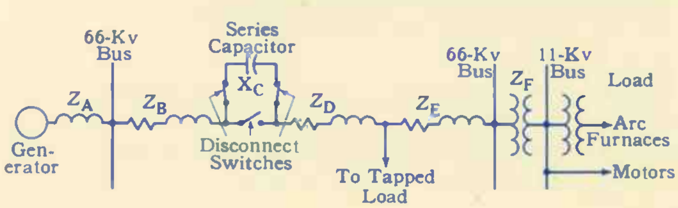
Capacitor banks can be assembled for any current rating and for almost any voltage rating, standard or non-standard. If the voltage across the bank is less than 230 volts, it may be economical to install a step-up transformer to permit using standard capacitor units of higher voltage and lower cost.

Location of Capacitors

In general, a series capacitor can be located at any convenient place on a feeder provided that certain requirements are met. First, the voltage level at the output terminals of the bank must not be too high for the line insulation and lightning arresters; and second, a capacitor on a radial feeder must be located between the source and the load whose voltage is to be improved. Where a radial circuit has a number of tapped loads distributed throughout its length, the best location of the series capacitor is at about one third of the electrical impedance of the feeder from the source bus. If a feeder is very long, two banks of capacitors may be preferable as more uniform voltage is obtained throughout the circuit. Where short-circuit current is high, it may be advisable to locate the capacitor, so that fault current through the protective gaps and switches is a minimum.

A series capacitor located in a substation can be connected

Fig. 9—The equivalent diagram of the circuit to which the 10 000-kvar series capacitor is applied.



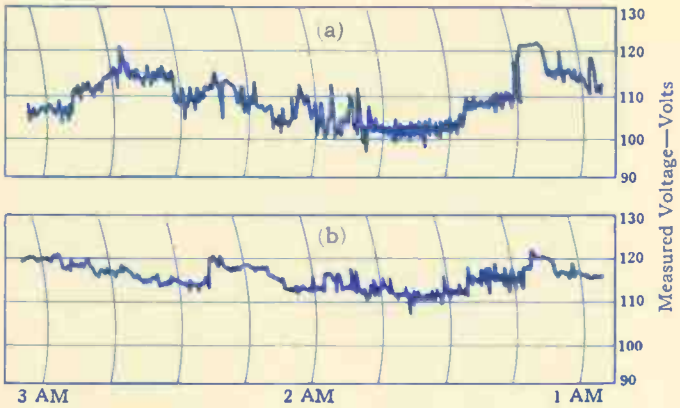


Fig. 10—Voltage conditions at the steel-mill bus (a) before and (b) after the capacitor was installed.

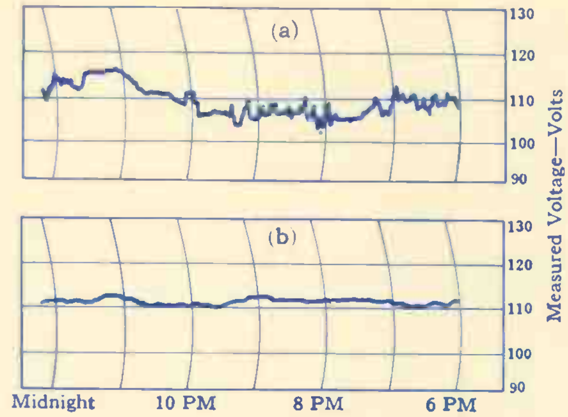


Fig. 11—Voltage conditions at the tapped load point (a) before and (b) after the capacitor was installed.

in each phase on the neutral ends of wye-connected transformer windings to permit use of a lower voltage class in the capacitor insulation. However, this practice raises the voltage-to-ground level of the transformer windings. The effectiveness of a series capacitor is independent of whether it is connected on the neutral ends or on the line ends of the transformer windings.

Protection of Series Capacitors

Because series capacitors must carry not only rated current but also overload or short-circuit currents, they have a five-minute current rating of 1.5 times normal. Capacitors can withstand twice rated current or twice rated voltage for brief periods without damage to the dielectric. To protect a series capacitor against excessive current, a gap is placed in parallel with the bank, as shown in Fig. 8. When the voltage drop across the capacitor (which is proportional to current) exceeds twice rated, the gap breaks down. The gap is designed for low arc drop and high stability and thus effectively short circuits the capacitor. The current through the gap circuit initiates closing of a magnetic or thermally operated by-pass switch, which in turn short circuits the gap. Current through the gap circuit ceases, and after a time interval the by-pass switch opens, automatically restoring the capacitor to service. If the installation consists of two or more groups of capacitor units in series within a bank, each may be protected by its own parallel gap.

Each individual capacitor unit is usually protected against overcurrent by its own fuse, particularly where a relatively large number of units are connected in parallel. Should a unit fail, for example because of an internal short circuit, it is disconnected by the fuse and the remaining units carry the load. The fuses are capable of withstanding the high momentary currents that occur at the instant the gap breaks down short circuiting the capacitor.

Circuit Relaying

On radial circuits fault-protection relaying is usually not affected by the addition of series capacitors. Fault currents are practically always considerably in excess of two times the rated current. Consequently the parallel gap breaks down on the first half cycle of fault current. This happens faster than most types of relays operate and thus relay and circuit-breaker operations are the same as without capacitors. Relaying of line-to-ground faults is accomplished usually by the residual or neutral current, which is not affected greatly by a series capacitor. Fault-protective relaying on a tie feeder, however, may be affected considerably by the installation of a series capacitor. Detailed studies must be made for each case prior to installation of the capacitor.

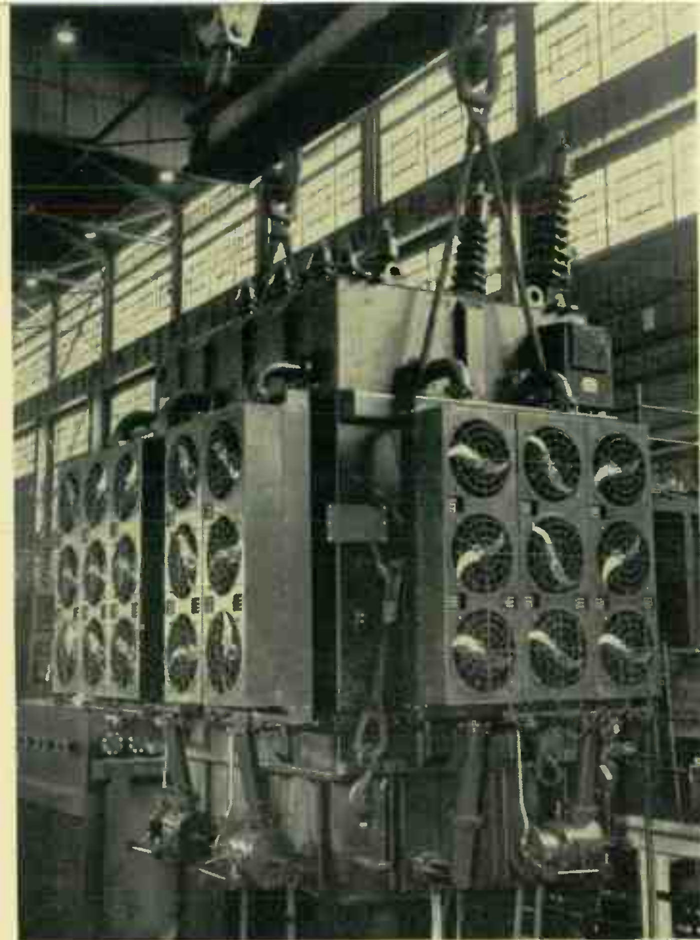
Relative Effect of Power-Factor Correction

A shunt capacitor improves load voltage by neutralizing part of the lagging current in a circuit, thereby reducing the line current and voltage drop. A series capacitor improves load voltage more effectively by compensating directly for part of the feeder reactance, which causes the volt drop. Consequently, the same voltage correction is obtained with a smaller rating of series capacitors than shunt, usually in the ratio of one half to one fourth. However, because the amount of power-factor correction increases with capacitor rating, the shunt capacitor corrects power factor to a greater extent.

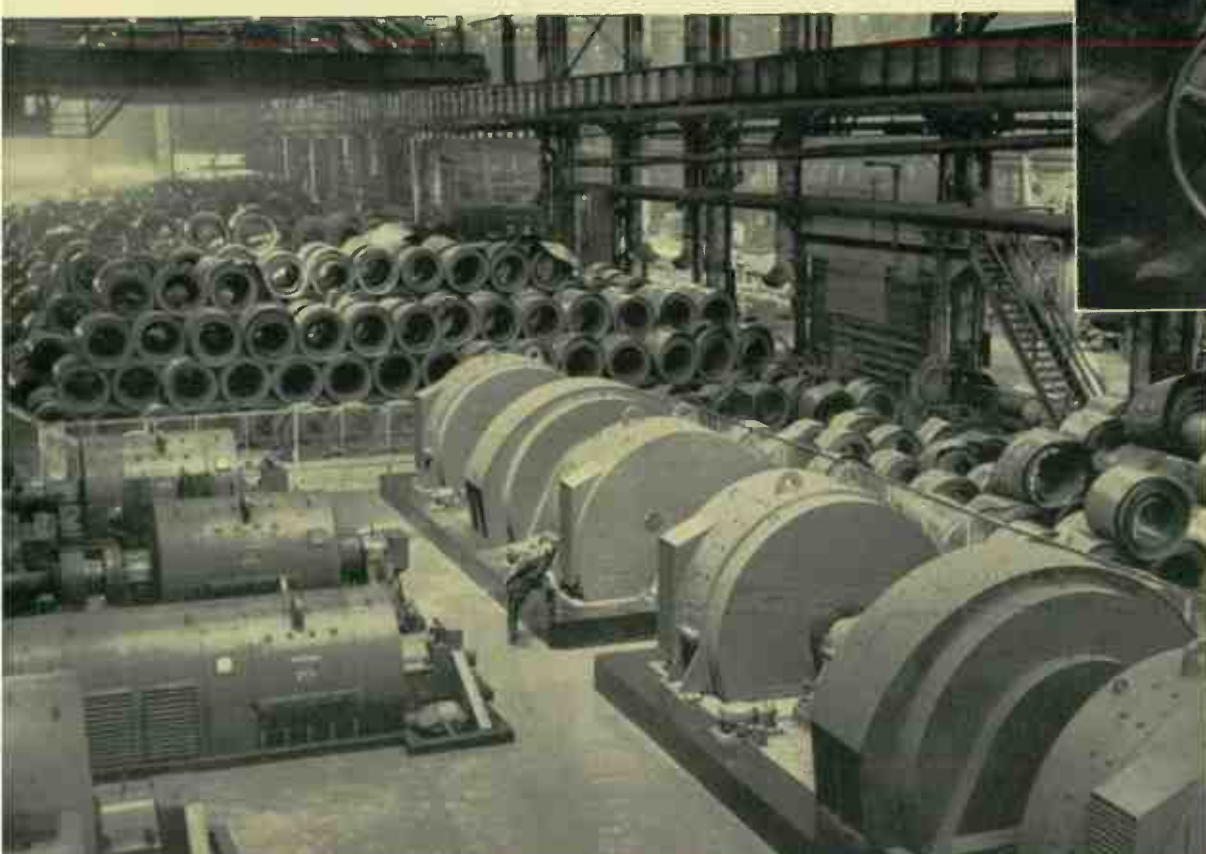
For example, on a 10 000-kva circuit having a load power factor of 80 percent and an R/X ratio of 0.3, 1100 kilovars of series capacitors are required to limit the voltage drop to 10 percent. This capacitor raises the source power factor from about 74 to about 78 percent. If a shunt capacitor is used in this circuit to obtain the same voltage correction, 3800 kilo-

Capacitor units in the 10 000-kvar bank.

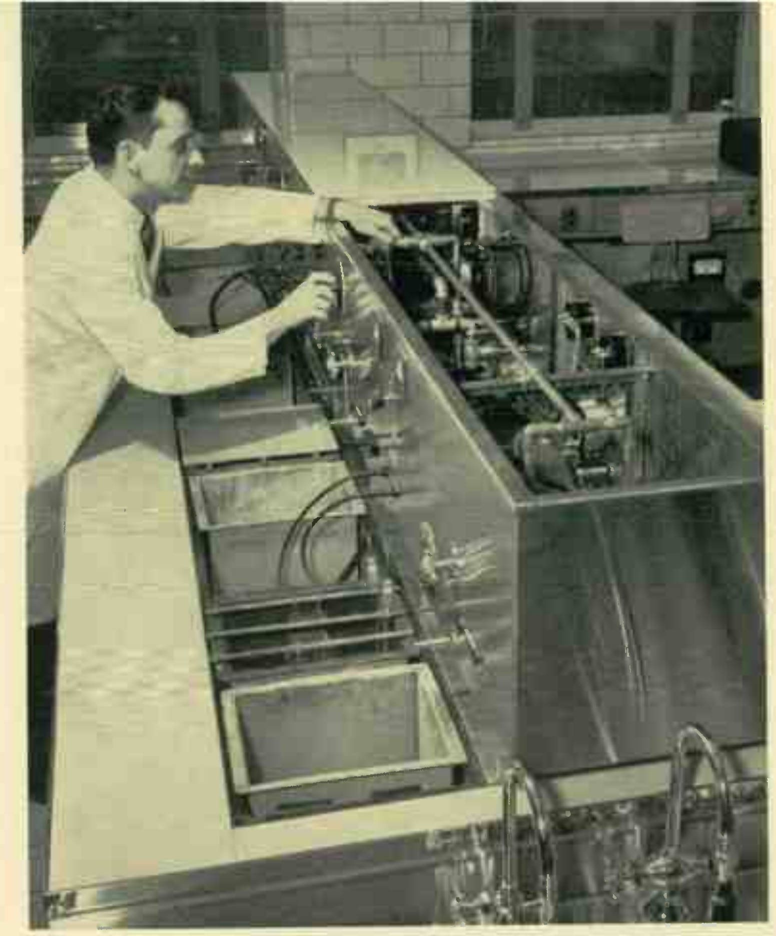
Another notch upward in power-transformer ratings is represented by this 110 000-kva, three-phase unit (right.) It will step up voltage from 13.2 to 115 kv for the Buffalo Niagara power system. Despite its large size the transformer was shipped assembled, except for bushings, lightning arresters, and cooling units. It was laid on its side in a depressed flatcar to meet railroad clearances and shipped with oil covering the insulation and with dry nitrogen gas over the oil.

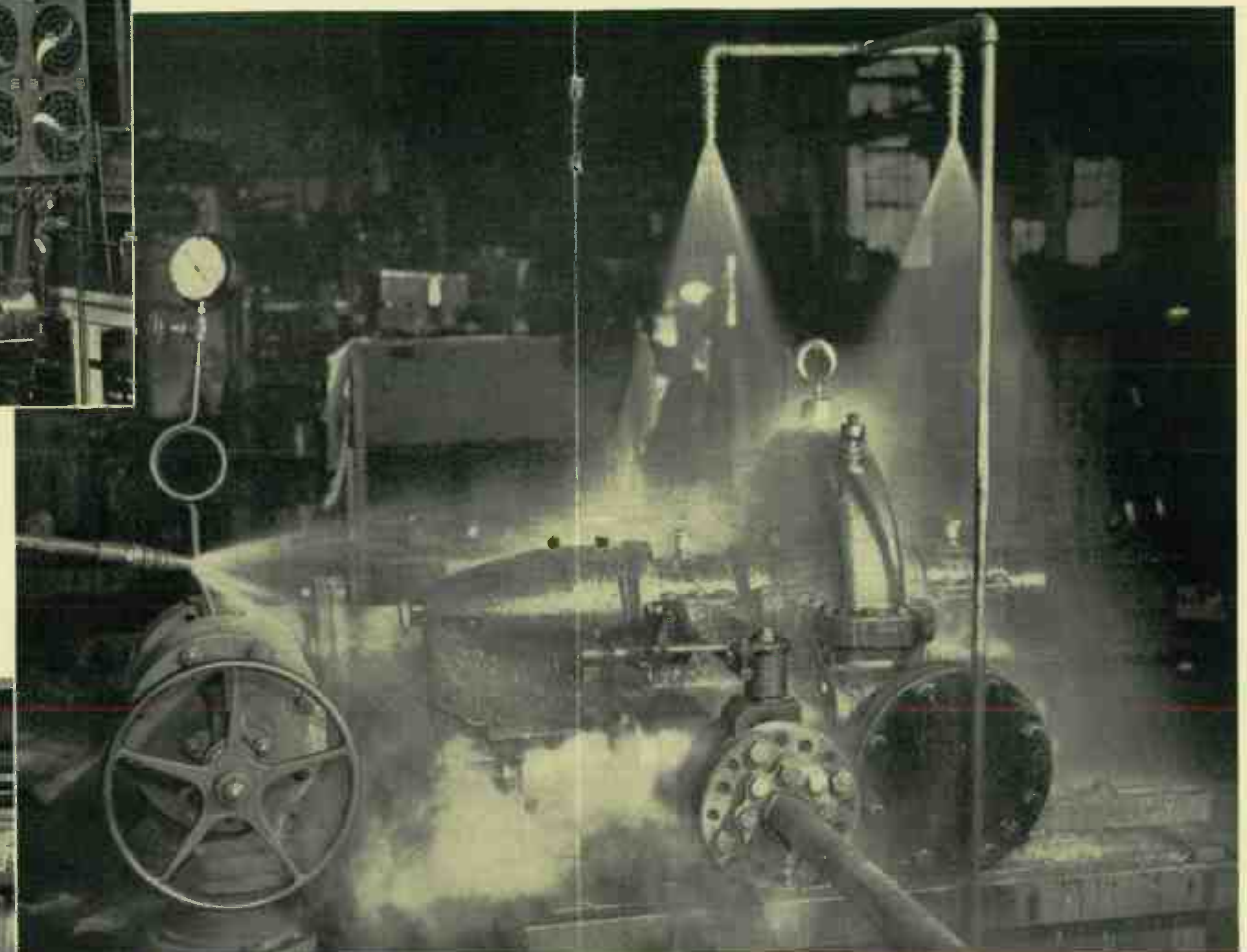


An unusual feature of the mile-a-minute tinplate mill at Weirton Steel Company is the location and method of cooling of the motor-generator sets and drive motors. Normally such rotating equipment is installed in a separate room to protect it from the dirt-laden air of main steel-mill work areas. But in this case the motors and generators are installed right in the mill area (below.) Air is supplied from a Precipitron, which removes dirt particles (below right.)



This new electroplating laboratory (right) will maintain indefinitely its look of newness. Corrosion-resistant materials on tanks, workbenches, and piping—and even on the ceilings, walls, and floors—make this possible. Studies are initiated in small cells, then progress to larger tanks (right) and finally to the pilot plant (lower right.) Below is a 24-hour water test on a new, general-purpose, weather-protected turbine. The water, equivalent to the average rainfall encountered in five years of service, thoroughly tests the watertight seals and lubrication system.





By a previously set "standard" the two pictures below are worth two thousand words. Certainly they tell a complete story of how better light can improve the business district of a small city. Football-shaped luminaires are employed, each housing a 400-watt, 20 000-lumen mercury-vapor lamp, to give a high, even level of glareless illumination.

Stories of Research

Bright Fluoroscopic Images!

X-RAY research workers stand on the threshold of a development, which, if successful, will be outranked in importance only by the discovery of x-rays themselves by Röentgen in 1895. It is a means of intensifying the image on an x-ray fluoroscope screen to such a brightness that the physician can read it almost as easily as he does his newspaper. The vital need for brighter fluoroscopic images was demonstrated to the Radiological Society of North America by Dr. W. Edward Chamberlain, Professor of Radiology, Temple University Medical School, Philadelphia, in 1941. Scientists have probed the problem, but the development of a workable device has defied their efforts.

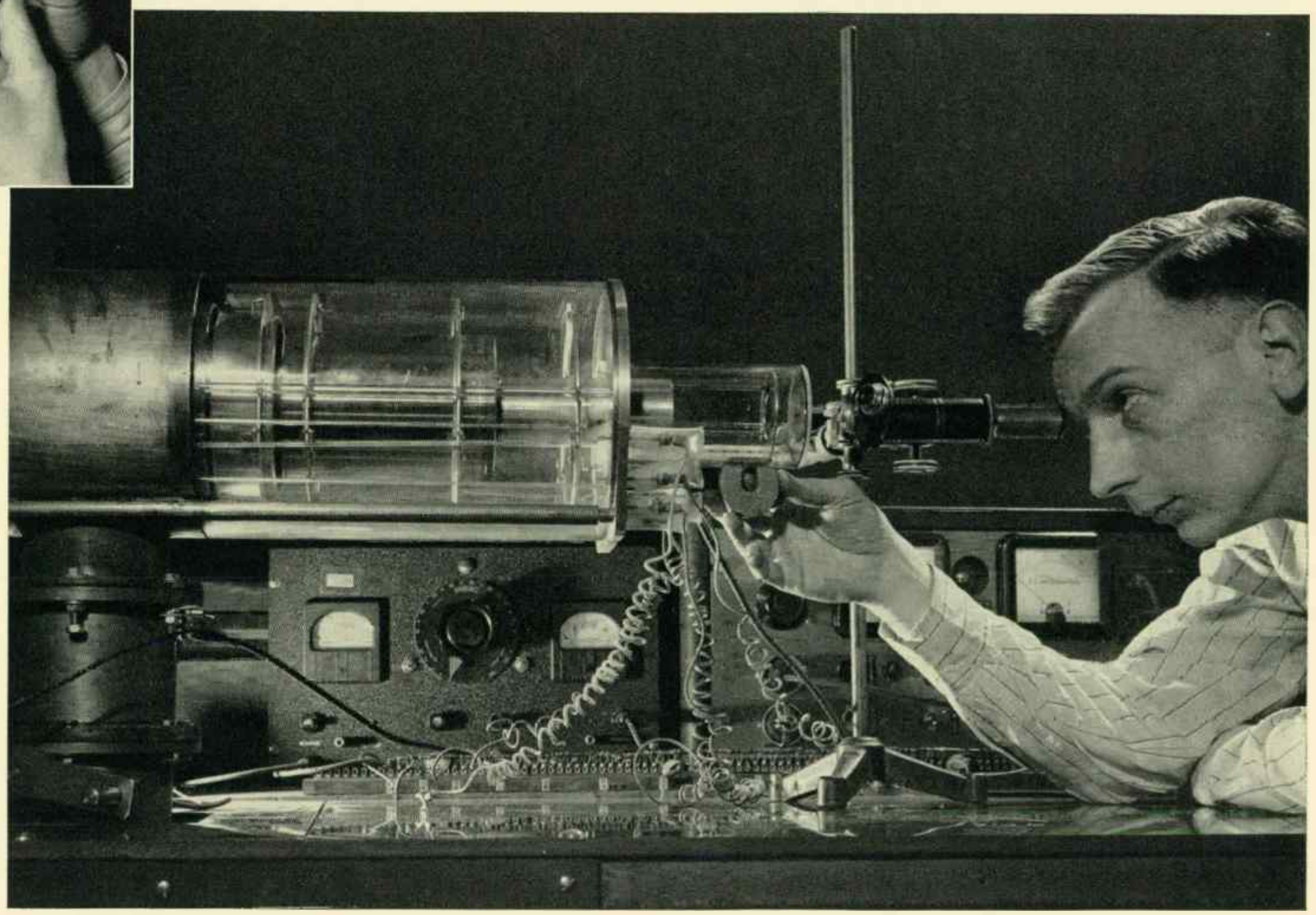
In mid-May, however, Dr. John W. Coltman and his colleagues at the Westinghouse Research Laboratories announced that they had succeeded in their four-year quest for an x-ray image amplifier. A pilot tube has been operated which has produced an amplified image five times brighter than the original x-ray image. With further refinement and the aid of an optical system of enlargement, the scientists expect to produce a commercially practical tube that can intensify the original x-ray image 500 times.

When completed, this should prove little short of revolutionary for the field of medical x-ray diagnosis. It would mean that the physician could examine the x-ray image without first dark-adapting his eyes for lengthy periods of time. It would lend greater resolving power to his eye, enabling him to distinguish between objects close together. Even more important, it would unmask the fine anatomic detail in the fluoroscopic image, thus revealing evidence previously obscure. It might even be feasible to transmit the intensified image via television.

The tube developed by Dr. Coltman and colleagues does its work after the x-rays pass through the subject. These are made to impinge on a fluorescent screen, releasing a stream of light rays. The latter, in turn, strike a photoelectric surface coated on the fluorescent screen. The electrons emitted are accelerated by voltages above 20 000 across the evacuated space within the tube and are focused by electrostatic lenses on a second fluorescent screen at the end, where light rays are produced to form the image.

In the full-scale tube now under construction at the laboratories, the original x-ray image will be reduced at the receiving end by a factor of five, so that if the original image measures five inches across, the final one will be but one inch in diameter. By thus "compressing" the stream of electrons, the final image is additionally intensified by a large factor, because many more

At left is the small tube on which x-ray image amplification has been successfully achieved. Below is Dr. Coltman with apparatus for exploring the principles underlying control and build-up of x-ray produced electron streams.



vars are required, but the source power factor is raised from 74 percent to 91 percent lagging.

To increase materially the source power factor as well as improve voltage, shunt capacitors at or near the load offer the best solution. Usually shunt capacitors must be switched in one or more groups to keep within desired voltage limits as load varies. Shunt capacitors do not reduce light flicker because they cannot be switched "on" and "off" fast enough to counteract rapid fluctuations in voltage.

10 000-Kvar Series Capacitor

Last fall a 10 000-kvar series capacitor*, the largest thus far, was placed in service on a 66-kv radial circuit having a rated load of 500 amperes. Each phase of this capacitor bank consists of 240 standard 15-kvar, 2400-volt units, divided into 3 groups connected in series. Each group, which contains 80 units in parallel, is protected by its own gap and accompanying by-pass thermal switch.

A series capacitor was selected because the desired voltage improvement is obtained more efficiently and at less cost than by any other method. The principal function of the bank is to improve the voltage level and decrease flicker voltage at a steel plant where the bulk of the load consists of four 10 000-kva electric-arc furnaces (Fig. 9). The heaviest load normally encountered is approximately 37 000 kva at about 78 percent power factor. The change in voltage conditions effected by the series capacitor is shown in Fig. 10, which indicates that the fluctuations are reduced and the average voltage level during periods of peak load is increased about 10 percent. Before installation of the capacitors, the voltage at the bus dropped from 12 000 volts at no load to 10 000 at full load. The full-load voltage is now about 11 300 volts. Furthermore, voltage conditions at the tapped point (Fig. 11), which was previously used only as an emergency supply to a nearby town, are so improved that this source now provides every-day power service.

The series capacitor compensates for 57 percent of the total circuit reactance up to the 11-kv steel-plant bus. This decreases by over 50 percent the magnitude of the change in voltage level during periods of heavy load and also reduces flicker voltage. However, the capacitor compensates for 100 percent of the total reactance up to the tapped load point. As a consequence the change in voltage level is reduced even more (about 80 percent) than at the steel-mill bus. Furthermore, the sudden fluctuations at the tapped point are almost entirely eliminated.

In addition to the furnace load the steel plant has several motors, the largest being a 4000-hp wound-rotor induction motor. A 400-ohm resistor across the capacitor gives sufficient damping for successful motor starting and prevents self-excitation or subsynchronous resonance. Such phenomena sometimes occur when large motors (relative to the circuit rating) are started through a feeder containing a series capacitor. The resistor, because of its continuous losses, is undesirable but experience has indicated that it is essential for successful motor starting.

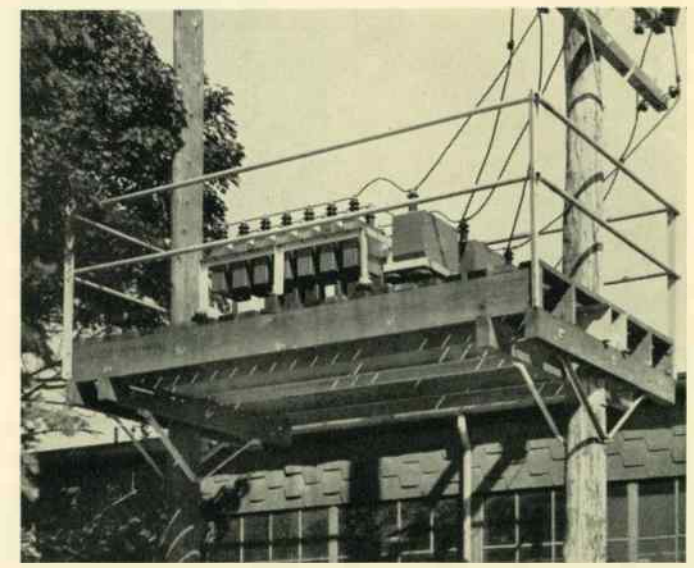
This large series capacitor has been very successful. Had a synchronous condenser been installed at the load instead of a series capacitor, the initial cost would have been at least doubled and the continuous losses would have been much greater. The installed cost of such a capacitor is estimated to be about sixteen dollars per kilovar.

Progress of Series Capacitors

About 100 installations of series capacitors are in service on power circuits throughout the United States. The best results are obtained where there are no relatively large motors and where the capacitive reactance provided by the series capacitor is less than the inductive reactance of the circuit up to the principal load point.

Good results have been obtained with capacitors in circuits supplying electric-arc furnaces, one of the worst types of industrial loads. Series capacitors are ideal for resistance-welding devices where they can reduce the kva demand by 50 to 75 percent. Welders can be provided with built-in capacitors. If a series capacitor is applied to an existing welder, modifications to the welding transformer must be made to prevent excessive current flow.

While most of the improper operations of series capacitors are due to the fact that circuits with series capacitance resonate at some frequency, some trouble with protective devices



A typical series capacitor on a distribution circuit.

has been encountered. But with new developments and information and experience gained on recent applications, more reliable performance is expected in the future. Some types of equipment should not be supplied through series capacitors because of difficulties that at present cannot be overcome. Overcompensation except in very special cases should be avoided as it produces undesirable results.

Twenty years ago shunt capacitors were used to a very limited extent. Today they have been universally accepted as practical, reliable, and economical solutions to many problems involving voltage level, power-factor correction, equipment loading, etc. Many shunt capacitors rated over 5000 kva and a few over 10 000 kva are in operation. Undoubtedly the same evolution is now in process with series capacitors. Several series capacitors rated over 1000 kva and one installation of 10 000 kva have been installed. Perhaps the "ice" has been broken and other large installations will follow. Experience gained on the 10 000-kva installation certainly indicates that large series capacitors applied carefully are economical and successful in operation. Still further progress is likely to result from studies now being made on the application of large series capacitors to extra-high-voltage transmission lines.

*AIEE Technical Paper, "10 000-Kva Series Capacitor Improves Voltage on 66-Kv Line Supplying Large Electric Furnace Load," by B. M. Jones, J. M. Arthur, C. M. Stearns, Duquesne Light Company; A. A. Johnson Westinghouse Electric Corporation.

light quanta are produced per square inch of fluorescent screen. The final step planned is to enlarge this small image optically, so that the physician reads the results on an image about five inches in diameter.

In addition to condensation of the electron stream, two other factors are responsible for the increase in image intensity. First, by accelerating the electrons to very high velocities, considerable additional energy is added to the electron stream before it strikes the fluorescent screen. The greater the energy of the electron stream, the larger the number of light quanta produced; and consequently, the more intense the final image. Secondly, the number of light-producing electrons plays an important role. It is estimated that each x-ray quantum striking the first fluorescent screen is productive of around 2000 light quanta, and that about one in 20 of these light quanta is able to shake loose an electron from the photoelectric surface. At the second fluorescent screen, the accelerated electrons may produce from 50 to 100 light quanta per electron, depending upon the voltage.

By increasing the image brightness 500 times, the amplifier tube will permit the physician to perceive structures at present indiscernible. It is mainly the limitations of the human eye that impose restrictions on present-day x-ray fluoroscopy. It has been estimated that an x-ray image taken through an average human abdomen on the best fluorescent screen available is about 30 000 times dimmer than a sheet of white paper viewed under a reading lamp. At this level, the eye can barely distinguish objects separated by as much as one-eighth inch.

To achieve even this low sensitivity, the x-ray diagnostician must dark-adapt his eyes, which means sitting in a dark room for times ranging up to 30 minutes or wearing dark red glasses.

With fluorescent screens at close to the peak of their efficiency, it soon became apparent to workers in the fields that the only solution lay in increasing the energy striking the screen. But the stopper here was that x-ray intensities were about as high as could be safely used. So the natural conclusion was that any energy increment had to be added after the x-rays had passed through the subject.

The new image-amplifier tube is still in the development stage. When commercially available, however, it will appear as an attachment that can be readily adapted to present x-ray fluoroscopic equipment.

High-Voltage Howitzer

The "offensive" looking apparatus above is not a new type of machine gun. Nor is it an atom-powered death ray. It shoots—yes—but it confines the charge to itself. The equipment is employed in a study aimed at finding new ways of controlling electrical arcs by use of gases instead of oils, for example, in transformers. The gun tests the suitability of new types of gases by determining their resistances or breakdown limits. Two electrodes within the gun are separated by the test gas. When the gas breaks down, the gun shoots a high-voltage charge across the electrodes. Here Carroll N. Works prepares to discharge 600 000 volts through a test gas.

Measurement by Millionths

In his efforts to detect the unseen or measure the impalpable, the scientist has found the mass spectrometer to be one of the most versatile of instruments. Its ability to analyze complex hydrocarbon mixtures, quickly and easily, has made it an important production aid in the manufacture of synthetic rubber, aviation gasoline, and similar products. As a leak detector in vacuum systems, it has proved to be uncannily sensitive. Wherever the purity and quantity of complex gases require checking, the mass spectrometer provides the answer.

W. M. Hickam, of the Westinghouse Research Laboratories, has recently added still another valuable application to this long list: the detection and measurement of extremely minute quantities of impurities in metals. With the aid of a resistance furnace to vaporize the sample, Hickam can obtain complete "spectrums" of impurities of the metal in proportions as small as one part in a million. Both in sensitivity and speed of analysis, the spectrometer is in many cases a big improvement over the conventional emission spectrographic method or simple chemical analysis.

A small tungsten-wire resistance furnace provides temperatures up to 2500 degrees F. The metal sample, which averages around two milligrams (0.00007 ounce) in weight, is dropped into the furnace by means of a device that allows consecutive testing of 16 samples without readjustment of the spectrometer. As the vaporized molecules are ejected from the sample they enter an ionization chamber through which an electron beam is passed whose energy ranges from 50 to 75 volts depending on the impurity being analyzed.

The ionized particles are then pulled by an accelerating potential, ranging from 300 to 1300 volts, into the curved tube of the mass spectrometer. Only those ions having a mass identical with that of the impurity being sought pass all the way through the tube and into the recorder; all others strike the sides of the passage and give up their charge. At the exit end of the tube, the ions reach the collecting electrode, where the current is amplified and measured. Since the ion current is proportional to the rate of evaporation, this current integrated with respect to time provides an accurate record of the impurity concentration.

A great aid to the sensitivity of the mass spectrometer in this form of analysis is the fact that the saturated vapor pressures of the impurities often are many times that of the base metal. Copper, for example, melts at 1981 degrees F, but some of its impurities melt at lower temperatures. Consequently, the impurities in copper boil off in a very short time as compared to complete vaporization time of the copper. This means that large numbers of vaporized molecules of the impurity are made quickly available for ionization and analysis, thus improving the sensitivity of the instrument to a large degree.

In addition to its use as a practical analytical tool, the new technique is expected to be productive of much new fundamental information on processes involving formation of ions.

W. M. Hickam of the Westinghouse Research Laboratories takes a reading on the mass spectrometer, which he has applied to the detection of extremely minute quantities of impurities in metals. The scientist is able to make 16 consecutive analyses without major readjustment of the device.

Power-Generating Units—All in One

By

J. C. Spahr
Turbine Engineer

M. A. Nelson
Condenser Engineer

J. G. Partlow
Generator Engineer

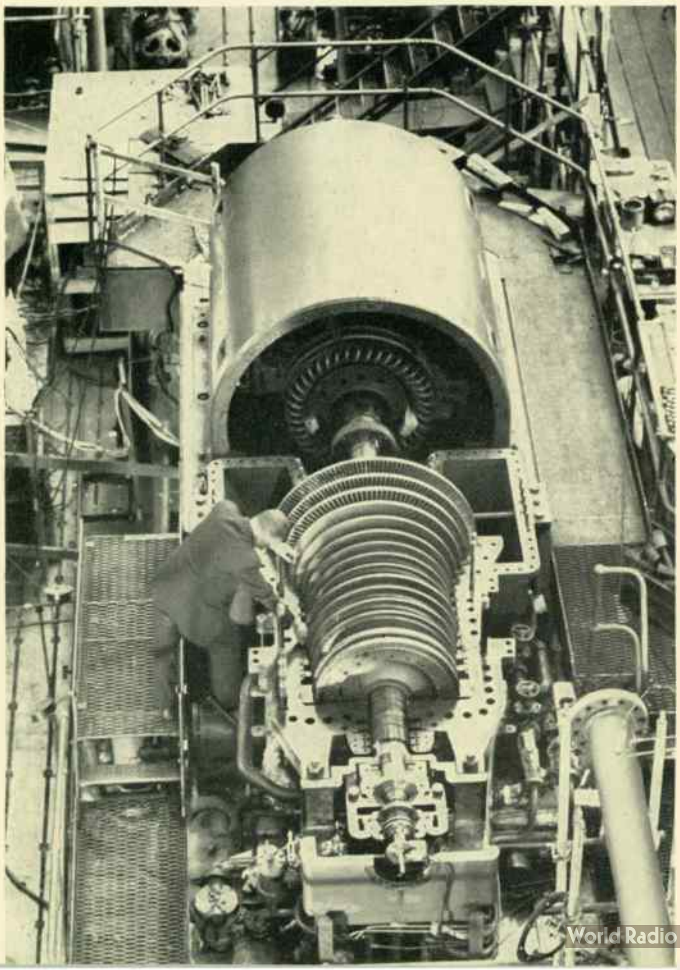
Westinghouse Electric Corporation

The final erection and assembly of a turbine generator in a steam power plant is an enormously complex undertaking. Even in smaller units, it may require months of coordinated effort between the manufacturer's engineers and the plant's construction crew to put together the major components and the many auxiliaries, each in its place and properly connected. The 5000-kw power-generating unit provides a major simplification to the process of installation, which is but one of its advantages.

Necessity, mother of inventon, stimulated by the recent war, has given us the simplified power-generating unit. Requiring only a supply of steam and cooling water, the unit consists of a turbine, condenser, generator, and accessories. All accessories, exciter, governor, lubrication system, air coolers, feedwater heaters, operating platform, etc.—even interconnecting piping and valves—are fitted to and mounted on the major parts. All components are thus completely assembled into a single, integrated machine.

The condenser acts as supporting structure for the whole. The foundation required is simple and inexpensive, comprised only of a concrete mat with eight short concrete piers. Installation consists merely of setting the assembly on the piers, attaching the accessories with pre-formed piping, and making the steam, water, and electrical connections.

The turbine rotor and its blading are checked before the installation of the top casing.



Housing may be as simple or elaborate as desired. No demands are made on the building structure for support. An operating platform at the turbine and generator levels is provided. It can be used in conjunction with an existing turbine-room floor, if desired.

The original units were produced to meet a need created by war. Large central stations having been destroyed, electric power needed for occupation and rehabilitation work could be supplied only by a small, easily transported power plant that was installed quickly. Many such units were built and shipped to various parts of the world.

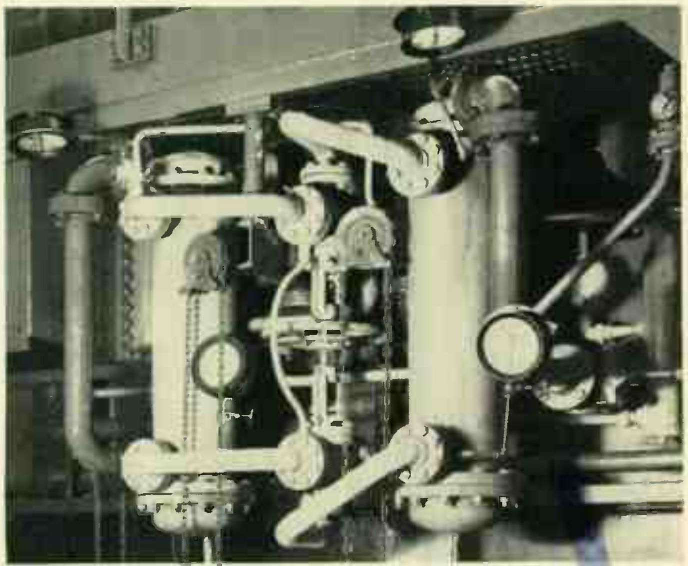
First built in 1000- and 2000-kw capacities, the 5000-kw size has come into peacetime prominence. The advantages, particularly attractive for isolated locations or where engineering talent and erection facilities are limited, include unit responsibility, coordinated equipment, and simple, quick, inexpensive installation.

The 5000-kw unit is designed for permanent installation. The components are aligned and doweled in place during manufacture. Due to the width of the complete assembly all auxiliaries are removed prior to shipment, leaving the turbine, generator, and condenser. Where necessary these major sections can be completely dismantled and quickly reassembled at the final site using the same dowels. The complete assembly weighs 85 tons; without auxiliaries, 72 tons. Overall dimensions, including the platform, are about 31 feet by 14 feet by 18 feet high.

Steam Details

The turbine is of standard design except for minor modifications required to make it a component of the assembled unit. For 3600-rpm operation, it is available for either 400 psi, 750 degrees F or 600 psi, 825 degrees F steam conditions; for 3000 rpm (50 cycles) 400 psi, 750 degrees F. The turbine is of the multi-stage, impulse type and has a nominal rated capacity of 5000 kilowatts. It has a maximum capability of 6250 kw (at unity power factor) even when extracting steam for a three-stage feed-heating system and exhausting at three inches of mercury absolute. The extraction pressures have been selected to obtain an efficient heat balance. While these extraction pressures must be adhered to, the choice of feed-heating cycle is as flexible as on any conventional 5000-kw power plant.

Steam is admitted to the turbine under control of a hydraulic speed-governing system. The governor is of the fully hydraulic type with the speed-sensitive impeller element mounted on the turbine shaft. The system also includes safety



Either one or two oil coolers (as shown) can be used.

devices that act in case of overspeed, low bearing-oil pressure, low vacuum, or high water level in feedwater heaters or condenser hot well. A breakable lead diaphragm, operating in conjunction with the low-vacuum trip, is built into the cover of the low-pressure casing. It eliminates the necessity of an atmospheric relief valve and associated piping.

The condenser, a two-pass, radial-flow type with a deaerating hot well, supports the entire unit. The lower half of the condenser shell is cylindrical. A thick flat plate, running the entire length of the assembly, forms the top of the shell and acts as the common supporting member. Differential expansion between parts of the assembly is provided for by flexible steel beams; all sliding surfaces are eliminated. This construction assures life-long alignment of parts.

The turbine and generator are anchored laterally and longitudinally to the condenser at the center of the turbine exhaust. Axial expansion from the anchor point is permitted but vertical and transverse alignment is maintained. The turbine exhaust is connected to the condenser through a diaphragm flexible in the vertical direction, thus allowing variations in exhaust temperature without disturbing alignment. Differential expansion between condenser and foundation in all directions is provided for by the eight flexible I-beam supports that rest on the concrete piers.

Auxiliaries

Auxiliaries include a lubricating-oil system, condensate system, feedwater heaters, generator air coolers, and air and gland ejectors. The lubricating system is complete, consisting of a main pump mounted on the turbine shaft, an auxiliary pump with its automatic regulator, cooler, reservoir, removable screen filter, and all interconnecting piping. Normally, only a single oil cooler is used but the power generator can accommodate twin coolers with a suitable three-way valve.

A single, vertical, two-stage condensate pump (a second can be added, if desired) with an automatic recirculating valve and a twin-element, two-stage air ejector comprise the condensate system. Either ejector is adequate for normal operation, the other serving as a standby. The air-ejector assembly also houses the gland condenser and ejector. Steam leaking from the turbine seal glands, auxiliary oil-pump glands, throttle valve, and steam-chest valve is taken to the gland condenser and then trapped back to the main condenser.

Either one or two closed-type feedwater heaters are mounted between the turbine and condenser. They are supported by hangers from the turbine base.

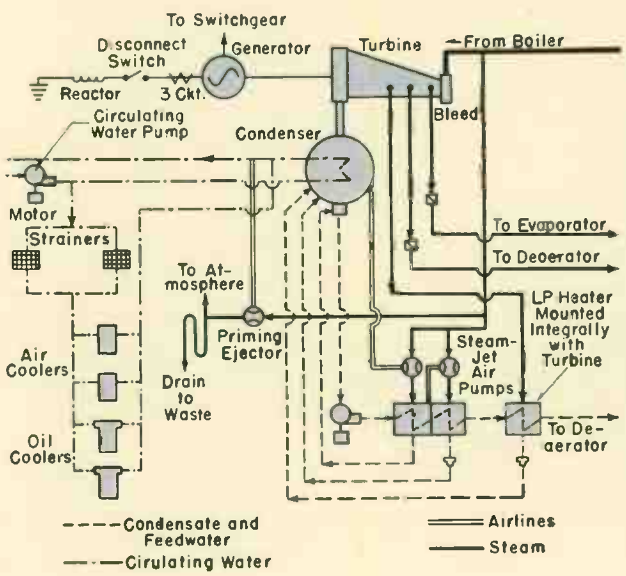
Electrical Details

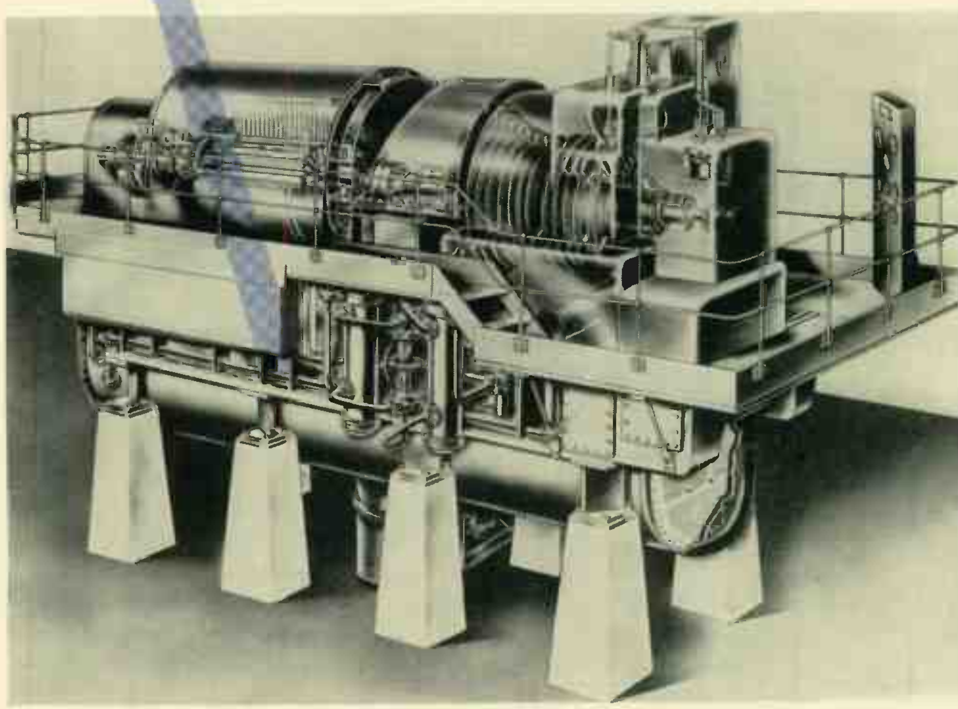
The generator* on the unit is rated 5000 kw, 0.8 power factor at 2400, 4150, 6900, or 13 800 volts, 60 cycles. Except for minor variations, the use of two air coolers instead of one and a different arrangement of main leads, it is a standard machine. To keep the length of the assembly to a minimum, solid flanged couplings are employed to connect the turbine, generator, and exciter.

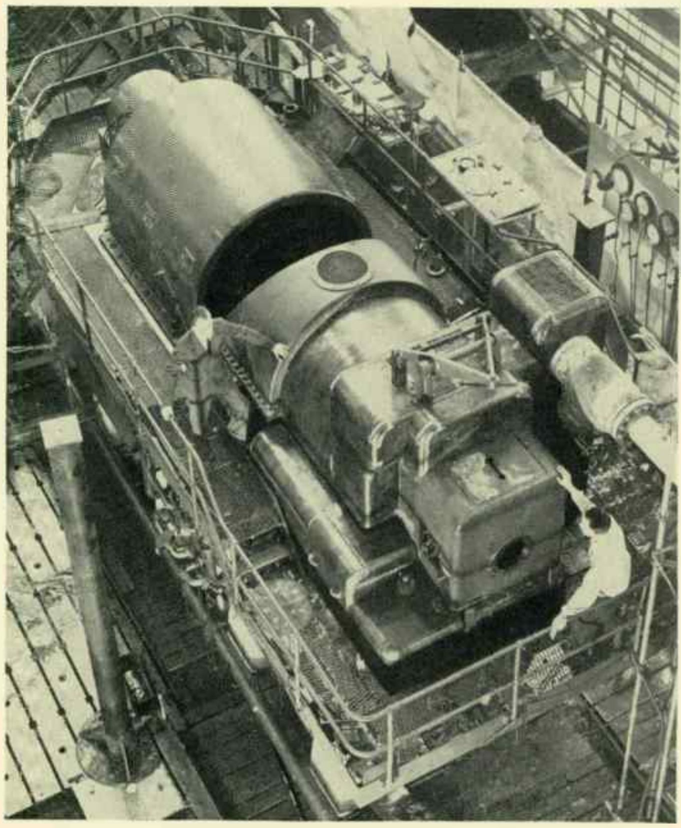
A significant feature of the generator is its exciter. De-

*"Small Turbine Generators Now Standardized," by J. G. Partlow, *Westinghouse* ENGINEER, November, 1947, p. 172.

Artist's conception (right) of the completed power-generating unit, illustrating internal construction and its components (below).

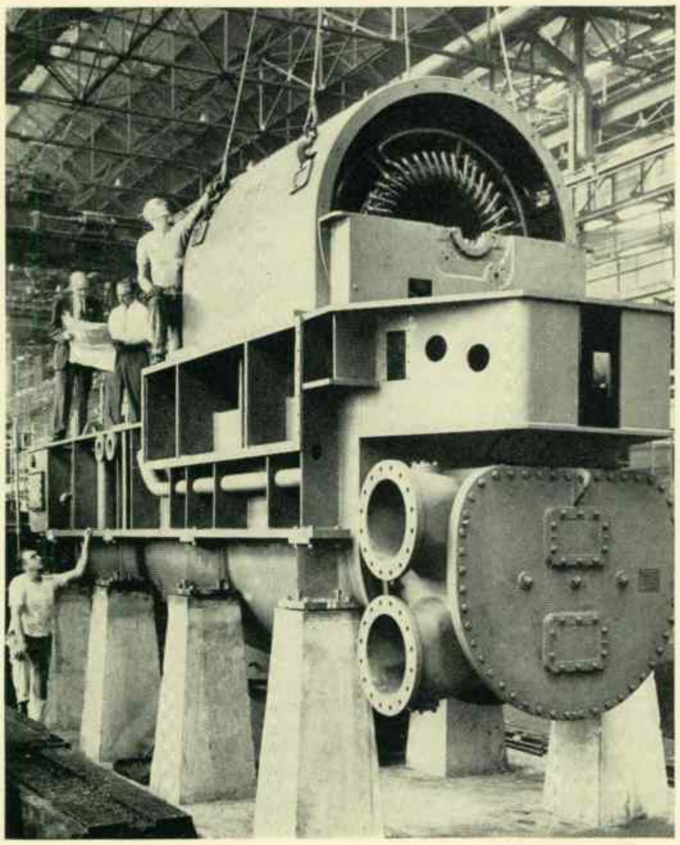


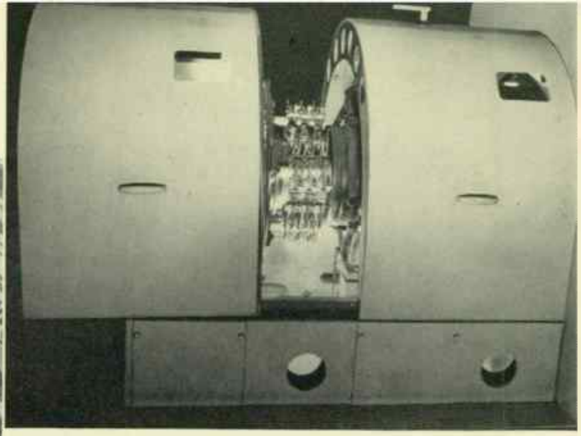




The power generator in its final stages.

Here the generator-condenser subassembly is being lowered onto the foundation for initial assembly prior to shipment. Note that window openings are used for lifting.





The first exciter cover is rolled back exposing the commutator. The second exposes the collector rings. Both covers can be removed completely.

signed to require a minimum of maintenance it has a shrink-ring commutator that permits axial and radial expansion of the bars to give excellent commutation even at the high speed of 3600 rpm. A two-section housing completely encloses the exciter. The sections roll back one at a time, revealing first the commutator and then the collector. Exciter brushes are quickly replaced without tools even when in operation. Excitation control is obtained by adjusting the field current of the exciter by means of a hand-operated rheostat. As a protective measure, a discharge resistor is permanently connected across the exciter shunt field.

Cooling air for the exciter and generator is supplied from fans mounted on the generator shaft. Air leaving the fans is divided into two parts, the larger being circulated through the generator stator core and windings and then through an air cooler, after which it is returned to the suction side of the fans. A smaller portion of the air is diverted to cool the exciter; it is then filtered to remove carbon dust and returned to the main air flow.

Generator accessories include a tachometer with a speed-indicating instrument mounted on the control board. Temperature detectors are located in the generator stator slots and in the inlet and outlet air ducts of both generator and exciter. Indicating instruments keep the operator informed of the temperatures at these locations.

Application and Advantages

The power-generating unit is suitable for applications requiring 6250 kilowatts (maximum) of electrical capacity. The amount of steam that can be extracted from the turbine is sufficient for such purposes as heating, deaeration, and evaporation of feedwater.

Particularly advantageous is the minimization of foundation and installation work. Compared to non-unitary equipment, the foundation is exceedingly simple. A minimum of field engineering and drafting work is required, as erection procedure and drawings are standardized. The usual design and procurement by the user of interconnecting piping, drain piping, main piping, valves, etc., have been eliminated. All such detail equipment is furnished.

The height being only 18 feet, extremely low headroom is required. This is very important when the unit is to be housed in older buildings.

To complete the station, the power-generating unit can be used in conjunction with standardized, factory-assembled, metalclad switchgear for control of generator and feeder circuits. A power center, incorporating a transformer, can supply station auxiliary power.

Recognition of the advantages of the 5000-kw power-generating unit, particularly abroad, is indicated by the fact that more than 38 (190 000-kw total capacity) have been installed or are under construction since its inception four years ago.

Torque Characteristics of Steam Turbines

Even the engineering profession with its penchant for accuracy has its erroneous notions. The introduction of the geared, steam-turbine locomotive raised, in many quarters, the question: "How does it start?" Contrary to a rather widely held belief, a steam turbine inherently possesses high starting torque.

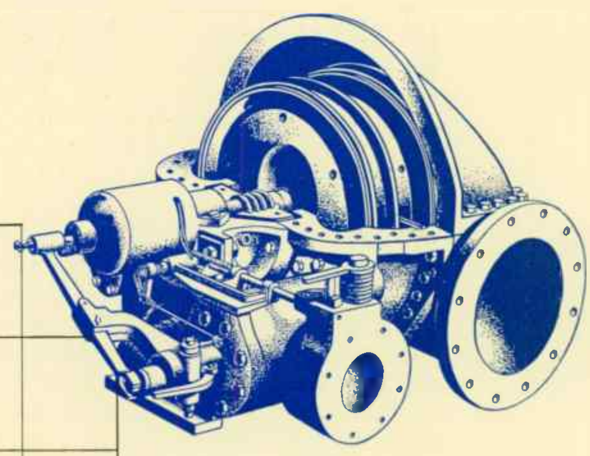
John S. Newton, *Assistant Manager of Engineering, Steam Division, Westinghouse Electric Corporation*

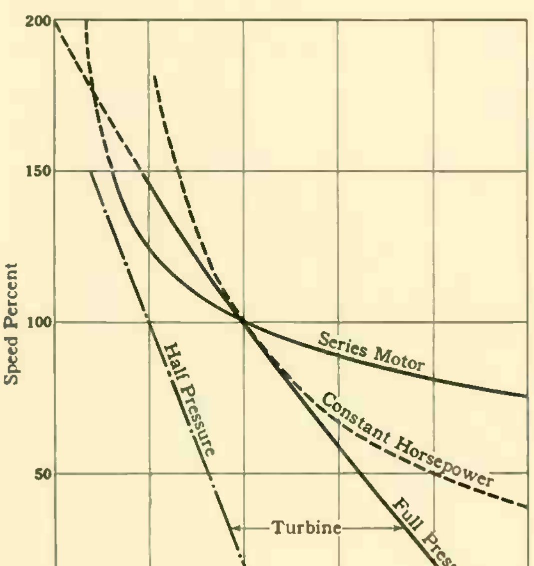
Engineers are so accustomed to steam turbines operating at constant speed or over a limited speed range that they are unaware of their starting characteristics. In applying steam turbines the speed-torque relationship is considered only in a few special instances such as reversing of ships' propellers and starting of heavy loads. Thus it is not surprising that there is an erroneous general impression that the starting torque of a turbine is low. If turbines were applied widely for the many applications served by motors, knowledge of their torque characteristics would be general.

An incident illustrating the degree of doubt concerning the starting torque of a turbine occurred immediately after delivery of the Pennsylvania's class S-2 geared-turbine locomotive. One of the first unofficial tests made was to couple successively increasing numbers of "cold" steam locomotives behind it, thereby simulating the resistance to starting of a heavy freight train and proving to the many doubters that a turbine really possessed the high tractive force necessary for railroad locomotives.

A multi-stage steam turbine supplied with steam at the designed inlet pressure and temperature and with exhaust pressure constant at the designed value develops slightly more than double its full-power torque at zero speed. Also, if it were mechanically strong enough—and few if any are—the turbine would run at a little more than double its rated speed at no load.

This characteristic is illustrated in Fig. 1 by the nearly straight solid line, dotted above 150 percent speed. For locomotive application, the usable speed range is zero to about 150 percent of the speed at which maximum efficiency occurs. For this speed range the torque ratio is a little over four to one, the same as a reciprocating steam engine with variable cutoff. Steam turbines are usually controlled to operate at substantially constant speed. This is accomplished by decreasing the steam flow and consequently the steam pressure over most of the turbine. For example, if the flow were reduced to one half, the speed-torque curve would be the dot-dash line. The turbine governor, then, as generally applied, adjusts steam flow, and consequently the effective steam pressure, by throttling the flow of steam and balancing the torque developed by the turbines against that required by the driven element. For a direct-drive, geared-turbine locomotive, steam is throttled in the same manner, but it has no speed governor. Thus for a given throttle position the torque can be anywhere between zero and the maximum for that steam flow, depending upon the turbine speed. A decrease in speed is accompanied by an increase in torque.





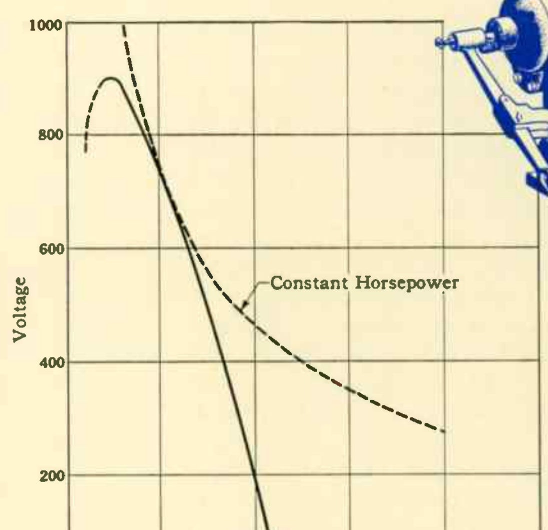
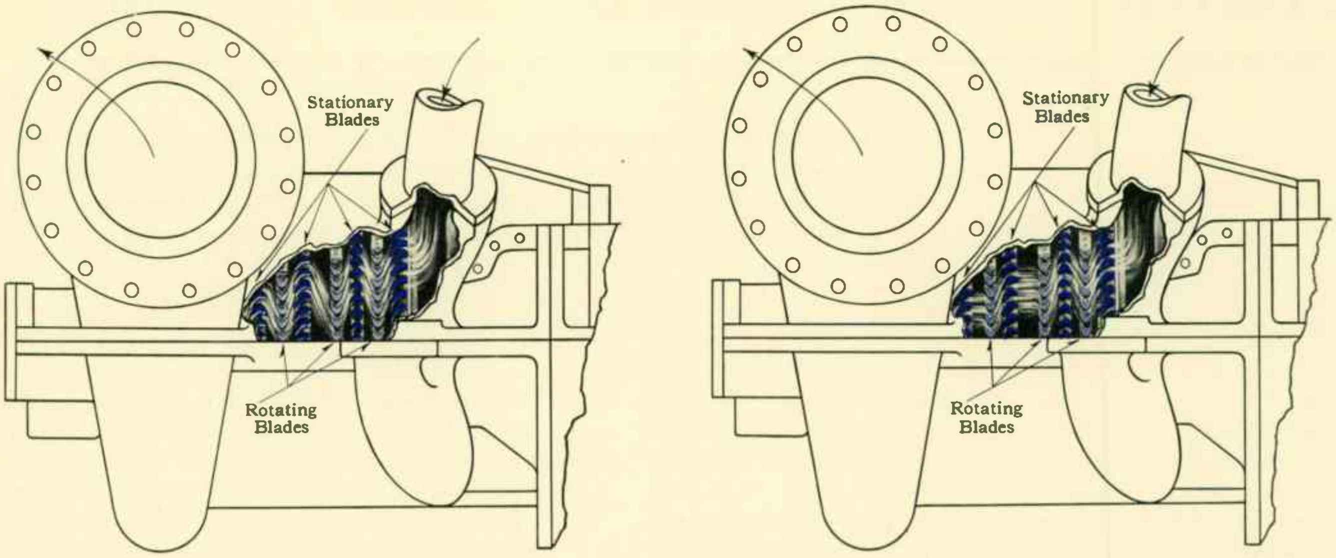


Fig. 1—Comparison of speed-torque relations of a steam turbine (operating at constant steam pressure) and a direct-current, series motor on a constant voltage supply.

Fig. 2—The characteristic of a direct-current series motor having speed-torque relations shown in Fig. 1.



These three views, which illustrate the path of steam flowing through the nozzles and blading of an impulse-type turbine, show the relation between the direction of steam leaving the moving blades and the speed of rotation of the rotor under three conditions: zero speed, maximum-power speed, and above-normal speed.

In the turbine at the left, the rotor is stationary. The steam leaves the rotating blades at the angle to which the blade exits are machined. The steam is turned through a wide angle and the torque is therefore highest, but because speed is zero the horsepower output is zero.

In the turbine at the center, the rotor is turning at the speed where maximum horsepower is developed. Except for the first row of rotating blading, one of three rows of the velocity-compounded stage, the steam leaves the rotating blades in an axial direction; the steam is moving counter

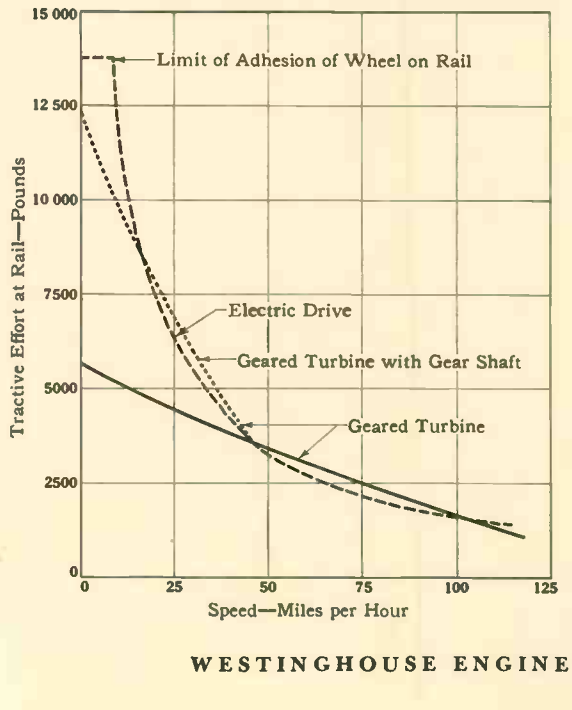
Perhaps for a better understanding of the application of a turbine to a locomotive, the turbine can be compared with a direct-current series motor, the speed-torque curve of which is illustrated by the curved solid line of Fig. 1. At constant voltage, analogous to steam pressure, the series motor has a steep speed-torque curve much the same as a turbine. Above 100 percent torque, its speed does not fall as fast as a turbine, but its ampere or torque capacity is limited by commutation and heating difficulties.

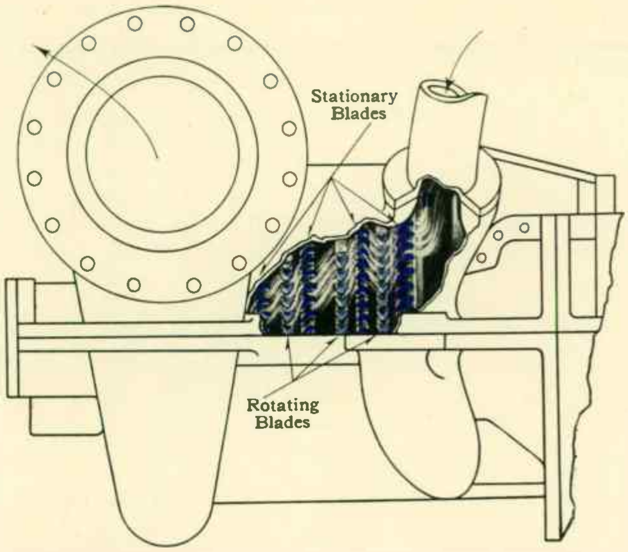
The dashed line in Fig. 1 represents a speed-torque relation for constant horsepower. It illustrates that a turbine can operate over a speed range from 80 to 120 percent without much change in horsepower. This is not as true for the series motor. At speeds above 100 percent, its voltage must be increased and at speeds below 100 percent its voltage must be decreased if rated horsepower is to be maintained. This is illustrated in Fig. 2. The volt-ampere or torque relation for a d-c series motor with the same speed-torque characteristics as the steam turbine is illustrated by the solid line. For constant horsepower, the volt-ampere characteristic is illustrated by the dashed line.

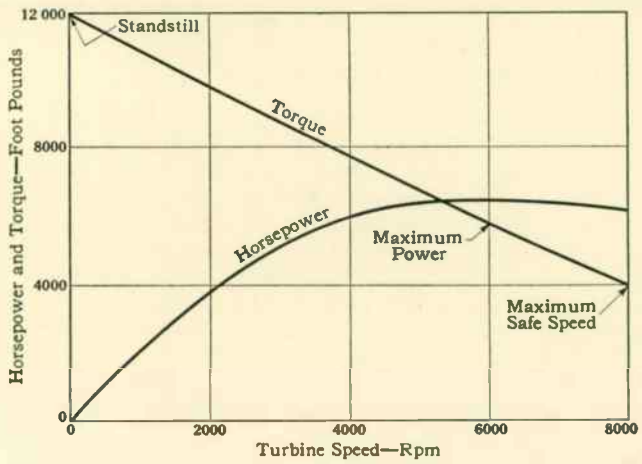
Constant horsepower over a wide speed range is desirable for a locomotive in order for it to utilize the maximum horsepower capacity of the plant at most normal operating speeds. The difference in the speed-tractive effort curve for a single-axle drive of 500-hp capacity, first for constant horsepower (electric drive) and second for a geared turbine or a reciprocating engine, is illustrated in Fig. 3. The torque ratio of the electric drive is nearly ten to one and of the mechanical drive only a little over four to one. The turbine for each of these drives is the same, but the one for the electric transmission operates at constant speed and the one for the geared transmission operates at variable speed. At 100 mph each can deliver the same power at the rail (approximately 400 hp).

In the normal operating range for a passenger locomotive (50 to 100 mph) the geared turbine actually delivers more power at the rail when supplied with the same maximum quantity of steam because the overall efficiency of the gear drive is greater than that of the electric transmission. However, with a steam-engine drive it is not economical to supply power to so many axles. The turbine is too expensive and it tends to be less efficient; also, provision must be made for operation in reverse. A practical and economical solution for

Fig. 3—Tractive-effort curves of a 500-hp single- and two-speed geared turbine and a d-c electric drive.







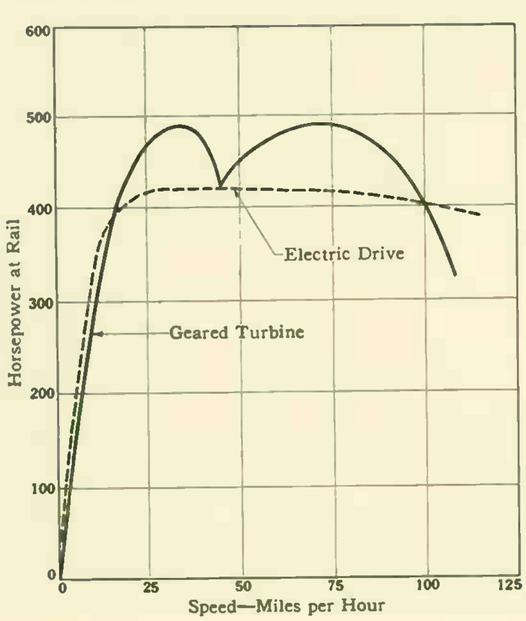
clockwise at the same velocity that the rotating blade is moving clockwise. Since the velocity around the shaft is zero, the maximum amount of energy has been extracted from the high-velocity steam. This is the point of maximum horsepower and maximum efficiency.

In the turbine at the right, the rotor is turning at a higher speed so that there is a component in the direction of rotation. The steam is turned through a smaller angle and the torque is therefore less. Also, there is rotation of the steam around the shaft as it leaves the rotating blades and therefore the horsepower and efficiency are less than the maximum.

The turning efforts or "torques" developed for these three conditions are shown on the torque curve. For a given steam flow, an increase in the angle through which the steam is turned as it moves through the rotating blading is accompanied by an increase in torque.

the geared turbine is the type of drive adopted for the class S-2 locomotive now operating on the Pennsylvania Railroad, which consists of a steam turbine connected by a double-reduction gear to four axles with drive rods. A second small turbine with clutch provides operation in reverse. It is well suited for a high-capacity, high-speed passenger locomotive where the ruling grade does not exceed one percent. For a locomotive to be generally applicable, however, it should have a tractive-effort characteristic of the electric transmission.

Fig. 4—Comparison of rail horsepower of a two-speed geared turbine and a d-c electric drive.



The speed-tractive effort characteristic of a 500-hp, two-speed, geared-transmission turbine as compared with the electric transmission is illustrated by the dotted line in Fig. 3. The two-speed geared transmission can be of a type similar to that used on some modern automobiles. It must be reversible. For the reasons of efficiency, reversing, and cost, this type of drive is not economical for steam-turbine, single-axle drive applications. For gas turbines, however, two-speed gears may be economical, because each gas turbine would be much smaller in physical size than a multi-axle turbine; also, the gas turbine would require only one or two stages. Also, a gas turbine does not sacrifice efficiency in the smaller capacities.

Finally, the maximum horsepower characteristics of each drive are illustrated in Fig. 4. The gear shift can be made at any selected speed. In this case it is made at a speed where the horsepower capacity of the geared-turbine transmission is equal to or greater than the electric transmission over the range from 15 to 100 mph, a range wide enough for any locomotive.

To state the desired attributes is simple, but rather difficult problems arise in the design of geared-turbine machinery to meet these characteristics. With the attractive possibilities of the gas turbine, such as compactness and simplicity, and with the gas turbine reaching a practical stage of development, perhaps the solutions will appear and a mechanical type of drive will become available to the railroads.

Editor's Note:

Plans to construct another steam-turbine locomotive have been announced. This will be a turbine-electric-unit, employing a high-pressure, high-temperature boiler of Babcock and Wilcox design. The drive will be similar to that employed on the three locomotives for the Chesapeake and Ohio Railroad.

What's New!

For Safe Mine Electrification

Fine combustible particles or gases mixed with air in certain proportions are extremely hazardous to equipment and personnel if ignited by an incendiary arc. Yet such a condition may exist at the working places in a coal mine if something interferes with the proper flow of ventilating air. To minimize the possibility of an explosion caused by incendiary arcing at a cable fault, and to protect personnel, cables, and mine machinery are the purposes of a new safety circuit center for low-voltage, underground power-distribution systems. The unit is engineered and built by the Mines Equipment Company.

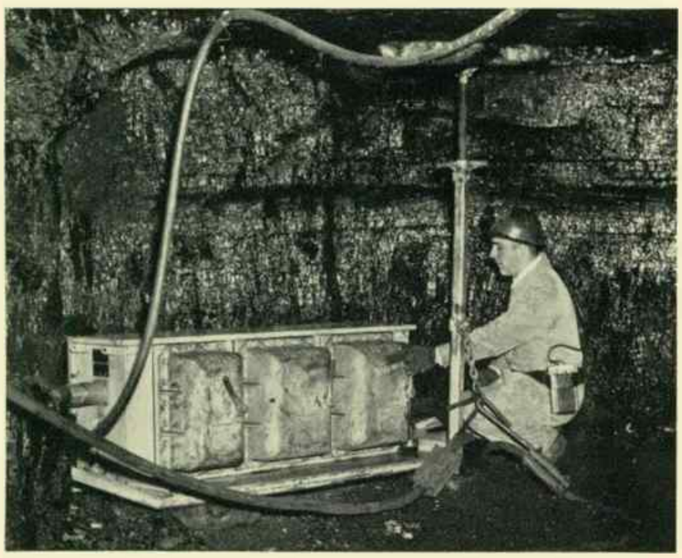
The safety circuit center is a distribution panel containing one, two, three, or four Westinghouse air-break, De-ion circuit breakers, one for protection of each outgoing circuit. The incoming and each outgoing circuit cable is provided with a plug-type connector for ease in making connections and to facilitate replacement of damaged cable. The power centers are built in 58 different standard combinations, in ratings up to 600 volts, 600 amperes current-carrying capacity, and 15 000 amperes interrupting capacity per circuit.

The circuit breakers are manually operated, with an external operating handle to apply or remove power at will. Should a fault occur, resulting in excessive current through the power conductors, the breaker on the circuit involved is tripped automatically by an electrical trip coil. Also, in case of fault or excessive leakage current in the safety ground conductor, the breaker is tripped by a safety, ground-current trip coil.

The circuit center has many safety features. The connectors, both incoming and outgoing, are interlocked with the breakers so that a connector cannot be inserted in a circuit on which the breaker is closed. Furthermore, a breaker cannot be closed until the connector is inserted, and, if an attempt is made to withdraw a connector when its breaker is closed, the breaker will open and drop the load before the power circuit is broken in the connector. Even in the event that several lengths of cable are connected together by plug connectors for a long run, this safety interlocking between plugs and breakers is still in effect. The breakers are, of course, trip free to prevent closing against an existing fault.

The safety circuit center is used near the working places in coal mines to supply power to equipment such as drills, cutters, loaders, and conveyors. It is built in "permissible" construction for hazardous locations, and in dust-resistant construction for locations where this type is acceptable. The unit is ruggedly yet (through extensive use of aluminum) lightly built, and mounted on skids for ease of moving as the coal face advances.

This explosion-proof unit is located right at the coal face in gaseous mines. A plug connector is visible at the left.

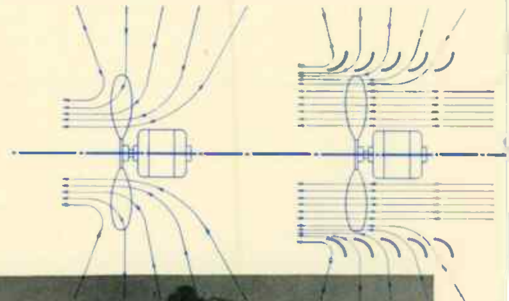


Air Traffic Control Increases Fan Output

The meaning of the word "fan" has changed. A Pharaoh of ancient Egypt was cooled during hot weather by a large ostrich feather waving over his head. A fan, for many centuries before and after that period, designated some such device—a forerunner of air conditioning. But since the advent of electric power, a fan has come to signify a motor-driven unit. It is the most common means of cooling off on a hot July day.

A new, portable, 16-inch, motor-driven fan, the Mobilaire, has several novel features that provide over 80 percent more cooling air than standard units of the same size. Its total air displacement of 3000 cubic feet per minute is almost equivalent to a standard 20- or 24-inch fan. This volume is sufficient for a com-

The height of the fan is adjustable to suit a variety of uses (below). Except for the chrome screens, the entire unit is finished in a baked-on, blue-grey enamel. Air entering from the side joins air entering from the rear without turbulence (right).



plete change of air every two minutes in the average four- or five-room dwelling.

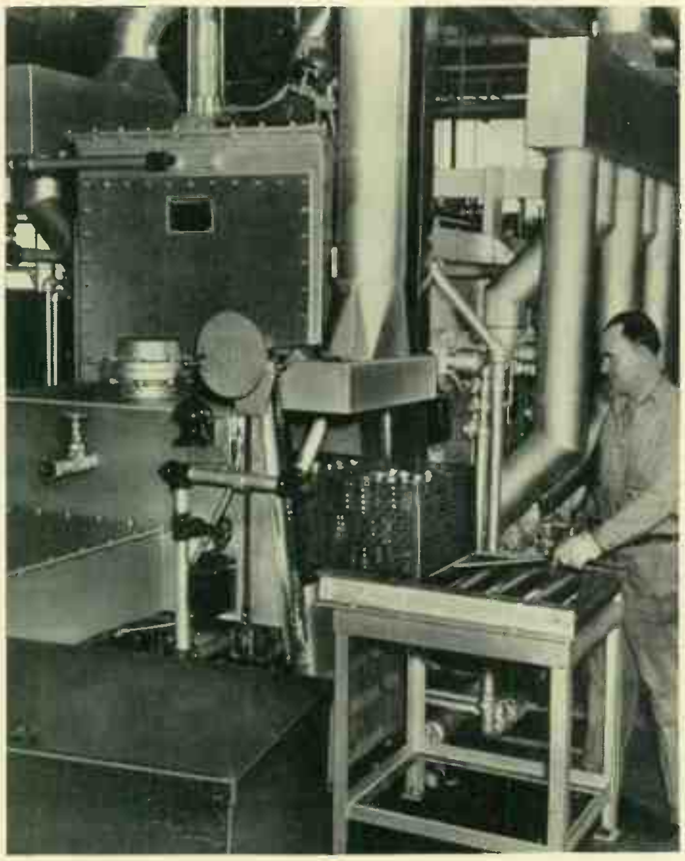
Two features make possible this increase in air supply. First, the large-surface, quiet-operating Micarta blades are more sharply angled than usual, thus permitting each blade to move larger "chunks" of air. Second, the air drawn into the fan from the side, a large proportion of the total, is more effectively directed and utilized. In the past, the direction of air coming from the side was changed in the blade zone, which blocked air coming from behind the fan. Now by the use of five stationary, air-injector rings surrounding the blades and curved in the forward direction, the side air is turned so that it slides into the main air stream without entering the blade zone. Thus, the rear of the fan is left free for the entrance of additional air already headed in the right direction. The operation is very much like merging lanes of traffic on a superhighway. In effect, the air-injector rings are propelling surfaces that add to the air delivery without additional expenditure of power.

The fan is particularly adaptable for cooling homes. When used to exhaust air from a room, the unit should be placed about three feet in front of the window to permit free motion of the side air. Otherwise, the fan loses one third to one half its air capacity, as occurs when it is installed in the plane of the window.

The Mobilaire fan is supported by two slender telescoping steel columns mounted on a pair of rubber wheels. Weighing only 35 pounds, the entire unit is easily transportable. The fan is driven by a 1/20-hp, two-speed, a-c, capacitor-type induction motor.

Gas-Fired Furnaces

This is the pusher type of a new line of gas-fired industrial furnaces for hardening, carburizing, dry cyaniding, and other metallurgical processes. The furnaces, which supplement the family of electrically heated units, are designed for use with a separately prepared protective atmosphere, such as Exogas, Endogas, Monogas, or Ammogas. Among others, roller-hearth-, conveyor-, and cylindrical-bell-type radiant furnaces are also furnished.



Combination Meter

For metering small loads where kva demand is considered in the rate, a new combination ampere-demand and watthour meter for single- or polyphase systems is available. Deflection of the demand needle, which is responsive to line current, is multiplied by a constant assumed voltage to obtain an approximation of kilovolt-amperes sufficiently accurate for many cases.

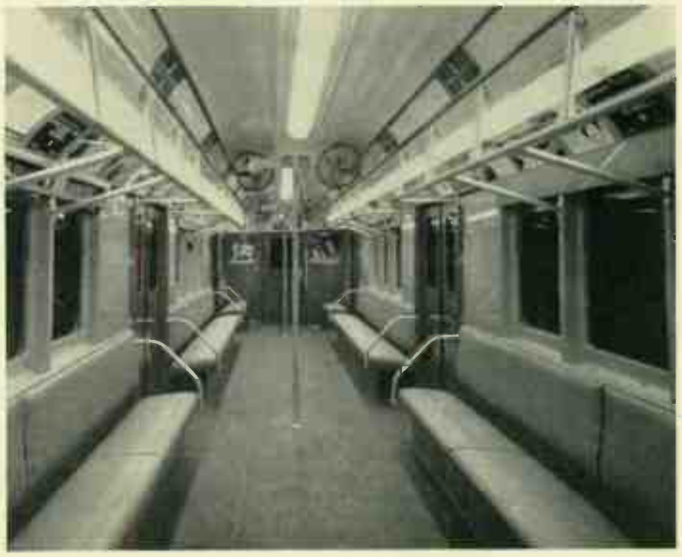
City Transportation Dresses Up

Tomorrow's subway and elevated trains are in the making. The cars, which are being built by American Car and Foundry Company for New York City's transportation system, not only bring improved appearance and new passenger comfort, but also incorporate significant engineering developments.

Two-tone exteriors and fluorescent-lighted interiors mean less eyestrain to passengers. Smoother rides are insured by roller bearings, vertical and lateral shock absorbers on the trucks, and new types of traction motors and control. Each car has four 100-hp motors (two 200-hp are common) with ball and roller bearings. The motors are spring suspended and connected to gears through flexible couplings. An important feature is a new unit-switch-type control with dynamic braking supplemented by air brakes. This control reduces brake-shoe wear and provides stops that are more rapid yet more comfortable than present equipment using air-brakes alone. The use of low-alloy, high-tensile steels and welded body construction has produced a sturdier car, weighing only 37 tons as compared to the previous weight of 41 tons.

An experimental train, incorporating these and other new features, will soon be built by Budd Manufacturing Company. It is to be a sleek ten-car train weighing 75 tons less than a similar train of present-day cars, a reduction of about 18 percent. A Precipitron and Sterilamps in the ventilation system will provide dust-free and germ-free air. A motor-generator set, with a flywheel on its shaft, will supply continuous power to the Precipitron, Sterilamps, and fluorescent lamps even when a car is passing over a third-rail gap.

Fluorescent lighting in this ACF subway car permits passengers to catch up on their reading without danger of eyestrain.



Thermoset Varnish—
The First Line of Defense

By

George F. Sutton
Section Supervisor

M. F. Hertel
Varnish Specialist

Westinghouse Electric Corporation

Varnish, the last layer of insulation on electrical apparatus, is truly the first line of defense against the attacks of heat, moisture, oil, and others. A failure in the varnish film almost certainly leads equipment into danger. Thermoset varnishes stand ready to repel the invaders before they can secure a toe-hold and damage the windings.

An insect has had an important effect on progress of electrical equipment. Many years ago, when the electrical industry was in its infancy, someone discovered that the secretion of an East Indies bug had unique insulating characteristics. The material, shellac, is fast becoming obsolete as an electrical insulation. But without shellac the development and use of electrical equipment would have been retarded by a number of years.

Shellac is usually applied in an alcohol solution, from which the alcohol is evaporated, leaving a hard, tough film of shellac. This film has good electrical-insulating properties but it is brittle at room temperature and softens when heated. These disadvantages became apparent quickly as the sizes and requirements of electrical equipment increased. Consequently, today shellac is used primarily as a finish and a wood filler and as an electrical insulation principally for bonding mica sheets. Shellac has been supplanted by new materials that can better meet the increasingly severe specifications demanded of varnish—materials that permit fuller development of better electrical apparatus.

Some of the drawbacks of a shellac-alcohol solution were overcome when the process of compounding asphalt, pitch, Gilsonite and other natural gums and resins with linseed oil was developed. Still further advances were made possible by oleoresinous varnishes, a union of gums, resins and oils, but these also soften when heated. The use of oleoresinous varnishes expanded but today they, too, are unable to cope with the growing needs of the electrical industry. This is true, although many oleoresinous varnishes are still in use. But the trends of a modern civilization toward faster and smaller motors, generators, and other equipment require in a great many applications, insulating varnishes with even better heat stability and bonding strength, more thorough drying characteristics in deep sections, and greater resistance to destructive elements than provided by the oleoresinous group.

Thermoset-treated stators for 2-hp loom motors being removed from a baking oven.

The discovery that a combination of phenol (carbolic acid) and formaldehyde (embalming fluid), aided by a catalyst, produces a phenolic resin highly resistant to heat, moisture, and oil, was a boon to the development of modern insulating varnishes. When subjected to heat, this chemical mixture is changed permanently from a liquid into a solid. This reaction, known to the chemist as polymerization, brought into being the family of "Thermoset" varnishes, which are set, or solidified, by heat. Thermoset varnishes employ a solvent to dissolve the solid constituents into a homogeneous liquid. But during solidification, the solvent is evaporated prior to completion of the thermosetting process. This permits the varnish to set into a uniform end product that is thoroughly dry in deep sections as well as on the surface. Other varnishes, such as the oleoresinous, set by a combination of oxidation and solvent evaporation. Early in the baking stage, they tend to form a surface film that prevents complete drying in deep sections. When Thermoset is completely cured, the film does not soften materially at the elevated temperature normally encountered in electrical service.

Thermoset varnishes were first introduced about 1932 by the Benolite Corporation of Manor, Pennsylvania (now the Benolite Department of Westinghouse.) Since then, rapid strides have been made toward the "perfect" varnish for all uses. Such a material has not yet been developed, but this goal is being approached.

Desirable Characteristics of a Varnish

The prime functions of a varnish are to improve the level of electrical insulation, to bind together the windings, and to protect the windings from harmful external influences. To perform these functions, a perfect insulating varnish would embody these characteristics:

1—High, constant insulation and dielectric strength under all conditions.

2—Unlimited resistance to heat.

3—Moisture absorption too low to be measured.

4—Strong resistance to oil and chemicals.

5—High bonding strength without brittleness, under all operating conditions.

6—Flexibility at all temperatures to permit ease of winding and movement without cracking.

7—Preferably require no solvent.

8—Should dry in air or require a drying time of less than one hour at conventional baking temperatures.

9—Ability to penetrate and dry thoroughly in deep sections.

10—Low cost.

The ability of a varnish to provide an extra measure of dielectric protection—the final layer of such protection over wire enamel, Fiberglas, tape, slot paper, and other insulations—is all important. The insulation strength of a varnish, which must remain constant and dependable, is, of course, contingent on its other characteristics.

Heat is enemy number one to an insulating varnish. The deterioration of varnishes by heat limits the design of electrical equipment, which must operate below the temperature permitted by the insulation. Because of this limitation, electrical apparatus has been classified into groups depending upon the temperatures the insulation will withstand with acceptable life. According to present NEMA classifications, the hot-spot limits range from 90 to 175 degrees C.

Moisture penetration is accelerated by the deterioration of a varnish film subjected to heat. The perfect varnish would absorb no moisture at any temperature.

Strong resistance to oil is important as it is often deposited on windings, either by direct splatter or as a mist. Also, varnishes are sometimes exposed to chemicals, principally acids and alkalies. Some varnishes react with the coating of enameled wire, causing deterioration of both; this is obviously undesirable as it may lead to failure of the equipment.

Bonding strength is the ability of a varnish to adhere to all types of conductors and insulations and to itself. Good bonding strength helps hold windings together against action of centrifugal forces in rotating applications and enhances rigidity of a treated stationary winding.

Flexibility, or pliability, is essential to permit the film to expand and contract with changes in temperature. This characteristic prevents cracking after repeated flexing by either thermal, electrical, or mechanical forces. Extremes of temperature should not change its flexibility. In many respects the physical characteristics required of a varnish film are similar to those required of a steel surface—hard, tough, adhesive, flexible—but not brittle.

A solvent is required in most insulating varnishes to dissolve the solid matter. The solvent is then evaporated by baking the equipment in an oven leaving the solid in the form of a film. If a solvent were not used, the varnish would not be liquid at room temperature or would remain liquid for only short periods. Solvents used in insulating varnishes are flammable and many are health hazards. But solvents are necessary evils. Varnishes that harden by polymerization as well as by evaporation are preferred as they dry in deep sections.

Curing, baking, or drying is required to set most varnishes. The perfect varnish would dry quickly on exposure to air—but this would limit its inactive tank life between batches because of more rapid oxidation and solvent evaporation. If heat is required, the temperature should be within the range of conventional ovens. After the apparatus reaches oven temperature, baking time should be less than one hour.

Some applications require the varnish to penetrate and dry thoroughly in deep sections. This ability is particularly important on magnet coils, which obtain much of their mechanical rigidity from the binding action of the varnish and on large rotating machines to prevent "throw out" of varnish particles by centrifugal force.

(Left) Armatures for small universal motors, such as used on adding machines, are treated with Thermoset. (Right) A high-voltage coil of a transformer immediately after dipping.

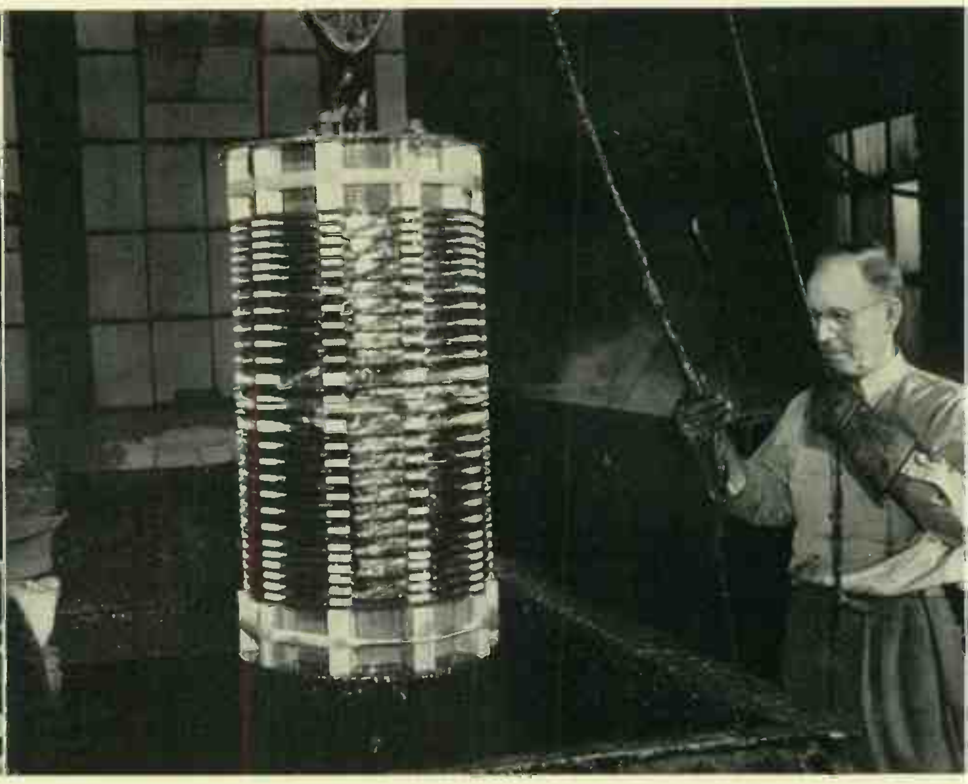


TABLE I*—RELATIVE PROPERTIES OF THERMOSET VARNISHES

Thermoset Varnish Number	Dielectric Strength	Flex Life Under Heat (ASTM)	Resistance to Moisture	Resistance to Oil	Resistance to Acid	Resistance to Alkali	Bond Strength	Flexibility After Baking	Solvent	Cost
B-165	1	5	1	1	1	1	1	5	Pet. Naphtha	2
7826-1	2	4	1	2	1	1	2	4	Toluol	5
7826-2	4	3	2	3	2	2	3	3	Toluol	6
7826-4	2	6	1	1	1	1	1	6	Toluol	3
8826-1	3	1	2	3	2	2	3	1	Pet. Naphtha	4
8826-3	3	2	2	4	2	2	3	2	Pet. Naphtha	1

*Lower numbers signify better properties and lower cost.

Small coils for dry-type transformers being lowered into a vacuum-impregnation tank. After evacuation and pressure impregnation coils are transported to ovens for baking.

The cost of an insulating varnish must be low enough to justify its use on the large volume of standard, general-purpose electrical equipment. While some varnishes, such as the new silicones, have some characteristics superior to Thermoset or any other type, their cost at present is too high for the general run of production work.

Applications of Thermoset Varnish

Thermoset represents a family of varnishes whose members have the properties necessary to satisfy the requirements of most industrial applications. Because applications vary widely, the choice of the correct varnish—the correct member of the family—is of utmost importance. This selection is a highly specialized science. Relative properties of members of the varnish family are indicated in table I.

Although Thermoset has been in use for some fifteen years, it has become well known only within the past eight. The recent war with its many new, rigid, and hard-to-fulfill demands on electrical equipment brought prominence to the Thermoset family. Electrical apparatus was required for every conceivable type of service; it had to withstand all enemies of insulation—moisture from the monsoons of India, heat of the tropics, the fungi of the jungles, lubricating oil, corrosive action of salt water, high-frequency vibration of aircraft, and others. All of these conditions were encountered. Thermoset varnish fulfilled its mission even under such grueling circumstances.

Thermoset varnishes combine two of the best-known synthetic resins, the phenolics and alkyds, to form a heat- and moisture-resisting film. Phenolics, derivatives of carbolic acid, alone impart a hard, brittle film with quick-drying properties. Alkyds, made from glycerine and phthalic anhydride, are not truly thermosetting and do not offer sufficient bonding strength or good drying properties. They do, however, have good moisture and oil resistance and produce a tough, flexible coating. In combination with drying oils, these resins form a varnish having the desirable properties of both. Phenolics are sometimes modified with other resins and in many cases with oils such as linseed or chinawood. Experience has shown that the best varieties of physical, electrical, and mechanical properties are obtained from different combinations of phenolic and alkyd resins and properly selected oils.

Thermoset in the Paper Industry

The paper industry imposes perhaps the toughest set of operating conditions on electrical equipment. Paper mills all over the country have long had the problem of high humidity, chemical fumes, and generally corrosive conditions. Such an atmosphere, inherently present in the mills, is detrimental to electrical equipment.

These mills usually operate on a 24-hour-a-day, 7-day-a-week schedule with maintenance shutdowns only twice a year. Shutdowns range from two to seven days, depending on the maintenance required. During these periods, it is customary to check all motors for insulation resistance. Many motors treated with ordinary varnishes show a zero megger reading after 12 to 24 hours' shutdown. Consequently, a drying operation is essential, for if insulation resistance drops below two or three megohms, it is considered dangerous to start the motors.

During one shutdown, motors were dipped in Thermoset varnish and baked for periods of from 6 to 12 hours at 275 to 300 degrees F. These motors at later shutdown periods showed an insulation resistance of hundreds of megohms after 36 hours. After this, resistance decreased somewhat but not sufficiently to make motor starting hazardous. Thus, the expense of a drying treatment after each subsequent shutdown was eliminated. Furthermore, Thermoset minimized the number of operational failures of electrical equipment during normal operation, thus reducing lost production time.

Paper-mill refiner motors are often called on to deliver overloads as high as 40 percent over long periods of time. Because of this, in addition to the external operating conditions, the motors are extremely subject to insulation failures. Refiner motors are now wound with class-B insulation, giving each coil a Thermoset dip and bake, and then dipping the entire stator, some as large as 400 hp. After all end connections are made, an additional dip and bake are given the stator, even out to the high-voltage leads. As Thermoset completely fills and dries in all the voids, this procedure greatly reduces the frequency of insulation failures. The overall dipping and baking are found by paper-mill operators to extend the life of the coat of paint over the motor to from three to five times normal and to prevent rusting of the frame.

Thermoset is also used to facilitate removal of subsequent deposits that, if not cleaned off regularly, provide a short-circuit path in d-c motors. Because Thermoset varnish dries to give a very hard finish, the deposits are very easy to remove. This same characteristic makes it easy to clean the surface of Thermoset-treated operating bars of motor-starting contactors, also to prevent short circuits.

Control panels and pushbutton stations must sometimes be installed in a location continually exposed to the highly corrosive fumes of free chlorine. In this atmosphere they deteriorate completely in two to three years. Recently such equipment was treated with Thermoset varnish in an effort to prevent its corrosion. While a complete report is not yet available, very good results are expected.

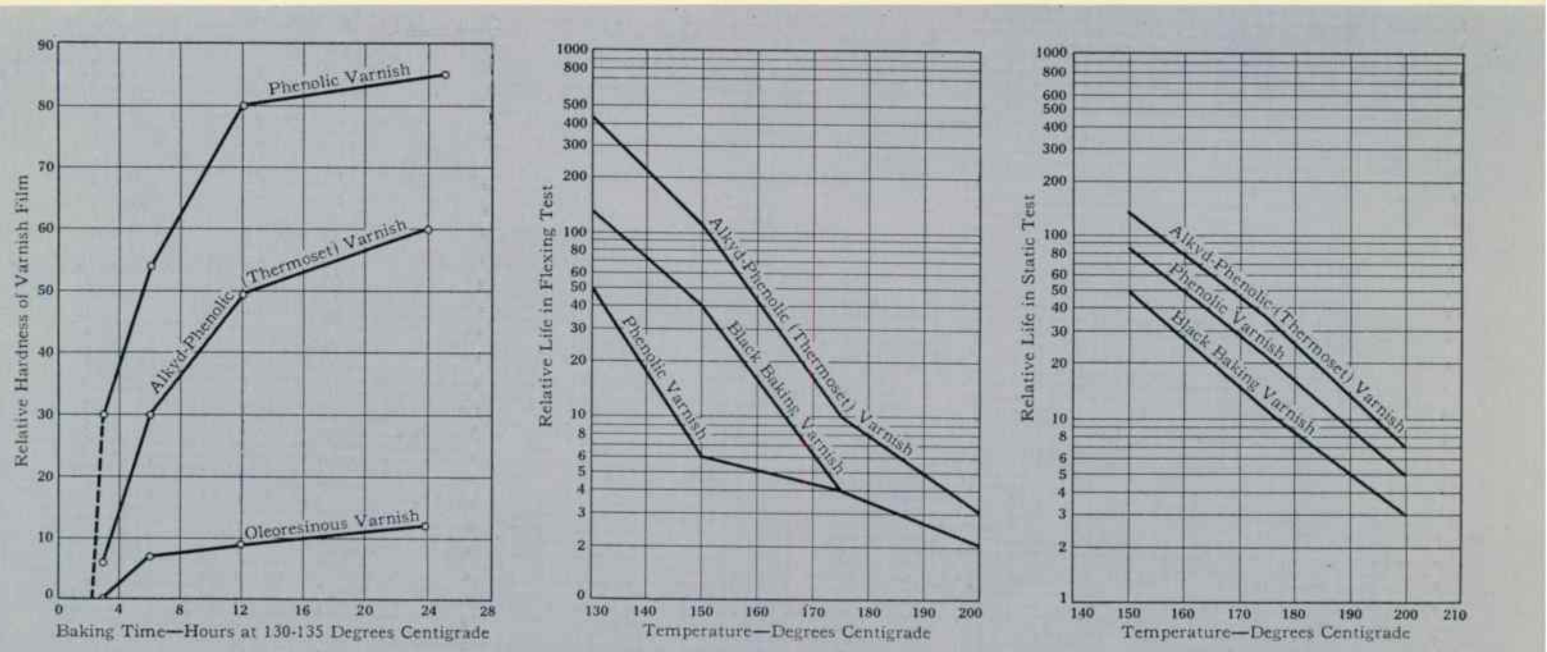
In paper mills Thermoset varnish has resisted corrosive atmospheres so well that it is now used as a coating on pipes and connections that carry highly corrosive chemicals. Exhaust fans, dipped and baked for protection against the very air they propel, last much longer. Although Thermoset varnish is not suggested as a cure-all for chemical resistance, its use under such conditions is interesting and indicative of the many unusual applications—aside from its electrical-insulating characteristics—to which it is being subjected.

Thermoset in General Industrial Applications

The properties of Thermoset varnish make it applicable not only in paper mills but in general industry as well. Trolley cars, for example, operate in weather and climates highly undesirable for electrical equipment. To select the varnish most suitable for such service, a test was conducted to determine the water resistance of a Thermoset film as compared to an oleoresinous. Two motor stators were wound, one for each varnish. In both cases the field coils were impregnated by a vacuum-pressure treatment to obtain the maximum fill. After assembly the stators were dipped and baked. Initial insulation resistances were measured by an electronic megohm bridge; the Thermoset coils were slightly better. To simulate field conditions, a fine mist of water was sprayed on the stators throughout each day for a period of three weeks. The spray was turned off in the evening and the coils were left standing overnight, as is normal in streetcar service. Insulation-resistance data was taken every morning and night, one minute after application of voltage. At the completion of the "shower bath" the Thermoset coils had four to five times the insulation resistance of the oleoresin coils. As a result of this test, Thermoset is now used in treating trolley motors.

Totally enclosed, explosion-proof motors are required in many locations. Ventilation of such equipment is extremely difficult. Operating temperatures in many cases approach, and during overloads sometimes exceed, the class-B hot-spot limit of 125 degrees C. The motors demand use of insulating varnishes that withstand such temperatures continuously. Conventional varnishes soften and often are thrown out of an armature by centrifugal force at temperatures in the class-B range. Thermoset varnishes do not soften when heated and consequently the danger of throw-out is eliminated. Thermoset varnish is also used on general-purpose motors. It is a contributing factor in the reduction in size of the Lifeline motor. Just another illustration of the trend of modern apparatus—more of this, less of that, but always better.

The inability of ordinary varnishes to set in deep sections (because they dry by oxidation) has for many years limited the life of magnet coils. These coils are tightly wound with fine wire. The varnish must thoroughly penetrate these layers (sometimes numbering in the hundreds) of windings and cement them together in a solid mass. Also the varnish film must not be cracked by mechanical or magnetic vibrations or be softened by elevated temperatures. These requirements dictate the use of Thermoset. The varnish used for this application is unique in that it contains a high percentage of solids and yet has a sufficiently low viscosity to permit complete

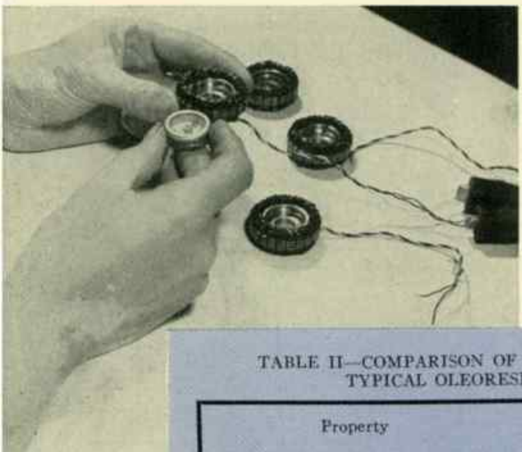


A comparison of some characteristics of Thermoset, phenolic, and black baking varnish films. A phenolic resin gives the hardest film, but it must be mixed with a synthetic resin to obtain good moisture and oil resistance and a tough coating.

penetration. It dries thoroughly and quickly at a temperature of 275 degrees F and bonds the wires into a solid mass. This reduces failures and because of improved heat-transfer properties, attributed to more thorough filling of internal voids, such coils have operated at lower temperatures.

The use of enameled magnet wire in the electrical industry is ever growing. This type of wire depends on a relatively thin coating of either oleoresinous or synthetic enamel for its insulation. Of great concern to electrical manufacturers is the possibility that wire enamels may be attacked by solvents in the insulating varnishes. If a wire enamel is injured by a solvent, short circuits between turns or to ground may result. It is therefore important to consider the type of solvent employed in the varnish.

Some heat-hardening varnishes require "high-powered" aromatic (coal tar) solvents such as toluol, benzene, or xylol. Such solvents are used to obtain proper solubility of resins or a fast rate of evaporation. They are detrimental to wire enamel of the oleoresinous type. Some synthetic wire enamels are also affected if exposed to the solvent for an extended period of time. The newest type of Thermoset varnish, however, does not employ these powerful aromatics, but instead, solvents of the petroleum type known commercially as Varsol, Solvasol, and V M & P naphtha. These solvents generally do not affect wire enamels. Also their higher flash point minimizes the possibilities of fire and increases tank life. Aromatics are frequently toxic in nature, but petroleum solvents can be tolerated in greater concentrations without deleterious effects on personnel exposed to the fumes.



The armatures for "inside-out" gyroscope motors are treated in Thermoset.

TABLE II—COMPARISON OF THERMOSET 8826-1 AND TYPICAL OLEORESINOUS VARNISH

Property	Thermoset No. 8826-1	Oleoresinous Black
Dielectric Strength (ASTM) Dry Wet	 2000 volts/mil 900 volts/mil	 1500 volts/mil 500 volts/mil
Heat Endurance Flex life on copper at 110 degrees C Flex life on copper at 150 degrees C	 Over 2000 hours Over 100 hours	 650 hours 17 hours
Resistance to Oil Moisture Acid Alkali	Excellent Excellent Excellent Excellent	Good Good Good Fair
Bonding Strength	Excellent	Good
Flexibility After Drying	Good	Good
Hardness of Cake Shore Durometer (Scale A) After 3-hour bake at 135 degrees C After 6-hour bake at 135 degrees C Six-hour cake after 48 hours in oil at 105 degrees C	 15 28 30	Does not harden internally
Solvent	Petroleum Naphtha	Petroleum Naphtha
Drying Time on Copper at 110 degrees C	2 hours	4 hours
Cost Range	Medium	Low

Oil is commonly thought of as a lubricating medium that forms a film on a rotating shaft to reduce wear on bearings. But it is also a cooling and insulating medium. Oil is used in distribution and power transformers, some as large as a house, for that very purpose. True, it differs from the type used for lubricating purposes, but it is a highly refined product of essentially the same chemical structure. Ordinary varnishes cannot withstand exposure to such oils for long periods. Oil at 180 degrees F, the normal oil temperature in many transformers, causes conventional varnishes to disintegrate in a short time. This is especially true of black asphaltic-type varnishes. Generally oleoresinous varnishes discolor when in contact with oil and a general softening of the film is noted. Thermoset varnishes, on the other hand, are usually unaffected by oil and some actually become harder and more impervious at elevated oil temperatures. For this reason many oil-immersed distribution-transformer coils and core-and-coil assemblies are treated with Thermoset.

This resistance to oil makes Thermoset varnishes applicable where the presence of oil is a detriment to electrical equipment. For example, it is used on oil-pump motors and welders.

Many manufacturers treat all but the smallest coils (and sometimes the core-and-coil assemblies) of dry-type distribution transformers with Thermoset varnish. In addition to dielectric strength and moisture resistance, other properties of Thermoset (high penetrating ability, bonding strength, and flexibility) are beneficial to transformer windings. The varnish is so successful in binding the other insulating materials such as tapes and the copper conductor together into a strong yet flexible winding that some transformer manufacturers use Thermoset principally for mechanical strength. In several medium-size ratings, Thermoset imparts such a high degree of strength that the transformers are capable of withstanding short circuits up to 125 percent rated voltage on the primary windings without mechanical support.

Thermoset—Its Present and Future

Insulating varnishes, because they are generally the last form of insulation applied to electrical apparatus, are the first line of defense. A failure in the film ultimately causes a defect or failure in the equipment. A good analogy is the dikes of a river. Dikes confine the flow of water to a given path; their failure results in havoc and suffering. A varnish helps confine the current to a given path; a failure may cause fire and the loss of production time and equipment. A good insulating varnish is an essential component of electrical apparatus.

Thermoset varnishes are used for coating motor armatures used in small, high-speed, hand tools—some as small as your little finger. The same basic varnish is used to treat generators so large that thirty freight cars are required to transport the components of a single one to its final site for assembly. Magnet, motor, and transformer coils of many sizes are dipped and baked in this varnish to obtain a better insulating film. The versatility of Thermoset is indicated by its use on all types and sizes of electrical equipment and particularly where application conditions are severe.

Continuous research is under way to improve further the qualities of insulating varnishes. The Thermoset family will be bettered as new developments are forthcoming. Recent progress with the silicones and fluorine compounds indicate that further improvements are possible. At present, the cost of these new materials, some properties of which excel those of Thermoset, greatly limits their use. Thermoset, however, combines the properties and economy necessary for mass production of general industrial equipment.

Personality Profiles

"What's his name?" you ask. "Dunno," comes as an apparently uninformative reply. But that is how *C. L. Denault* pronounces his name.

Visitors are as likely to find design-engineer Denault at a lathe as at a sketching board or desk, for he combines both theory and practice—something rare. He relishes design, but wants also to see that design through until it works perfectly and is manufactured easily.

Denault showed design capabilities as early as his pre-college days when he worked on a predecessor of the Garand rifle at Springfield Arsenal. While attending Worcester Polytechnic Institute (B.S. in E.E., 1924) he worked part time for Westinghouse under Professor H. B. Smith, a company consultant. After graduation, Denault joined the Company and helped establish the high-power circuit-breaker test lab at East Pittsburgh. From 1929 until 1942 he was with the Research Laboratories under Dr. Joseph Slepian. The war brought Denault's transfer to welder research, where he engineered a new, improved high-frequency stabilizer.

Louie Denault's gadgeteering does not end at home. Working on the theory that "an engineer should be able to fix it," his neighbors have appointed him no. 1 general repair man in his community.

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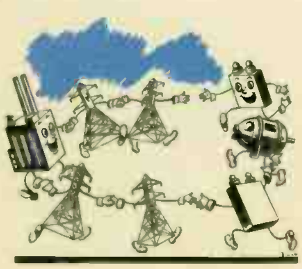
Central-station operators and equipment builders view a problem from two somewhat different angles. As in a range finder these two views must be swung into line before the problem can be seen in "focus." *A. A. Johnson* is one who can do the swinging, for he has seen many problems from both angles—first as a utility man and now as a builder.

After graduating from the University of Virginia in 1930 with a degree in electrical engineering, Johnson acquired his utility experience in what is now the Consolidated Edison Company. After some time on the test course he went to work in the electrical engineering department, specializing in problems on transmission and distribution, particularly those relating to system interconnections. Not satisfied with devoting his days to engineering, he spent many evenings at Pratt Institute teaching mathematics and electrical engineering. Early in 1941, Johnson joined the Central Station Division of Westinghouse to aid utilities with their application engineering problems. A good mixer, Johnson is chairman of his local AIEE Publicity Committee.



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The East (*J. C. Spahr* and *M. A. Nelson*) and West (*J. G. Partlow*) have met—and productively, for the power-generating unit is the result.

J. C. Spahr, the "turbineer," joined Westinghouse in 1927 after receiving his formal education at Girard College and Drexel Institute, and has since been engaged in turbine design. As assistant manager of the Industrial Turbine Section, Spahr is called on to answer a lot of questions concerning industrial steam turbines. His answers, backed by 20 years of experience, carry a lot of weight. After hours, Spahr spends his time at sports and in singing with the church choir. His vocal activities do not end here for he is renowned as a public speaker of talent.

M. A. Nelson, the condenser designer, started at Westinghouse in 1929 after leaving Johns Hopkins University with the degree of Bachelor of Engineering. After completing his courses in design school, he was assigned to condenser engineering. He is now manager of the Condenser and Heat Exchanger Section.

In 1941 J. G. Partlow graduated with a B.S.E. from California Tech at Pasadena, his native city, and came forthwith to Westinghouse. After taking the student course he entered generator engineering, which has continued to hold his interest. In November, 1947, he presented an article in these pages on his specialty, industrial sizes of turbine generators.

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When *John S. Newton*, who had graduated as an M.E. from Oregon State in 1930, finished the Westinghouse student course in 1931, the Company was fresh out of jobs for young mechanical engineers—times being as they were. However Floyd Hague, then manager of large d-c rotating apparatus, needed an engineer. He called Newton to his office. "John," he said, "you being a mechanical graduate, we think you might make a good electrical designer." Thus Newton began a six-year career as a designer of d-c motors and generators and allied machines. By 1938 Mr. Hague had moved on to new fields; he had become manager of steam-turbine engineering. One day he called Newton and said, "John, we need a good mechanical engineer. Since you've done well with electrical stuff, we think we can use you on mechanical design." Thus Newton was reconverted, undertaking all manner of problems connected with marine gears and turbines. His work in these fields during the war won him high praise from the services—and his appointment as assistant engineering manager of the Steam Division.

Newton's career illustrates the versatility of an engineer well grounded in basic principles. Boundaries to such men mean little, as is indicated by the variety of Newton's associations: torsional vibration of diesel-engine generator sets and d-c machinery, electric couplings, electrical marine applications, design and application of gears and turbines to ships, the geared-turbine locomotive, and gas turbines. Young engineers, please note!

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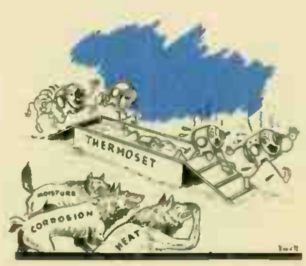
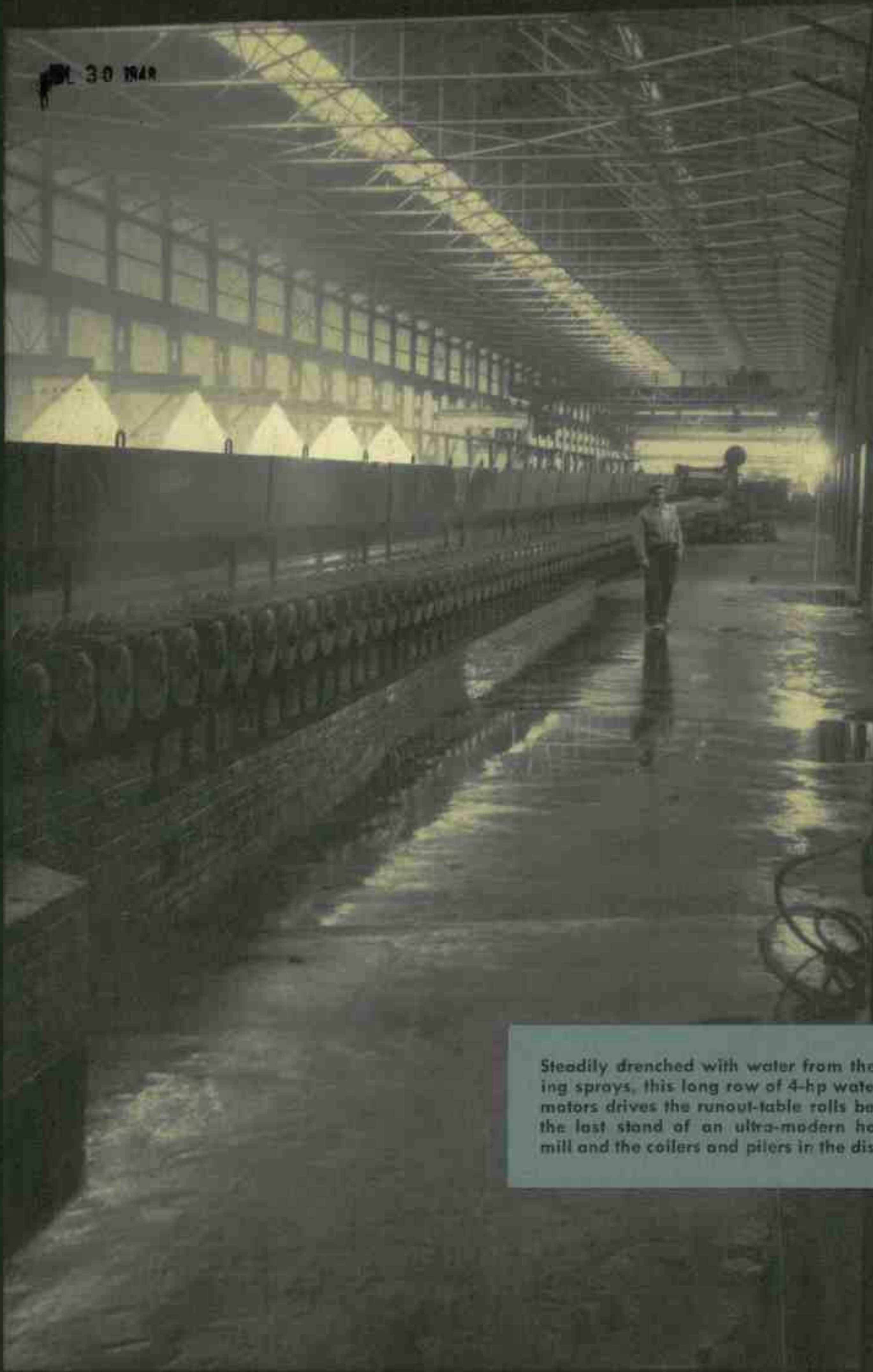
A duet of pianists, *George F. Sutton* and *M. F. Hertel*, authored the article on Thermoset varnishes. The duet would also make a fine golf twosome. Sutton shoots in the 80's; Hertel, like many another golfer, prefers not to discuss his scores. Both started in accounting and business administration, but found the fascination of electrical insulation overwhelming.

Sutton, in 1936, after a year at Westinghouse in business administration, transferred to the insulation field. In 1938, having two years of training to support him, he was sent into the field as an insulation specialist. In 1942, Sutton returned to Insulation Division headquarters.

"Mike" Hertel, as he is known to the trade, joined Westinghouse in 1945 with a background of almost 20 years of extensive experience in the application of electrical insulating materials. As varnish specialist in Cleveland, he is concerned with application of only such products.





Steadily drenched with water from the cooling sprays, this long row of 4-hp waterproof motors drives the runout-table rolls between the last stand of an ultra-modern hot-strip mill and the coilers and pilers in the distance.