WESTINGHOUSE Engineer

MARCH 1951

The Evolution and Place of *Railroad Radio*

Use of radio to facilitate railroad operation is an outstanding example of an obviously good idea that has required many years to become practical. Attempts to use radio for this purpose are as old as radio itself. As early as 1914 experiments were made with voice-modulated spark transmission. However, it was quickly evident that radio was not yet ready for such difficult service.

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Westinghouse began its exploration of the possibilities of radio for railroad-type service just 30 years ago. In 1920 and 1921 experiments were made on tugboats in cooperation with the New York, New Haven, and Hartford, but range proved inadequate. Three years later the job was tackled again. While the result was much improved, noise prevented satisfactory results. The equipment tried was amplitude modulated and the frequency very low. Antennas were bulky, woefully inefficient.

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Next year began the first of two trends that have finally led in the last few years to rather complete technical success of railroad radio. This was the move to higher frequencies. The 1925 tests with the Norfolk and Western Railroad and the Westinghouse Interworks Railway were with frequencies of 2 to 4 megacycles AM, and again on the Chesapeake and Ohio in 1927. The results were much better, clearly pointing to the advantage of higher frequencies. As circuits and tubes capable of operation at the higher frequencies became available they were tried. In 1934 tests were again made cooperatively with the New Haven, this time at 34.6 and 62.5 megacycles. The experiments were extensive, covering 36 000 track miles and 1500 hours' operation.

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But all this was done with AM, which is inherently plagued with noise. Every spark at a rail joint, the sparks between rivets, and freight-car bodies are radio transmitters whose broad spectrum of frequencies is just so much background noise.

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By 1944 FM had become important and offered the answer to the millstone of noise that AM cannot shake loose. Development and use of radio for railroad service then became rapid. In 1945 the Federal Communications Commission reserved for railroad usage 60 clear channels in the 152–162 mc band. By 1949 the demand for channels in industrial and public safety became so great that the FCC reduced the railroad allotment by 21 frequencies, and assigned adjoining channels even to neighboring rail systems, as discussed by Mr. London in this issue.

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When one thinks of railroad radio, one thinks of main-line freight trains. While such use is beginning, the extent is still small. Small, at least, by comparison to the proportion of use of radio telephone by industrial-plant railroads, and "captive" railroads serving a particular company. Probably this follows because the advantages in yard operation or for heavy industrial traffic are more conspicuous. Many railroads serving large steel companies or other industries with considerable trackage and local haulage movements could not now maintain operation without it. For industries whose functioning depends on the haulage of bulky materials between different parts of the plant, the ability to communicate between central points and locomotives and crews is indispensable.

Many unusual episodes, besides the routine economies of time, are told of railroad radio. As these words are written, the Pittsburgh area has just experienced the heaviest snowfall in history, sufficient to paralyze traffic and to close most industries for several days. The steel companies that were able to maintain approximately normal operation were those whose rail systems were 100 percent equipped with mobile radio telephone, which maintained the flow of ore, slag, hot metal, billets, etc., between the widely separated sections of the plants.

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Mobile radio telephone used in steel mills will expedite the movement of raw materials and finished materials throughout the plant area, as the design capacity is limited by the movement of raw materials to the mill and the finished product away. For example, in one steel plant approximately 12 hours were required to make the necessary car movements in order to supply the six blast furnaces with raw materials. With radio, this time has been reduced to approximately six hours for this operation. The metal in the majority of cases is hauled a considerable distance, sometimes several miles. Before the use of radio mobile telephone, and due to the fact that this metal was delivered to four different open hearths, conditions arose where the hot-metal train was sent to one open hearth, only to find the mixer had broken down. The metal then had to be poured to the floor, subsequently requiring several hours to dispose of it to the open hearths. Or sometimes there was too much metal at one mixer, and therefore the crews had to wait until their metals could be taken. If the delay was four hours the furnaces lost four hours of tonnage production. Since radio has been installed on this particular operation, over the past two years no casts have been lost chargeable to railroad operation, and they are operating with fewer ladles than they did before.

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Main-line railroads also have had many unusual incidents in which radio has been of great value. It was during the New Haven tests in 1934 that the crew of a freight train observed a blazing journal on a car of inflammable material several cars ahead. By mobile radio telephone contact with the engineer and a wayside tower, the train was stopped at a nearby town where the local fire department was waiting to extinguish it.

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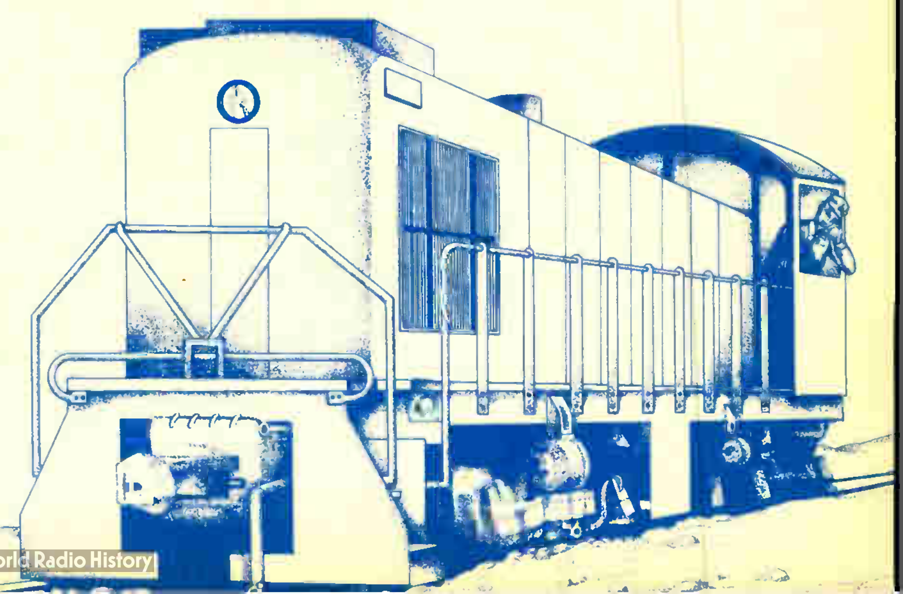
Railroad radio has finally turned its corner. It is now proved equipment. It has solved its major technical problems of providing good communication and being reliable. Its future problems are largely those of cost, regulations, establishing procedures for its use, and the time required for any new device to find acceptance in a going industry.



WESTINGHOUSE Engineer

VOLUME ELEVEN MARCH, 1951 NUMBER TWO

On the Side

With a bow to Picasso and apologies to Rembrandt, we present on this month's cover Dick Marsh's impression of the stator winding of a large a-c generator—looking from the inside. Said Dick when he submitted it, "Hope it isn't too reactionary!"

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Did you know that Westinghouse builds roads? Not roads you can go anywhere on, but electrical test "highways" that will tell the Ford Motor Company how their cars and trucks will perform in climbing Pikes Peak or roaring along a super-highway at 90 miles an hour. The 17 dynamometers and controls being built at Buffalo will simulate every conceivable driving condition. Eleven 200-hp machines will put 9000 miles of high-speed driving on Ford-built engines. Others will test transmissions and axles. The finished products will be tested too. With the front wheels blocked and the rear wheels free to turn on rollers, they will be operated completely assembled.

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The nature of two new Westinghouse plants to be opened in 1951 seems to be indicative of the times. One, at Union City, Indiana, will turn out fractional-horsepower motors, which are essential to the nation's defense program. The other, at Hampton, South Carolina, will make Micarta. We usually associate Micarta with decorative materials, but it is also used for bearings, helmet liners, and other defense-important products. Although both plants will increase production of normal peacetime goods, their essential military applications will make these expansions more significant than usual.

In This Issue

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Fig. 1

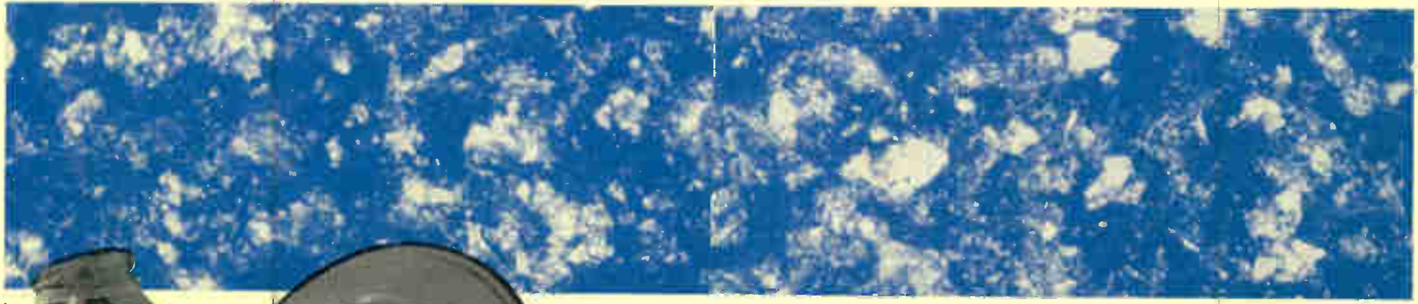

Fig. 2

Coastal Finish Extends Life of Distribution Transformers

J. G. Ford and A. J. Kuti
Manufacturing Engineers
Transformer Division
Westinghouse Electric Corporation
Sharon, Pennsylvania

Sea air—beneficial for humans—is bad for pole-top transformers. It makes them old before their time. But, with a new finish, not so much as before, by a factor of at least two to one. The new "Coastal" finish is also effective against other corrosive gases.

Fig. 1—This 100 X microphotograph shows mica flakes after a weathering test of the second of the triple-coat system.

Fig. 3

Fig. 4

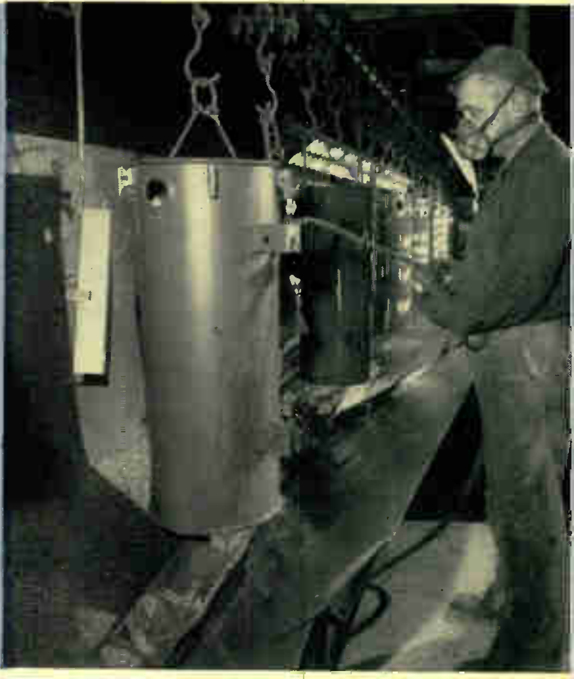

Fig. 2—Tiny mica flakes are added to the paint for the second coat.

Fig. 3—After 2000 hours of exposure to salt spray a large area of the standard finish on the panel to the left was badly corroded while the mica-base finish on the panel (right) remained in the original condition.

Fig. 4—The prime or first coat is applied by flow coating, using standard equipment, after which it is dried in an infrared-lamp oven.

Fig. 5—Tanks emerging from the oven are ready for the next coat.

Fig. 6—The intermediate, or mica-base coat, is applied by spraying.

Fig. 7—Two transformer tanks, one with conventional finish and one with Coastal finish, after 1000 hours' exposure in the salt-spray cabinet.

Acids, alkalis, salts, and oxygen—commonly found in seacoast and industrial atmospheres—are mortal enemies of most paint finishes. Given time they may even eat completely through the finish and destroy the metal underneath. Unfortunately, distribution transformers must often face at least one and sometimes a combination of these corrosive elements, and therefore need the best protection available. A new three-coat paint system—called Coastal finish—provides superb protection for these distribution transformers; in fact, it more than doubles the life of the finish.

Other difficult conditions also confront distribution transformers. For example, the surfaces of fully loaded transformers exposed to direct sunlight often reach temperatures of 200 degrees F or higher. During the winter months these same surfaces may be exposed to temperatures as low as minus 50 degrees F. With an operating range of 250 degrees the paint must be sufficiently flexible not to flake off due to differential expansion and contraction between paint and metal.

Elevated temperatures and oxygen of the atmosphere also cause paint films to age and become brittle. This accelerates the tendency to flake or craze during the winter months. It is important, therefore, to select a finishing material from the standpoint of heat resistance as well as initial flexibility.

Moisture in liquid or vapor form is perhaps the greatest enemy to the finish on pole-type distribution transformers. It readily attacks exposed steel surfaces, forming rust, and gradually penetrates paint films, corroding the metal underneath. Rust formation and hydrogen generated at the metal surface cause the paint to blister and lift. Once the film is broken, corrosion is accelerated and pits develop. If they are not given attention they may eventually completely penetrate the tank wall. This may drain the insulating oil from the tank and cause the transformer to fail. If it were not for moisture, the finishing of pole-type transformers would present no serious problem except in rare cases. Oxygen, salts, acids, and alkalis present in the seacoast and industrial atmospheres usually are destructive as they deteriorate the film and pave the way for moisture to do its damage. Also, certain metallic impurities behave very much like catalysts to accelerate metal corrosion by moisture.

Three-Coat Coastal System

The individual coats of the new three-coat system act cooperatively to resist moisture penetration and also the elements that promote it. Proper preparation of the metal surface is necessary before the finish is applied. Good adhesion is generally obtained by removing all rust, scale, grease, or other extraneous material. Best surfaces are obtained by treatment with phosphate solutions to form iron phosphate at the surface. The phosphate film retards corrosion by the passivating effect, and offers a tightly adhering porous surface for the base coat of paint to penetrate and grip the metal surface mechanically.

The prime or first coat applied to the prepared surface is composed of a vehicle giving good adhesion with flexibility and chemical resistance to salts, acids, and alkalis. The pigments are primarily zinc chromate and iron oxide. Zinc chromate is one of the best corrosion-inhibiting pigments due to the availability of the chromate ion in the presence of moisture. However, if used as a single pigment, it usually produces a somewhat brittle film. When combined with iron oxide, the brittleness is reduced and the vat or storage life of the paint is increased. Surprising as it may seem when this combination is tested as a priming coat alone, in comparison with other primers containing, for example, lead chromate or red lead, it sometimes appears to be inferior. The superiority stands out when the tests are repeated after the finish coats have been applied.

The second or intermediate coat—containing mica flakes—is without doubt the key to the successful performance of Coastal finish. The vehicle is composed of modified phenolic and alkyd resins. These are chosen for resistance to heat, oxygen, salts, acids, and alkalis in concentrations encountered in the atmosphere. The resin is the thermosetting type. By proper selection of solvent and adjustment of setting time of the resin, the solvent can be removed completely during the initial part of the drying cycle, before the resin has set to the hard state. This permits the resin to flow after solvent elimination and prevents "pinholes" through which oxygen and moisture could enter.

The pigment is composed of selected mica flakes that over-

Fig. 5

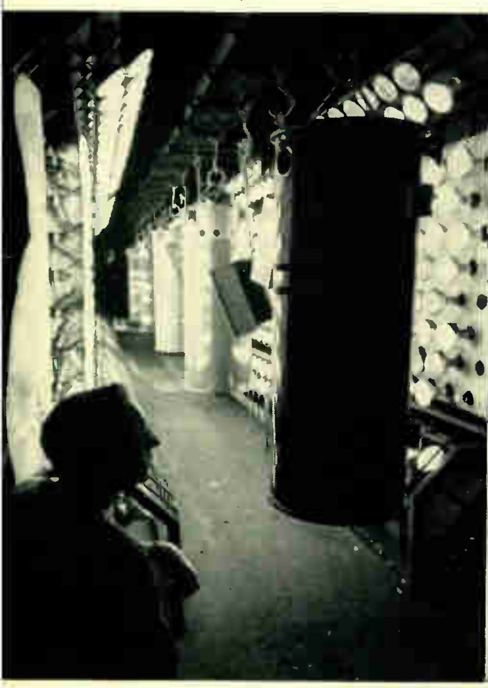

Fig. 6

Fig. 7

lap each other in the film and produce a "shingle-roof" effect to assist further in warding off moisture and oxygen. Mica also increases heat stability of the intermediate coat as much as ten times at elevated temperatures.

Mica in paint is not new, but its method of application is. The relatively large mica flakes used, plus their tendency to settle, presented problems, but these have been overcome by equipment that keeps the mica in suspension and thoroughly mixed during the application.

The third and final coat is composed of resins and pigments to withstand the elements and to provide good appearance. It can be tinted to give any desired color. When chalking takes place, a slightly darker shade develops, which does not detract from the appearance of the transformer.

The final coat has several functions: (1) It adds to appearance, (2) it enhances the resistance of the other two coats to oxygen, moisture, etc., and (3) it screens out the ultraviolet light of the sun's rays.

A series of test panels was made to demonstrate the salt-spray and weather resistance of the combination of primer and mica-filled second coat. They were tested simultaneously with panels painted with the standard finish.

After 2000 hours' exposure to the salt spray the mica finish showed no change, whereas the standard finish was approximately 50 percent deteriorated. At 3000 hours the standard finish was completely gone. It required a total of 10 000 hours continuous exposure to salt spray before small blisters began to appear on the mica finish. When, at the conclusion of this extreme test, the blisters were broken, there was evidence of trapped gas, possibly hydrogen, and a thin film of rust.

Other mica-finished panels were exposed for 18 months on Florida and California seacoasts. Weathering took place at the surface, exposing some of the mica flakes. However, there was still no sign of corrosion. A micro-photograph of a small section of the surface is shown in Fig. 1. The exposed mica flakes, shown being added to the resin Fig. 2, appear to be mostly parallel to the film surface and definitely indicate a shingled effect, which may partly account for resistance to salt spray (Fig. 3) and added heat stability of the vehicle. Also, mica improves the coverage on sharp or burred edges, thus reducing the tendency to corrode at these points.

Methods of Application

The metal surface is first alkali cleaned and rinsed, followed by phosphatizing and a dip in dilute chromic acid. This renders a clean surface, light gray in color and of sufficient porosity for good paint penetration with maximum adhesion. To prevent contamination of the prepared surface, transformer tanks are given the first or priming coat within a matter of hours by flow coating, Fig. 4. Viscosity and gravity are controlled. The flow-coating process is used for priming to fill any crevices left between tank wall and projection welded parts. It also assures complete and uniform coverage of all parts. The tank then is conveyed through an infrared dryer, Fig. 5. A surface temperature of approximately 340 degrees F is reached by the time the tank leaves the oven.

After cooling, the second coat is sprayed on, Fig. 6. A dark-green dye is incorporated into the otherwise clear mica-base paint or enamel to assist the operator in determining coverage and to facilitate inspection. The dye fades out—leaving a dark-brown color—on the subsequent infrared baking, which is similar to the first. The film dries to make a hard, tough

Fig. 8—This equipment dips test panels into a bath of either acid or alkali and then lifts them out of the solution to dry in air on a four-hour cycle—two in the solution followed by two in the air.

Fig. 9—Panels with mica-base finish and panels with standard finish were exposed in this Weatherometer. After 12 weeks of alternating cycles of one hour in fog and three in ultra-violet light, these samples showed chalking but no bad deterioration.

Fig. 10—Various finishes on hanger irons were exposed to 2000 hours of salt spray. From left to right the finishes are: galvanized; cadmium plated; galvanized and bonderized; cadmium plated and bonderized; galvanized plus mica-base finish; cadmium plated plus mica-base finish; galvanized and bonderized plus mica-base finish; and cadmium plated and bonderized plus mica-base finish. Only the cadmium-plated and bonderized plus mica-base finish hangers (at extreme right) showed no signs of attack.

coating that is highly abrasion-resisting.

Not until the transformer is completely assembled and tested is the third and final dark-gray coat applied. The transformer is then conveyed through a steam convection oven operating at 160 degrees F, where the final coat is dried tack-free. Further hardening of the film takes place in storage and shipment.

TABLE I—RESULTS OF LABORATORY TESTS ON STANDARD AND "COASTAL" FINISHES FOR DISTRIBUTION TRANSFORMERS.

Finish	Salt Spray 1000 Hours	Acid Resistance 0.5% HCL + H_2SO_4	Alkali Resistance 0.5% NaOH	Weatherometer 6 Weeks
Standard 100°C	Rusting around identifying numerals	No apparent change after 250 cycles	No apparent change after 250 cycles	No apparent change
Standard 150°C	Heavy rusting around numerals and at edges of panels	No apparent change after 250 cycles	Two top coats eaten away exposing primer after 250 cycles	Fading but no corrosion
Standard 200°C	Panel 50% rusted and peeling	Completely stripped off and rusted after 126 cycles	Completely stripped after 24 cycles	Badly faded with heavy chalking. Edge corrosion
Coastal 100°C	No evidence of corrosion	No apparent change after 250 cycles	No apparent change after 250 cycles	No apparent change
Coastal 150°C	Very faint rusting around numerals	No apparent change after 250 cycles	Faded but film intact. No corrosion	Fading but no corrosion
Coastal 200°C	Very slight numeral and edge corrosion	Faded appreciably but film intact and no corrosion	Finish coat eaten away after 126 cycles. Intermediate coat apparently untouched after 250 cycles	Badly faded with heavy chalking. No corrosion

Note: 100°C, 150°C and 200°C indicate that the panels were aged one week at these temperatures before making the above tests.
One cycle in acid and alkali tests consists of 2 hours' immersion and 2 hours' air exposure.

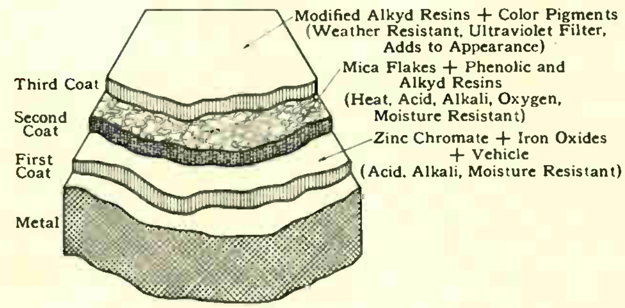

Fig. 11—Diagrammatic representation of the Coastal paint system.

Laboratory and Field Tests

Salt-Spray Resistance Test

Salt-spray tests are made in standard equipment (using a 20 percent solution of sodium chloride at 90 degrees F with 15 pounds pressure on the spray head). The effect of 1000 hours' exposure on two tanks is shown in Fig. 7. The standard finish on the tank shows considerable deterioration and severe corrosion, although the photograph does not fully bring this out. The finish was completely gone from the cover and from many areas on the tank wall. By comparison, the Coastal finish on the transformer showed no signs of either deterioration or corrosion, as indicated in table I.

Acid or Alkali Resistance Test

The acid and alkali resistance test was performed in the equipment shown in Fig. 8. Test panels were periodically exposed to an acid bath and then to air. The equipment is motor-driven and has a cam-operated arm on which the panels are hung. It operates on a four-hour cycle, two in the solution and two in the air. For the test a 0.5-percent solution of hydrochloric and sulphuric acid is used.

The standard finish has excellent acid resistance and there is little difference between it and the mica-base finish after 500 cycles exposure, or a total of 1000 hours in acid and 1000 hours in air. Deterioration takes place first at the extreme bottom edge of the panel, due largely to the increased concentration of acid at this area. When the panels are removed from the bath for air exposure, drainage continues. Evaporation of water during the drainage period results in increased concentration of acid at the bottom of the panel.

The alkali test is performed in a duplicate set of equipment. For this test an 0.5-percent solution of sodium-hydroxide is used. A distinct difference exists between the effect of alkali on the standard finish and on the mica-base finish. The three coats of the standard finish were completely removed, exposing bare metal, which at the end of 500 cycles had begun to show a rust stain. In the case of the mica-base finish under the same exposure, some deterioration of the final coat was shown; however, all three coats were intact and no signs of corrosion of the base metal were observed.

Weatherometer Tests

One week's exposure to Weatherometer conditions is considered to be about equivalent to outdoor exposure for a period of one year under average conditions. In this test, panels are attached to a cylinder and rotated continuously. They are exposed to periodic cycles of one hour in fog and three hours under ultraviolet light. The standard finish and the mica-base finish, after 12 weeks' exposure, are shown in Fig. 9. Neither finish showed severe deterioration. The final coats on both the standard and mica-base finish showed some dulling and evidence of light chalking. After 20 weeks neither finish had failed. Tests are being continued.

Outdoor Exposure Tests

Panels of the standard three-coat finish and the three-coat mica-base finish were prepared and exposed on both Florida and California coasts. At the end of 18 months none of the mica-base panels had shown signs of corrosion. The standard panels showed edge corrosion and rust creepage to the extent of about one-sixteenth inch in from the edge. Some chalking had taken place on both panels. This was particularly true for the panels exposed on the Florida coast. It is interesting to note that the panels exposed on the California coast at San Francisco still have most of the original gloss.

To determine the effect of heat aging on the film, the following tests were made. Panels of both Coastal and standard finishes were baked for one week at 100, 150 and 200 degrees C. After this heat treatment, a series of panels were heated to 100 degrees C, then quenched in a bath at −50 degrees C. Five such cycles showed no evidence of cracking or peeling.

One rather interesting result was the severe action of the salt spray on galvanized parts, Fig. 10. This was indicated by the white deposits on the hardware. As a result the mica-base finish was tested on hanger irons for distribution transformers, where standards now call for galvanizing.

Summary

This three-coat, mica-base paint system of the baking type was developed specifically for pole-type distribution transformers. Laboratory and field tests show that Coastal finish is superior to that previously used on distribution transformers; and that, as a result, the service life of the finish will be more than doubled.

Personalities IN ENGINEERING — J. G. Ford

The orthodox way to become a nationally known industrial chemist is to go to college, study chemistry or chemical engineering, probably add a year or so of graduate work, and then take a position with a large company where chemistry is important. But James G. Ford didn't do it that way. One day in 1918—a few months after he had finished high school—he quit a job in the Westinghouse factory at East Pittsburgh because he decided the job led nowhere. Walking home, he observed a large, new building up on a bluff above the highway, which he had heard was the new Westinghouse research department. Why not try for a job there? He climbed the many steps, and boldly asked to see the boss. Dr. P. G. Nutting, the director of the department, came to the anteroom and heard young, brash Jim Ford say he wanted a job. "Young man," said Director Nutting, "you've got a job. You can start washing dishes for the chemists." Thus began the illustrious career of an industrial chemist, which led to an award of the Westinghouse "Silver W" in 1939.

Jim Ford did more than wash dishes for the chemists. He took every means to learn what the beakers, bottles, Bunsen burners, and nose-insulting odors were all about. He enrolled in Carnegie Tech night school and later took summer courses in chemistry at the University of Pittsburgh. His diligence was soon observed, and he was elevated from laboratory flunky to chemist's assistant. In the next several years he worked with such men as Dr. J. F. Slepian and Dr. Karl Compton on insulating oils, carbon-brush problems. He had just developed a new C-battery for the then-infant radio when the a-c tube appeared, which made batteries no longer necessary. He had the distinction of presenting a paper on insulating oils before the American Chemical Society before he had taken a course in organic chemistry.

In 1931 he was named head of the Organics Section of the Chemical Division and in 1937 appointed section engineer in the Insulation Division of the Research Laboratory. As such, he performed further work on insulating oil, developed compounds for the removal of oxygen for the Inertaire system for power transformers, devised methods (still used) for drying out the compressor system of domestic electric refrigerators just being developed, and formulated fireproof dielectric liquids. He also was the leader in the program that led to the development of the pressboard tube for oil-filled core-type transformers, eliminating the Bakelite material with consequent improvement in electrical strength and reduction in cost. One of the most troublesome obstacles to the use of Hipersil steel in transformer cores during the middle 30's was lack of a suitable binder for the individual turns. Ford developed the bonding material still in use.

By 1941 the Transformer Division at Westinghouse decided they had to have this problem-solver closer at hand. So Jim Ford went from Research to Sharon, Pennsylvania, as manager of Manufacturing Engineering, which position he still holds. But this transfer was really only a change in locale, not a change in character of work. He has since led the way to new coatings for steel, new core-winding methods, improved filling compounds and varnishes, oxygen-inhibitors for transformer oil, better bushing cements, condenser-bushing varnishes, and ways to apply silicone and other heat-resisting insulations to railway transformers and to open and closed air-cooled transformers. He played an important part in the development of Hipersil grain-oriented electrical steel and in solving the many problems incident to its practical application in transformers. During the war he was deeply involved with many defense projects—for which he has since received the Navy Development Award. His adaptation of nylon to valve seats solved a troublesome and expensive electric-torpedo problem. For that same torpedo he devised a way to protect, simultaneously, the interior against corrosion from battery acid and the outside against salt water by a single treatment consisting of dipping and baking in Thermoset varnish. He devised the device now generally used for measuring dewpoint.

Ford has always been one to tackle a problem with vigor and determination. As a young man he was slight of build. In his community—his father was a coal miner—any physical weakness had its disadvantages. So he obtained a punching bag and went to work—and became a better-than-average boxer. He also went in for baseball—and became a semi-pro southpaw pitcher.

His love for sports and the outdoors has never left him. His associates never look for him in the office on the opening days of small game and deer seasons. Usually does pretty well too. Except last fall, after equipping himself with an expensive new rifle and telescopic sight, he tramped the hills of Pennsylvania's Elk County without so much as firing a shot. He loves golf but insists on using only iron clubs, and does better than most golfers with them. Says he can't be bothered with wood clubs. Is reputed to be a difficult man to bluff in a poker game—his favorite indoor sport. Ford has a penchant for practical jokes.

As one contemplates Ford's career, one fact stands out: an obstacle or handicap only makes him determined to excel. Mechanically ingenious (he has been granted 30 patents and has 13 more pending) new problems fascinate him, hold his attention. Like as not if you enter his office, he will start the conversation by "I've got a new idea," and proceeds to tell you about it before you can state your own question. That happened to us when we sought some facts for this piece. On that occasion the new idea had to do with solving the long-troublesome problem of oil seepage around screw fittings on oil-filled transformers. That story will appear in these pages shortly. There will undoubtedly be many more.

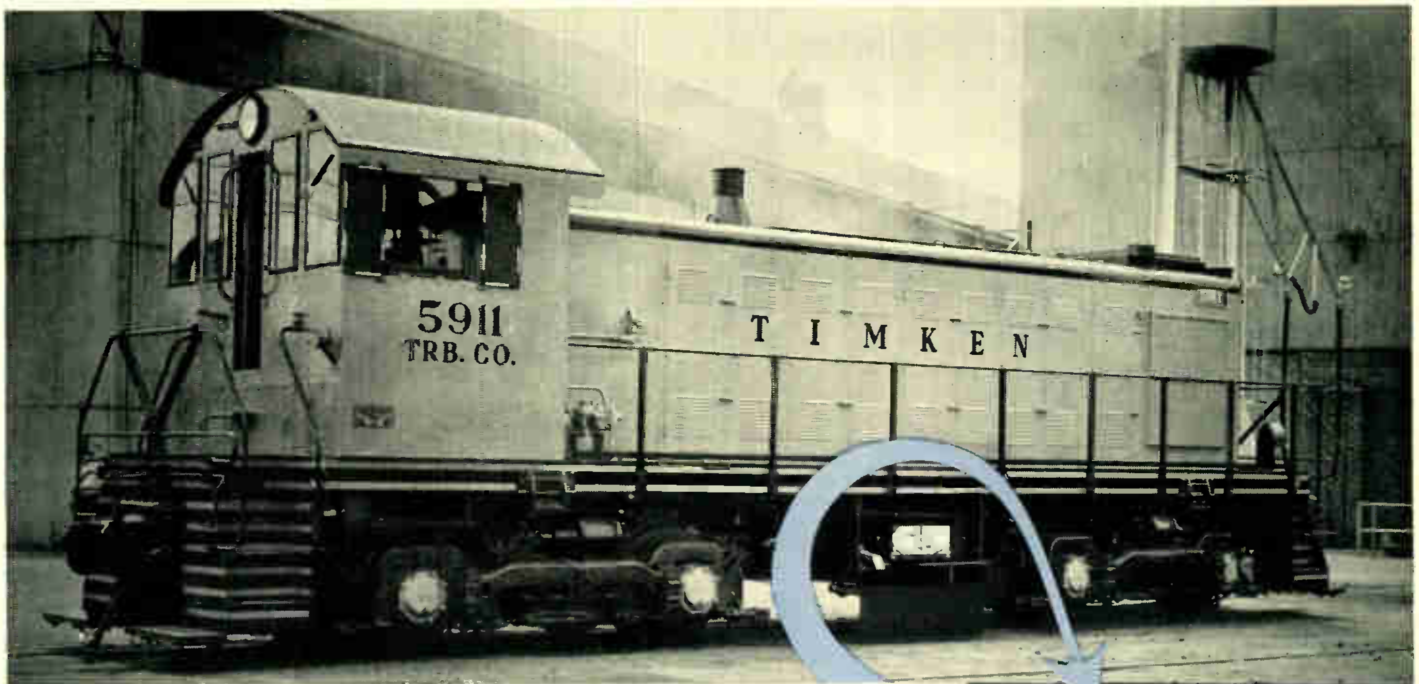

Fig. 1—Radio, such as type MR shown here, has accumulated a good record of dependability in industrial railroad communication.

Railroad Radio
Takes a New Step

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Communication Equipment Eng. Section
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In the development of a particular class of apparatus, the establishment of industry-wide standards for its use is akin to the 21st birthday in the life of a man. It signifies both that an advanced stage of development has been reached and that enlarged opportunities and obligations are at hand. This has happened to railroad radio.

The Association of American Railroads has drawn up a new requirement specification for frequency-modulation railroad-radio equipment in the VHF (very high frequency) band. This is, in part, an outgrowth of the action taken in 1949 by the Federal Communications Commission when that regulating body found it necessary to reduce the number of channels set aside for railroad use and to allocate frequency assignments with adjacent channels separated by only 60 kc. Previous radio equipment supplied to the railroads had been designed for alternate channel separation of 120 kc. To enable different railroads in the same area to use radio equipment on adjoining channels requires receivers with a high degree of selectivity. Modulation of an FM transmitter has to be limited to give a reduced spectrum width for operation in the narrow channels. Frequency stability of both receivers and transmitters has to be improved to keep the equipment closer to its assigned frequency.

To meet the new industry standards and to take advantage of the newest ideas in radio design and manufacture, both transmitter and receiver have been redesigned. This also gave opportunity to improve even further the equipment for more dependable operation. The result is a new type of railroad-radio equipment known as the FE.

Radio for railroad service must meet certain difficult but paramount requirements. In addition to the two essential ones of being suitable for adjacent-channel operation and meeting the industry standard specifications, the apparatus must be economical. While first cost is, of course, always a consideration, of greater significance to railroad operation is the cost of installation and maintenance. Most important of all is a high order of reliability or, as railroad men term it, availability, which is the percentage of time that installed equipment is available for use.

A modern diesel-electric locomotive is inspected once every 30 days and is given a major overhaul only after so many thousand miles or hours of service, depending on type of operation. This is not likely to be oftener than once a year. Otherwise the locomotive is in service or ready for service. Thus the availability factor varies from 81 to 99 percent[1]. The radio equipment must have a higher degree of availability. Should a locomotive or train be delayed due to need for repair

[1] I.C.C. Bureau of Transport Economics and Statistics, File 66-A-11, Statement 5025, Study of Railroad Motive Power, May, 1950.

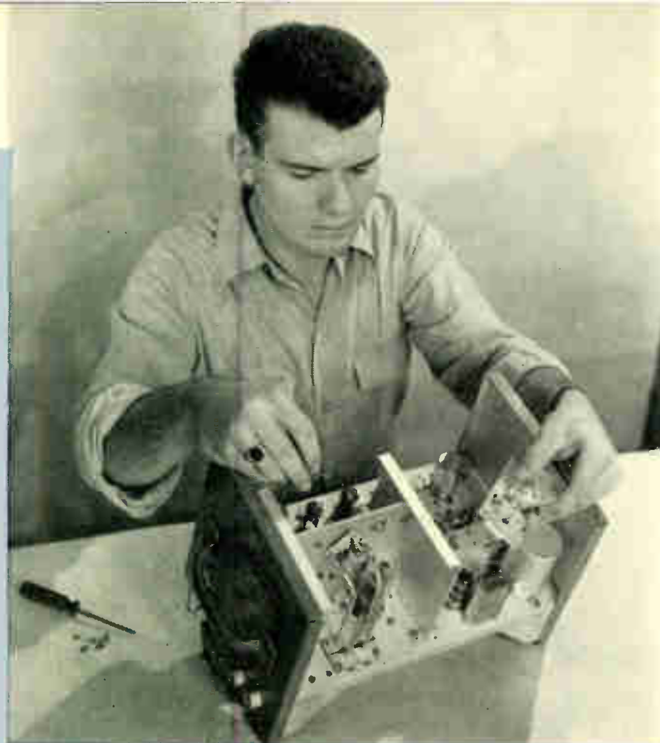


Fig. 2

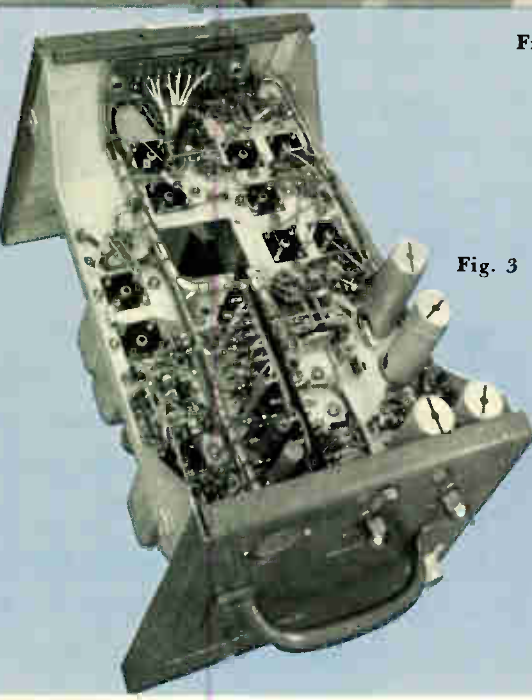


Fig. 3

Fig. 2—The basic type-FE mobile radio-telephone equipment is designed to provide all the functions required in every application. Where other services are required allowance is made for their easy addition, as is the case here where an accessory is being added to permit four-frequency operation. Fig. 3—A remarkable degree of openness has been achieved in the wiring and the components of the three units, of which the receiver is shown here. This is a great asset when servicing a unit. Fig. 4—The mobile radio-telephone equipment is made up of three basic elements installed in standard, uniform-size metal cabinets. These are transmitter, receiver, and lightweight power supply.

→ Fig. 4

to some radio part, it entails not just the few cents or dollars cost of the part itself but that incident to the time lost and wages of crew made inactive. Remembering that cargos may run into millions of dollars and are oftentimes perishable, the cost of a delay is many hundreds of times greater than the direct cost of a radio repair. This thought has been uppermost in the minds of designers of radio for railroad use. The previous radio equipment—type MR—established an industry record of performance in this regard. The new equipment is designed to better it.

One of the hazards to electronic equipment is the presence of high relative humidity. High-quality varnish-impregnated transformers stand up even under high humidity if the equipment is operated continuously. But if the equipment is not operated, i.e., has a chance to cool, and is exposed to humid conditions, transformer failures can be expected. To eliminate this source of component failure, all transformers used in the FE mobile equipment have been either hermetically sealed in metal cans or sealed with the Fosterite treatment.[2]

In electronic equipment using many resistors and capacitors, and other pig-tail type components, quality control is extremely difficult. If these components are wired point to point, covering up each other in layers, inspection is difficult or impossible. Often the wires supporting the parts are weakened when the inspector pries the components apart to examine those underneath. This occurs not only in manufacture but during maintenance. As shown in Fig. 3, wherever possible, the pig-tail components are mounted on terminal boards and connected to the various circuits by preformed laced cables. Where high-frequency circuit requirements demand point-to-point wiring, the parts are placed in an orderly manner with tie point provided to avoid long supporting leads on the parts. Although the units are constructed in compact chassis, 8 inches by 8 inches by 14 inches deep, the circuitry has been arranged to spread out the components to leave adequate space for good workmanship and easy access for inspection.

One major change in the new design has been the change from two-unit to three-unit construction. In the two-unit type MR equipment, the receiver and transmitter each had its own a-c power supply, and weighed 25 and 35 pounds, respectively. By separating the power supply the FE uses three lightweight chassis: the receiver weighing 14.5 pounds, the transmitter weighing 12.5 pounds, and the power supply weighing 25 pounds. The lightweight power supply is achieved by the use of transformer cores made of Hipersil grain-oriented steel, which effect approximately one third reduction in transformer size and weight compared with transformers using silicon-steel cores. All three lightweight units have integral plug connectors. When removal for servicing is necessary, a standby unit can be easily plugged into the mounting rack, returning the radio immediately to normal operation.

In addition to setting standards for adjacent channel operation, the AAR specifications cover standards of good engineering practice. These include detail requirements for mechanical construction, standardized RTMA components, and operation at high temperatures. Housing sizes and interconnection between hous-

[2]"Fosterite Insulation for Small Transformers," by Reuben Lee, Westinghouse ENGINEER, November, 1950, p. 233.

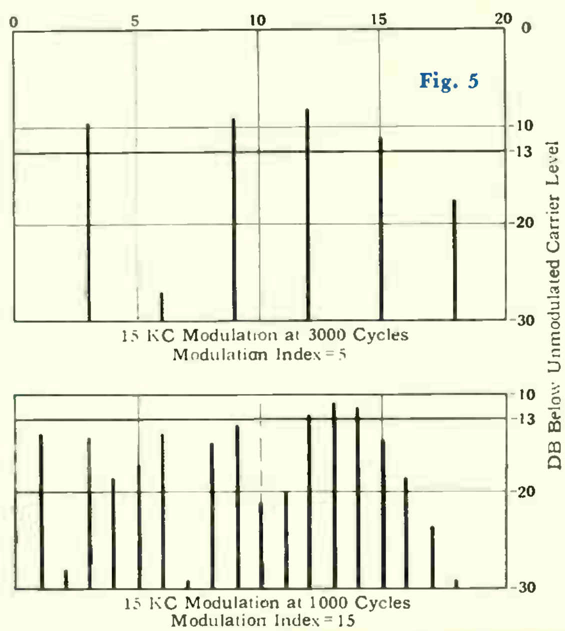
ing and control facilities are specified. The type FE equipment meets all these requirements.

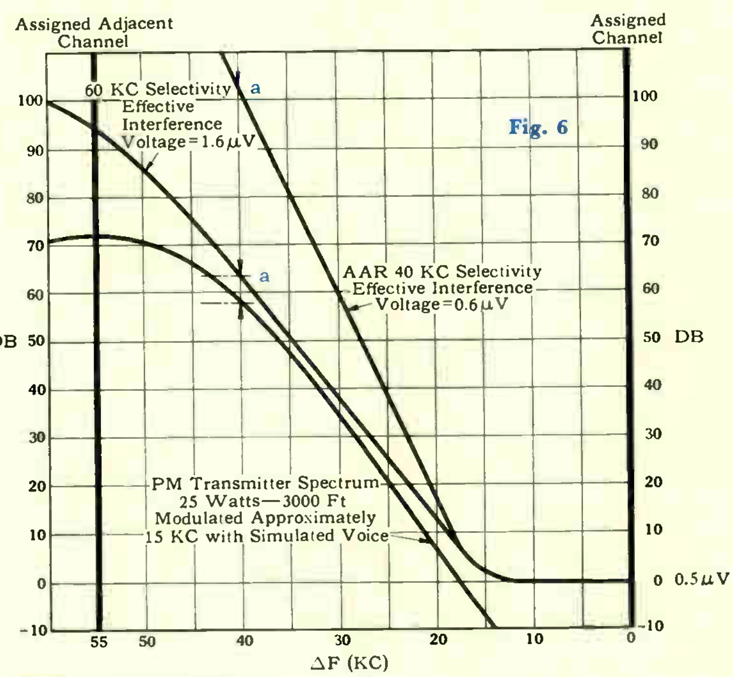
It is not economically feasible to build into a given equipment every feature required in all classes of service; yet, certain minimum requirements are needed by every user. The basic FE transmitter, receiver, and power supply contain the necessary circuitry for simplified operation in end-to-end, train-to-train, and wayside-to-train communication. Thus, where the basic system is applicable, only the essential equipment need be purchased to achieve the most economical installation. For more complex operation, the FE equipment contains a maximum of versatility. An integrated system to meet present or future complex operating requirements can be obtained by adding standard accessory units to the basic equipment. Thus, systems' requirements for multifrequency operation, talk-back operating positions, intercommunication between control positions, and a variety of remote control procedures can be obtained with standard components at a minimum expense. Or, additional features can be added to the basic mobile-telephone system as the requirement of the particular railroad changes.

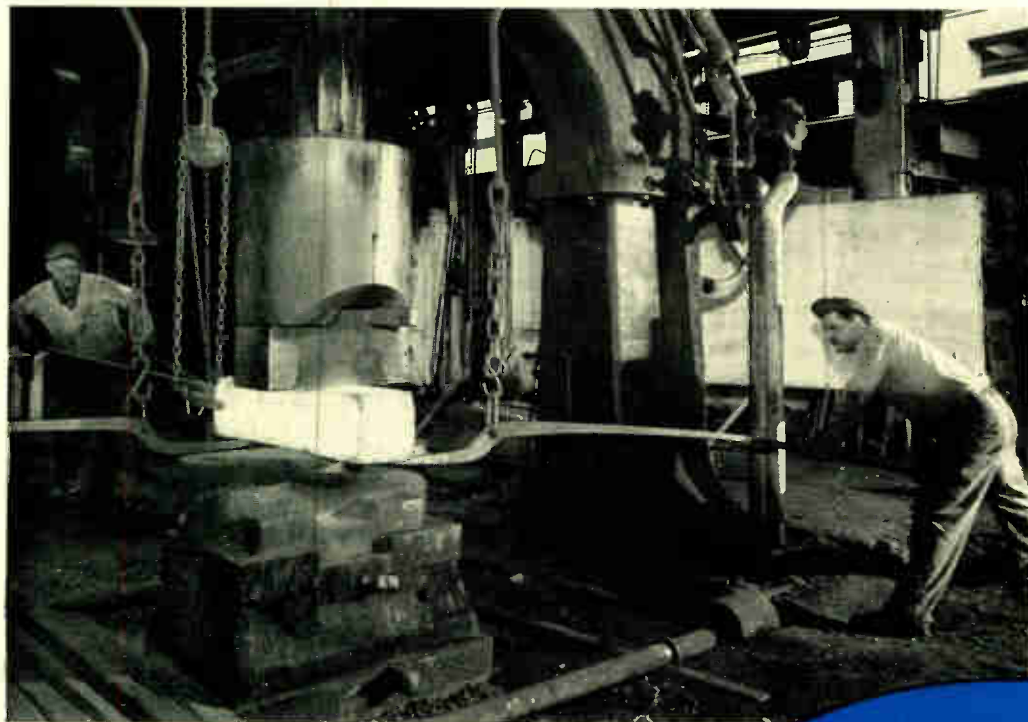
Figs. 5 & 6. Adjacent channel operation presented the toughest problem in the new design. The FCC assigns channels with 60-kilocycle separation and allows a frequency modulation or phase modulation deviation of ± 15 kilocycles. To realize optimum receiver sensitivity the transmitter modulation deviation should make use of the full deviation allowed. To avoid exceeding the FCC limit on modulation peaks deviation limiting is used. Fig. 5 shows the frequency spectrum of a frequency modulated wave with 1000 cycles and 3000-cycle modulating signals giving 15-kc deviation. To accept all pairs of sideband products contributing 10 per-cent or more of the total transmitted energy (those components greater than —13 db) a receiver bandwidth of approximately 15 kc each side of resonance is needed. To allow a nominal additional bandwidth for receiver and transmitter frequency stability, the type FE receiver has been designed with a total nose or acceptance bandwidth of 34 kc. A narrower bandwidth would result in loss of sideband energy and corresponding reduction in operating range.

Fig. 5 shows the portion of the transmitter spectrum which the receiver must accept. The transmitter spectrum extends in diminishing level beyond the range of frequency plotted. It is that portion of the transmitted energy that the receiver operating on an adjacent channel must reject. Fig. 6 shows the effect of the transmitter spectrum on a receiver with the AAR specification skirt selectivity of 40 kc and the effect on a receiver with a skirt selectivity of 60 kilocycles. The spectrum of a typical phase-modulated transmitter using a simulated voice signal to give approximately 15-kc deviation is shown plotted with a center frequency 55 kilocycles removed from the receiver frequency. Fifty-five kc instead of 60 kc was used to allow for the stability and accuracy of transmitter and receiver frequencies. The transmitter power has been attenuated to simulate a space separation of 3000 feet between receiver and interfering adjacent channel transmitter. In the case of the 40-kc selectivity the effective interference voltage is 0.6 μv while, with the 60-kc selectivity the effective interference voltage is 1.6 μv.[2] Thus, almost a 3:1 improvement is obtained by use of the narrower AAR selectivity. The FE receiver provides a skirt bandwidth of 35 kc to reject the undesired spectrum of the adjacent channel transmitter.

[2]The transmitter spectrum was measured with a receiver having a one-kilocycle bandwidth. In calculating the interference voltage, the interference voltage at any frequency was considered to be the attenuated "a" db below the receiver sensitivity of 0.5 μv. The interference voltage was determined at one-kilocycle intervals. The effective interference voltage was calculated by taking the square root of the sum of the squares of these voltages.







A 1200-pound ingot of Discaloy alloy undergoes a forging operation to obtain the proper shape and to get a better grain structure.

The development of a device or a material to fill a specific need oftentimes leads to its successful application for other uses not contemplated prior to that development. This is proving true with Discaloy, a high-temperature alloy originally developed for aviation gas-turbine disks.

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DISCALOY

THE DEVELOPMENT of alloys capable of withstanding high service temperatures and high stresses for extended periods of time is a major contribution to jet-engine progress. One of the latest alloys that has materially improved performance and lengthened aviation-gas-turbine life is Discaloy alloy. It was developed to make better turbine disks—the rotating member to whose rim the turbine blades are attached—a most critical part of jet engines because of the high stresses and temperatures to which these parts are subjected. The alloy's high resistance to plastic flow (creep strength) permitted a considerable reduction in disk weight, giving the improved performance.

Discaloy has exceptionally high creep strength combined with good ductility and excellent oxidation resistance in the temperature range 1000 to 1350 degrees F—the range in which present gas-turbine disks operate. It is an alloy having a minimum of the scarce strategic elements and attains its superb physical characteristics through heat treatment rather than cold work. Because of this it has, in addition to its excellent properties, the capability of being more easily machined, forged, and worked than other alloys having these high-strength, high-temperature properties. This is of special importance in fabricating intricate production parts. Thus Discaloy alloy is outstanding among disk materials, and has a versatility for a wide variety of other high- and low-temperature applications.

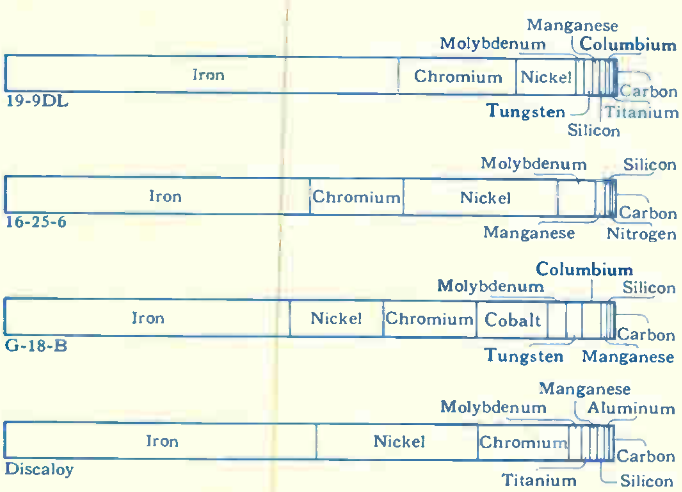

Fig. 1—Percentage compositions of some gas-turbine disk materials are compared (bold-face type indicates a scarce strategic element).

Containing from 50 to 59 percent iron, Discaloy is an iron-base alloy and has a minimum percentage of alloying elements commensurate with its high-temperature properties. None of the relatively scarce elements—columbium, cobalt, and tungsten—usually found in this type alloy are used in Discaloy. It is made up only of the relatively plentiful elements—iron, nickel, chromium, molybdenum, titanium, silicon, and manganese (the small quantities of manganese are obtained from the common ferromanganese). However, its combination of creep strength and ductility in the range 1000 to 1350 degrees F is comparable to, and in many cases surpasses, that of several heat-resistant alloys much higher in alloy content.

Heat Treatment

All commercial alloys except Discaloy that are presently used for jet-engine turbine disks develop their strength through cold working*. Discaloy, on the other hand, is pre-

*Cold working indicates an operation in which the material is subject to plastic deformation, carried out at temperatures below the recrystallization point and usually at room temperature. Hot working is done above this point. "Hot-cold" working is done at an elevated temperature but below the recrystallization temperature.

cipitation hardening, deriving its strength through heat treatment. This is important because it makes possible the attainment of uniform properties in various sections of a forging despite wide variations in the forging's size and shape. Thus it has been possible to establish guaranteed minimum strength properties that are considerably higher than those specified for disk alloys relying on "hot-cold" work to develop high strength.

Another advantage in developing properties through heat treatment rather than cold work is that forging operations are simplified. They can be carried out at relatively high temperatures where the material's formability is high. Smaller forging equipment can be used to fabricate parts from Discaloy alloy whereas much larger equipment is needed to form the same part from a "hot-cold" worked material. Also, with this alloy, large forgings having intricate shapes can be fabricated with relative ease in closed dies, with savings in material and machining costs. On the other hand, with alloys that rely on "hot-cold" work for their strength, the amount of contouring (forming of intricate shapes) that can be done is limited even when the largest forge hammers are used.

The treatment that gives Discaloy its excellent characteristics is actually two separate operations. The first involves solution treating by holding one to two hours—depending on size of the part—at 1825 ± 25 degrees F followed by oil or water quenching. This places the hardening constituent in solid solution and relieves all prior working stresses. In this condition the material is soft, 131 to 170 Brinell, and thus amenable to forming operations. The second step involves precipitation hardening (or aging). The material is held 20 hours at 1350 ± 15 degrees F, furnace cooled to 1200 ± 15 degrees F and stabilized by holding 20 hours at this temperature. When fully heat-treated, the hardness and strength properties of Discaloy remain above satisfactory minimums over the entire service-temperature range.

General Characteristics

Discaloy is unusually strong in the presence of stress raisers such as machined notches. Bolts, which usually break in the threads when pulled in tension at room or elevated temperatures, exhibit considerable ductility in the vicinity of the break when made from Discaloy. The yield and ultimate tensile strengths of Discaloy bolts are actually higher than those of unnotched specimens. Appreciably higher creep-rupture strength is also obtained for notched, compared to unnotched, bars between 1000 to 1350 degrees F. This feature of Discaloy is important in forgings having drilled holes and sharp corners, and gas-turbine disks that develop highly complicated stress patterns in the vicinity of blade-root serrations in the disk periphery.

Compared to other wrought heat-resistant alloys, Discaloy has excellent machinability. All machining operations, such as turning, drilling, planing, milling, broaching, can be performed in the alloy's fully hardened (aged) condition. For some parts requiring small diameter holes, drilling may be simplified and speeded up by performing the operation while the material is in the soft, as-forged, or solution heat-treated condition. Hardening by aging can then be carried out as a final operation.

The oxidation resistance of Discaloy is entirely adequate for its useful temperature range, i.e., up to 1350 degrees F. The alloy withstands much higher operating temperatures for extended time periods without encountering excessive oxidation. It will not scale at forging temperatures as high as 2150

Precipitation Hardening

In the last 15 or 20 years of experimenting with alloys, a method of producing greater hardness and strength other than the age-old cold-work process has been discovered. The phenomenon of precipitation hardening—or age hardening as it is sometimes called—was first experienced in connection with an aluminum-copper alloy, Duralumin, about 1900. It was found that by proper treatment, submicroscopic particles of one constituent of this alloy could be induced to form a strengthening and hardening structure within the basic crystal structure.

Since then this principle was found generally applicable to a certain class of alloy, the solid-solution alloys. In metals, as in liquids, it is possible to have a solution of one constituent (element or compound) in another and they are similar to liquid solutions in every respect except mobility. As the temperature changes, the solubility of one in the other varies, and ordinarily, at the lower temperatures the amount of the first constituent (solute) that can remain in solution in the second (solvent) is reduced. Thus if the alloy is cooled from an elevated temperature, a portion of the first constituent will come out of solution.

In the precipitation-hardening process, the first step—solution treatment—dissolves the hardening constituent in the other. This is accomplished by heating to a relatively high temperature, but one at which the alloy is still a solid. It is then cooled rapidly to retain the hardening constituent in solution, but now in a supersaturated state (i.e., there is more of the hardening agent in solution in the second step than can be accommodated under equilibrium conditions). The submicroscopic particles of this supersaturated constituent then slowly precipitate out of solution and agglomerate, revealing themselves as fine, discrete particles within the crystalline structure of the basic solid solution.

The second part, or the actual aging, begins when precipitation starts. It is the precipitated particles, wedging themselves into the normal crystal structure, that give the alloy the much-sought-after increased hardness and strength. The precipitated particles increase in size with time, and the hardness and strength of the alloy correspondingly increase. But this is true only up to a critical particle size. Above this size, the hardness and strength are lowered. The aging process in which this particle growth occurs can be carried out at various temperatures and for various time periods, depending on the chemical composition of the particular alloy. In general, increasing the aging temperature of a given age-hardening alloy (while maintaining the temperature below that at which solution of the aging constituent occurs), shortens the time required to reach maximum hardness and lowers the maximum hardness attainable. Thus, with a properly adjusted temperature-time relationship, optimum hardness and physical properties are possible.

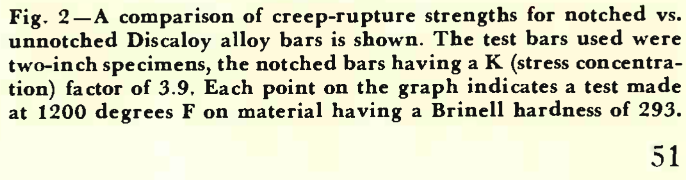

Fig. 2—A comparison of creep-rupture strengths for notched vs. unnotched Discaloy alloy bars is shown. The test bars used were two-inch specimens, the notched bars having a K (stress concentration) factor of 3.9. Each point on the graph indicates a test made at 1200 degrees F on material having a Brinell hardness of 293.

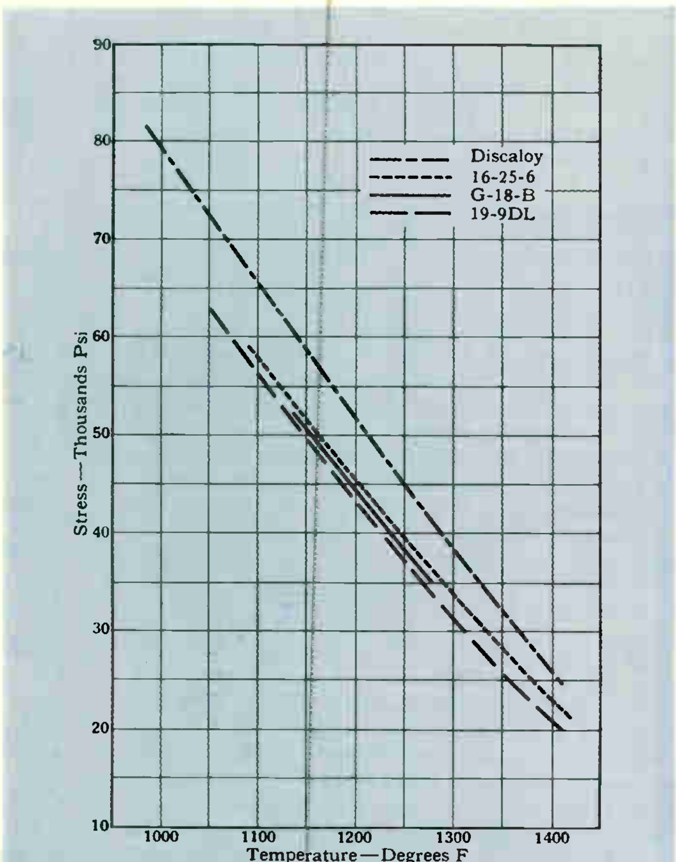

Fig. 3—Creep-rupture strengths of several gas-turbine disk alloys. These curves were drawn from data of tests made by the Materials Engineering Department.

TABLE I—PHYSICAL AND MECHANICAL PROPERTIES

Linear Coefficient of Thermal Expansion: Temperature Range (°F)	Linear Coefficient of Thermal Expansion: (in/in/°F / 10^6)	Temperature (°F)	Tension Modulus of Elasticity (10^6 psi)	Fatigue Strength* (psi): one million cycles	Fatigue Strength* (psi): 100 million cycles	Impact** Strength (ft-lb)
70	8.4	70	28.4	67 000	56 000	
70–200	8.5	200	27.6			41
70–400	8.7	400	26.4			45
70–600	9.1	600	25.0			42
70–800	9.4	800	23.5			37
70–1000	9.5	1000	22.3			34
70–1200	9.6	1200	21.0	59 000	50 000	
70–1400	9.8	1350	20.0			

*Cantilever test bars subjected to repeated bending at a frequency of 7200 cycles per minute.
**Standard Charpy V-Notch test specimens.

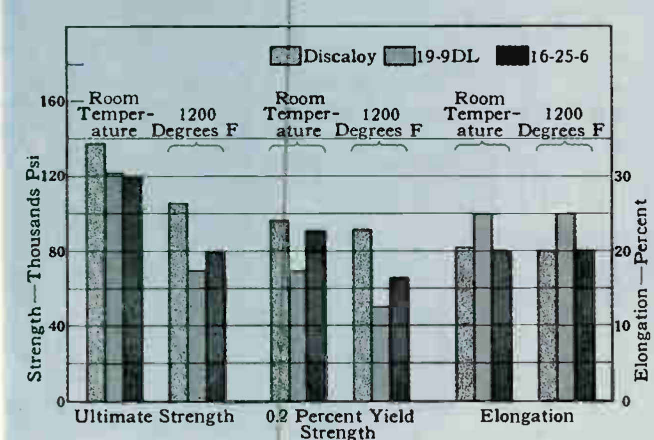

Fig. 4—Comparison of tensile properties of several gas-turbine disk alloys. Data from tests made by Materials Engineering Department, Westinghouse.

degrees F. The maximum operating temperature is not limited by lack of oxidation resistance but by a decrease in strength above 1350 degrees F. At higher temperatures the effect of age hardening decreases, the alloy over-ages and partially softens with time.

Properties

The density of Discaloy is 0.287 pound per cubic inch—about the same as steel. Its magnetic permeability is 1.008 (comparable to annealed 18–8 stainless steel) and remains essentially constant despite subjecting the material to drastic cold work, extended holding times at elevated temperatures, or cooling to liquid-helium temperatures. Low magnetic permeability has made the alloy desirable for a number of applications in rotating electrical equipment where high strength and low power losses are of prime importance. Its melting range is approximately 2550 to 2600 degrees F. The linear coefficients of expansion, elastic moduli, fatigue and impact properties are listed in table I. The low coefficients of expansion are important in minimizing stresses in parts subjected to wide temperature variations. The high moduli, which vary linearly with temperature, indicate high rigidity at both 70 and 1200 degrees F.

Whereas the hardness of Discaloy in the solution heat-treated condition ranges between 130 and 170 Brinell, the hardness of the fully heat-treated material depends on hardener content, i.e., titanium. For gas-turbine disks, hardness may vary from 248 to 302 Brinell, depending on whether the titanium content is on the low or high side of the specified range, 1.35 to 1.85 percent. For forgings that require exceptionally high tensile strength, titanium content, hence hardness, is increased. A hardness range from 302 to 400 Brinell is used for such forgings, depending on the specific needs of the piece.

Forgings requiring very high tensile strength combined with low magnetic permeability have been fabricated from Discaloy having a hardness range of 321 to 363 Brinell. The standard 0.2-percent yield strength of this material is specified as 125 000 psi minimum at 500 degrees F. Values as high as 140 000 psi have been obtained at this temperature with ultimate strengths of 160 000 psi and elongations of 10 to 15 percent. The high yield strength does not markedly decrease until temperatures above 1200 degrees F are reached. This is true for both gas-turbine disk forgings in the lower hardness range and for exceptionally high-strength forgings in the higher hardness range.

Although samplings have indicated that the variation in tensile properties in any one piece is slight, there is the usual variation between heats due to differences in composition and hardness within the specified ranges. Thus samples from a large number of heats have been tested and results plotted on a statistical basis. This gives an accurate picture of the minimum as well as average properties. The average values for tensile strength, 0.2-percent yield strength and elongation are 136 000 psi, 95 000 psi and 20.5 percent, respectively. For specified creep-rupture tests conducted at 1200 degrees F and 60 000 psi on gas-turbine disk material, a similar analysis yields an average rupture time of 22 hours and rupture elongation of eight percent.

Fabrication

Discaloy can be forged over a wide temperature range, 1600 to 2300 degrees F. Because of its relatively high formability, however, it is not necessary to employ the higher temperatures. The recommended hot-forging range is 1800 to 2150 degrees F. The upper part of this range is used for initial operations on large forgings while the lower range is used for final shaping and for small sections. Hot rolling is carried out in the same temperature range.

The relatively high degree of formability of Discaloy is reflected in the numerous methods used to fabricate parts. Gas-turbine disks of relatively small diameter are upset* forged into pancake shapes and the final disk configuration is machined from the pancake. Disk forgings of relatively large diameter have also been made in this way. When the large disks entail considerable machining to produce an intricate shape, pancake forgings result in material waste; contour forging in closed dies then becomes desirable. When forging costs are secondary to the saving of even the less critical alloying elements, high-strength alloys capable of being contour forged take on added importance.

Another method of fabrication that saves material and reduces machining is tire rolling, a process in which the metal is formed into a ring or doughnut shape. Tire rolling of Discaloy is performed at elevated temperatures where formability is good. Rolling of rings, which has distinct advantages over mandrel forging, cannot be employed for alloys requiring cold work to attain high strength. Rings can be tire rolled much closer to finish machined dimensions than is possible by mandrel forging. To a limited extent flanges and other projections can be produced as an integral part of the ring; these changes in cross section are impractical in mandrel forging. Tire rolling and contour forging have another advantage in that the metallurgical structure of the part is improved.

For small parts, savings result if cold-forming operations can be substituted for machining. This is done with remarkable success on Discaloy bolts and studs. Bolt heads are formed by upsetting at room temperature, using cold-drawn bar stock as a starting material. Threaded sections of bolts and studs are cold-rolled. After heat treatment the strengths of these bolts are high and uniform throughout.

All machining operations can be performed on Discaloy using standard high-speed steel and cast-alloy cutting tools. Cemented-carbide tools have also been used but in most cases are not necessary. Final machining is usually done when the material is in the fully hardened condition to obtain a smooth surface. Such difficult operations as drilling, milling, and broaching are performed with relative ease. At the expense of surface smoothness it is possible to obtain longer tool life and more rapid machining for hogging cuts and interrupted cuts when the material is in the solution heat-treated condition. Discaloy may be readily cut in either the soft or hard condition with abrasive wheels, power hack saws or, in the sections two inches or less in thickness, with band saws.

Experience in welding of Discaloy is limited. Where welding has been used, however, no unusual difficulties have been encountered. For example, Discaloy rods up to 1.0 inch in diameter have been successfully flash butt-welded to S.A.E. 4130 steel. Discaloy sheets have been joined successfully by spot, seam, and inert arc-welding methods.

*In "upset" forging the metal billet is placed on end and squeezed or hammered so that its longitudinal axis is shortened.

Application

In addition to forgings such as disks, bolts, couplings, spacer rings, and extension pieces for gas turbines, the use of Discaloy strip is being considered for other gas-turbine components where temperatures are not in excess of 1350 degrees F. Steam-turbine elements such as throttle valves operating at temperatures up to 1050 degrees F have been made from the alloy. It is also used in turbine-generator rotors and other electrical equipment such as coil-retaining rings that require high strength as well as nonmagnetic characteristics. By replacing magnetic steels with this alloy, power losses have been reduced and overall efficiency improved.

Extrusion dies made of high-strength Discaloy have, in some instances, replaced high-alloy tool steels. Hot-work, tool-steel backup dies, used to extrude Phos-Copper wire, cracked after extruding 5000 to 10 000 pounds of wire, and required regrinding after extruding 3000 pounds. Discaloy backup dies have extruded over 30 000 pounds of Phos-Copper wire with only one-fifth the wear and are still operating. Also, because of the alloy's greater stability at high temperatures, it has been possible to increase extrusion temperatures from 1050 to 1275 degrees F. After more than 2000 hours at the higher temperatures the Discaloy dies have shown no loss in hardness or strength.

High-strength Discaloy has also been used as a spring material at room temperatures. Belleville springs made from this alloy have been used in mercury-arc rectifiers.

• • •

Railway Carhouse Lighting

While a city sleeps, its transportation equipment—buses, streetcars, and trolley buses—so indispensable to the city's daytime existence, must be readied for the morrow's chores. As a part of a general maintenance improvement program undertaken by the San Francisco Municipal Railways, their Portrero carhouse has been completely renovated and their Ocean Avenue carhouse has been relighted. The general maintenance areas of the Portrero carhouse (shown at right), previously served by World War I vintage lighting, and the Ocean Avenue carhouse have been given a 25-30-footcandle intensity of lighting throughout. Lighting for all other service areas has been tailor-made to fit the needs of each specific job.

Secondary Metering

Gets a Current Transformer of Its Own

Tradition often overrides both the impetus of modern technology and the impatience of those striving for a change. Such was the case with metering current transformers until engineers recently broke away and designed a new current transformer for low-voltage metering.

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In early electrical history, power at 220 or 440 volts was measured without current transformers because loads were not beyond the capacity of self-contained meters. Large loads in the big cities were still d-c loads.

With the advent of the low-voltage a-c network, some 25 years ago, the d-c systems were replaced and, for metering purposes, the large loads began to require current transformers. Many varieties were available, but these current transformers were not especially designed for this service; they were too large and expensive, having been designed for high voltages and heavy impedance burdens. ("Burden" is secondary load, and is measured in ohms because the current is the standard five amperes.)

There was, and still is to a lesser extent, a school of thought that only one design of current transformer should be made for use on all circuits up to and including five kv. A lengthy discussion could be presented on the pros and cons of this problem. But, with the advent of the low-voltage current transformer discussed here, it is difficult to justify the much higher cost of installation of five-kv current transformers on low-voltage circuits.

Current transformers for low-voltage service have had a long evolution. Both designers and operators have been too much tied to the old practice. Modify the old stuff to do a new job was their idea.

About two years ago, some design engineers met with some operating engineers, determined to forget old practice and tradition, and to develop a current transformer for low-voltage metering. The results of these meetings was a new, smaller transformer (shown with older types in the photograph on page 55). The reduction in size is interesting, useful, and valuable to the operator in itself, but he is doubly pleased by being able to buy the new instrument transformer at a much lower price.

Certain questions arise at once:

1—The new transformer looks like a toy. Can it be any good?

2—In what current ratings is it built?

3—What are used as primary terminals?

4—How was this great reduction in size accomplished?

It has a continuous current capacity of 200 percent and the excellent ratio and phase-angle performance is shown in

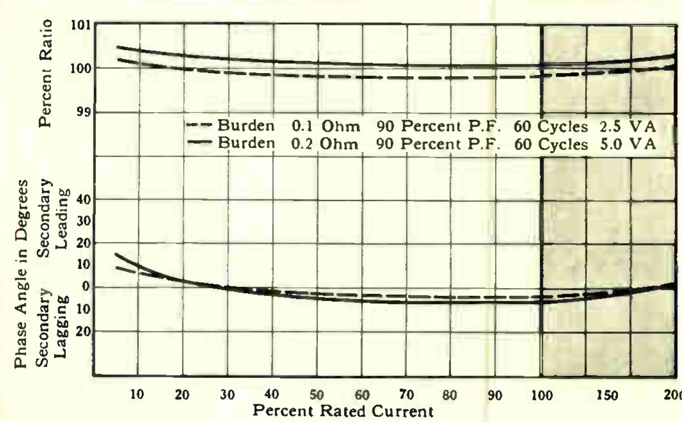


Fig. 1—Ratio and phase-angle curves for the MR current transformer. Ratio is 200 to 5 amperes (600-volt class).

TABLE I—BURDENS OF METERS WITH LEADS (LEADS OF NUMBER 10 WIRE)

Meter Types	Meter Alone			With 10 ft of wire			With 20 ft of wire			With 50 ft of wire		
	Volt-Amps	Ohms	Percent Power Factor	Volt-Amps	Ohms	Percent Power Factor	Volt-Amps	Ohms	Percent Power Factor	Volt-Amps	Ohms	Percent Power Factor
OA-RA	1.2	0.048	56	1.36	0.054	70	1.54	0.0616	78	2.86	0.0874	89
OB	0.35	0.014	77	0.56	0.022	90	0.79	0.0316	96	1.52	0.061	99
RB	0.48	0.0192	56	0.65	0.026	75	0.826	0.033	93	1.55	0.062	97
CS, CA, OC Serial number less than 15 000 000	0.57	0.0228	38	0.707	0.0283	66	0.865	0.0346	83	1.56	0.062	94
CS, CA, CB, CBF, TCA, TCS, OC Serial number above 15 000 000	0.32	0.0128	56	0.50	0.02	86	0.705	0.028	96	1.45	0.058	98.6
C-2, etc.; R-2, etc.	0.59	0.0236	44	0.73	0.0293	69.6	0.92	0.0369	82.6	1.6	0.064	94
CA-2, etc.; CS-2, etc.; CB-2, etc. Serial number less than 15 000 000	0.31	0.0124	65	0.495	0.0198	91	0.737	0.0295	94.8	1.467	0.058	98.8
CAH and CSH (Thermal)	0.86	0.0344	95	1.087	0.0435	98.5	1.337	0.0535	98.6	2.08	0.0822	99.5
CAH-2, etc. (Demand)	0.82	0.0328	95	1.054	0.0422	97.6	1.303	0.0521	92.2	2.045	0.0818	99.2
KAH-2, etc.	0.62	0.0248	95	0.855	0.0342	98.2	1.102	0.0441	98.8	1.847	0.0739	99.4
QCA-2, etc.	1.5	0.06	95	1.7	0.068	97	1.955	0.0782	97.1	2.682	0.1075	98.6
RL-2, etc.; RK-2, etc.	0.59	0.0236	44	0.732	0.0293	69.6	0.92	0.0369	82.6	1.6	0.064	94

Fig. 1. The ratio error is practically negligible at full load. And because a phase shift of three minutes is required to effect meter registration by 0.1 percent, phase-angle errors—representing phase shifts in the secondary output current—are also negligible. These units are tested to withstand 10 000 volts for one minute between primary and ground.

The new transformer is built in ratings of 200 amperes, 400 amperes, and 200 + 200 amperes, 3 wire (all good for 200 percent continuous current). The primary terminal can be any one of the solderless connectors designed for connection to a round bar. New terminals recently developed are shown on the lower transformer in Fig. 2.

How was this accomplished? A corollary to this question is, why wasn't it done 20 years ago? Three principal factors have contributed to the new design: (a) meter burdens have decreased; (b) grain-oriented silicon steel (Hipersil) with extremely high permeability at low inductions has become cheap and plentiful; and (c) scientific and analytic design methods for the biased-core current transformer construction have been worked out.

In addition, the new transformer resulted from a determined idea that a current transformer should not be much heavier and cost much more than the meter it operates. This idea merited greater attention because of the greatly increased number of low-voltage current transformers required in recent years.

Meter burdens began to decrease 30 years ago; but even 20 years ago metermen considered it necessary that a transformer carry 0.5 ohm with good accuracy. EEI standards adopted over ten years ago specify a standard metering burden of only 0.2 ohm. But full advantage of this reduction was never taken. Table I shows that the actual burden—meters and leads—rarely exceeds 0.1 ohm. The size of a low-voltage current transformer is almost proportional to the burden it must carry, so that the reduction from 0.5 to less than 0.2 ohm permits considerable reduction in size.

The new grain-oriented electrical steel known as Hipersil alloy has a permeability at low inductions nearly twice as great as the old hot-rolled silicon steel. Twice the permeability means that only half as much steel need be used.

The final step was the scientific application of the biased-core principle of current transformer construction. This construction is not at all new. Descriptions of it have appeared in German, English, and American literature for over 20 years. The idea is simple. Use two cores instead of one, with an additional turn or two of the coil wound around one core only; a biasing flux in the core is set up that effectively doubles (approximately) the permeability. The only difficulty is that if the relative sizes of the cores aren't correct, and the proper number of biasing turns aren't used, it won't work. And no one knew how to calculate the core proportions or number of turns. The best combination of cores and turns could be found only by trying all possible combinations. With the design analysis worked out by T. Specht[1], it was possible, for the first time, to apply the biased-core idea to best advantage.

Consider then these possibilities: meter burdens less than half what they were 25 years ago; core material twice as good; and a design method capable of doubling the good qualities of the material. It is then not surprising that the new transformer can be small, especially considering that its design was undertaken with a determination that it be small, and that the resulting transformer be more comparable in size and cost with the associated meter.

One advantage of great practical importance incidental to the reduction in size of the core is the reduction in open-circuit voltage to a relatively safe value because the voltage induced in the winding is proportional to the cross section of iron.[2] The crest value is less than 140 volts, equivalent to the crest value of an ordinary a-c voltage of 100 volts. This permits omission of the short-circuiting device with its attendant cost and loss of registration due to misconnection.

The new design will be of great value to metermen and utilities in their effort to give better service at lower cost.

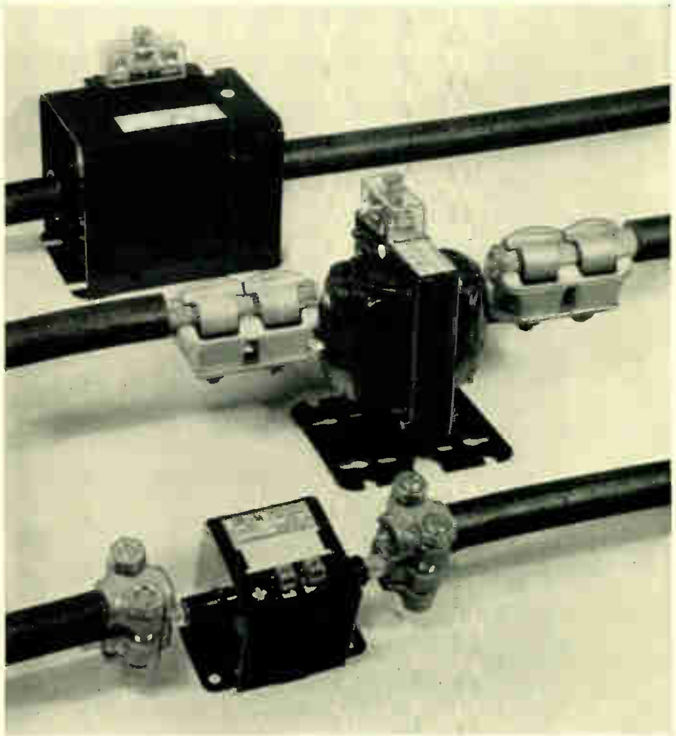


Fig. 2—The MR current transformer (foreground) is compared in size with two older types (the WE and FW). Note new types of terminals on the type MR.

REFERENCES

1. "Biased-Core Transformers," by T. Specht, *A.I.E.E. Transactions*, Vol. 64, 1945, p. 365.
2. "Open Circuit Secondary Voltages," by E. C. Wentz and T. Specht, *A.I.E.E. Transactions*, Vol. 65, 1946, p. 254.

Have You Ever Seen 1 000 000 Kva?

You can, in a color-sound movie recently released by Westinghouse. The 16-mm film, titled "Electrical Proving Ground," shows the important role that the Westinghouse high-power laboratory has played in the development of the De-ion-grid oil circuit breaker, switches, arresters, and other switchgear apparatus.

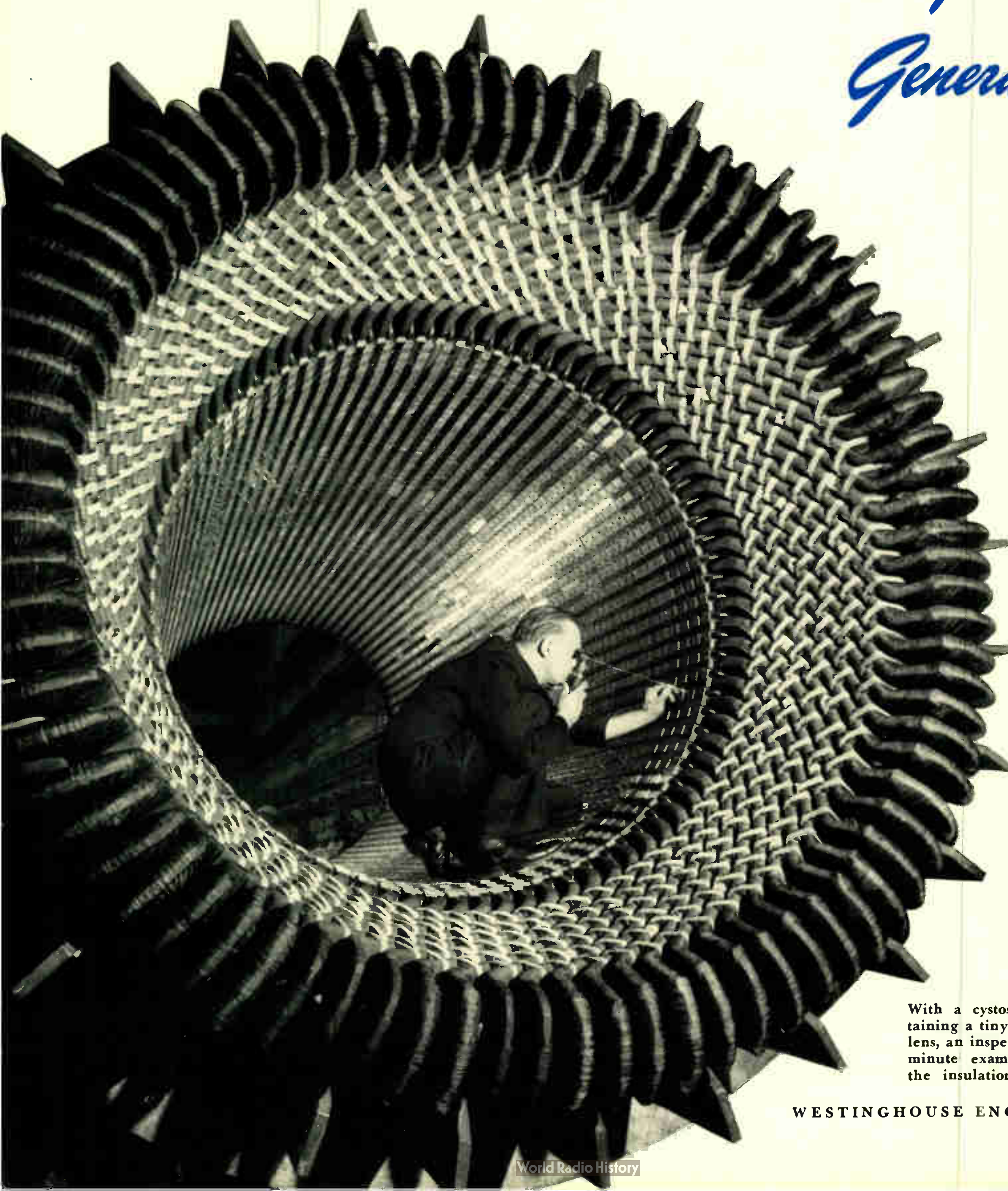
Highlight of the picture is a slow-motion study of a short circuit on a 132-kv line. A dramatic comparison is made of the action of two circuit breakers in clearing the fault from the line. One is a high-voltage breaker built in 1925, the same year that the high-power laboratory was built. The other is a modern De-ion-grid oil circuit breaker, which disconnects the line ten times faster than the old one, and restores service automatically. This and other spectacular scenes indicate the many possibilities for utilizing the 3 000 000 kva available at the high-power laboratory.

The film, which lasts 26 minutes, is available to technical, civic, and educational groups for the cost of mailing. Applications for the film should be made to the nearest Westinghouse District Sales Office.

That the maintenance and inspection of insulation on large high-voltage rotating machines have great influence on power-system reliability is not questioned. But the best way of maintaining this insulation in proper condition is occasionally questioned. A planned inspection program incorporating the experience of both the operators and the manufacturers can detect and protect against insulation difficulties.

J. S. Johnson, *A-C Engineering*
Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania

Check-ups for Generators



With a cystoscope containing a tiny lamp and lens, an inspector makes minute examination of the insulation surfaces.

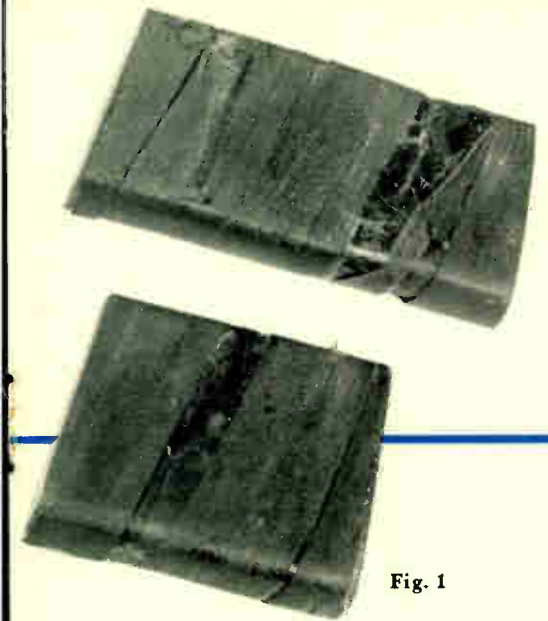


Fig. 1

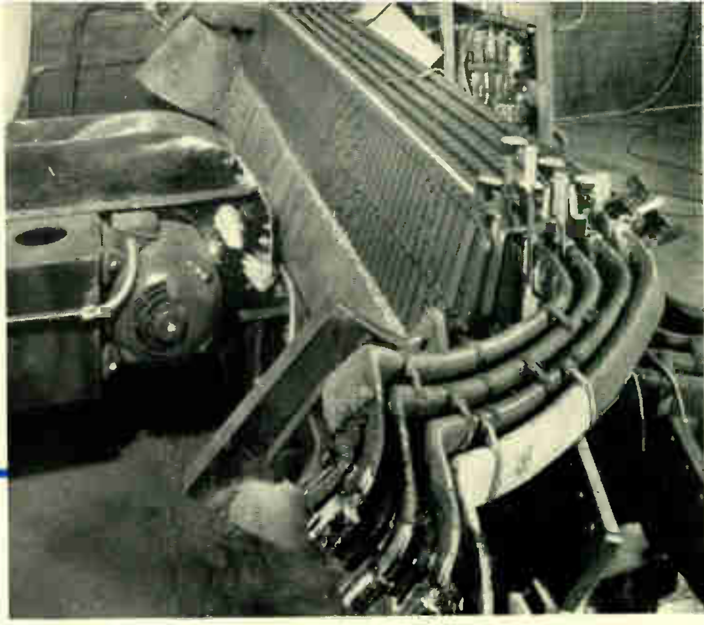


Fig. 2

Fig. 1—Two segments of coils showing the types of tape separation—superficial (lower) and acute (above) taken from set-up at right. Fig. 2—Set-up for testing full-size half coils under actual operating conditions.

Manufacturers of large high-voltage rotating machines are interested in, and feel a responsibility for, the field performance of machines they build beyond the completion of successful acceptance tests; to them a continuing, thorough maintenance program is of more than ordinary interest. The insulation of these machines—turbine generators, waterwheel generators, and synchronous condensers — is sufficiently important in itself to justify a well-planned program. Regular inspection of the coil insulation to detect indicators of possible trouble and thus give the maintenance program purpose and direction is only logical.

Maintenance Inspection Service

A Maintenance-Inspection Service has been organized to assist users with their maintenance, inspection, and testing problems. Basically this program makes available to the users of Westinghouse machines an integrated program designed to anticipate and correct difficulties that may arise and to promote the greatest usefulness of the machines. Another objective is to encourage consultation and to cooperate with the user in the administration of existent or partially developed programs.

The service is presently directed at large turbine generators, waterwheel generators, and synchronous condensers, and includes examination by engineers having broad field experience. It is aimed specifically toward detecting likely causes of trouble and is based upon thorough visual examination. To supplement this visual inspection, certain tests of the machine insulations are included in the service. However, no test methods now available (or likely to be developed) make it unnecessary periodically to examine visually the equipment's insulation to determine its physical condition.

The first inspection should be made jointly by manufacturer and user after approximately the first year of operation. The time for and the extent of the subsequent inspections is usually determined on the basis of conditions found at the time of the first inspection. In the case of steam and hydraulic generators, generator inspections can be made at the time normal turbine inspections occur, which reduces the number and total duration of outages of the complete unit to a minimum.

Insulation Problems

There are a few definite sources of trouble that should be looked for in the maintenance program. Some of these (tape separations and end-winding corona) can be attributed primarily to the machine's physical size and shape, and all (including slot discharge and conductor short circuits) to casualties of the insulation due to operating stresses. Based on years of experience, it is the search for these primary insulation difficulties that should be made the basis of any good inspection program.

High-voltage machine insulation is subjected to physical stresses caused by varying temperatures and electrical stresses during loading extremes not encountered by other insulations. The large physical size of these machines, the relatively high operating stresses, the difficulty of limiting corona on the intricately shaped end windings, and the need for high service reliability all contribute to the complications of the insulation engineer's job. In addition to selecting chemically and thermally stable materials having the necessary physical properties, these engineers face the problem of processing them into desired form. The insulation must then be resistant to normal deterioration and contamination as well as possess all the necessary insulating qualities.

Improvement of high-voltage machine insulation has been continuous. Since the early years of this century the basic insulation has been mica, but the form of the insulation, bonding resins, and supporting structure has changed. Materials and insulation-processing techniques have changed radically over the years; insulations on modern machines are distinctly different from the earlier units. Also the physical size of machines has increased and will continue to increase. Thus a knowledge of the particular type of insulation on a given machine and the performance obtained with it have an important bearing on the unit's maintenance.

The physical structure of the insulation in these machines is rather complicated. Primarily it is a barrier of adequate dielectric strength between conductors and grounded parts. The insulation itself and the mechanical supporting structure are at times subjected to severe mechanical shock and other physical forces during machine operation. And the extent to which an insulation is stressed varies with the type of machine, its physical dimensions, and loading characteristics.

Tape Separation

For asphalt-bonded mica insulations the degree of accommodation of conductor expansions and contractions is somewhat unpredictable. On a severely stressed machine (long conductors with variable loading) a phenomenon called tape separation can occur. This appears to be characteristic of asphalt-bonded mica insulations only, however. The newer, synthetic-bonded mica insulation has withstood severe cycling in laboratory tests with no tape separation.

Basically, tape separation occurs where stator-coil insulation is unable to follow the successive expansions and contractions of the copper conductors. The insulation elongates longitudinally with the conductors during loading (temperature rise while output is being increased). Because the asphalt bonding material is essentially a high-viscosity liquid, the insulation lacks the elas-

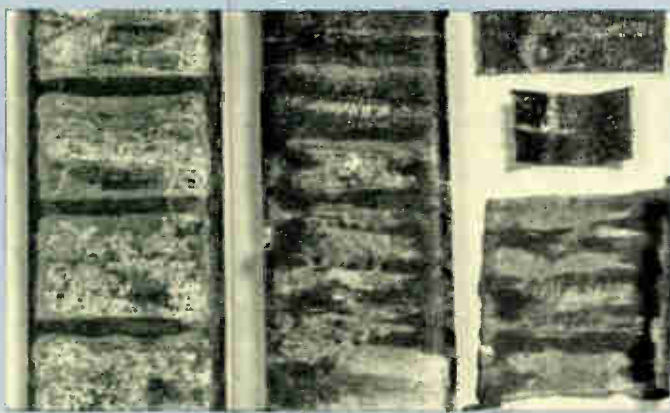
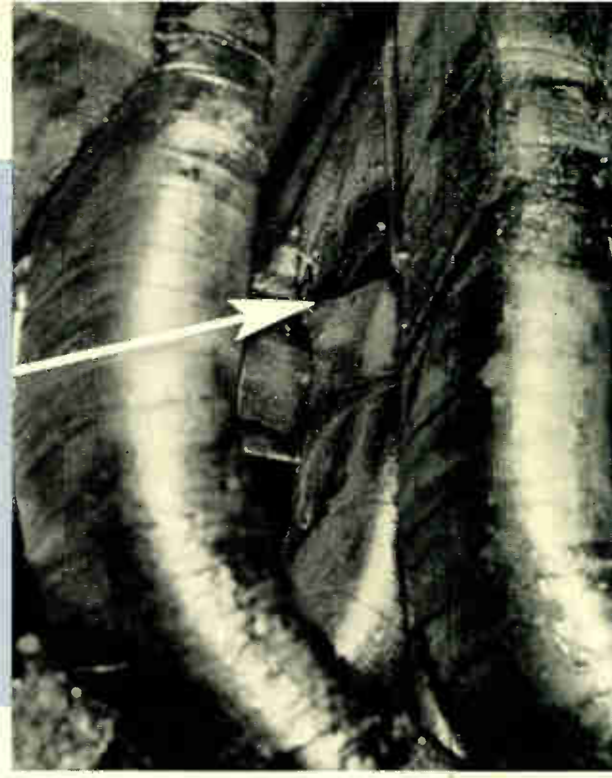


Fig. 3—The binding tape of several coils shows surface deterioration due to slot-discharge effects produced in the laboratory.



ticity of the conductors. Therefore, on cooling, the insulation can fail to return to its original position. The total permanent stretch for a given cycle is small (being only 0.001 to 0.002 inch). Sometimes, however, the effect is cumulative; after a large number of thermal cycles, appreciable separation can occur. As a rule, this separation takes place near the end of the straight part of the coil (under the end wedge) or, as in the majority of instances, in the curved part just outside the end of the core.

Tape separations fall into two classifications (Fig. 1). The most frequent is the superficial or surface separation. Here the dielectric strength of the coil insulation has not been significantly reduced. The other and relatively rare type is acute separation. In this, insulation migration has produced a serious fracture of the insulation at or near the observed separation. Under this condition operation is hazardous and the coil insulation must be repaired or replaced. Superficial separations are generally characterized by relatively firm insulation in the vicinity of the surface separation and acute separations by a "necking down" of the insulation wall in the vicinity of the visible separation. This more serious condition is usually detectable by inspection.

For developing tape separation, the first few years of a machine's operation are the most critical; in this period the extent and the seriousness of tape separation will ordinarily be fixed. Most machines operating under average conditions have, at most, only a negligible amount of tape separation, and the shorter machines generally have none.

Acute tape separation has been observed on several long hydrogen-cooled turbine generators, but many such machines have been inspected that show no evidence of this. There are, however, a number of turbine generators having the superficial separation in varying amounts and it is important to watch for these conditions and note trends.

Slot Discharge

Prevention of corona in the straight portion of the coil resting in the slot (slot parts) of stator windings is accomplished by coating these coil surfaces with a low-resistance conducting finish such as the varnish-base compounds in present use. In the past colloidal graphitic water suspensions were used. This coating treatment, which has been used by Westinghouse for over 20 years, has successfully eliminated slot corona. In a few cases, however, electrical contact is broken between the conducting coil finish and the core. Under this loss of contact, which has been limited entirely to the top or last coil side placed in a slot, a rather intense capacitive discharge occurs between the ungrounded coil sides and the core at the higher operating voltages. This phenomenon, called "slot discharge," can be seriously destructive to the coil surface finish and the ground insulation if it continues for a protracted period.

When slot discharge was discovered, an investigation into the reasons for it was begun. A core model (Fig. 2) to study the factors that might lead to surface discharging was made and the phenomenon was successfully reproduced in the laboratory. Consequently, the insulation processing was modified to overcome the tendency toward this discharge phenomenon and rigorous tests including high voltage, temperature cycling, and severe vibration were made.

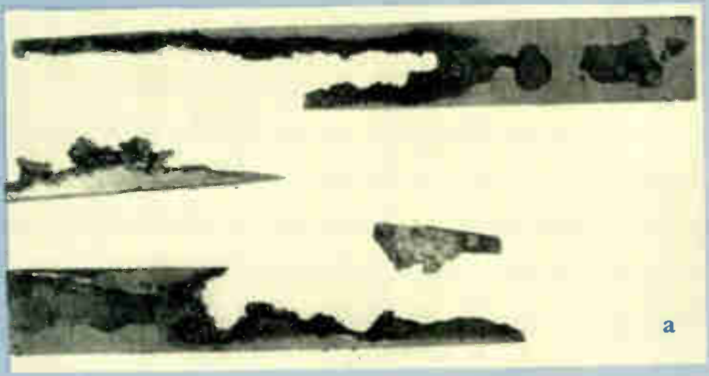
The incidence of "slot discharge" has been small, but the possibility, however remote, of trouble from this phenomenon necessitates that suitable tests be made to watch for its appearance. Suitable and economical corrective treatments have been developed that are effective in suppressing this surface discharging. Effects of slot discharge are shown in Fig. 3.

End-Winding Corona

End-winding corona is minimized in modern windings by stress-relieving semi-conducting finishes and by providing spacing between the stressed members. Inorganic binder tapes and twine, Micarta spacers and synthetic resins with inorganic pigmentation provide surfaces that are highly resistant to the deteriorating effects of corona. Even a fairly high level of end-winding corona is not a serious hazard, in general, and does not significantly limit the usefulness of a machine insulation. However, attempts have been made to reduce this phenomenon on machines in service and it is possible to improve conditions with proper treatment. Reduction of end-winding corona is achieved by an increase in stress on portions of the end-winding insulation. Treatments recommended are dictated by the conditions observed and a consideration of the machine's design and construction.

Conductor Short Circuits

Conductor insulation of multi-turn stator coils of large rotating machines is designed with large factors of safety. And this insulation is subjected to relatively high overpoten-



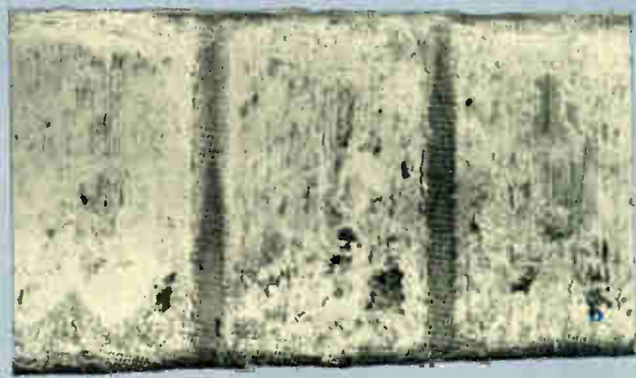


Fig. 5—(a) Burning of filler pieces and (b) surface deterioration of waterwheel-generator insulation.

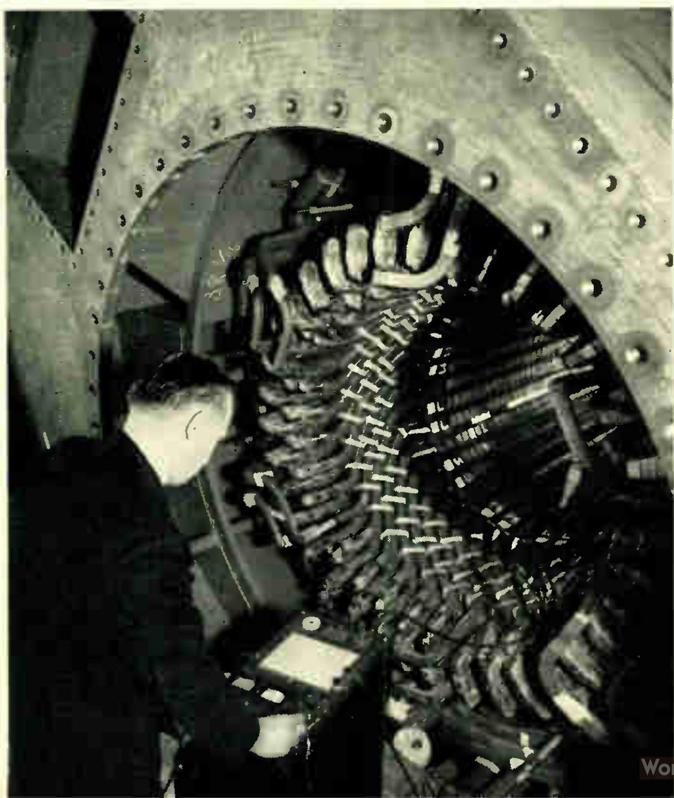
←
Fig. 4—An acute separation of coil insulation in service is here shown on a bottom coil.

tial tests. Nevertheless a certain percentage of winding failures that occur probably originate as turn-to-turn faults. Obviously, then, testing this insulation at voltages above operating stress is desirable and a method has been developed for surge testing the conductor insulation of large machines at voltages up to several times the operating voltage. This is a routine test for certain types of machines at the factory. The equipment is also available for field tests.

Likely Failure Causes

Modern high-voltage stator windings have enjoyed a high level of service performance; failures in service have been rare occurrences. From available experience, some general conclusions are possible. Failures do not result from prolonged electrical stress at operating voltages on insulation that is physically intact. And for relatively undisturbed insulation (i.e., not physically damaged) the mechanism that produces failures at higher voltage stresses is present to such a minor extent at operating stress that it does not significantly limit the life expectancy of properly designed insulation. Failures are far more likely where something has occurred to destroy the physical integrity of the insulation. Maintenance inspection and testing should be directed toward the detection of conditions where insulation has been physically weakened to the extent that failure at operating stress or normal overpotentials may result.

Fig. 6—High-voltage equipment for the d-c overpotential test shown attached to coils of a medium-sized 3600-rpm generator.



Maintenance Tests

The combination of thorough visual inspection and proper interpretation of tests permits a reasonable estimate of insulation condition. Thus, these periodic tests and inspections should establish conditions of the insulation over a period of time. Extrapolation of the performance trend established should be justified and a better judgment as to when a machine winding is in need of repair or ultimate replacement can be made. No single test that will provide all the desired information relative to insulation condition is known. Nor is it likely a test will be developed that can directly indicate the remaining useful life of an insulation. There are a few basic tests that give excellent indications of insulation condition when properly interpreted in the light of information gained from the visual examination by experienced service men.

General Non-Destructive Tests

The non-destructive tests—insulation resistance, power factor, polarization, ionization—are of greatest value when related to changes in the physical condition that may be occurring in the insulation. Frequently the absolute measured values have only limited significance. Large areas of insulation are involved in machine windings and the few small particular areas of weakness would not be expected to affect significantly the characteristics as determined for the entire machine winding.

A sudden drop or a sustained downward trend in insulation resistance might be interpreted differently, depending on whether it was measured on the stator or rotor. Different levels of insulation resistance should be expected of different types of machines; totally enclosed hydrogen-cooled stator windings should have a relatively high level of insulation resistance. A large drop in normal insulation resistance should be seriously regarded. It may be indicative of moisture condensation in the housing that may lead to failure of creepage surfaces. Open-type machines, particularly those with water-spray air cleaners, would naturally be expected to have lower values. The same value of insulation resistance that would be indicative of hazardous conditions in the closed machine might not be at all alarming on the open-type machine. Of the non-destructive tests, the insulation resistance and the dielectric absorption tests appear to have the most merit to indicate contamination by moisture or other agents that have a tendency to decrease either the volume or surface resistivity of the insulation.

Overpotential Tests

Overpotential tests are the only means for showing that winding insulation has a certain level of insulation strength. Depending on the test value used and the minimum insulation strength, such tests can damage the insulation. Although it is possible to use either a-c or d-c overpotentials, the d-c overpotential test appears to be advantageous because, for equal searching effect, it is considerably less damaging to good insulation.

The a-c test values should be high enough only to give assurance of certain required minimum insulation strengths. For frequent tests a somewhat lower value should be used, based on the theory that for shorter times between tests a lower margin would be required to give the same overall safety factor. The application of this test is a calculated risk that is subject to justification based on the overall economics of making repairs during scheduled-maintenance versus under-emergency conditions.

While there is a greater background of experience with a-c tests, d-c overpotential testing is believed to be fundamentally advantageous. High-voltage mica-tape machine insulation has d-c insulation strengths 2 to 2.5 times the one-minute a-c rms strength. An equally searching d-c potential therefore is a smaller percentage of the d-c strength than would be the case with comparable a-c stress. Another advantage in favor of the d-c test is that deterioration of insulation with time at equal percentages of one-minute strength is considerably less for d-c than for a-c stresses. This means that a given test may be applied longer or repetitively with insignificant deterioration of good insulation. Also the d-c test equipment is much less expensive and far less costly and cumbersome to transport. D-c overpotential tests for maintenance purposes are therefore preferred by Westinghouse because the risk of damage to good insulation is much less than with a comparable a-c test. The instrument used in connection with this test in the Westinghouse Maintenance-Inspection Service is a multi-range high-voltage d-c tester made by Tekk corp.

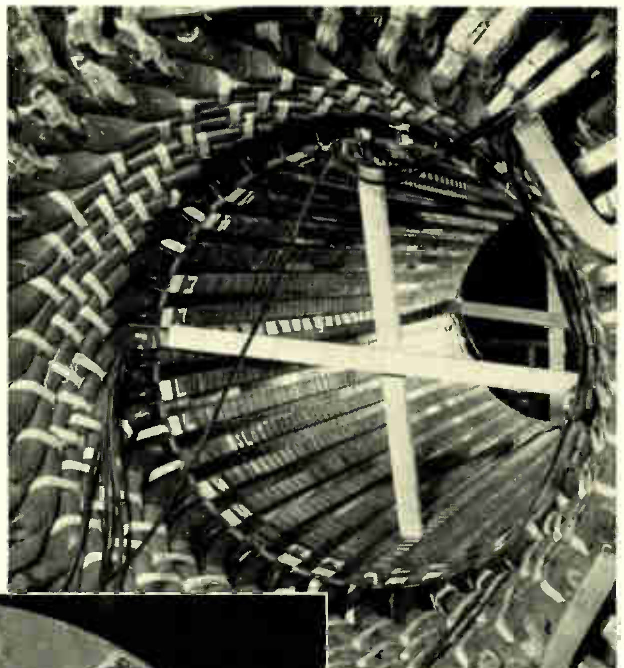


Fig. 7—Two surge-inducing coils are shown in position in the bore of a 3600 rpm generator adjacent to two machine coils for detecting short-circuited conductors.

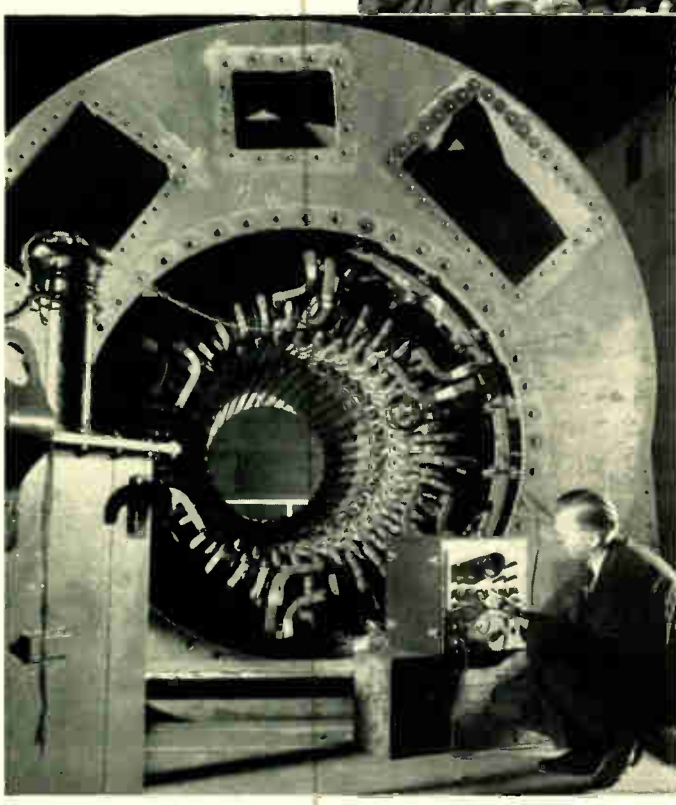


Fig. 8—The phenomenon of slot discharge is searched for with this portable cathode-ray oscilloscope equipment.

Slot-Discharge Testing

The slot-discharge analyzer is a single-purpose instrument; it checks the adequacy of contact between the low-resistance conducting surface of the straight part of the coil and the core. An a-c test potential is applied to the winding equal to approximately maximum line-to-ground operating voltage. Any high-frequency discharge between core and coil is observed on an oscilloscope. If these line checks indicate existence of discharging, the affected coil sides are located by probing coil surfaces at accessible areas such as in vent ducts.

Conductor Insulation Tests

The surge-induction test checks multi-turn conductor insulation at voltages several times the normal operating value. Two primary or surge-inducing coils are located in the bore of the machine adjacent to two coils of identical electrical position in the winding. Surges are alternately applied to these coils with a conventional surge-comparison tester. An oscilloscope is connected to the winding terminals. Normally the oscilloscope traces of the induced surge in each coil under test are superimposed and appear as one trace. When there is a short-circuited conductor in one of the coils the traces are not superimposed, indicating the fault. The surge coils are moved progressively around the bore until all coils have been tested. This test method is presently used in the factory for routine testing of multi-turn half-coil designs. Prior to this test no method was available for testing conductor insulation at the half-coil joints.

Stories of RESEARCH

Stainless Gets Tough

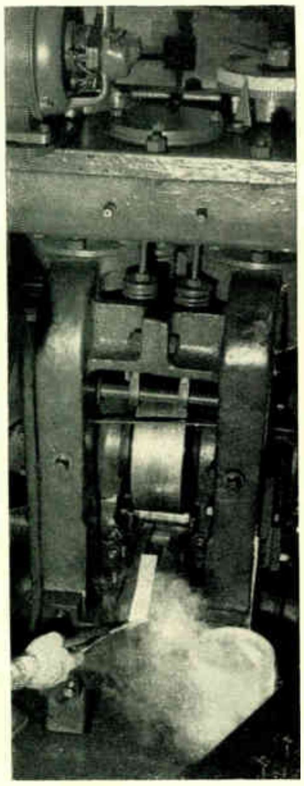
FOLLOW-UP of an unexpected result from routine tests, i.e., the presence of magnetism in a fractured piece of stainless steel, has led to a new process whereby this metal can be made some 100 percent harder than has been possible by conventional metal-working procedures. This hardness increase, achieved by working at sub-zero temperatures (down to minus 300 degrees F) makes stainless steel, never noted for its hardness, a more versatile metal.

During the course of some fundamental investigations of cast stainless steels of Crane Company laboratories, impact tests were conducted at the temperature of liquid nitrogen (about 300 degrees F below zero). After the tests had been completed, one of the samples, which had by then returned to room temperature, exhibited a strong magnetic effect near the fracture. Other samples broken at room temperature showed none of this magnetism. Subsequent tests showed that temperature alone was not a factor. Apparently the increase in permeability had been caused by a combination of the severe plastic deformation—caused by the impact tests—and the low temperature.

It is well known that when steel is either heated or cooled certain changes in its crystal structure may take place. In cooling to sub-zero temperatures, stainless steel can be made to change from the gamma to the alpha state, and this transformation brings about various changes in physical characteristics. Magnetic permeability is but one property affected.

To research engineers this was a clue that other improved properties could also be expected by working the metal at low temperatures. A few tests with the broken impact samples were made by Dr. Ziegler of Crane Company and confirmed this supposition—adjacent to the fracture, hardness had increased over that in the "as-cast" condition by some two to three times—to about 400 V. P. N. (Vickers Pyramid Number, standard hardness test).

This rather startling discovery was the basis for intensive co-operative studies by Dr. Ziegler and Mr. P. H. Brace of Westinghouse Research Laboratories whose engineers explored the effects of rolling and drawing at sub-zero temperature. Several combinations of preparatory heat treatment, sub-zero working, and subsequent high-temperature aging were tried. Some of the best results were obtained by a short period of heat treatment at about 2100 degrees F; quenching in water; cooling to about −300 degrees F; rolling the metal while at that temperature from one-fourth inch down to one-sixteenth inch; and then aging for several hours at about 750 degrees F. The results were better than obtainable by low-temperature rolling alone, by preparatory heat treatment alone, or by any combination of these processes. Significantly, the highest hardness and strength values were obtained in those specimens rolled at the lowest temperature. Tensile strength, yield stress and hardness were all increased markedly by this process as compared to conventional rolling. Of particular interest was the increase in proportional limit, which proved to be more than double that obtained by rolling at room temperature. Torsional yield stress and fatigue strength were also increased by about one half. The process is called Zerolling.

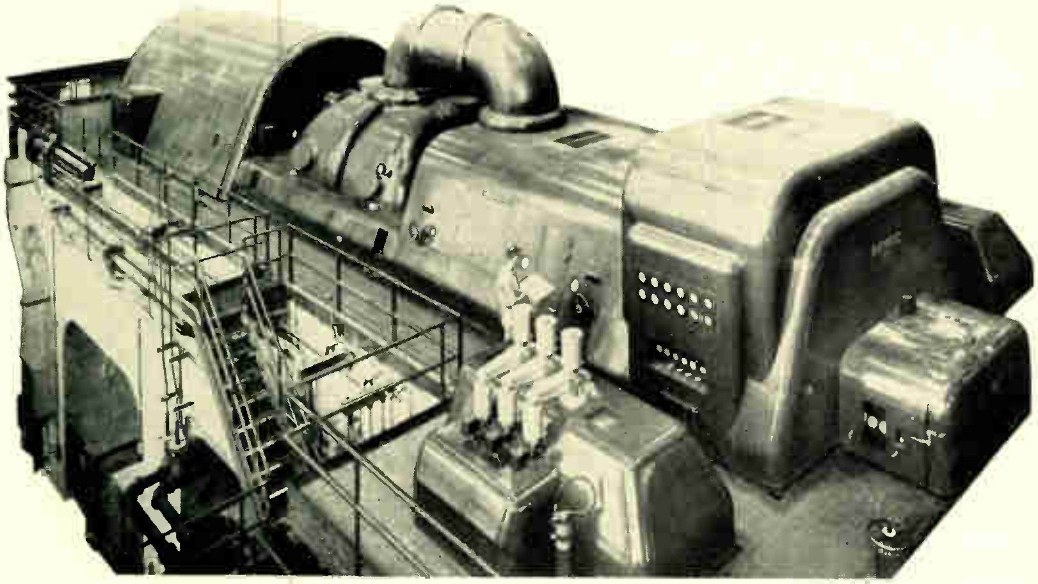


One sample tested showed an even more remarkable characteristic. Austenitic stainless steels worked by conventional methods have a very low wear resistance, as compared to the best wear-resistant metals, such as certain of the cobalt-chromium base alloys frequently used because of their excellent resistance to wear under sliding friction. Yet one of the specially processed stainless-steel specimens, differing slightly in composition from the others, showed a wear performance equal to or better than the best wear-resistant metal combinations. Possibly these unusual results can be reproduced consistently.

"Yardstick" of Light Waves

The pattern of light rings below, magnified some 100 times, may help create a new standard for the international meter. The present standard, a platinum-iridium bar on which are scratched two lines a meter apart, is stored away in an underground vault in France. More desirable would be a standard that could be easily reproduced in laboratories throughout the world.

To arrive at such a standard, scientists take a tube containing a small amount of the 198 isotope of mercury, excite it with ultra-high-frequency energy, causing it to radiate waves of its own. These are then directed through an interferometer, which breaks the light into patterns of concentric rings. The diameter of these rings is a function of the wavelength of light; thus the number of waves per centimeter can be calculated, and from this the number of waves per meter determined. The proposed standard would then be based on the number of waves per meter. Such a standard can be made accurate to within one part in 75 million.



The reheat cycle is returning to popularity after a couple of decades in relative retirement. With the promise of better performance combined with increased simplicity, it is gaining favor for the increased efficiencies it offers.

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O. N. Bryant
Land Turbine Engineering
Westinghouse Electric Corp.
South Philadelphia, Pa.

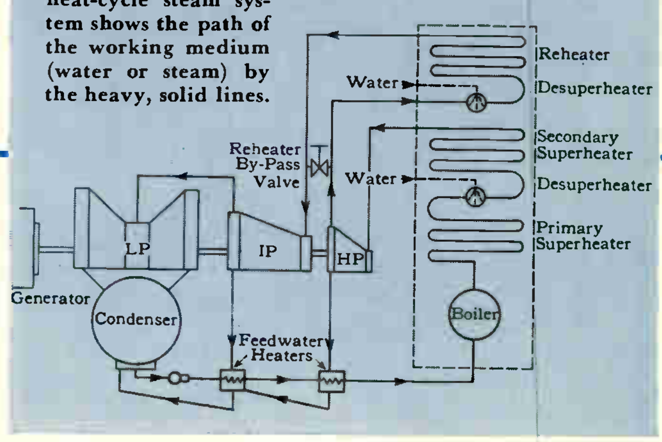
The *Reheat Turbine* and Its Control

The regenerative-resuperheat steam cycle—more commonly called reheat cycle—begins where superheat leaves off. Early steam turbines operated on saturated steam alone. Following this, it was found that heating the saturated steam to even higher temperatures (superheating) gave more conversion of thermal energy to mechanical work, i.e., more watts per pound of coal. Increasingly higher temperatures and higher pressures were employed to this same end until other considerations began to enter the picture. Operating temperatures approached the point that turbine materials could not maintain adequate strength. Also, the higher pressures, higher condensing vacuums, and greater volumes of exhaust steam introduced further complicating problems of moisture content in the last rows of turbine blades. Thus, several basic changes to the steam cycle were undertaken to remove these barriers to higher turbine outputs. One was the regenerative-resuperheat cycle.

The reheat cycle and its control has presented an interesting problem in the central-station field since the middle 20's. At that time the maximum operating temperature was limited to 750 degrees by turbine materials, and inlet pressures were limited to about 400 psig so that the exhaust moisture would not exceed 12 percent, beyond which blade erosion may be excessive in the last few stages. Turbine construction and details also presented other limitations.

Reheating improves thermal efficiency and reduces exhaust moisture so that the inlet pressure can be increased. Thermal

Fig. 2—General arrangement of the basic elements of a reheat-cycle steam system shows the path of the working medium (water or steam) by the heavy, solid lines.



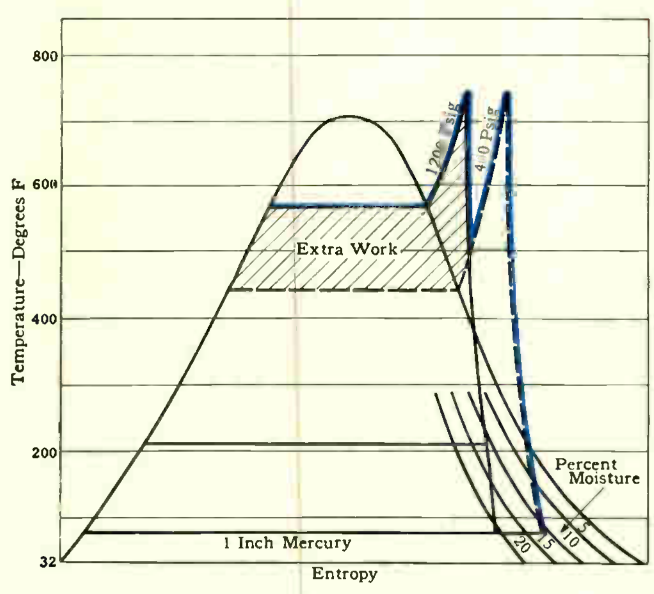


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Fig. 1—For a cycle having a maximum temperature of 750 degrees F and a maximum permissible moisture of 12 percent, several process lines are shown. The straight superheat cycle (dotted line) at 400 psig is within the limit, but to raise the initial pressure of a superheat cycle to 1200 psig (solid line) raises the moisture to a prohibitive amount. And to keep moisture within the limit (i.e., 12 percent) for this 1200 psig initial steam condition, the condensing pressure is high and more energy would be rejected to the condenser than added because of the higher pressure. By reheating (shown by colored line) moisture is kept down and initial temperature is not exceeded.

efficiency is improved by (a) permitting a higher initial pressure, and (b) utilizing more of the heat energy at the lower end of the cycle without increasing the heat loss to the condenser. The thermal gain is clearly illustrated in Fig. 1 where all the heat added to the cycle with the higher inlet pressure is available for work. Note that temperature and exhaust limits have not been exceeded. Subsequently, inlet pressures were increased to 1200 psig with inlet and reheat temperatures of 750 degrees F; thermal efficiencies corresponded to non-reheat units having inlet temperatures around 900 degrees F.

During the 30's the use of reheat was limited by: (a) a reduction in fuel costs; (b) the complexity of the reheat controls being used; (c) development of water catchers for moisture removal and the addition of erosion-resistant strips attached to the inlet edges of the rotating blades in the low-pressure end; and (d) development of alloy-steel materials that permitted the adoption of higher initial steam temperatures and pressures.

Today the picture has changed. Increasing fuel costs have revived interest in the reheat cycle where improvement in thermal efficiency justifies the extra cost of a reheat installation. Simplification of the control system and development of modern super-heat reheat boilers have made reheat units as reliable as the conventional non-reheat units used in central-station practice for many years.

The Reheat Cycle

The path of the steam through a reheat-cycle system is shown in Fig. 2. High-pressure saturated steam from the boiler is partially superheated in the primary superheater; a desuperheating spray introduces sufficient water into the steam so that it will leave the secondary superheater at the desired temperature. Superheated steam from the boiler flows through the throttle valve and steam-chest valves into and through the high-pressure (HP) element and returns to the boiler reheater tubes. It passes another desuperheating spray prior to entering the reheater tube nest where again enough water is introduced so that steam leaves at the desired temperature. The reheated steam returns to the intermediate-pressure (IP) element where it continues on through the turbine blading (both IP and low-pressure (LP) elements) and exhausts to the condenser. After the steam is condensed, it then flows through the feedwater heaters and returns to the boiler, completing the cycle. This is a simple one-stage reheat cycle; the use of two, three, or more stages of reheat has not been found practical in the central-station field.

Although other methods of reheating have been developed, they have not been too successful. In steam reheating, the steam, after expanding through the high-pressure element, is reheated by initial-pressure steam in a heat exchanger at boiler pressure. In the reheater, steam is raised almost to the temperature of saturated steam at the inlet pressure, but in this method there is little or no efficiency gain, only reduction of moisture in the exhaust. Another method is a combination of boiler reheat and steam reheat through a steam heat exchanger. Due to the general complexity of piping, controls, etc., of these other methods, only the simple single-stage boiler reheat cycle is considered today.

Reheat Thermal Efficiency

For an ideal turbine, the thermal efficiency of a cycle is the ratio of heat converted into useful work to the total heat added to the cycle. The saturated, superheat, and reheat cycles are shown on the temperature-entropy diagram,

Temperature—Entropy

Thermodynamic explanations — never simple — are done on the basis of an ideal cycle—one in which there are no friction losses in piping, turbine blading, etc. This ideal cycle can be depicted on a plot of two steam characteristics, temperature and entropy. The entropy of steam is a defined property, i.e., steam has a definite value of entropy at each of the many conditions at which it can exist. It is a mathematically calculable quantity combining several physical properties and not a measurable quantity. However, it is the change in this property, as steam passes through the various stages of the cycle, that makes entropy useful. A change in entropy indicates the "unavailability" of energy.

That contained thermal energy can be unavailable is based upon the fact that, even in an ideal turbine (one having no friction losses) all the energy of steam cannot be converted into mechanical work. This is true, first, because, theoretically thermal energy is completely dissipated only when the temperature goes to the as-yet-unattainable absolute zero. Obviously this experimentally unattainable temperature cannot be used in a practical cycle. Second, the energy of movement of the steam—kinetic energy—cannot be zero, else the steam would not leave the turbine exhaust passages. Temperatures, although labeled in degrees F, are considered in relation to absolute zero (−459.7 degrees F).

The temperature(T)-entropy(S) diagram is used because on it an area is a quantitative indication of work or energy. A point on this diagram gives the temperature and entropy for steam at one specific condition. Also, each point has other definite properties such as pressure, enthalpy, and moisture. The curved line is the saturation line; left slope for liquid and right slope for vapor. A line on this diagram shows changes in the condition of the steam as it passes through the various phases of the cycle. Typical ideal cycles are depicted in Fig. 3 on the T-S diagram.

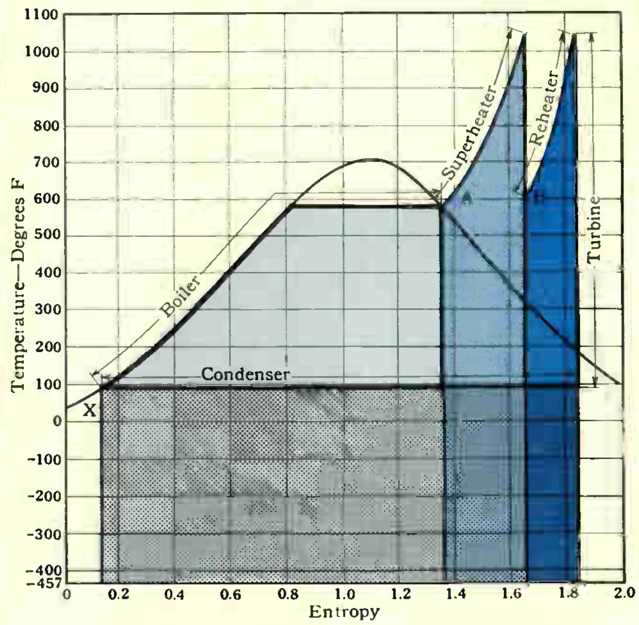


Fig. 3—This T-S diagram shows the thermal relationships between the old-time saturated cycle, the conventional superheat cycle, and the one-stage reheat cycle. The total colored area indicates thermal energy and the dotted colored area indicates thermal energy rejected to the condenser.

Fig. 3. (See section on Temperature-Entropy above diagram).

In the saturated-steam cycle (heaviest lines), feedwater is heated to its saturation temperature along the left saturation line and evaporated along the horizontal line to *A*. Here, the dry and saturated steam is admitted to the turbine, and expands along the vertical line to the horizontal (condensing) line. The exhaust steam is then condensed along the lower horizontal line, returning to its initial condition. The total heat added is represented by the total light-colored area. Heat given up to the condenser circulating water is represented by the dotted light-colored area. The heat converted into useful work for an ideal turbine is the difference of heat added minus heat rejected or the plain light-colored area. The thermal efficiency of the cycle is the ratio of the plain light-colored area to the total light-colored area.

In the superheat cycle, feedwater is heated along the left saturation line and evaporated along the horizontal line to *A*. It is superheated to a higher temperature and then admitted to the turbine, where it expands to the condensing line, and condensed to point *X*. The additional energy available for work is represented by the plain medium-colored area and the energy added by superheating is the total medium-colored area (plain and dotted). The ratio of the work added to the energy added is greater than that of the saturated steam cycle. Therefore, superheat-cycle efficiency is greater than that of the saturated-steam cycle. This superheat efficiency is the ratio of the light- and medium-colored plain areas to the total of the four areas—plain and dotted parts of both light and medium sections. In the superheat cycle, the reduction of moisture in the last blades of the LP element adds further to the thermal gain due to superheat.

In the reheat cycle, the steam follows the same path as the superheated cycle to *B* where it has expanded through part of the turbine. Here it exhausts to the reheater and is heated to the initial steam temperature and returned to the turbine. The reheated steam expands along the vertical line in the IP and LP turbines to exhaust. For the reheat cycle, the additional heat available for work is represented by the plain dark area and the additional heat added is indicated by the plain and dotted portions of the dark-colored area. Reheat-cycle efficiency is the ratio of all three plain-colored areas to the total of the plain and dotted areas. As in the superheat cycle, reheat further reduces the moisture in the LP end, again increasing efficiency.

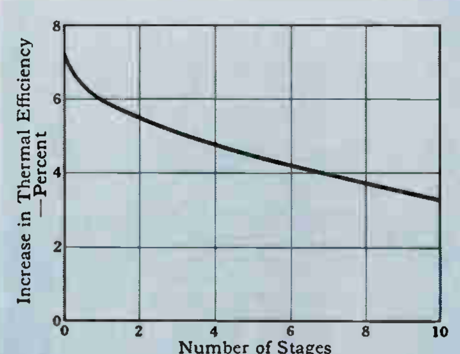


Fig. 5—The effect of several stages of feed heating on efficiency gain due to reheating at the optimum reheat pressure is shown.

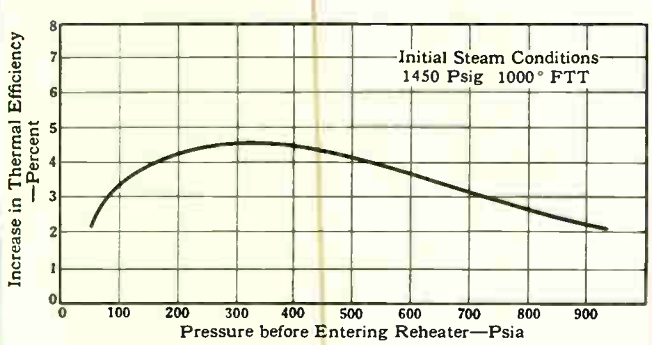


Fig. 4—This curve for gain in thermal efficiency is typical for a reheat turbine having five stages of feedwater heating and a ten-percent steam pressure drop through the reheater piping system.

The increase in thermal efficiency due to reheat varies with the pressure at which the steam is reheated. This improvement, including the effect of the reduction of moisture in the low-pressure end is indicated in Fig. 4. Note that the optimum reheat pressure is approximately 25 percent of the initial pressure and that the gain is fairly constant over the range of 200 to 500 psia. Reheat pressure can thus be selected over a wide range without materially affecting the gain obtained. Although this gain is affected slightly by the number of feed-heating stages used (see Fig. 5), the average is around 4.5 percent at rated load.

In addition to the thermal gain, reheat reduces steam flow through throttle and condenser by approximately 15 and 13 percent, respectively. The reduction in the total volume of exhaust steam is around seven percent. All this aids in reducing the size of the main boiler, steam piping, condenser, and feed-heating equipment, including pumps and piping.

Reheat Control

A number of control problems have had to be solved to make the operation of a reheat turbine as safe and generally satisfactory as is customary with normal (non-reheat) condensing steam turbines.

When the full load on any turbo-generator is suddenly lost, the incoming steam will then accelerate the machine at a rate of 8–12 percent speed rise per second. The governing system of the normal turbine will close the valves as the speed increases and prevent an excessive speed from being attained. In a reheat turbine it is not enough to close only the high-pressure steam inlet valves. The steam piping from the extraction point in the turbine to the boiler, the piping in the reheater tube nest and the return piping to the intermediate-pressure turbine contains enough steam at 400 to 500 psi to accelerate the turbo-generator to a disastrous rotational speed. Therefore, it is necessary to provide an intercepting valve just ahead of the inlet to the IP turbine that closes along with the high-pressure steam inlet valves whenever the turbine loses its load. This valve must close within one-half second or less to prevent a dangerous increase of speed.

In some of the earlier reheat boilers, a minimum steam flow through the reheater of at least 20 percent of rated flow was necessary to prevent the tubes from being overheated. In more recent designs, by a suitable arrangement of the various heating surfaces and by automatic control of certain of the burners, overheating of these tubes is avoided.

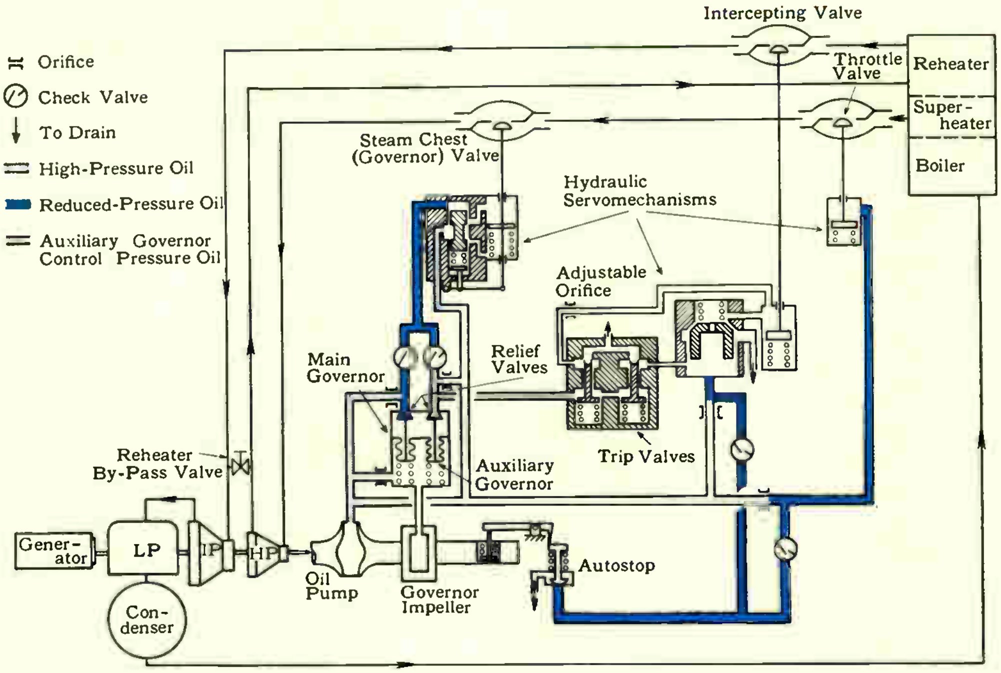
Control Diagram

The simplified diagram (Fig. 6) gives the basic elements of the reheat-turbine control system and their relation to steam flow. The basic components of the control system that are in addition to those on a regular high-capability superheat turbine are the interceptor valve and its servomotor.

The throttle valve is operated by high-pressure oil from the oil pump through a hydraulic servomotor that moves in response to a handwheel (not shown). An emergency speed-actuated autostop on the turbine shaft trips open a valve when overspeed occurs, discharging the oil from the throttle servomotor much faster than it is supplied through the orifice. This closes the throttle rapidly—in something less than one-half second.

The steam chest valves that supply steam to the high-pressure turbines are operated by one or more pressure-responsive hydraulically operated servomotors. There is a definite steam-chest valve position corresponding to any given value of control oil pressure on this servo. For example, at 10 psi the valves are wide open; at 22.5 psi they are about one half open; and at about 35 psi they are closed.

Fig. 6—Hydraulic Control Diagram



The governing system consists of an impeller, the main governor and the auxiliary governor (indicated here as two bellows in a common chamber). These elements produce the control oil pressure for the steam-chest servomotor and the trip valves that control the intercepting valve servo-motor.

The impeller is mounted on the turbine shaft adjacent to the oil pump, and produces an oil pressure of about 30 psi at 3600 rpm. This varies as the square of turbine speed, or about 1 psi for 60-rpm speed change. It is the speed-sensing part of the governing system.

The main governor consists of a small relief valve loaded by a bellows upon which the impeller pressure reacts. Because the bellows has five times the area of the relief valve, a change of one psi on the bellows causes a change of five psi on the relief valve. A speed-changer spring balances a portion of the load on the bellows and permits adjustment of the main governor speed range. The impeller pressure of 30 psi at 3600 rpm is balanced by the spring load plus 35 psi oil pressure on the relief valve. When the speed-changer spring is tightened, the relief-valve pressure is reduced causing the small piston in the servo to move up, which admits more high-pressure oil on top of the servo piston. The steam-chest valves open wider. Turbine speed increases until increased impeller oil pressure restores the relief-valve pressure to approximately 35 psi and the valves move back to their former position to pass the no-load steam flow.

The auxiliary governor operates on the same principle but produces 20 psi change in control pressure for each 1 psi change in the impeller pressure. It has a speed changer that is locked after adjusting the governor to produce about 35 psi control pressure when turbine speed is 3700 rpm. It is capable of supplying a large quantity (about 50 times that of the main governor) of control oil to operate the main steam-chest servomotor relays quickly after a sudden loss of turbine load.

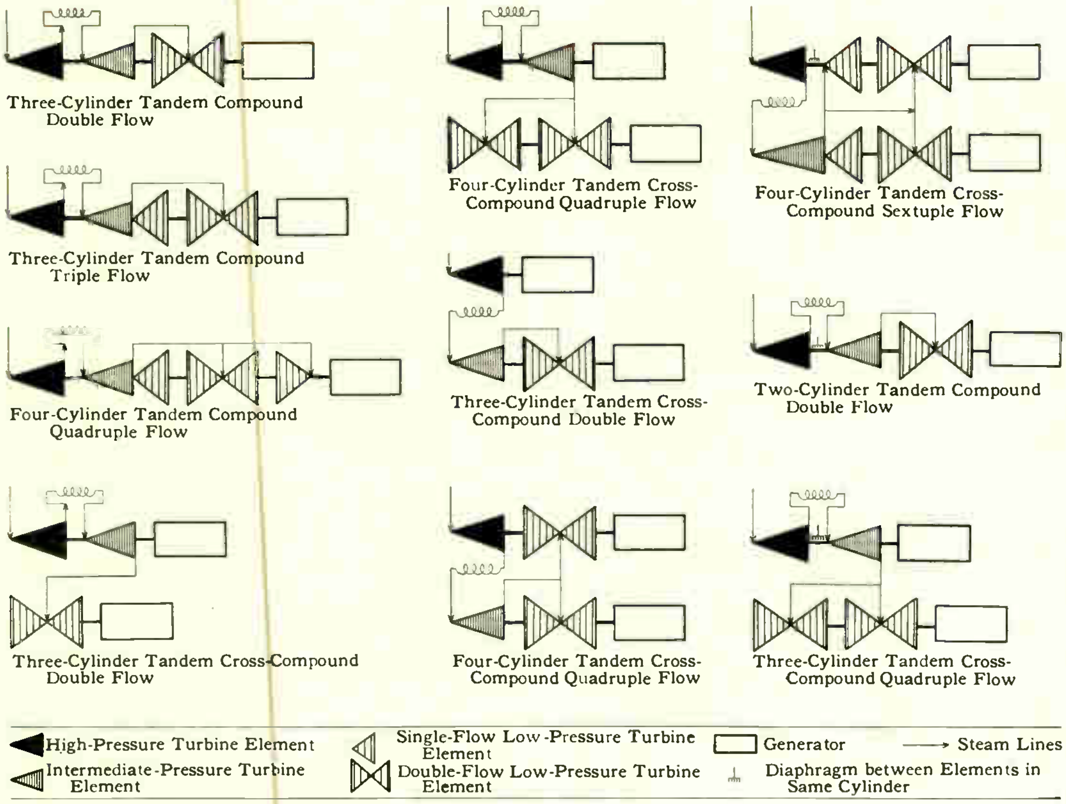
The auxiliary governor has no effect on the governing system as long as turbine speed is below 3630 rpm. Its control pressure is then less than 5 psi, whereas the control pressure from the main governor is between 10 and 35 psi, depending upon the turbine load carried. In most power plants the frequency is held within ±0.2 cycle per second (±12 rpm) by readjusting the speed changer occasionally. Hence in normal operation there is little likelihood that the auxiliary governor will take control.

If generator load is suddenly lost by the opening of circuit breakers, the turbine will accelerate rapidly. This causes the impeller to increase oil pressure upon main and auxiliary governors, which in turn increase their control pressures. The greater pressure ratio of the auxiliary governor causes its control pressure to exceed that from the main governor and it assumes control, closing the steam-chest valves. All of the above are identical functions of the turbine-governing system.

The important extra valve on the reheat turbine—the intercepting valve—is operated by a separate servomotor similar to the throttle servomotor. It is opened by pressure from the oil pump when a handwheel (not shown) is turned. If the oil supply is cut off, a heavy spring closes the intercepting valve, but when the oil supply is restored the valve is opened again. If the autostop is tripped, or the right-hand trip valve opens, the intercepting valve closes rapidly. But if only the left trip valve is opened, reduced oil pressure through the orifice closes the intercepting valve slowly.

As acceleration continues, the auxiliary governor not only sends an increasing control pressure to the steam-chest servomotor, but also to both trip valves. These open in quick succession at about 3700 rpm for the left trip valve and 3725 rpm for the other, and close the intercepting valve.

With steam flow cut off both at the steam-chest valves and at the intercepting valve, speed falls gradually until the trip valves close, whereupon the intercepting valve begins to admit steam from the reheater. Then as the speed rises above 3700 rpm the left-hand trip valve begins to open, causing the intercepting valve to reduce the steam flow. Thus the speed varies slightly around 3700 rpm until the excess steam in the reheater is exhausted. A slight decrease in speed then opens the steam-chest valves enough to prevent further decrease.

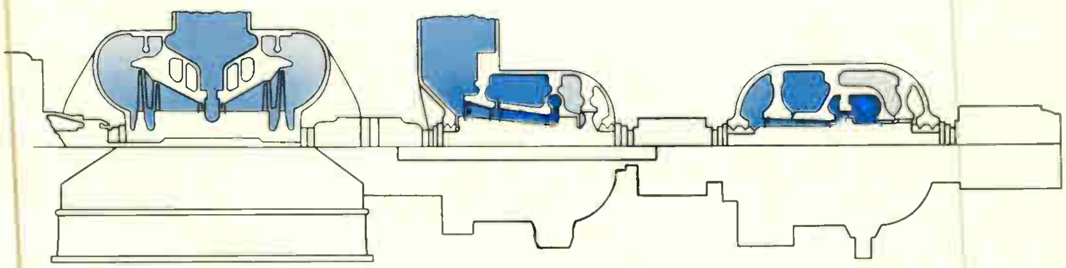


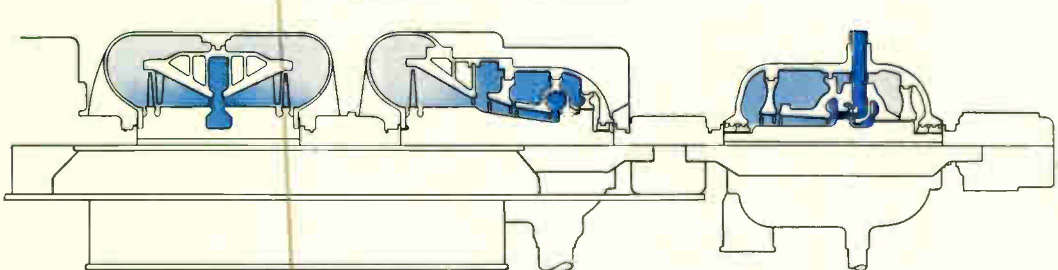
← Fig. 7

The various arrangements of turbine components are not limited by the reheat cycle. On the contrary, a much wider variety of different combinations of turbine elements is made possible. Thus, building requirements can be more easily met. Certain types of units such as the tandem cross-compound quadruple or sextuple flow machines have the highest kw capacity per unit area of any turbine to date. The turbines that have the diaphragm indicated between HP and IP elements (right column) combine these two elements in the same casing (cylinder).

Fig. 8 →

A three-cylinder, tandem-compound double-flow turbine such as is shown in Fig. 7 (upper left corner).



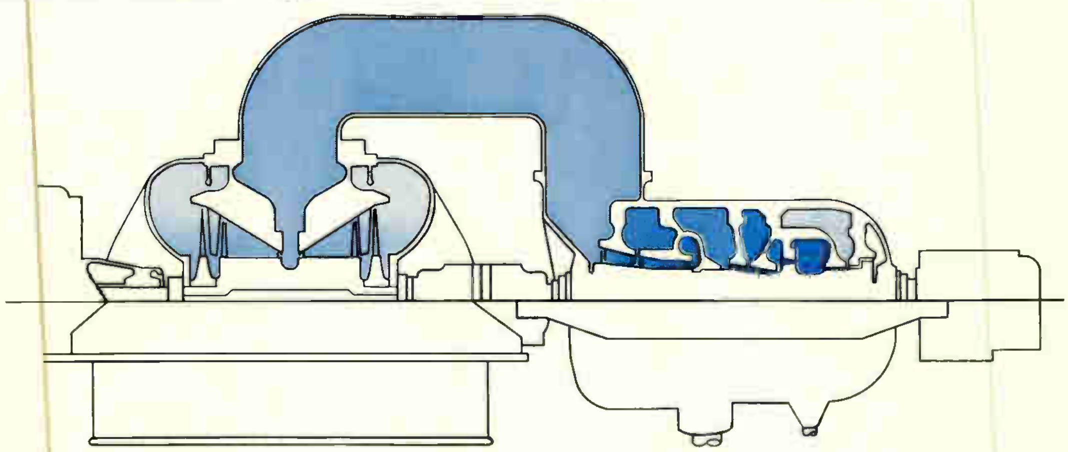


← Fig. 9

A three-cylinder tandem-compound triple-flow turbine such as shown in Fig. 7 (second from top, first column).

Fig. 10 →

A two-cylinder tandem-compound turbine with the high- and intermediate-pressure elements in the same cylinder and separated by a diaphragm. Schematic diagram is shown in Fig. 7 (right-center).



The speed is brought to normal by running the speed changer of the main governor in the "decrease" direction. This raises the control oil pressure from the main governor until it exceeds that from the auxiliary governor. It again resumes control and reduces the speed in response to further motion of the speed changer. After synchronizing the generator, the breakers can be closed and load can be restored as determined by the operator.

Operating Cycles

Governing of a reheat turbine at no load is just as steady as with a non-reheat turbine. The large uncontrolled volume of steam in the reheater piping does not pose a problem while governing at no load because at very light loads the intermediate-pressure and low-pressure turbines do no work, and, in fact, act as a drag on the high-pressure turbine.

Ordinary load changes cause no difficulty in governing. As with any high-temperature turbine, the limiting factor is the rate at which the turbine parts can accommodate themselves to the resulting temperature changes. When the turbine-generator suddenly loses nearly all of its load, while retaining a small amount of the local system load, it must not accelerate the local system to an unduly high frequency nor should it allow the frequency to drop below normal after the excess steam in the reheater is dissipated. The intercepting valve is designed to close rapidly if the no-load speed of the governor is exceeded, and to open again as soon as the speed falls below this value.

If for any reason the turbine governor fails to operate in case of excessive speed, an emergency autostop mechanism closes the throttle valve, the steam-chest valves, and the intercepting valve before a dangerous speed is attained.

In operation the reheat turbine is little, if any, more complicated than a conventional high-capacity superheat turbine. The starting procedure for these turbines is conventional, steam being introduced slowly at first and gradually increased to obtain the desired clearances between moving parts and stationary parts. The automatic hydraulic governor controls are put into operation and load is put on and increased at a standard rate after the machine is brought up to speed. Emergency starts can be made as in any turbine with particular attention paid to rub indicators. Normal shutting-down cycle is also practically identical with conventional superheat-turbine practice.

Under conditions of load loss, however, the functions of the additional valve become important. For sudden load loss, the intercepting valve as well as the steam-chest valve is closed by governor action. On reduction to a certain nominal speed, about 3700 rpm, the interceptor valve is permitted to open to allow the steam stored in the reheater piping to expand through the unloaded turbine; turbine speed is kept near 3700 rpm until the reheater steam is dissipated. The interceptor valve then continues opening to its widest position. When reheater steam is dissipated, regular governor action takes over and controls the turbine.

For a partial loss of load while retaining the electrical tie to the system, the main governor controls the steam flow. For a partial load loss and loss of electrical tie, but with retention of the local load, the speed can rise above 3700 rpm and the auxiliary governor takes over. And when the loss is extreme, approaching total loss, action similar to that for a total load loss is taken to dissipate the steam in the reheater piping.

If overspeeding occurs because of improper operation of the governor mechanism, the autostop valve closes both the throttle and intercepting valves. (Reheater steam is trapped and must be released by a manually operated drain valve.)

Modern Reheat Turbines

Turbine arrangement for combining the high-pressure, reheat (intermediate pressure), and low-pressure elements varies. The chosen design depends upon many factors; capacity of the unit, efficiency level, and choice of the steam-generating plant and building considerations—cost vs. space. Usually the two initial elements—high and intermediate pressure—are combined in tandem (on the same shaft) either in separate cylinders (casings) or in the same cylinder. The low-pressure elements are either cross-compounded (on a separate shaft from the HP and IP elements) or in tandem with them.

As you can see from Fig. 7, there are many combinations of the high-pressure, reheat, and low-pressure elements. In Fig. 8 is a 65 000-kw three-cylinder design having separate cylinders for the high-pressure, reheat and double-flow low-pressure elements. This unit has been in operation for over a year. Another arrangement for the three-cylinder design is shown in Fig. 9 where the reheat element is combined with a single-flow low-pressure element. Several of these are in production and the first one is now being installed.

For a small sacrifice in turbine efficiency the length of the three-cylinder design can be reduced by combining the high-pressure and reheat elements in one cylinder (Fig. 10). This design—having double-flow LP stages—is presently limited to 100 000 kw. Steam enters the inlet to the impulse element near the thrust bearing, flows through the high-pressure turbine, and exhausts to the reheater at the center of the cylinder. The reheated steam enters the cylinder again at the center and flows in the same direction as in the high-pressure element. Here, the pressure drop over the center gland is only the pressure drop in the reheater system. On leaving the reheat element, steam passes through a crossover pipe into a double-flow low-pressure element. This design has been well accepted and we are manufacturing many of these units.

For the cross-compound units there are many arrangements of the high-pressure, reheat, and low-pressure elements that are somewhat dependent on the number of low-pressure elements, capacity, and vacuum. Some of these arrangements are shown in Fig. 7. Capacities of these units are expected to range from 150 000 to 300 000 kw.

On all these reheat units, you will note that the reheated steam returning to the cylinder is confined in an inner cylinder that excludes it from an outer one. This reduces the temperature gradient and thermal stresses in the outer cylinder.

Conclusions

Where high fuel costs and load factors are of prime importance the modern reheat turbine-generator-boiler unit with its simplified control system offers many advantages. The thermal gain due to reheating, when compared to the incremental cost of reheat and non-reheat units, more than justifies the extra cost for reheat in a majority of the cases.

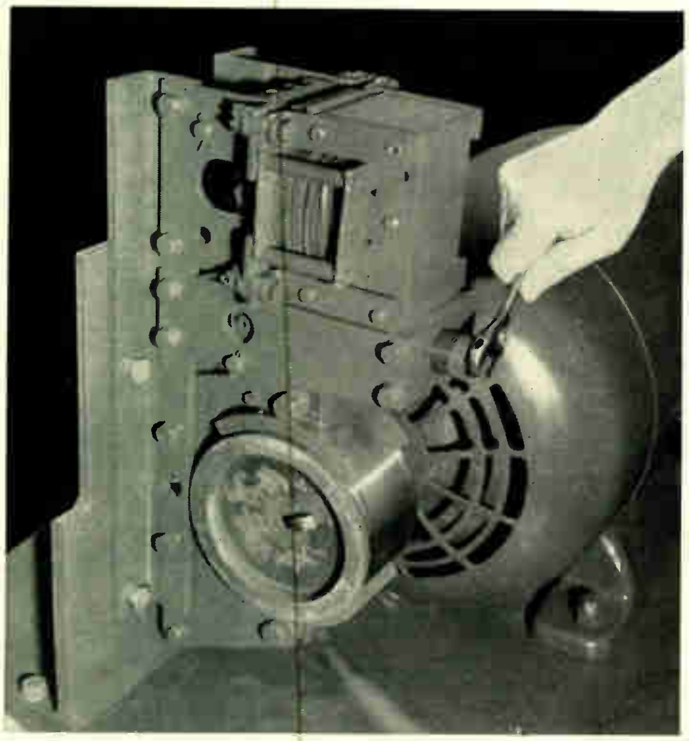
Reheating, which was formerly proposed chiefly to reduce exhaust moisture, is now a means for achieving a major gain in efficiency at an attractive overall cost. At present operating temperatures of 1000 and 1050 degrees F, the gain in thermal efficiency is between four and five percent.

Modern boilers for superheating and reheating have been developed to the point where they are little, if any, more difficult to operate than a boiler without reheat operating in the same pressure and temperature range. And modern reheat turbine controls have been simplified to the point where operation is as easy as with the conventional non-reheat units.

What's NEW! in Products

Single-Adjustment A-C Brake

Adjusting an alternating-current motor brake has been a difficult problem. It has three interrelated adjustments, for shoe wear, for equalizing spacing between shoes and drum, and for spring compression. Changing one adjustment may change the others. Furthermore, the mechanical connection between them is not visible to the mechanic. As a result a-c brakes are often poorly adjusted.



A new brake reduces the field adjustments to one. Turning one adjusting screw automatically positions the shoes for wear, for distance from the drum, and spring compression. The magnet lever is connected to the brake arms carrying the brake shoes by means of a threaded spindle, An adjustable spring that bears against a point on the magnet lever provides the force to produce the braking torque. The threaded spindle, which projects at the top, is turned to adjust the magnet travel to the value necessary to free the wheel, and the spring is compressed to the amount required to supply the desired torque. As the shoe linings wear, the magnet travel increases and the spring force decreases. Turning the threaded spindle restores both to their original setting. Equalizing the shoe clearance is automatically taken care of by the linkage that converts the magnet travel into equal and opposite movements of the shoes.

Heating Elements for Carburizing Furnaces

In gas carburizing—a case-hardening heat treatment in which carbon is added to gears, shafts, pins, etc., from a surrounding carbonaceous atmosphere—the high-carbon gases react with any surface they contact, including the electrical heating elements. To prevent this exposure of coils and insulators to possible carburization, heaters now have been enclosed in alloy tubes welded into the furnace structure.

The atmospheres used are high in carbon content and, at elevated temperatures, the carbon is absorbed into the surface of the pieces undergoing treatment. However, when the metallic heating elements exposed to this atmosphere also pick up carbon, their electrical resistance is altered and thus the amount of heat released is changed. Any change in temperature disturbs the equilibrium of the process and accurate control is hindered. The carbon may also form a layer on the surface of insulators and provide a conducting path; resulting in short circuits.

The heating coils of these furnaces are now placed in alloy tubes welded into the furnace structure. These tubes are sealed into the furnace walls and extend through the interior of the furnace from one side to the other above the heat-treatment area. They extend through the furnace sidewall and are open at one end to receive the helically wound coil. The coil is supported by a porcelain insulator shaped to prevent the wires from contacting the welded tube and thereby grounding of the circuit. At the open end the terminal wires are brought through a sealing gasket, which minimizes the heat lost externally. The tube radiates the heat generated by the heating element throughout its own particular area of the furnace, and the carbon atmosphere does not affect it. Efficiency and accurate control of the heat in the furnace is maintained and short circuits are avoided. Thus gas carburizing in an electric furnace is made practical.

Switches for Large Shunt Capacitors

Shunt-capacitor banks on transmission lines are becoming so large that the switching device used is becoming a special problem. Banks of 25 000 kvar are in service. Installation of 10 000 and 15 000 are numerous. Compressed-air breakers have been used on some of the largest banks when unusual performance was required, but the oil switch is usually employed.

A switch for a large capacitor has special problems. For one, if arc restriking occurs during an interruption, resulting voltage surges may be of sufficient magnitude to cause arrester operation or even damage insulation of apparatus some distance away.

For these applications, interruption of oil breakers has been much improved by the addition of a booster to otherwise standard magnetic De-ion grids. A spring-driven piston drives oil into the arc to hasten its extinction, practically avoiding restrikes.

Size 0, 1, 2 Contactors and Linestarters

Following the adoption by NEMA of standard mounting sizes for starters and contactors, the 0, 1, and 2 size Linestarters have undergone extensive development. The changes in these equipments are basic in character and a completely new product has been made. The new Life-Linestarters and Life-Linecontactors are available in 2-, 3-, 4-, and 5-pole, non-reversing and reversing types.

To provide more positive action, this simplified, trouble-free starter was designed around a knife-edge fulcrum mechanism having a kickout spring to open the contacts. This inverted clapper or seesaw design supersedes the previous lift-type solenoid. The knife-edge fulcrum of hardened steel forms a friction-free bearing and the single seesaw moving element is center-balanced on this knife-edge. The seesaw principle eliminates the possibility of false operation because of vibration or accidental impact, minimizes friction, and affords precise self-alignment.

Any inquiries relating to specific products mentioned in this section should be addressed to the *Westinghouse* ENGINEER, 306 Fourth Avenue, P. O. Box 1017, Pittsburgh 30, Pa.

On these contactors it is possible to match a change in voltage and frequency requirement and to change the coil by merely removing three screws from the front of the unit. By removing only one part, the coil can be removed and replaced by one of another rating. All parts are front-removable for easy maintenance.

The De-ion arc interrupters are used in these contactors and starters, providing rapid arc extinction within one half cycle or less. All starters are equipped with improved snap-action bimetallic disk-type overload relays, which give positive and reliable protection against motor overloads.

Reversing types are provided with a mechanical interlock, which eliminates the possibility of both contactors being closed at the same time.

These units are rugged and have been found to operate satisfactorily through more than seven million operations.

New Milk Cooler Reduces Farmer's Liniment Bills

Electric refrigeration has been a great labor-saver to the dairy farmer. Also it enables him to comply more readily with milk laws that, in general, require milk to be reduced from animal temperature to 50 degrees F within two hours, and held there.

But milk coolers have not altogether eliminated the back work. They have consisted of tanks of refrigerated water into and out of which the cans must be lifted.

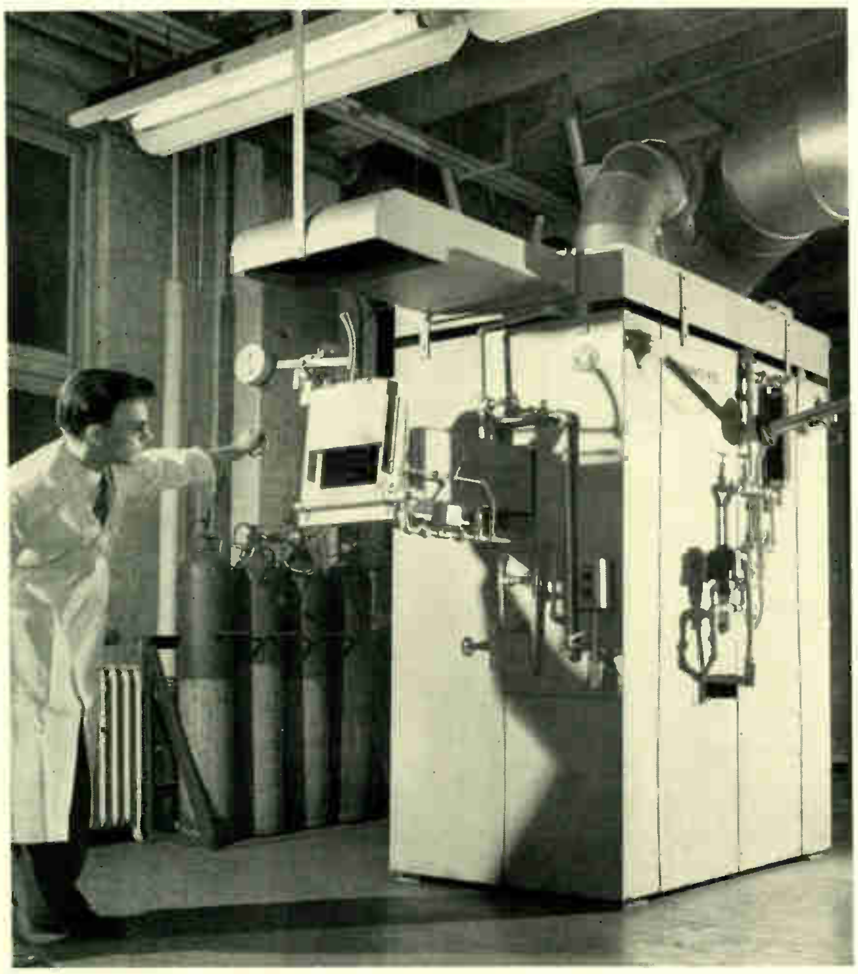
The new milk cooler opens on the side so that cans can be simply slid in and out on stainless steel tracks. Gravity being what it is, with a front-door cooler, chilled water is literally out. Instead the refrigerator system provides a miniature ice rink five inches thick in the bottom. With a load of warm milk cans in place, a motor pumps gentle sprays of water (hard sprays might result in watered milk) over the cans and down onto the ice. This spray process continues for 1½ hours—long enough to carry the milk well below the legal 50 degrees—and then operates again for 10 minutes every 2½ hours to maintain the milk at this low temperature.

Bus Duct

Distribution of power from transformers or substations to electrical equipments or to other step-down stations in industrial plants or buildings is done conveniently and efficiently by bus ducts. A new type of duct, the Westinghouse low-impedance bus duct, is designed specifically for feeder functions at currents up to 4000 amperes where low-voltage drop is important. The voltage losses for various loading conditions are much lower than in other types of duct, not exceeding three volts drop per 100 feet at the poorest load condition.

The new duct utilizes close spacing of the conductors, two or more conductors for each phase and phase conductors not adjacent to each other. This close spacing gives a low reactance, which leads to the low-impedance characteristic. Also the close spacing of the conductors makes a small, compact unit for convenient installation. The low-impedance duct can carry twice as much current for a given cross-sectional area of the duct as the plug-in type duct. The duct is made in standard ten-foot lengths and the connecting fittings—tees, elbows, and end flanges—are no larger in cross section than the duct itself. A typical cross-sectional area (for 2500-ampere duct) is 71 square inches.

High-Temperature Heat-Treatment Furnace



In conventional heat-treatment operations, temperatures above about 2600 degrees F have seldom been needed. But with increased emphasis on alloys having higher temperature properties and upon the sintered-metal product of powder metallurgy, higher and higher temperatures are being required. Now a small, high-temperature, controlled-atmosphere electric furnace for heat-treating has been built that produces temperatures in excess of 3200 degrees F.

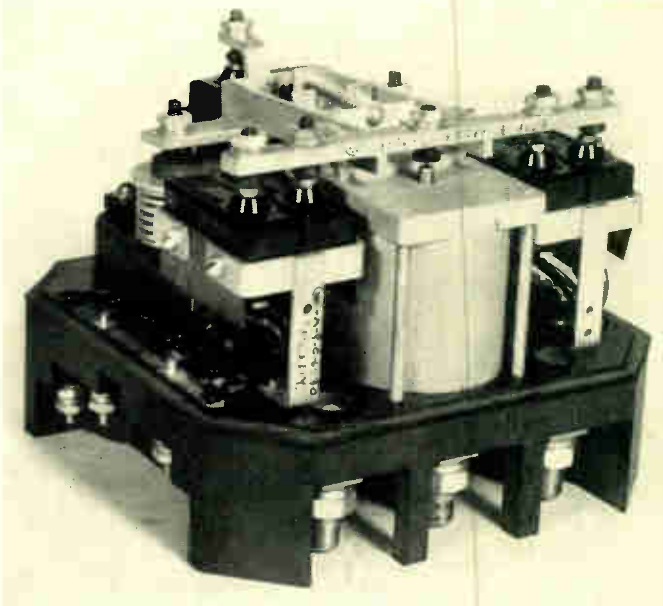
The high temperatures are attained by using rod-type heating elements made of molybdenum. Because of the great change in resistance coefficient over the range of temperatures (room temperature to 3200 degrees F), the current fed to the heating elements must be varied as the temperature changes. To do this a small manually operated tap-changing transformer provides the proper voltages to obtain desired power inputs. After operating temperature is reached, it is automatically maintained by a pyrometer that controls magnetic contactors. A high heating rate and small temperature gradients in the chamber are primary advantages of this furnace.

This unit is used in the production of small powdered-metal pieces such as tiny silver electrical contacts and for both experimental and production work on tungsten-base powder metallurgy alloys and on materials to be used at high temperatures. It is a pusher-type furnace; the material to be treated is loaded (on trays) into the charging end of the furnace chamber. Previously loaded material is removed through the cooling chamber at the other end. A reducing atmosphere such as dry hydrogen or an inert gas must be used.

Flashgun Tester for Sure Firing

The camera enthusiast who uses a flashgun knows well the exasperating experience of setting up a picture arrangement and then having the gun fail to fire because of weak batteries or a broken circuit. In the past, test devices have been available only for the regular screw-in type flashgun socket. But the camera fan who owns a miniature-lamp flashgun, utilizing a bayonet base, has been overlooked. A new test lamp with a bayonet base, called the "Flashure," now enables quick and sure checking of the flash circuit and batteries. This is particularly valuable when the flashgun is used as a sidelight with several feet of wire between batteries and bulb.

A companion "Flashure" bulb for the larger screw-base type of socket is also available. Both of these bulbs are considerably less expensive than conventional testing lamps.



AVR-110, 120-Volt A-C Aircraft System Circuit Breaker

On aircraft as in industry, electrical loads are continually growing. Now a new 250-ampere, 3-phase a-c circuit breaker, the AVR-110 supersedes the 120-ampere breaker, the AVR-10, that has been in use for the last five years.

This new breaker is built around the same basic solenoid as its predecessor, the AVR-10, and uses the conventional double-break contact. That is, each phase has a silvered copper strip connector that bridges a gap between two terminals. However, in the new breaker, each of the three contactors is housed in a separate case and the position of the insulating button that forces each connector strip onto the line to "make" the circuit is adjustable. This permits individual regulation of the point of contact of each connector strip (all three must make contact within 0.005 inch of each other although their total travel is more than a quarter of an inch). On previous breakers a more-or-less coarse adjustment was made by positioning a single screw on the solenoid. To give better control of the four single-phase contacts at the other end of the breaker (used for auxiliary circuits) independent adjustment is also possible. Improved action for this higher current rating is provided by increasing main contact pressure 50 percent.

Built for heavy-duty service, the AVR-110 is a rugged but compact unit. It has been possible to double its rating by using more copper (30 percent), increasing the clearance between phase contacts, and by increasing spring pressure. The 8-pound weight of the AVR-110 is only 45 percent greater than the AVR-10.

...in Engineering

Potted Resin Electronic Circuits

One of the newest ideas in one of the newest sciences—electronics—is millions of years old. Every museum and classroom in biology and botany have specimens of insects or plant life that lived in prehistoric time, beautifully preserved in clear amber. Now, small electronic circuits, developed cooperatively by the Materials Engineering and Special Products Development Divisions of Westinghouse, are assembled of miniature components, and sealed in plastic—usually opaque.

Fig. 1—The sub-miniature components—standardized tubes, condensers, resistors, connectors, etc.—are small, but, like their larger brethren, have definite and precise functions and capabilities, which are sometimes essential.

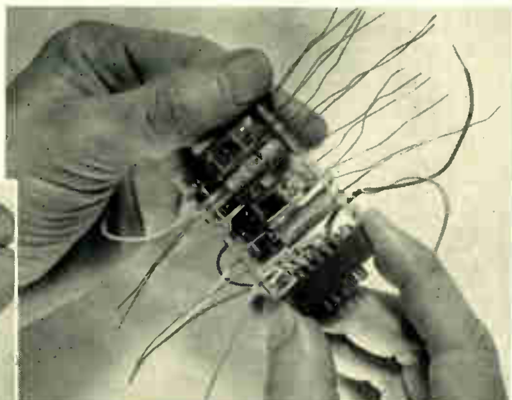


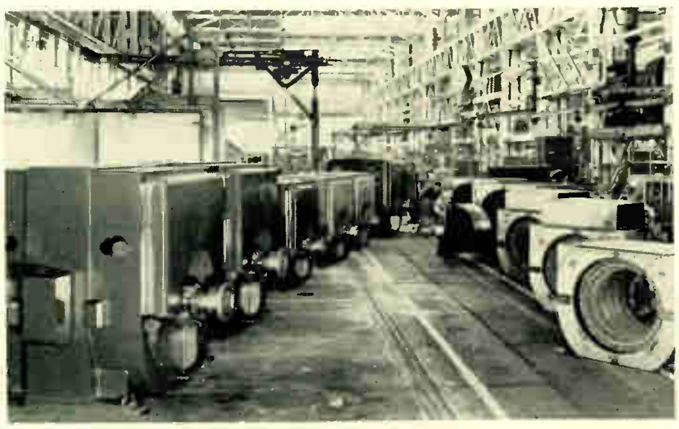
Fig. 2—They are assembled in plastic tie-strips that support the various electronic parts. These strips also support the wiring that makes up the desired circuit, in this case a phase inverter that provides the input to a push-pull amplifier. Attempts to use printed circuits on a solid material to replace both the tie strip and the connecting wire have failed because of the ambients encountered.

Fig. 3—Following assembly, the electronic circuit is tested for operation and is then prepared for the molding process that makes it a complete unit. The connector-base of the circuit assembly is placed in a wax plug in the baseplate of the mold. This holds the unit rigid while the liquid filler is being poured and also prevents the connector points from becoming fouled in the plastic. At left, the unit and one half of the mold is in place for pouring; the mold is held by a C-clamp.

These electronic-circuit assemblies are applied where there is necessity for light weight and small size. Moisture-proofness and good resistance to mechanical and thermal shock are provided by casting the complete circuit—tubes, resistors, capacitors and connectors—into one of the synthetic resins. The cost, somewhat higher than for conventional circuitry, is low when size and dependability are important.

Salt-Water Cooled Motors

No ordinary motors these. Shown below during construction, these salt-water cooled motors are equipped with special gunmetal-bronze cooling water boxes. They are being built for Pacific Gas and Electric's Moss Landing steam plant and are shown in various stages of construction. Six of the motors, rated at 800 hp each, will power the forced-draft fans at the intake ends of the six boilers. The other six, rated 1000 hp each, will operate the induced-draft fans at the exhaust. All twelve are of the squirrel-cage induction, totally enclosed type.



Hermetic Refrigerator Motor—A Lesson in Technical Progress

The hermetically sealed refrigerator motor has just celebrated its 20th birthday. A glance at its progress is interesting as it typifies well a kind of development common in engineering. The principles of construction and general arrangement have changed not at all in that period. Neither has there been any startling improvement at any one time. Yet the two decades of integrated betterment is quite something. Weight has been reduced nearly 30 percent; weight per horsepower has been reduced 45 percent; physical size has been reduced 30 percent. With all this the maximum torque has been improved by 22 percent; the efficiency has risen from 62 to 75 percent. The cost of constructing such an improved machine has fallen by nearly a third, even with much more costly materials and labor. It is a story of many small, unspectacular gains, resulting from improvements in both design and manufacturing methods.

Some of the more recent changes that have led to improvement include the use of aluminum die-cast rotors, the provision by the steel maker of a more consistent magnetic steel, the annealing of all such iron for both rotors and stators of the motors, and the adherence to much narrower manufacturing tolerances at every step of motor and compressor manufacture. An example will serve. Die-casting is highly desirable from a low-cost quantity-manufacture point of view. But die casting normally has given a quite variable product due to holes or bubbles in the casting, broken bars, or stray load losses due to short circuiting of the steel punchings. However, the variability has been greatly reduced by rigid process control and by new test methods that unerringly ferret out flaws. For example, a finished rotor is tested by driving it at synchronous speed in the reverse direction. Any abnormally high stray-load losses can be instantly detected. Another device writes a green trace on an oscilloscope screen to indicate the condition of each bar of the cage winding. The presence of a broken bar or a high-resistance bar becomes visually conspicuous.

Last year refrigerator engineers took another hitch in motor size. Ten years ago the core of a motor stator was two inches thick. Later it was reduced to 1¾ inches. Now it is 1⅜ inches. While the reduction seems insignificant, it sets off a chain of size reductions that leads to an important objective—to increase the "pay load" of a given refrigerator cabinet size. Reduction of motor length and other changes permit better telescoping of parts. This sets off a chain of improvements. It leads to a closer approach to a sphere, which means the enclosing shell can be lighter for the same strength, and finally that the compressor mechanism can be reduced in length about 1⅝ inches, and the weight can be cut about 6 pounds. In the long run it means more space for milk, butter, vegetables, beverages, and watermelon. Improvements in the other parts of the refrigerator have been keeping pace with motor improvements. Adding all the gains, power consumption has been reduced about 60 percent.

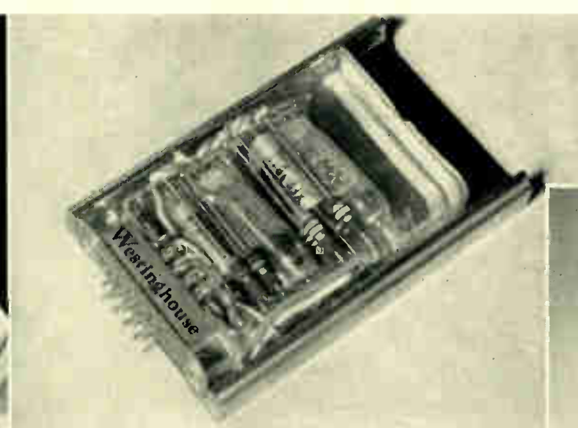


Fig. 5—After the plastic solidifies, the mold is removed and the plastic block is buffed to remove any irregularities that may be formed.

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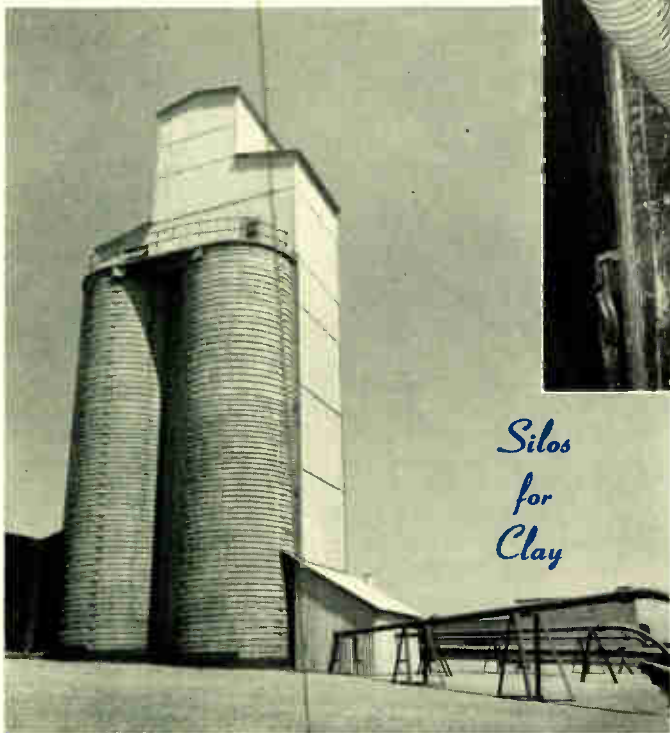
Fig. 4—The liquid filler must be poured carefully so as not to form bubbles. Also prior to pouring, the liquid is placed in a vacuum chamber to remove entrapped air.

Fig. 6—In production models, instead of using the clear plastic, another inert filler is used that makes the final product opaque. The silhouette shows the relationship of the tiny components of the finished electronic circuit.



Silos for Clay

A TRANQUIL, "down on the farm" scene is suggested by the huge "silos" shown in the picture at left. Actually these are storage areas for the powder-like clay and other materials used in the manufacture of porcelain insulators at the Westinghouse Porcelain Plant. Each of these new silos has a capacity of six carloads—about 300 tons of material. Much valuable floor space is saved by their vertical construction; twice as much material can now be stored in one half the floor space previously required.

Another innovation in the storage and handling of these fine powders is a giant "vacuum cleaner" used in unloading the material from freight cars. A 30-inch vacuum tank on top of the silos has enough suction to draw the material up through the six-inch tube, and drop it into the silos. This system is capable of moving six to eight tons of material an hour, compared to the previous standard of about two and a half tons per hour.

Other advantages of this system are the reduction of the dust problem, and lessened material contamination due to storage in a dust- and waterproof silo.

Ground-Fault Protection for Mining Circuits

THE ELECTRICAL engineer's approach to short circuits has been the only sensible one—where you can't prevent it, control it. A new current transformer for detecting ground faults helps do just that for mining circuits (three-phase) and does it better than previous methods. It is particularly applicable to 2300- and 4160-volt circuits.

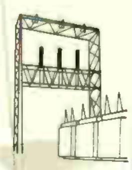
The problem of isolating short circuits in a mining circuit is much the same as in any other distribution system, except that the chances of faults occurring are greater, and the results are apt to be somewhat more disastrous. Greatest danger is to workmen; but the other circuits of the system, and the equipment, are also susceptible to damage. A good protective system must therefore eliminate the possibility of dangerous voltages existing between a faulted piece of equipment and ground, keep the ground-fault current small, and must also trip only the circuit affected, thus isolating it from the rest of the system.

The new current transformer consists of a core, upon which are wound three primary windings (one for each phase), and a single secondary winding. The primary windings are insulated from each other and from the core, for full line voltage; the secondary is connected to the circuit-tripping relay. Under normal operating conditions the currents in the three phases of the primary add to zero, and thus the fluxes also cancel each other. Since an unbalance in the three-phase system can be treated as a balanced three-phase load plus a single-phase load (whose flux also cancels), the three-phase load current has no net effect, and produces no current in the secondary of the tranformer.

However, when the system develops a fault, there is a current through one phase wire to ground—a current that does not exist in the other two-phase wires. This unbalance current produces a flux in the core and thus a current in the secondary winding proportional to the fault current. This secondary current is used to operate a tripping relay to isolate the circuit.

This transformer was designed primarily for shovel switchhouses in open-pit mines, but can be used to equal advantage in underground mines. The transformer is rated at 300 amperes continuous primary current; the turn ratio is 10 to 1. The device is insulated for 5000-volt class and is braced (mechanically) for 50 000 kva at 2400 volts, and 100 000 kva at 4160 volts.

What's NEW! . . . . in Literature



Standardized Substations show how Westinghouse, through standardization of structures, has met 95 percent of rural substation requirements with seven basic units. Six typical arrangements are shown with outlines, single-line diagrams, and bills of material. Booklet B-4697; 12 pp.

Characteristics and Applications of Watthour Meters is a thorough review of the performance, protection, calibration, and general theory of watthour meters. Curves, charts, and illustrations supplement the text. An appendix features a question-and-answer section on watthour-meter performance, a bibliography, and an illustrated fold-out chart to aid selection of watthour meters and demand meters. Booklet B-4684; 30 pp.

The *Buyer's Guide to Passenger Elevators* is useful to those concerned with selection of elevators for either new buildings or old. It contains a description of component parts of elevators and controls, an outline of important points to be considered in selecting and applying passenger elevators, typical pricing data, and practical layouts. Booklet B-4572; 52 pp.

Micarta, the Silent, Lasting Gear Material furnishes comprehensive information for the design and application of Micarta to gearing problems. Included are tables containing complete design data, sample calculations, machining data, and recommendations for the proper use of Micarta in gears. Booklet B-4661; 16 pp.

*To obtain literature, write to Westinghouse ENGINEER, 306 Fourth Ave., Pittsburgh 30, Pa.

Personality Profiles

For a man who started so earnestly to become a civil engineer, *H. R. Reese* has a lot of steam-turbine accomplishments behind him. He studied civil engineering at Bucknell University and Swarthmore College—B.S. in Civil Engineering in 1933. Following this he worked at various civil engineering jobs, becoming a civil engineer for the Pennsylvania Department of Forests and Waters.

But in 1937 the "indoors" beckoned and he turned to the mechanical-engineering field. Reese joined Westinghouse as a steam-turbine design engineer at the South Philadelphia Works near his home in Ridley Park, Pa. Since then he has worked in the thermodynamic, mechanical, development and, finally, central-station design sections. The only interruption to this design experience was during the war (1942–1945) when he became supervising steam service engineer in the Philadelphia Office. In the central-station design section, where he is now located, he has worked on some of the largest steam-turbine units ever built.

Although his vocation has long since brought him indoors, his avocations, golf and fishing, show him still to be an outdoor's man at heart.

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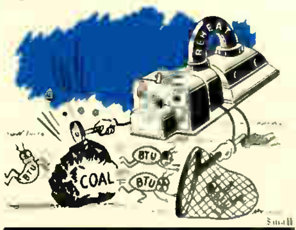
O. N. Bryant, who holds more than 25 patents on steam-turbine controls and control systems, relaxes from this technical weekday life by spending his good-weather weekends sailing the waters of Chesapeake Bay. In fact, he has done so consistently for the past 17 years. Also, almost as consistently, ever since 1924, his career has been devoted to steam-turbine control problems. When fresh off the Student Training Course, he devised a successful hydraulic control system for an extraction turbine.

Although Bryant's original aim was to be an electrical engineer, his attention was diverted to mechanical engineering, in which he obtained his degree from Case Institute of Technology in 1923. He came directly to the Westinghouse Student Course of the Steam Division and, aside from a year's development work on diesel engines, development and control engineering was his forte until 1940. Then he became a design and application engineer for the central-station turbine engineering section.



"Busy as a bee" aptly describes *E. F. Losco*. Besides his present duties as Supervising Engineer in charge of the special alloy development groups of the Materials Engineering Department, Jack is working nights on his doctorate at the University of Pittsburgh; he's also building a home and doing photographic work.

A native of Boston, Losco graduated

from M.I.T. with a B.S. in Physical Metallurgy in 1939. Following this he came to Westinghouse and, under a Graduate Fellowship, continued his studies at Carnegie Tech with summers being spent at the Westinghouse Research Laboratories. In 1941 he received an M.S. degree in Metallurgical Engineering and then was called to active duty. He subsequently served five years with the Army's Ordnance Research and Development Center at Aberdeen Proving Ground.

After the war, Losco returned to Westinghouse and joined the Materials Engineering Department, Metallurgical Development Section. In 1947 he transferred, temporarily, to the Research Labs to initiate development work on gas-turbine alloys. He returned to Materials Engineering in 1948 as Supervising Engineer.

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A. J. Kuti began life in Sharon, Pa., left to obtain his college and professional training, and some industrial experience, and then returned to Sharon to seek fame and fortune with Westinghouse in the field of chemistry. He obtained an A.B. degree in chemistry in 1938 from Bethany College in West Virginia and laid on top of that two years of graduate work at the University of Colorado. This was followed by a year with a steel company, after which, in 1941, he joined Westinghouse. Here he has been engaged in chemical testing of transformer materials.

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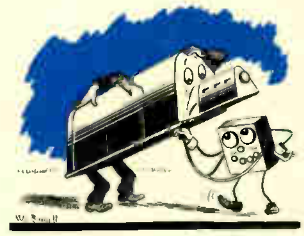
When it comes to engineering writing *Ed Wentz* is a double-threat man. When he writes for the professional magazines—and he often does—the text is highly technical, replete with long-hair mathematics. Yet the same Ed Wentz can present a discussion on so unglamorous a subject as secondary-metering current transformers in a highly entertaining and even humorous fashion.

Wentz is a University of Minnesota man, class of '26. After graduating from the Westinghouse Student Course he entered the Transformer Division, in the Instrument Transformer Section.

Wentz has been head of the Westinghouse instrument transformer design section since 1942, which suggests current and potential transformers. True, but



perhaps he is even better known for other apparatus. He developed linear couplers for bus-differential protection, did much theoretical and design work on saturable (three-leg) reactors. He was in charge of design of that granddaddy of magnetic amplifiers—a 75 000-ampere transductor.

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The editors of *Westinghouse* ENGINEER have been playing a sort of hide and seek game with *J. S. Johnson*. Definitely Johnson was the one sought during the preparation of his article. He could be found at his desk only for brief snatches between trips from East Pittsburgh to California where he has been busy practicing the preachments of his article on testing generator insulation. This rapid getting around has been a characteristic of Johnson ever since he graduated from Newark College of Engineering (B.S. in E.E.) in 1935. He first garnered practical experience with Weston Electrical Instrument Corporation. In 1937 he joined The Consolidated Edison Company, New York City. Here he obtained experience testing all types of central-station equipment. He came to Westinghouse in 1941.

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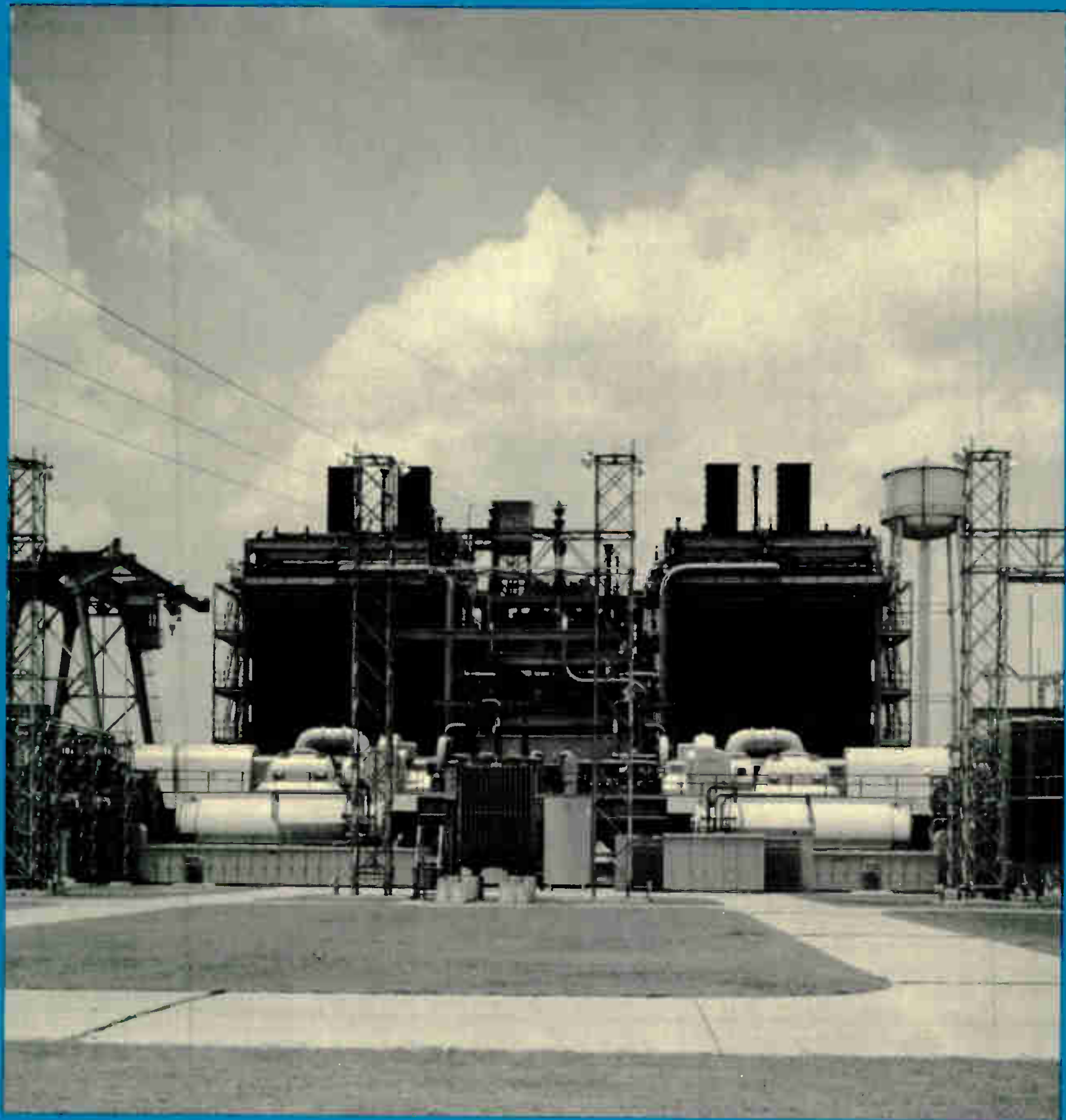
Coleman London graduated from college only 13 years ago (Johns Hopkins University, 1938, B.S. in E.E.). Yet in that brief time he helped develop the famous SCR-240 radio receiver for the U. S. Army, the RBM receiver for the U. S. Navy, was instrumental in the design of a long-range aircraft-detection radar, and a design of gun-laying radar. After the war he led the work converting military radar design know-how to radar for commercial vessels, assisted in developing the modern point-to-point communication apparatus, and mobile radio. Since 1946 he has been head of the section in which commercial radar, microwave apparatus, and mobile-radio equipments are designed.



Generators Outdoors

These two 60 000-kw turbine generators, operating without benefit of a building, indicate the trend to greater use of equipment outdoors, possible in mild climates. Large economies in station construction costs are thus obtained.