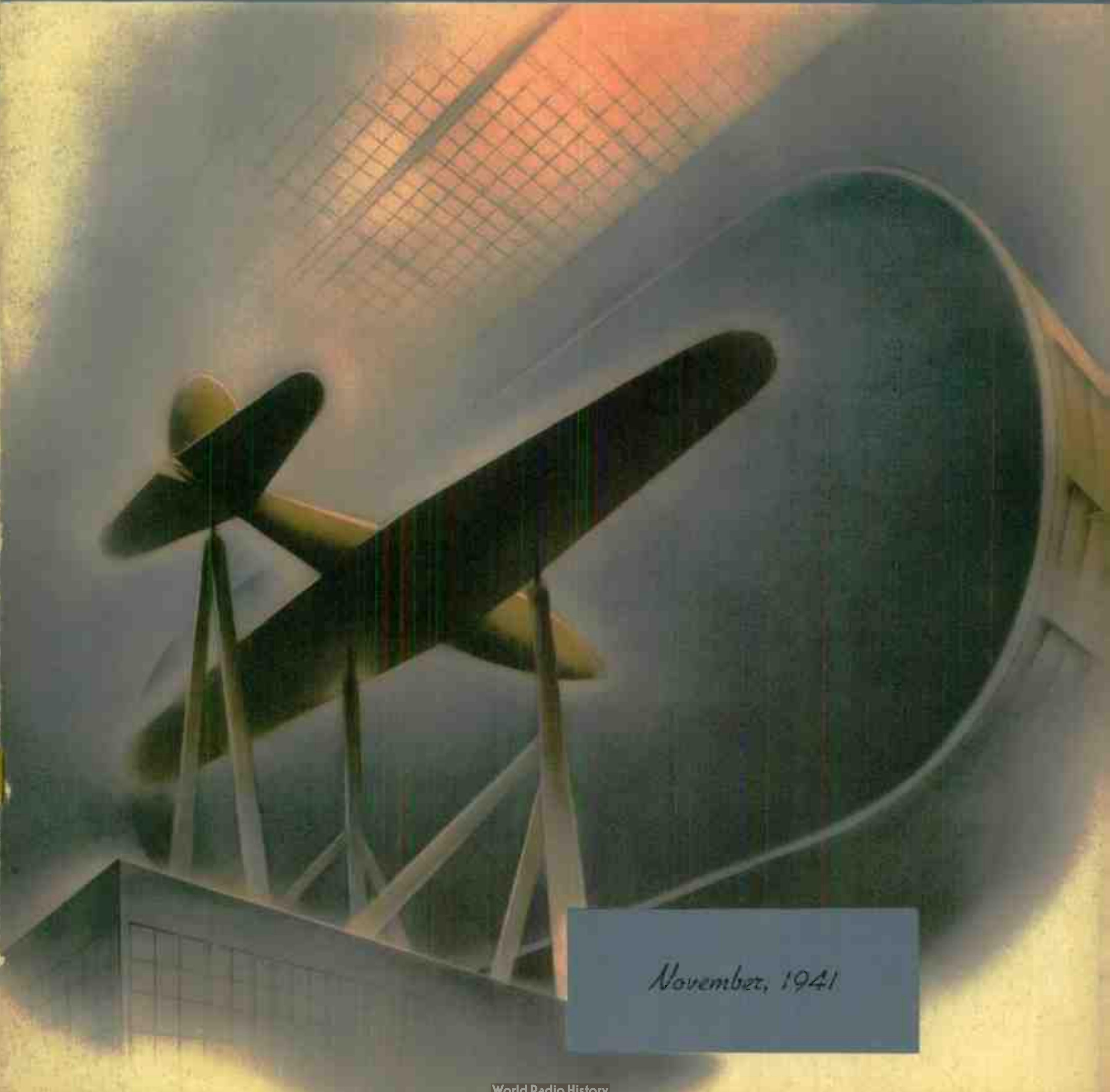
WESTINGHOUSE Engineer



November, 1941

Engineering FOR NATIONAL DEFENSE

Munition dumps are usually semi-cylindrical mounds, about fifteen feet high, scattered over a wide area. Although no one dump is a more likely target for lightning than any other, the whole extensive ground over which the dumps are scattered is sure, sooner or later, to be struck by a thunderbolt. For absolute protection of such a vital area, lightning engineers have developed a "shielding tent." Four 18-foot tent poles are placed at the corners of a rectangle surrounding the mound. A cage is formed by a shielding wire strung over the poles, guy wires from the tops of the poles to ground, and a counterpoise buried in the ground. This cage is so effective a shield against lightning that an ammunition dump so protected just *cannot* be struck by a bolt.

There is no "ersatz" for skilled labor, but here is how substitution of a defense material can be accompanied by a considerable simplification in manufacturing procedure. By molding shell caps out of plastic material, valuable aluminum will be released for more vital uses; more important, however, will be the saving in machining operations that will conserve precious man-hours and relieve the burden on machine tools.

The word "mechanized" applies not only to the mode in which the modern army travels, but also to the methods by which the sundry devices for training and firing the guns are operated. An up-to-date gun mount may contain several pumps, motors, relays, lights—all calling for a large supply of electric power. This is usually delivered by mobile gasoline-driven generators, ranging up to 25 kva. With an eye for protection against failure of the generator engine, a special belt and pulley are now added to the generator so that it can be run by the engine in any army truck. This emergency arrangement, good for as long as twelve hours, may mean the difference between victory and defeat in a 1941-model battle.

Something "modern" in national defense dates back almost a century. Fresnel lanterns, long used for beacon lights because of the sharply directional, flat beam they produce, are gaining wide acceptance in a "flood-lighting blackout" scheme to protect ammunition plants or other vital centers of production. A string of lights surrounds the entire plant, and the Fresnel lenses direct a blinding flood of light outward. Any prowler within many yards of the plant is plainly visible to the guards. On the other hand, very little illumination is "spilled" between the lanterns and the buildings, so that the watchmen are completely blacked out of the view of a would-be saboteur.

Nothing attracts a bombing plane more than a tall factory smokestack—and for two reasons. It is highly visible, and of course, where there is smoke there is essential industry. The only purpose of a stack is to provide the force, in the form of draft, to carry the smoke away. Means are being studied to eliminate the stack and give smoke enough of a "kick" as it leaves the furnace to rise as high as it would with a stack.

Rather than provide separate fixtures and circuits for blackout lighting of streets and yards of industrial plants, a new control scheme allows dimming all the street lights in the city (or yard). Nothing is visible to an attacking plane, but there is still enough glow in the lamps to make the street and building outlines distinguishable from the ground. By turning one gang switch in a central location, one operator can insert a current-limiting reactor into each lamp circuit, thus diminishing the illumination to less than one-half foot candle, the highest permissible without being seen from the air.

VOLUME 1 • NOVEMBER, 1941 • NUMBER THREE

WESTINGHOUSE Engineer

In This Issue

COVER: The artist produces his version of a model plane facing the controlled man-made hurricanes of a wind tunnel, a subject of feature articles in this issue.

Wind Tunnels—Birthplace of Streamlining 67

Power for Man-Made Hurricanes 71
L. A. Kilgore and J. C. Fink

Stories of Research 74

High Frequencies, Metallurgist Extraordinary 76
F. T. Chesnut

Trends in Power-House Auxiliaries 81
J. C. Cunningham

Secondary Networks for Industrial Plants 85
J. S. Parsons

ABC of Oil Conservation 89
J. R. McClain

Battle of the Substitutes 91
W. M. Layton

What's New! 94

Personality Profiles . . . . INSIDE BACK COVER

•

Editor—CHARLES A. SCARLOTT · *Editorial Advisors*—R. C. BERGVALL · T. FORT · R. E. WILLIAMS

PUBLISHED QUARTERLY BY WESTINGHOUSE ELECTRIC & MFG. CO. ANNUAL SUBSCRIPTION PRICE: U.S.A., $2.00; CANADA, $2.50; OTHER $2.25. SINGLE COPIES, 50c. ADDRESS, WESTINGHOUSE ENGINEER, EAST PITTSBURGH, PA.

PRINTED IN U. S. A.

From "toys" engineers learn how to make machines look better. Here industrial designer D. L. Hadley is with a model of a large hydrogen-cooled turbine generator.

Wind Tunnels ... Birthplace of Streamlining

The progress from the flying crate of the last war to the sleek pursuit ship of this one has been based on a great fund of aerodynamic facts. The wind tunnel has been the schoolhouse for that learning. Just as airplanes have grown in size, speed, and complexity, so has the need for tunnels of larger size and different constructions developed. The newest tunnel, at Wright Field, Dayton, is capable of driving a wind of 400 miles per hour past models 16 feet long. Its two 40-foot propellers are driven by a single 40 000-horsepower wound-rotor induction motor—the world's largest.

Prepared from Information
Supplied by
DR. F. L. WATTENDORF,
U. S. Army Air Corps
Wright Field
and
S. PAUL JOHNSTON
Coordinator of Research
National Advisory
Committee for Aeronautics

THE medical profession has its guinea pigs; the aviation industry, its wind tunnels. The reasons are almost identical. A new idea, in either field, explored by the cut-and-try process, is too costly of human life—if it fails. Test piloting in untried planes is risky business. The wind tunnel helps cut that risk.

Although this is reason enough for wind tunnels, they would have been built had there been no such human reason. Only in wind tunnels can each variable or each proposed change be isolated and studied for its individual effect on flight. Time as well as money is a great factor in their favor; right now time is especially precious. Models formed of wax or plasticine can be altered and tested in a few minutes, whereas for full-scale flight conditions several days are needed for each change. Also, engineers can establish trends by carrying changes to extremes in tunnel experiments not possible in actual flight. Likewise, weight can be forgotten in model testing, and left for solution after the aerodynamics have first been determined.

It has been, in short, through the use of wind tunnels that man has learned to fly. Although for centuries history had been dotted with records of men who experimented with flight, it remained for the Wright brothers to apply the wind tunnel in the modern sense. They built a box 22 inches square by five feet long, placed one model after another inside, and fanned air past them at 27 mph. Facts learned with this crude tunnel enabled them to build the plane that left the ground, at Kitty Hawk in 1903. It was there that the airplane was born.

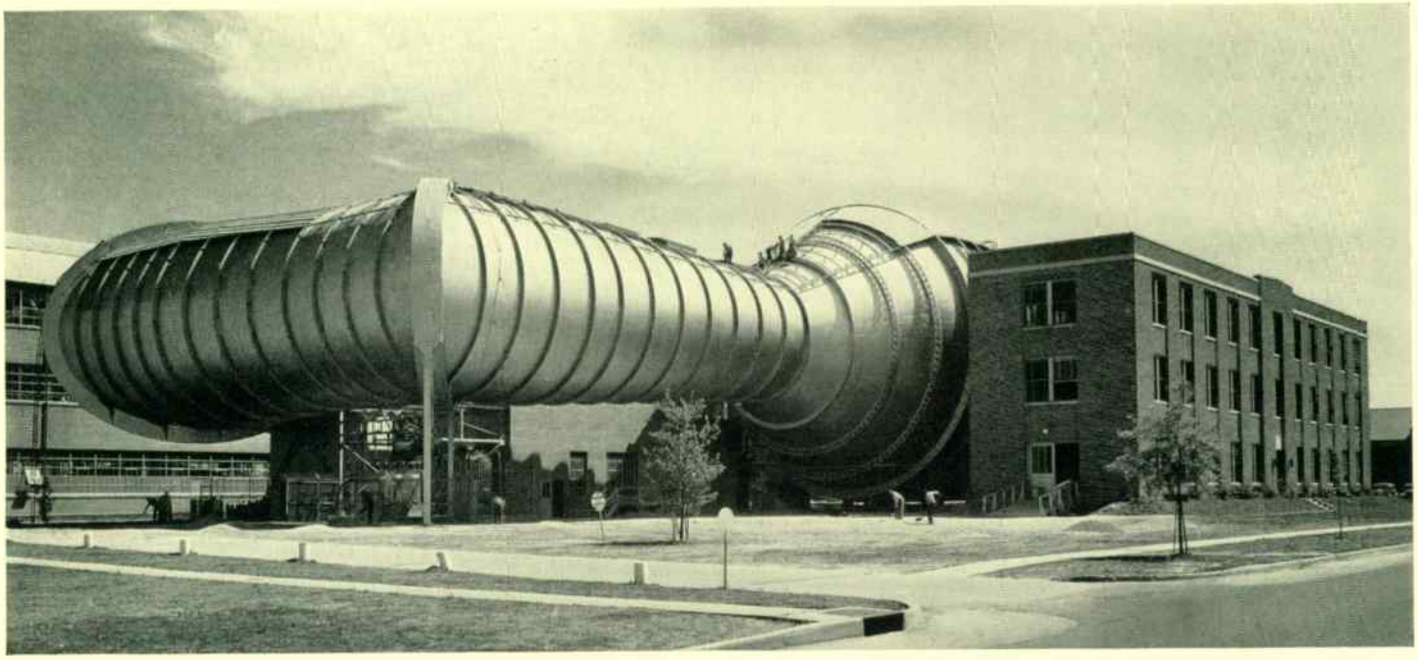
The Wright brothers' wind tunnel contained all the basic ideas of today's tunnels, the principal one being that, aerodynamically, holding a model stationary and blowing air past it is equivalent to moving the model through still air.

Not alone has the airplane benefited from the fruits of wind-tunnel investigation. Nearly everything in which the word "streamline" has any true significance has either already been perfected or can be improved by studies in tunnels. High-speed Diesel-electric trains "ran" first as models in tunnels. Automobiles show results of wind-tunnel experience; cars that set new speed records on the Utah salt flats were first shaped in wind tunnels. Giant skyscrapers have been tested as models before construction to prove in advance their stability, comes a big wind. Problems in the ventilation of subways, mines, and buildings have been solved in like fashion. Smoke problems have been studied in tunnels. Valves have been improved in interior contour to reduce the resistance to flow. Transmission-line towers and their conductors have been investigated for strength under different conditions of wind and ice. A bridge can be studied for its reaction to winds of different intensities and angles, thus anticipating and preventing a disaster as befell the Tacoma, Washington, bridge. These are but some of the wind-tunnel subjects of importance in this streamline age, but it is the airplane that is of surpassing interest at the moment.

The Problem of the Wind Tunnel

It would be highly desirable to have a wind tunnel capable of testing a full-size plane complete with engine-driven propellers, with air moving at maximum flight velocities. There would then be no need for extrapolating results from small-scale models or from low air speeds. Practical considerations rule out this ideal—emphatically. There are two wind tunnels large enough to accommodate an actual-size pursuit plane. One is at Chalais-Mendon, France. The other, at Langley Field, Virginia, has a test section of 30 by 60 feet. Air is driven through it by an 8000-hp plant at 118 mph. But, pursuit ships have passed the 400-mph mark. To increase the velocity of the Langley full-scale tunnel four times or to 472 mph would require 64 times the present power input, or 512 000 hp. This is because the power required increases as the square of the tunnel area and as the cube of the speed.

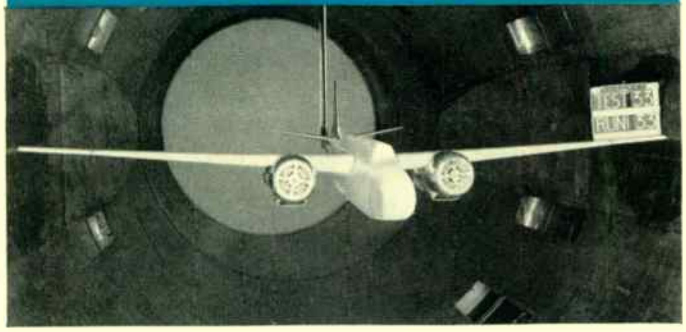
An actual airplane ready for test in the N.A.C.A. full-scale tunnel at Langley Field. The air stream is 60 feet wide by 30 feet deep. Two 35½-foot propellers, driven by 4000-hp motors produce a wind of 118 mph.



Wind tunnels have been called the world's largest precision instruments. This one is the 19-foot variable-density tunnel at Langley Field.

Until about 1920 airplanes were slow and small. It could be assumed that the aerodynamic force distributions in small-scale wings and bodies would be similar to those in actual planes, with only a few corrections necessitated by the character of the air stream itself. For this reason wind tunnels of simple construction and low power were satisfactory for the time. However, as speeds and sizes began to grow rapidly, discrepancies between forces in models and in actual planes became important and led to more thorough study of the wind tunnel itself, including inherent advantages, disadvantages, and errors of the different types.

This is an eight-foot model of a twin-engine bomber being studied for compressibility effects in the N.A.C.A. 500-mph wind tunnel.



Two extremely important factors make it impossible to apply results obtained on small models directly to full-scale conditions. One factor has to do with a so-called scale effect. It physically represents the relationship of two forces acting on a body by moving air, those pertaining to mass or inertia forces of the moving air, and the viscosity of the air. The relative "scale" of any particular test is measured by the Reynolds number, which is stated as

$$RN=\frac{\textit{Air Density}\times\textit{Air Speed}\times\textit{Length of Object}}{\textit{Viscosity of Air}}$$

If model-test data is to be *strictly correct*, the Reynolds numbers for the test condition and the flight condition must be the same. Thus if the length of the model is less than its flying counterpart, i. e., its "scale" is less, to get equivalent Reynolds numbers the air density or air speed of the test condition must be increased. In practice identical Reynolds numbers can seldom be achieved and correction factors must be applied to test data to scale them up to full size. For many aerodynamic problems identical Reynolds numbers are relatively unimportant; much indispensable data comes from wind tunnels of low Reynolds number.

The second factor affecting the results of model testing comes from the compressibility of air. This is the one that has given trouble as airplane speeds have risen. Because air is compressible, any solid object sliding through air sends ahead of it a pressure wave. This wave, in effect, prepares the air for the coming of the object so that the air can divide and flow freely around it. In normal air this pressure wave travels at about 1120 feet per second (765 mph). If the object runs ahead of its "warning" pressure wave, the air is "unprepared," and the effect is shock. The air, instead of flowing freely around the object, is forcibly pushed aside, causing shock waves with great loss of energy. It is much like the difference between pulling a canoe paddle through the water and slapping the surface with the paddle broadside.

In this compressibility phenomenon lies the reason for the often-heard statement that man can never fly faster than sound. Sound itself, of course, has nothing to do with flight; sound is simply the physical effect of this same pressure wave, the speed of which sets the upper practical limit for flight speed.

The extent of compressibility effect is expressed as the Mach number.

$$M=\frac{\textit{Air Speed}}{\textit{Speed of Sound}}$$

The critical velocity of air flow (velocity of sound) is 765 mph; the speed of present-day craft still is only about

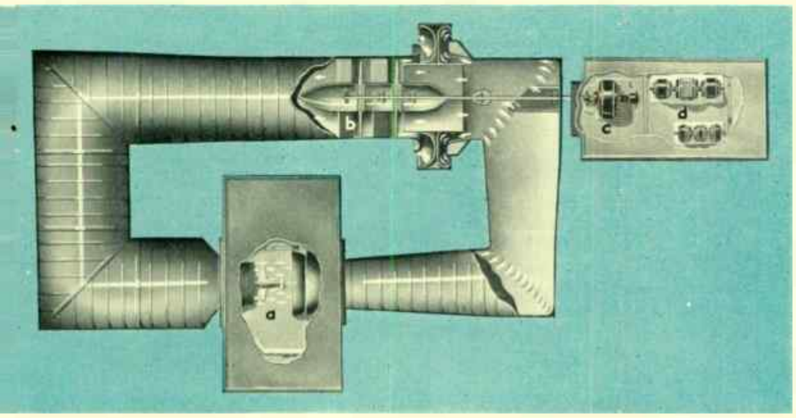
400. It may seem, then, that designers still have a comfortable margin before reaching the nature-imposed limit, that the Mach number is not yet a serious factor in wind-tunnel work. Not so. Although a plane be traveling through air at slightly more than half the velocity of sound, air may be swirling about some parts of the plane at higher than critical velocity. This is because of localized disturbances, set up by engine cowling, propeller tips, air scoops, etc. This condition is accompanied inevitably by a loss of lift and an increase in power consumption. Actually the Mach compressibility effect makes itself felt at flight speeds above 200 mph. Some experimentation at the high speeds has been done, but much remains to be learned in the region above 400 mph. It is probable that the plane structure for these speeds will eventually differ radically from what is good practice for ships of 200 to 300 mph. Wing shapes may in the future be altered to accommodate the swirl imparted to air by the tremendous propellers necessary for these speeds. These and many allied problems await answers in the wind tunnels.

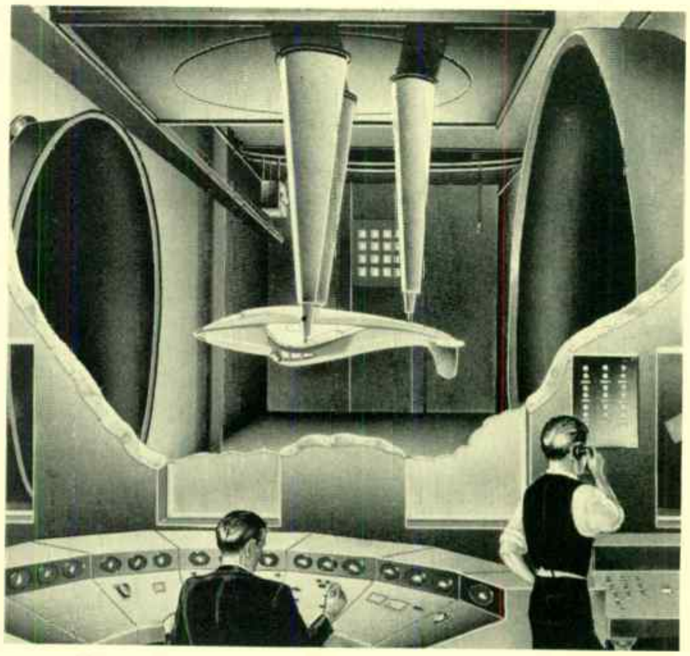
For many problems in which compressibility is important, scale models cannot be used. Engines, for example, of 2000 hp and more present double-edged problems of adequate cooling and minimum interference with the air stream. Obviously, scale engines cannot be built. Propellers capable of delivering 2000 hp to the air have already reached sizes and speeds in which the tip velocity exceeds sound velocity. These and some other plane appurtenances should, for most usable results, be tested full size.

Several Important Wind-Tunnel Types

Because the factors, scale effect and compressibility effect, are unrelated and because of the new problems introduced especially by military craft with their tremendous engines, gun turrets, bomb racks, and the need for the utmost in maneuverability, there has come a need for the large variety of wind tunnels extant. No single tunnel can provide all the answers; each tunnel is in effect a specialist, contributing its share to the mosaic of fundamental knowledge of the movement of objects through air. Several distinct tunnel types have appeared. One is the full-scale wind tunnel, previously mentioned, at Langley Field, of large throat dimensions but operated at low velocity (118 mph). High Reynolds numbers can be obtained, and, most important, actual planes investigated, but it is unsuitable for studies of compressibility effects, because of its low air speed.

In this plan view of the Wright Field wind tunnel the air is circulated in a counterclockwise path through the test section (a), by the propellers at (b), which are turned by the motor (c), through a long shaft. The motor-generator sets for power recovery and speed control are at (d).





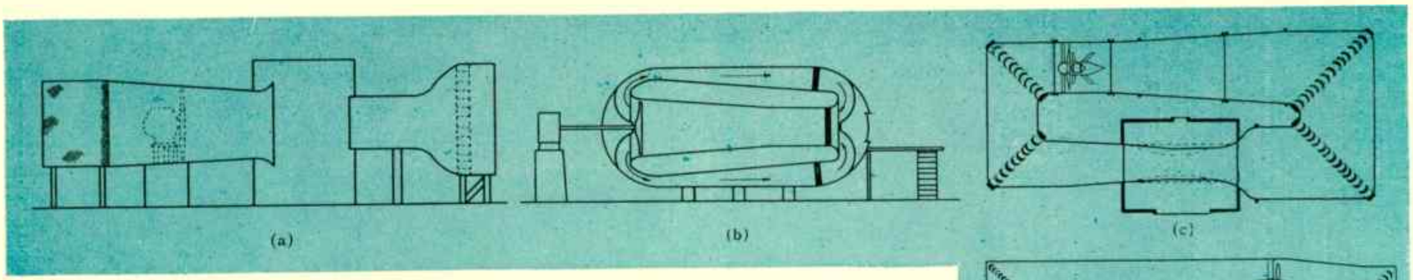
In the Wright Field wind tunnel, tests are controlled and data are recorded automatically in a separate control room beside the test chamber.

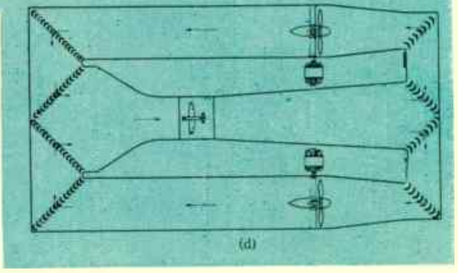
The project engineer seated in the sealed, air-conditioned control room can change the attitude of the model at will without stopping the fan-driving motor. An assistant at his right watches the instruments that automatically record pressures, velocities, and temperatures. When the conditions for one desired test point are correct, the operator presses a button and all instrument readings are simultaneously recorded on tape. These include, in addition to the physical conditions of the test, data showing the behavior of the model under those conditions. The performance of any model requires measurement of the six reactions of a body in moving air. Three are forces tending to cause movement in the three dimensions and are called lift, drag, and side forces. The remaining three are moments tending to turn the body in each dimension. These are pitching (turning end over end), yawing (twisting in a horizontal plane), and rolling (corkscrew) moments. By properly linking the three supports of the model to scales, these three forces and three moments are independently measured as pounds or ounces.

Another type is the variable-density wind tunnel. Ordinarily wind tunnels operate at atmospheric pressure, but as the formula shows, a high Reynolds number can be obtained without large dimensions or high air speed, by increasing the density of the air. This was done for the first time at Langley Field, where a variable-density tunnel was built in 1923. It can be pumped up to 20 atmospheres. Other compressed-air tunnels have been built in England, in Germany, and in U.S.A. Wright Brothers Tunnel at Massachusetts Institute of Technology, Boston, can be operated at pressures up to four atmospheres. Also it can be operated under partial vacuum to obtain the equivalent of high altitudes.

For planes carrying heavy loads at medium speeds, with the good engine economy required in commercial flying, the available types of wind tunnels have been satisfactory. The need for military planes of the highest available top speeds, where economy is no longer a factor, has required high-speed wind tunnels. One of the earliest and most important is the one built at Langley Field in 1936. It can produce a 500-mph wind through a test section eight feet across.

A larger and more powerful high-speed tunnel, in fact the most powerful in the world, is the 400-mph, 20-foot wind





Wind tunnels take several different forms.

Wind tunnels can be either closed or open at its ends. The open type (a) has the advantage of simplicity and low initial cost, but is subject to external winds unless properly sheltered. Also, it requires relatively more power because the air is not recirculated. Most tunnels are closed, the air following a closed path, as in (b), (c), and (d), which differ only in the manner of returning the air to the throat. The double-return (d) requires less overall length for the same expansion of the air than the single closed return (b), and is more readily adaptable to construction in conjunction with a normal rectangular type of building. In the annular return (c), the test section is completely surrounded by a housing so that the return air passes between the inner duct and the outer shell. This tunnel is especially applicable to compact construction, but has the disadvantage that the test section is not readily accessible. In any tunnel the test section can be either closed or open, some being built for either operation. The open jet is more accessible and has less wall constriction effect on large models. It requires considerably greater power to compensate for the losses caused by the open air jet. In addition, the pulsations and noises occur over wide operating ranges, causing discomfort to personnel and making accurate measurements difficult. The closed throat, on the other hand, is much more quiet and consumes less power, but the problem of mounting model supports and test equipment is more difficult. The choice of type of tunnel rests on questions of cost, space, and convenience. Validity of results is not essentially affected by the choice of tunnel type.

tunnel now nearing completion at Wright Field, near Dayton, Ohio. This wind tunnel is truly colossal. It is driven by a 40 000-hp induction motor, by far the largest wound-rotor motor in the world. The losses of the secondary of the motor are recovered and returned to the power lines by the modified Kramer system.* It drives two fans, each with sixteen wooden blades, through a solid steel shaft 16 inches in diameter and 120 feet long. At top speed the two 40-foot propellers deliver 40 000 hp of energy to the air. This energy must be dissipated as heat, partly by natural radiation and convection from the steel housing of the tunnel, and partly by exhausting one-third of the air each revolution and sucking in immediately an equivalent amount of fresh air.

Airplane models of 16-foot wing spread can be tested in the Wright Field tunnel. The several forces and moments can be measured and recorded simultaneously at a remote control station. The size of the throat also permits the vitally important testing of full-scale airplane motors with rotating propellers housed in their normal nacelles.

Thus, although wind tunnels capable of testing full-size large ships at extremely high wind velocities are still not economically feasible, the Wright Field tunnel is a long step in this direction. Still another and larger tunnel has been designed and will be built in the near future at N.A.C.A.'s Ames Laboratory, in California.

There are several other types of wind tunnels. To illustrate, Langley Field has sixteen wind tunnels of different sizes and air speeds, each with its own work to do. Most of them belong to the three general classes—full scale, high-speed, or variable-density—or to some combination of them, but two specialists deserve mention. One is a free-flight tunnel, with a 12-foot diameter test section that can be tilted at various angles. Models of planes are turned loose in the test section where, by proper choice of the angle at which to tilt the tunnel and of the wind velocity, the plane is flown almost motionless. The models have actual controls that are operated by small solenoids on board the model. Power to the solenoids is transmitted by light trailing wires. The effect of the controls on the behavior of the plane in free flight can be observed and photographed. This tunnel can also be operated under pressure.

A somewhat similar tunnel is used to study tail spins. It is a vertical tunnel with upward-flowing air in which small models are deliberately set in a spin and photographed. By this means the suitability of various anti-spinning devices can be checked.

Millions of dollars are being poured into the construction of new wind tunnels. The immediate primary objective is to secure facts from which faster, better fighting planes can be built. This is worthy, indeed vital, in the present emergency. However, unlike much of the large sums now necessarily being spent, this money, as with all research money, will produce full-value-received for peace-time activities long after the present international conflict becomes but a painful and expensive memory.

Blades for the Most Powerful Fan

When nature stirs up a 76-mph wind, it is called a hurricane. But the man-made wind that will howl through the Wright Field wind tunnel will have more than 25 times the force of a hurricane when the tunnel is operated at its maximum air speed of 400 mph. To create such a blast of air, fans unlike any ever built were designed in the propeller laboratory at Wright Field. Because of their great size, the individual blades look more like airplane wings than blades. Two fans, each 40 feet in diameter, are used in tandem. Each consists of 16 blades mounted on a hub. A blade weighs 1500 pounds; a complete fan, 394 000 pounds. Six tons of air per second will pass through each fan. When rotating at 300 rpm, the centrifugal force tending to tear each blade loose from the hub is nearly 400 000 pounds. The blades are built up of spruce, the carefully cut and shaped layers being glued together under a pressure of two million pounds. After careful smoothing by hand two coats of aluminum paint provide the finish. (Abstracted from *Army and Navy Register*, June 14, 1941, p. 6.)

---

*This and other types of wind-tunnel drives are described by Messrs. Fink and Kilgore in this same issue.

Power for Man-Made Hurricanes

Air is heavy stuff, when you start pushing it around at high speed. Not only do wind tunnels require powerful drives, but also their speed must be accurately controllable over a wide range. The drives described here relate specifically to wind tunnels, but they are applicable as well to other propeller loads.

L. A. KILGORE
A.-C. Motor Engineer,
and
J. C. FINK
Application Engineer,
Westinghouse
Elec. & Mfg. Co.

The 13-foot propeller of the Wright Brothers wind tunnel at Massachusetts Institute of Technology is driven by a 2000-hp induction motor.

WIND-TUNNEL drives have an importance at present far out of proportion to their part of the total volume of electrical machinery produced. Just as the present defense needs have resulted in new and larger tunnels of various types, as explained in the preceding article, so have several different systems for driving the wind-tunnel propellers been created.

A wide range of air velocities is required in wind-tunnel testing. The propeller-drive motors must be capable of wide speed adjustment, usually six or eight to one, or the pitch of the propeller must be adjustable. Variable-speed drives must be able to hold any desired speed nearly constant at least for the several minutes required to take a full set of readings. The required accuracy of speed control is different with different tunnels, but is usually of the order of ¼ to ½ per cent. The speed must be held constant regardless of supply-voltage or frequency fluctuations and regardless of load changes within a limited range.

The nature of the speed-torque or speed-power curves of a propeller in a tunnel, as shown in Fig. 1, should be kept in mind. Fortunately, as speed decreases the power drops off nearly as the cube and the torques as the square. If different propellers are to be used, or if the density is to be varied, the load at a given speed may be changed, and this must of course be considered in the choice and rating of the drive.

The Direct-Current, Variable-Voltage System is one of the oldest and most thoroughly tried methods to obtain speed variation over a wide range. It has been successfully applied to practically every industry.

For wind-tunnel use the system normally includes a constant-speed motor-generator set consisting of an a-c driving motor (usually synchronous), a separately excited d-c generator, and a constant-voltage exciter. This motor-generator set is the source of variable-voltage direct current for the propeller-driving motor. The electrical simplicity of this system is evident from Fig. 2.

The controls are simple and readily understood; experienced attendants are not essential for their operation. They consist of, first, a means for starting the motor-generator set. Usually this control provides across-the-line starting, by a magnetic contactor operated from a pushbutton. Second, to obtain d-c variable-voltage output it is necessary only to vary the voltage on the separately excited d-c generator field, usually by a simple rheostat. It can be either hand operated or motor operated, if it is to be controlled from several remote locations. In this system the excitation for the shunt field of the propeller-drive motor is held constant while the generator shunt field is varied from zero to a maximum, thus varying the generator terminal voltage and hence the voltage impressed on the propeller-drive motor. The motor field requires no adjustment unless variation of the armature voltage is insufficient to give the desired speed range. Because the motor speed varies directly with the impressed voltage (its field remaining constant), the speed range usually required in tunnel work can be obtained. The increments of speed can be made as small as desired, within the limitations of practical vernier rheostats.

The variable-voltage drive has good speed regulation, drooping sufficiently to insure stability, and, at the same time, low enough to cause a minimum change in speed as a result of load fluctuations within the tunnel. Inherently this system maintains constant speed under constant load. As the rotating machinery warms up, the resistance of the generator field increases slightly, causing a slight downward drift in generated voltage. However, this change is largely compensated by a similar but opposite effect as resistance of the motor field also changes with temperature. In wind tunnels that demand control of the speed within extremely close limits, a voltage regulator can be applied to the generator to maintain constant generated voltage, and a current regulator can be applied to the motor field to maintain constant current in the motor field. This arrangement, combined with a slightly drooping speed characteristic, results in essentially constant speed under conditions of varying load and small fluctuations in voltage and frequency of the power supply.

The present trend in tunnel designs toward higher wind velocities, and the need for larger electrical machines make it increasingly more difficult to apply the d-c variable-voltage system. Present design limitations restrict this system to ratings of approximately 4500 hp at 650 rpm. However, at

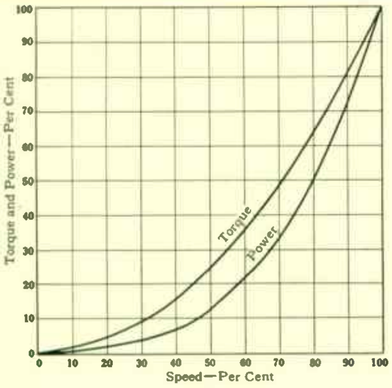


Fig. 1

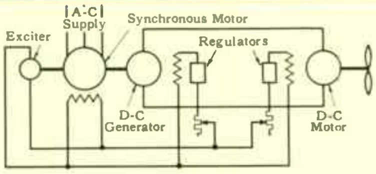


Fig. 2

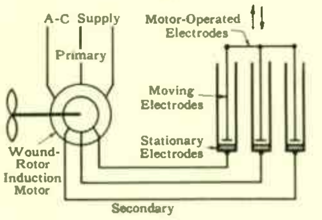


Fig. 3

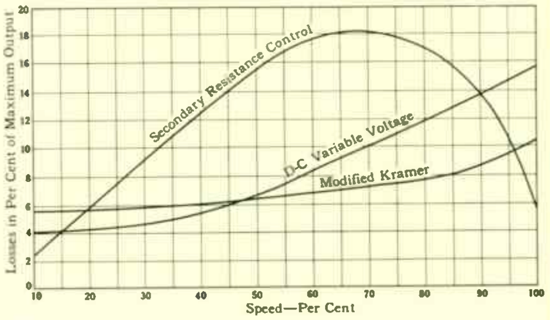


Fig. 4

Fig. 1—Typical power and torque curves of wind-tunnel fans.

Fig. 2—The basic d-c variable-voltage drive consists of a three-unit constant-speed motor-generator set and a d-c fan-drive motor.

Fig. 3—The wound-rotor motor with a liquid rheostat for secondary control is a drive with an almost infinite number of speed steps.

Fig. 4—Comparison of the losses of different drives of about 5000 hp.

lower speeds and by using motors with two armatures the horsepower can be increased.

Wound-Rotor Motor with Liquid Rheostat—One of the earliest forms of a-c variable-speed drives, shown in Fig. 3, is the wound-rotor or slip-ring motor with an adjustable secondary resistance. It is commonly used to drive variable-speed fans and pumps. The characteristics of this drive make it particularly suitable for wind tunnels.

At half speed the secondary power, normally wasted in a resistor, equals the output. But because a fan load varies as the cube of the speed, this is only ⅛ maximum power. The total losses of such a drive are shown in Fig. 4; they reach a maximum at ⅔ synchronous speed. One reason for the present popularity of this drive is the great improvements made recently in liquid rheostats. These new rheostats are described on p. 83 of this issue.

One disadvantage of the wound-rotor system is the variation of its torque and speed with the supply voltage. For a given slip the secondary power, and hence the torque, vary as the square of the secondary voltage. At full speed when the slip is small the difference is slight, but at the lower speeds, the resulting per cent change in speed is nearly equal to the per cent change in voltage. This limitation can be overcome by connecting to the induction-motor shaft a small d-c machine. By regulating its current with the voltage fluctuation, it provides the necessary additive or subtractive torque to hold speed constant. When the speed tends to rise too high, the d-c machine acts as a brake, generating power, which is fed back through its motor-generator set to the line. A particularly desirable combination is shown in Fig. 5, where such a d-c machine is used alone as the propeller drive for speeds below about 30 per cent of field speed and as a speed-regulating device for higher speeds.

Modified Kramer Set—Many early variable-speed drives were built using Kramer sets. They consisted of a synchronous converter connected to the secondary of the wound-rotor motor. Usually they fed power into a d-c motor on the same shaft as the main motor. A modification of this idea, Fig. 6, which has seldom been used, is well suited to drives for large wind tunnels. Connected to the secondary of the induction motor is a synchronous motor that drives a direct-current generator. The direct-current power is reconverted to alternating-current power at line frequency by a constant-speed motor-generator set. In this manner a large portion of the power losses in the rotor of the induction motor is saved. When the induction motor is large and when it is operated at low speed these losses are large, and present troublesome ventilation problems unless some such scheme as this is employed.

This scheme for large installations has another advantage. It simplifies starting the induction motor. The small constant-speed set is started from the line at a low starting current. The large variable-speed set is then brought up to speed gradually, and the large induction motor is then excited from the secondary by applying approximately no-load field current and synchronizing the set with the system.

The variable-speed set must have a rating approximately equal to the maximum torque at the synchronous speed; it is roughly the same size as the main drive. However, for the large sizes some advantage can be taken of the fact that the

TABLE I—COMPARISON OF WIND-TUNNEL DRIVES

Scheme of Speed Control		Range of Speed	Accuracy of Speed	Efficiency	Relative Cost	Inrush Current	Application Best Suited For
1	D-C Variable Voltage	10–1	Good	Fair	Very high	Starting of full capacity set	Small capacity moderate speed
2	Wound-Rotor Motor and Liquid Rheostat	3–1[1]	Fair depending on voltage variation	Poor except near full speed	Lowest	Magnetizing current of induction motor	Any application where accuracy not required
3	Wound-Rotor Motor with Liquid Rheostat and D-C Speed Control[2]	10–1	Good	Poor at medium speed	Low	Same as (2)	Where efficiency is not most important
4	Modified Kramer	10–1	Good	Best except at full speed	High	Starting current of a 30% capacity set	Large capacity
5	Variable Frequency[3]	10–1	Good	Fair	Highest	Starting current of full-capacity set	High-speed drives
6	Multispeed with Variable-Pitch Propeller	4 Speeds	Good	Best	Medium	Starting current of full-capacity squirrel-cage motor	Small capacity limited by propeller design

NOTES:—[1] By using two liquid rheostats in series on large installations it is possible to go to ⅙ speed.
[2] See description at end of section on Wound-Rotor Motor with Liquid Rheostat.
[3] These general comments would apply to either scheme described for obtaining variable frequency.

high current is drawn only at low speed and that the voltage can be limited to lower speeds. This reduces the size.

The constant-speed set handles the same amount of power as the variable-speed set except for the losses, but the speed can be higher than for the variable-speed set at maximum power. The rating based on maximum current and voltage is about 25 to 30 per cent of the rating of the unit.

The speed is controlled by regulating first the field of the d-c motor and generator, then that of the generator. This scheme has the same inherently good speed regulation as the d-c variable-voltage system. Automatic speed control can be readily applied.

The modified Kramer drive is suitable only for the larger installations, of, say, at least 2000-hp induction motor. This is because of the tendency to hunt if the speed is carried too close to synchronism. In a large set with eight or ten per cent slip, this hunting tendency can be avoided, but becomes more difficult to handle in units of lesser capacity.

Variable Frequency—A squirrel-cage induction motor or a synchronous motor could, of course, be supplied with variable frequency to drive them over a wide range of speed. The expense of obtaining the variable frequency has limited its use to applications where the motor speed and capacity are beyond practical limits of d-c or wound-rotor motors.

One method used for supplying variable frequency is shown in Fig. 7. It consists of a-c to d-c and d-c to a-c motor-generator sets. One large installation for propeller testing has provision for changing the number of poles on both the variable-speed synchronous generator and on the propeller-driving synchronous motor. This reduces the wide speed range and large size otherwise required of the d-c machines.

Another means considered is shown in Fig. 8. It consists of a large wound-rotor induction machine used as a frequency changer, similar to that often used for small, high-speed tools. This requires a full-capacity induction machine with a relatively high slip frequency in the rotor at maximum current, creating difficult design problems when large capacities are required. Also, it necessitates a variable-speed drive for the frequency changer. This is a large d-c motor and a d-c to a-c set of slightly greater capacity for the full range of speed than for the modified Kramer set because the total losses of the propeller-drive motor must be converted. The speed of the variable-speed set can be kept high and the size reduced by taking advantage of the fact that the high current occurs only at low speed, just as for the modified Kramer set.

Multi-Speed Motor with Variable-Pitch Propeller—A 2000-hp drive (shown on p. 71) was built in 1938 with a four-speed squirrel-cage motor and a variable-pitch propeller. Using two complete windings in the slots, each with two connections for a two-to-one change in speed, it is possible to obtain speeds corresponding to 6, 8, 12, and 16 poles. The pitch of the propeller blades is varied under load to give intermediate air speeds. A high efficiency is obtained through most of the range. This particular tunnel has a range in pressure from ¼ to 4 atmospheres and a corresponding range of 16 to 1 in density. This requires a wide range of load at the various speeds. The chief limitations of this scheme are the difficulty and expense in variable-pitch mechanisms for larger ratings, also the relatively high starting currents required.

The several types of drives are compared in table I. The final choice is, of course, a balance between many factors. For example, the relative efficiency can be evaluated only after estimating the hours of use at each speed, cost of power, and relative investment. For large installations where extensive use justifies the investment on an efficiency basis, the modified Kramer set probably remains the choice. For smaller units at high efficiency, either the d-c variable-voltage or the multi-speed motor with variable-pitch propellers seems the better choice. Often, however, where the probable use will not justify the investment, the wound-rotor motor and liquid rheostat secondary control should be used. If the range or accuracy is beyond that attainable with simple rheostat control, the addition of a small auxiliary d-c machine with suitable control will be the answer.

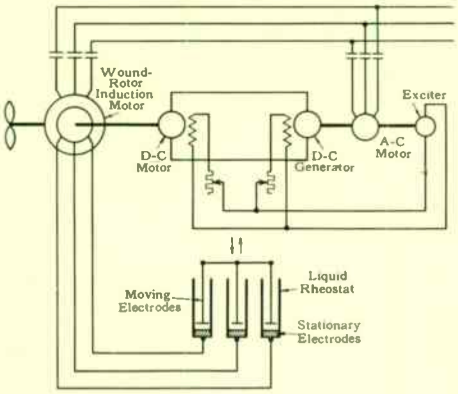


Fig. 5

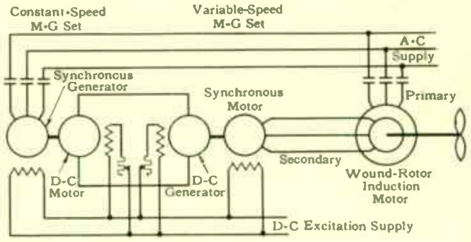


Fig. 6

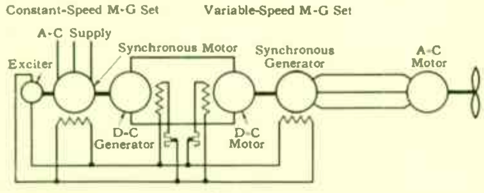


Fig. 7

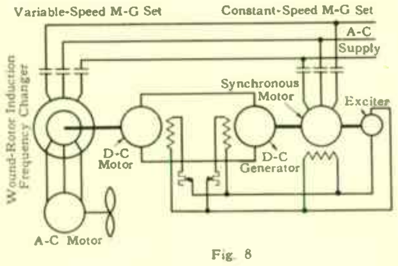


Fig. 8

Fig. 5—*A wound-rotor motor and liquid-rheostat control with a d-c speed regulator to obtain a speed below that obtained by control of the motor secondary resistance.*

Fig. 6—*The modified Kramer drive is a wound-rotor fan-driving motor and two motor-generator sets to return some of the secondary losses to the line. Speed is controlled over a wide range by control of the fields of both direct-current machines.*

Fig. 7—*Variable frequency can be supplied through two motor-generator sets to a main synchronous motor.*

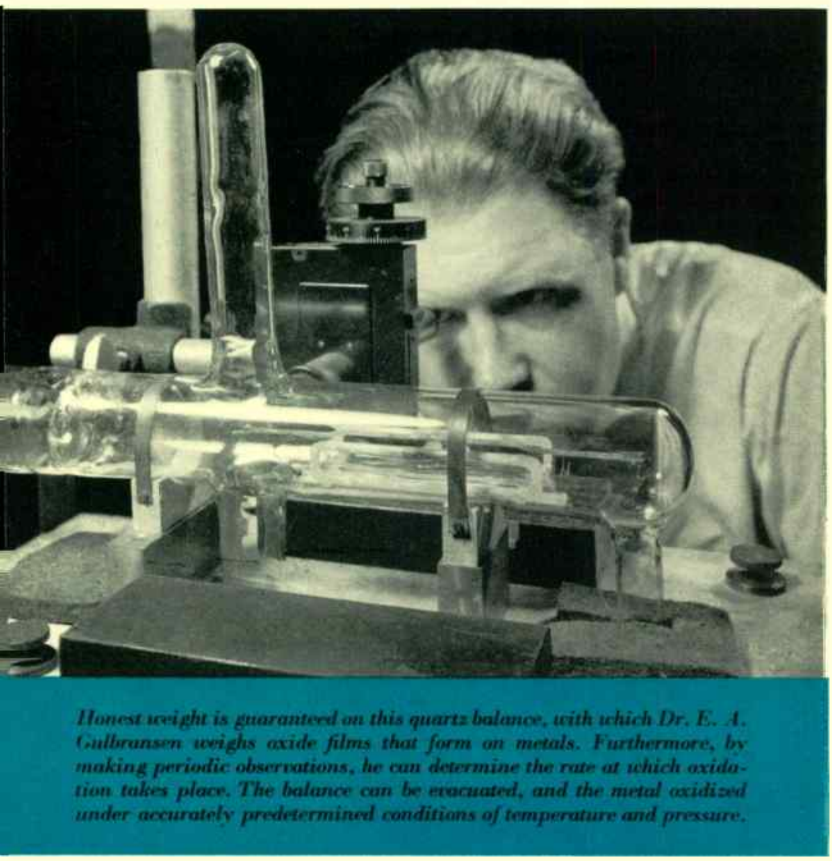
Fig. 8—*Variable frequency can also be supplied by a wound-rotor induction frequency changer system.*

Stories of Research

Weighing a Layer of Molecules

Stainless steel is stainless because it acquires from the atmosphere an oxide film that protects the underlying metal. On ordinary steel the film becomes unwanted rust. It is just possible that there might be something correlative about these contrary reactions; in other words, maybe at a different temperature or pressure a stainless steel would rust and an ordinary steel would become stainless. At any rate Dr. E. A. Gulbransen intends to find out.

Usually a metallurgist studies oxidation by observing the reaction in ordinary air, though probably the effect of Pittsburgh air is different from that of San Francisco air. Gulbransen intends to deviate from the usual plan by polishing the specimen carefully, removing all oxide in vacuum, then observing the rate of oxidation under carefully controlled conditions. For quantitative work he uses a tiny balance made entirely of quartz rod and sealed in an airtight glass tube.



Honest weight is guaranteed on this quartz balance, with which Dr. E. A. Gulbransen weighs oxide films that form on metals. Furthermore, by making periodic observations, he can determine the rate at which oxidation takes place. The balance can be evacuated, and the metal oxidized under accurately predetermined conditions of temperature and pressure.

Only six inches from end to end, the little weighing machine is so sensitive that it can detect the weight added by a single layer of oxygen atoms on a metal specimen of the same thickness and area as a special-delivery postage stamp. To convert the weight of this infinitesimal film approximately to ounces, put down a decimal point, follow it by seven ciphers and a 3.

On one end of the balance is a small counterweight; on the other hangs the specimen at the end of a hair-like tungsten wire. The tube surrounding both balance and specimen is carefully evacuated, then oxygen, air, or ozone is admitted carefully. As soon as a film begins to form on the metallic surface, deflection of the balance is observed through a microscope, and by taking periodic readings Dr. Gulbransen can determine the rate at which the oxide accumulates.

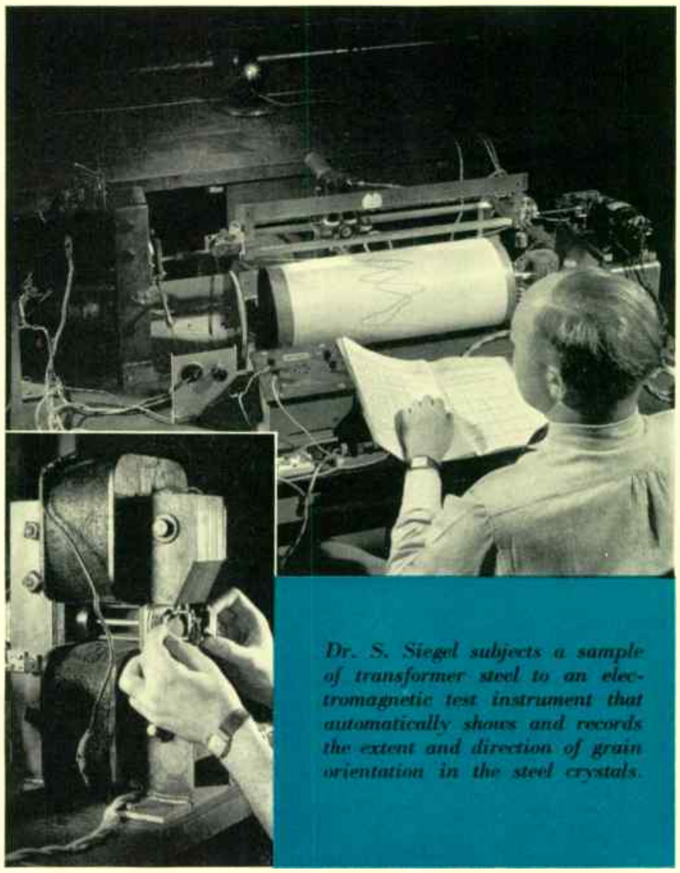
One usually thinks of oxidation as a slow, gradual process, but preliminary tests with the fragile balance prove that a surface film sometimes forms almost completely in about two minutes. This experimentation has a long way to go, because Gulbransen intends to study the reaction at temperatures varying from the sub-arctic cold of liquid air (about 292 degrees below Fahrenheit zero) to that at which steel glows visibly, and in vacuums of varying degrees.

• • •

How Far Can Iron be Regimented?

The blitzkrieg is not an invention of modern war—it is a technique that has always been used by research workers. Significant inventions, like victories, come first from carefully prepared plans followed by scouting experiments that prepare the ground for the great offensive, leading to the first successful results. But to make the invention tangible and lasting, a procedure akin to consolidation of position is necessary. This, in research, consists of checking and double-checking the results obtained, to insure that the offensive resulted in a real victory.

The discovery that the structure of iron can be oriented at will, so that the crystals are all magnetized in the same direction, has been commercially perfected to produce Hipersil transformers that do the work of ordinary-steel transformers with less weight and bulk. It is of great importance to be able to test a sample of magnetic steel and to know whether it is grain-oriented or not. To accomplish this, Dr. S. Siegel uses an electromagnet producing a field of 2500 gausses in a gap about two inches wide. A one-inch disc punched from the material to be tested is rotated in this field. A pair of flat coils, each having 300 turns, surrounds the disc, and as it is rotated, the grain orientation causes variation in the voltage induced in the coil, and this voltage is impressed on a sensitive galvanometer. A motor-driven pen recorder, actuated by photocells following the path of the light beam reflected from the galvanometer mirror, traces a permanent record of the test data on a large sheet of paper.



Dr. S. Siegel subjects a sample of transformer steel to an electromagnetic test instrument that automatically shows and records the extent and direction of grain orientation in the steel crystals.

Instead of a step-by-step curve, this apparatus draws the results of a complete test in a very short time. The record is obtained in about 30 seconds, and reveals to what extent the crystals of the sheet material have been properly oriented. The records are also useful in developing future materials and improving the present ones.

• • •

Photoelasticity of porcelain insulators is being studied for the first time by Dr. M. Hetenyi. Here the projection of fringes caused by polarized light shows the distribution of the mechanical stresses that occur in a large bakelite model of a porcelain insulator mounted on its pin.

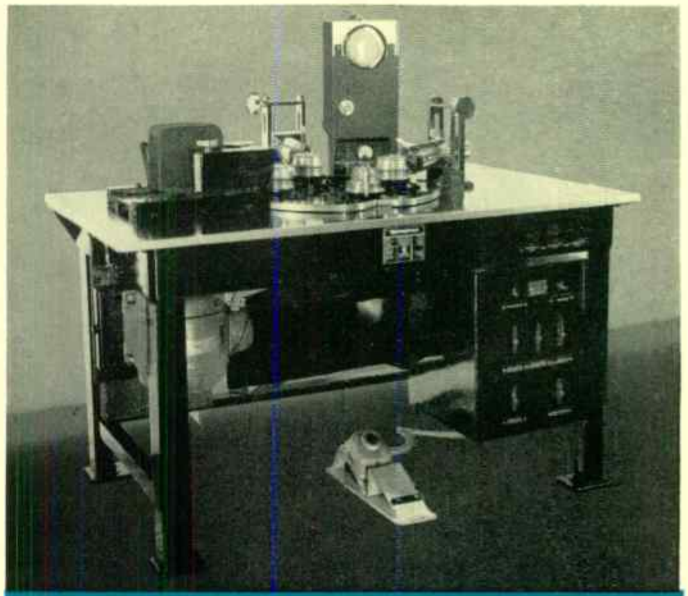
Tiny Magnetic Impulses Detect Steel Flaws

A SENSITIVE measurement does not always call for ultra-complex, delicate instruments. With comparatively simple apparatus research metallurgist P. H. Brace developed a fault detector for ground and polished surfaces on round pieces of steel. Like all ingenious devices, his is based on an elementary natural law. Steel can be magnetized. The external field of a perfectly round radially magnetized sample is uniform. But a surface with, say, a local heat-treating defect on it is no longer magnetically symmetrical, because the faulty region has a different permeability than the adjacent steel. Therefore measuring the magnetic field of such a piece of steel should show a deviation wherever the material is defective.

The practical procedure for testing such a sample is first to demagnetize it completely, so that residual magnetic flux from previous machining operations is completely removed. The piece is next rotated at high speed, and at the same time strongly magnetized, so that uniform flux extends outward from the sample in all directions. Finally this flux is probed with an electromagnet consisting of a Hipernik bar surrounded by a coil. The magnetic field thus measured induces a voltage in the coil, which is amplified and indicated by means of oscilloscope. The test piece is rotated synchronously with the cathode-ray sweep, so that a uniform field is seen in the tube as a straight line, but faults show up in the oscilloscope trace as dips. A second trace in the tube acts as a reference line and carries twelve index points, corresponding to 30° angles around the test piece. By this means a fault can be spotted on the periphery within a few degrees.

In addition to its speed and accuracy, the electromagnetic test for flaws, since it requires no contact with the inspected object, has the virtue of leaving the sample unscarred.

The scheme has been commercially applied to inspection of bearing races, to detect hard or soft spots that often appear during the final processes of manufacture. Such races are weak and may fail.



Hard or soft spots on bearing races are readily shown in the cathode-ray oscilloscope, the seeing eye of a test instrument operating on the principle that the permeability of steel varies with its heat treatment. Flaws are detected electromagnetically without marring or denting the polished surface.

Although the oscilloscope affords only a visual indication of the fault, it is possible to add a relay system to give an audible signal by means of a bell or buzzer, or even to operate automatic machinery for segregating defective pieces coming from a production line.

• • •

Dollars from Dirt

SEPARATING the wheat from the chaff has been an early criterion of human discernment, and an easy one. Modern economic harvests, however, more frequently assume the form of mined minerals or ores, rather than gleaned grains, and distinguishing "pay dirt" from ore that is too lean to process profitably calls for more complex knowledge than that of our forefathers. A clever electrostatic ore separator, pictured on the back cover of this issue, makes use of basic electrical principles to segregate metallic ore from unwanted bits of rock and dirt.

The separator designed by G. W. Penney and G. W. Hewitt was possibly suggested by their Precipitron air cleaner. Low-grade ore, finely ground, is sprinkled in a thin layer over a grounded rotating cylinder, about which are arranged several electrostatic fields. Each particle passing through the electric field becomes charged, and because the particles are about the same size, each receives an essentially equal charge. However, the basic difference between a conducting and a dielectric material is that a charge, in response to changing fields, can move readily on a conductor but not on a dielectric material. Therefore, when the conducting ore and the dielectric dirt particles impinge upon the grounded cylinder in the ore separator, the conducting particles give up their charge at a faster rate than the dielectric particles and are thrown into one pile. On the other hand, the dielectric particles are held against the drum by the force of another electrostatic field, and are carried away to another pile. The separation depends upon the difference in discharge rates of the particles, and can be applied to any mixture of materials differing sufficiently in electrical conductivity. The mixture must be dry, because surface moisture allows all particles to discharge rapidly.

It may be too early to speculate whether a full-scale ore separator will become a commercial success; that depends upon economics. But a small-scale model may allow rapid analysis of some ore samples. This is another example of how research keeps on recombining the same fundamental principles into new inventions, just as composers keep on making new music from the same twelve notes.

High Frequency . . . Metallurgist Extraordinary

Hold your hand in an induction coil, nothing happens; hold an iron rod in it, and it is red hot almost instantly. The principle behind this fascinating stunt is the foundation for a swiftly growing industry—induction heating. Already equipment exceeding 175 000 kw is in use, and last year more kilowatts of equipment were ordered or placed in service than in any previous three-year period. Use of high frequencies has three general fields. Melting, the oldest, is discussed here. Heating and surface hardening will be featured in the next issue.

FRANK T. CHESNUT
Secretary, Ajax Electrothermic Corp., Trenton, N. J.

A GOLD or platinum inlay for somebody's molar, or an ack-ack shore gun to "discourage" enemy planes—here are but two of the many applications for which induction heating is being applied with ever increasing regularity. Although widely diversified in purpose, these applications are generally divided into three main classes—melting, heating, and surface hardening. Many different frequencies, types of furnace, and sources of power are used, but the applications generally involve the same physical laws, and the same principles apply to each. A summary of such applications is given in table I.

Principles of Operation

The coreless induction furnace is essentially a transformer without a core and operating usually, but not always, at a frequency above normal. The furnace proper is a coil carrying this alternating current and surrounding the charge to be heated in inductive relation. The coil is the primary of the transformer and the secondary is the charge, which can be considered a coil of one turn short circuited on itself.

The effectiveness of this type of furnace depends on the supply frequency; on the resistivity, permeability, and physical condition of the charge; on the coupling between the inducing coil and the charge; and on the heat insulation used. By far the most important single phenomenon involved in induction heating is the concentration of current on the surface of the charge, commonly termed "skin effect."

Skin Effect Increases Effective Resistance

Unlike direct current, which distributes itself uniformly through the conductor area, alternating current, because of its inductive effect, tends to concentrate on the surface of the conductor. This skin effect is not generally prominent at 60 cycles, but is pronounced at the frequencies commonly used in induction heating. The alternating-current density in a conductor decreases logarithmically inward from the surface, and the overall resistance can be conveniently expressed by imagining a hollow conductor that has the same resistance to direct current that the solid conductor has to alternating current. The wall thickness of this hollow conductor, which of course varies with the frequency, has been defined as the "depth of penetration." The current distribution in a conductor, based on the depth of penetration, is shown in Fig. 1. About 94 per cent of all resistance heating takes place within the limit of the depth of penetration.

Since, at the frequencies used for induction heating, the center of the conductor carries almost no current, hollow tubing is commonly used, through which cooling water is circulated to carry away the heat developed by the current and the heat conducted to the coil from the charge.

Skin effect is obviously of great importance in determining the proper frequency to be used for a given charge. The higher the frequency used, the shallower is the penetration of induced current, with a consequent increase of resistance and faster heating of the charge. For example, the depth of penetration in copper is about half an inch at 60 cycles and at that frequency an impractically large current must be induced into the charge to melt it. If the same current is applied at 1000 cycles, the depth of penetration drops to one-tenth inch, increasing the resistance five times, and with a suitable charge and thermal insulation the copper can be melted. At 100 000 cycles the effective resistance of copper is some 50 times greater than at 60 cycles. There is a different depth of penetration for each material and for each frequency. Some figures for materials commonly used with induction heating are listed in table II.

From the foregoing it follows that the selection of frequency for a particular job depends not only on the material but also on the diameter of the charge piece. If the total penetration

TABLE I—THE INDUCTION-HEATING APPLICATION SPECTRUM

Frequency	Power Source	Power Range	Heating Application
60	Network	Unlimited	Chemical vats, dies for thermoplastics, etc., annealing or heating magnetic charges to low temperatures.
180 to 540	Motor-Generator	Unlimited	Preheating, annealing or heating magnetic charges; heating dies, rolls, etc., drying.
1000 to 12 000	Motor-Generator	To 1250 Kw and up	Main field—commercial induction heating, melting, and heat-treating.
20 000 to 60 000	Mercury-Hydrogen Spark-Gap Converter	To 40 Kw	Laboratory and small-scale heating, melting and heat-treating.
150 to 500 000	Quenched Spark-Gap or Vacuum-Tube Converter	To 20 Kw (Possibly higher)	Special surface-heating applications, heating small charge where coupling is poor, degassing vacuum tubes, therapeutics.
5 to 50 000 000	Vacuum-Tube Converter	To 20 Kw (Possibly higher)	Special surface-heating applications degassing vacuum tubes, therapeutics, dielectric heating.

TABLE II—DEPTH OF PENETRATION IN INCHES

Material	Frequency in cycles per second			
	60	1000	10 000	100 000
Graphite	10.1	2.5	0.78	0.25
Molten Iron	4.3	1.1	0.33	0.11
Stainless Steel	2.5	0.62	0.19	0.062
Molten Copper	1.4	0.35	0.11	0.033
Copper	0.42	0.10	0.031	0.009
Cast Iron	0.18	0.045	0.014	0.005
Rail Steel	0.043	0.011	0.004	0.001

of the current exceeds the radius of the charge, the furnace obviously does not operate at full efficiency, as there is a neutralization of the induced current at the axis. The diameter of the charge should, if possible, be about eight times the depth of penetration, as Fig. 1 shows, and if the charge is a hollow cylinder, the wall thickness should be at least twice the depth of penetration.

Crowding of the current at the surface of the charge is responsible for the two greatest advantages of the induction furnace, namely the differential heating used mainly in hardening and heat-treating operations, and the stirring effects valuable in melting operations. Because currents can be crowded into shallow surface layers of a charge, it is possible, by using large currents at high frequencies, to heat a surface so quickly that portions below it are not allowed time to be affected by the heat. The depth of the heated surface can be rigidly controlled by regulating the frequency of the current, the power applied, and the time of heating. This is known as differential heating.

The second effect, stirring, is caused by the fact that adjacent conductors carrying current in the same direction attract each other. The charge can be considered as a number of concentric rings stacked on top of each other, each carrying current in the same direction, therefore attracting each other. Restrained by the bottom and sides of the crucible, the molten metal flows up at the center and down at the sides in the upper part of the pool, and in the reverse direction in the lower part of the pool, as shown in Fig. 2. In addition, there is also the mechanical repulsion between the opposing currents in the coil, and in the molten charge. This pushes the metal from the sides toward the center. The two forces are additive in the upper half of the charge, and subtractive in the lower, but both result in thorough stirring, thus making possible alloys of extremely homogeneous structure. Melting is further accelerated because the hot and cold parts of the pool are continuously and thoroughly mixed.

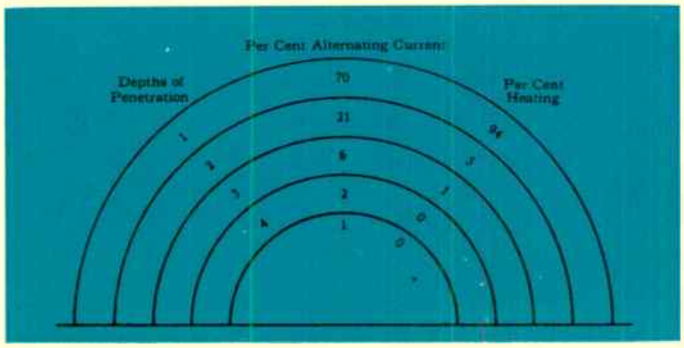
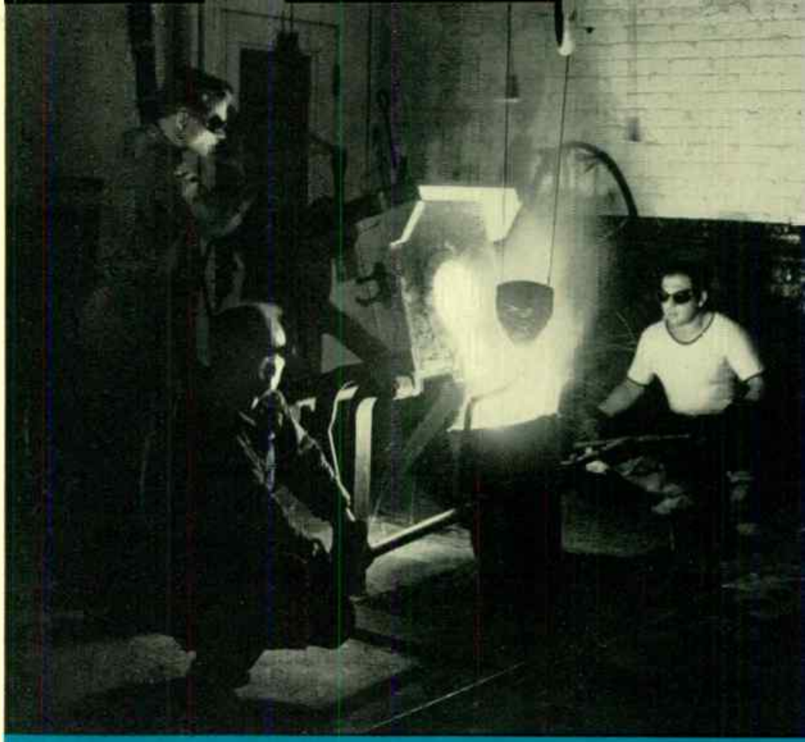


Fig. 1—*The high-frequency resistance of the whole conductor is equal to the d-c resistance of the depth of penetration. Most of the current and of the heating is confined to the first depth.*

Effects of Physical Properties of Charge

Increased heating caused by the magnetic properties of the charge is often confused with hysteresis heating. While it is true that hysteresis heating increases with the frequency, the total heating caused by hysteresis at commercial furnace frequencies is quite low. Higher energy is absorbed by magnetic charges because the effective depth of penetration of the induced current is considerably less. For example, table II shows that the depth of penetration for non-magnetic stainless steel is about 0.62 inch at 1000 cycles but is only 0.01 inch for magnetic rail steel. Furthermore, the charge assumes the rôle of an iron core, increasing the effectiveness of the furnace as a transformer and causing greater short-circuit currents to flow. This effect is particularly useful in low-temperature, low-frequency heating, but of course disappears at the temperature where the metal loses its magnetism.



A 300-pound induction furnace used by the Crane Co., Chicago.

The resistance of the charge affects greatly the rate at which it absorbs energy, hence its heating rate. Both graphite and copper, for example, have high depths of penetration, but the high resistivity of graphite enables it to absorb large amounts of energy, whereas the low resistivity of copper makes heating it by induction difficult. For this reason, it sometimes is advisable to melt copper or other low-resistance metals or alloys in a conducting crucible of graphite composition.

Where the charge has a high resistance, either because it is not an electrical conductor, or because it is a conductor in a finely divided state, the indirect or "muffle" heating method is frequently used. An alternative is to include with the low-conducting charge lumps or a pool of material sufficiently conducting to absorb energy and to transfer it to the non-conducting part.

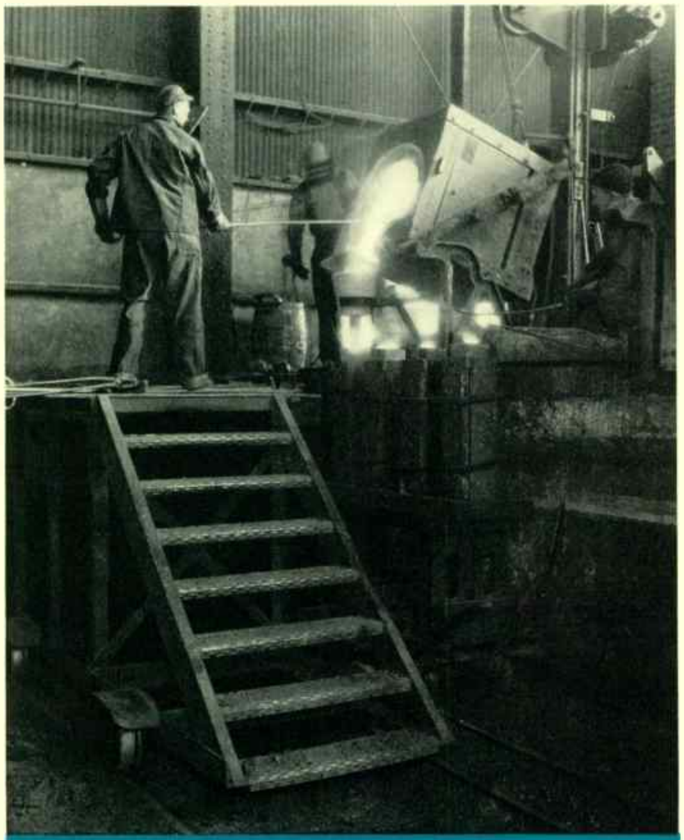
Coupling and Insulation between Coil and Charge

In any transformer the effectiveness of the transfer of energy from primary to secondary greatly depends on the coupling between the two. By coupling is meant the ratio of the average charge diameter to the coil diameter. The average charge diameter is the largest diameter of actually contacting pieces. With a few charge pieces the actual contact may be slight and the effective coupling poor until the charge melts and the contacting pieces form a pool close to the inducing coil. It is usually better practice to build up a charge of small pieces making good electrical contact with each other, rather than to try to melt a charge composed of a few large or irregular pieces.

Inducing energy into a charge does little good unless thermal insulation allows the energy to accumulate and raise the temperature of the charge. This insulation must be placed between the coil and the charge, and the designer is always faced with the difficult choice between thick insulation that results in poor coupling between the coil and the charge, or thin insulation that allows more heat to be lost. Practically each design problem has to be solved on its own merit, but the tendency is toward keeping the thermal insulation down to a minimum, thus placing emphasis on the electrical coupling.

Advantages of Induction Furnaces

Once an induction furnace is installed, the power plant and controls, comprising about nine-tenths of the investment, are slow to wear and depreciate. Damage to the furnace proper, even beyond repair, involves only a slight loss as compared with damage to a fuel-fired or resistance furnace. The low furnace cost permits carrying a spare, or the use of several different-size furnaces operated from the same mains. Thus at slight additional cost a single installation can be used to take care of special or oversize castings when necessary or to make small melts quickly, in addition to handling the charge for which it is primarily intended.



The Carpenter Steel Co. of Reading, Pa., employs induction heating to make high-speed tool steel and to remelt stainless steel.

Melting by induction is quick. As a rule, a 600-kw furnace melts a ton of steel in one hour, two tons in little over two hours, and 500 pounds in fifteen minutes—a total daily production of between 20 and 24 tons. Because of the ease of handling and making analyses, the production rate of the induction furnace greatly exceeds that of other furnaces.

The speed of melting and the stirring caused by the electric forces in the induction furnace result in a more homogeneous mixing and alloying of the constituents. Deoxidizers and other refining additions are mixed throughout the melt almost instantaneously, and the refining time is considerably less than in non-stirring furnaces.

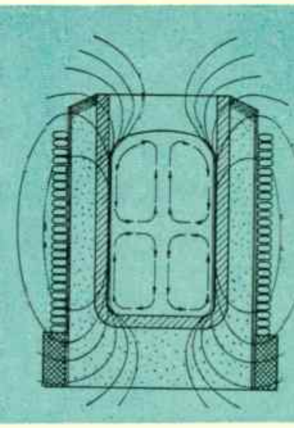


Fig. 2—The magnetic forces between the furnace coil and the charge, and between neighboring layers of the charge cause a constant stirring motion in the directions of the arrows.

Because the induction furnace is clean and thermally insulated, it offers the best working conditions for the operator. Although the average melting furnace can be operated by one man, an additional man usually is employed to help with the routine labor. Once the process is established, relatively inexperienced operators can be employed. The plant as a whole can be clean and compact.

A melt in this type of furnace is under complete control at all times. There are no carbon arcs to contaminate the melt; slags can be added or skimmed off at will; special atmospheres are easily introduced; stirring and temperature are readily controlled. The furnace can be poured clean and no holdover charge is necessary. Established analyses can be duplicated with a minimum of variation; or melts of widely varying composition can be made successively in the same furnace. The power can be kept on high-temperature melts until the instant before casting, and the charge can be hurled quickly into a waiting mold; furthermore, the mold can be preheated by induction and the speed of solidification thus regulated. The furnace itself can be used as a ladle and carried to the mold by a crane.

Induction-melting furnaces are widely used in ordnance work, especially in centrifugal casting of guns. The metal is melted and prepared to the exact analysis required, then poured into a rotating mold. Any slag present is forced to the inside of the bore and removed when the barrel is machined. The main advantages of induction melting for this work are the speed with which the metal can be prepared and the flexibility of the furnace in pouring the charge. A better gun is made in a shorter time and at considerably less expense than by other methods.

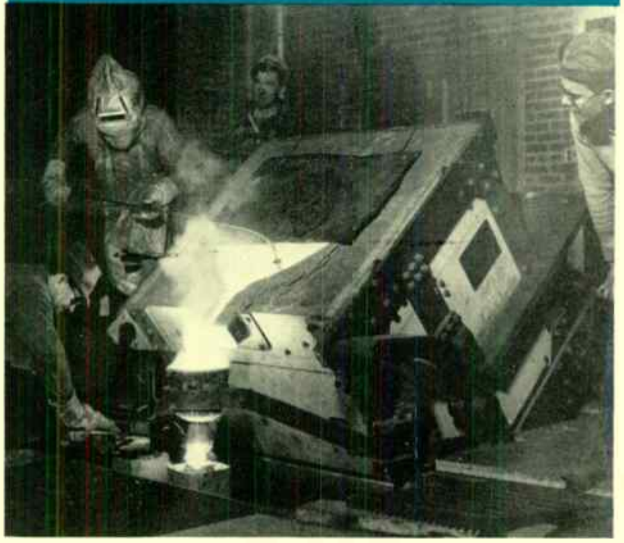
Induction-Melting Applications

The coreless induction furnace is used to best advantage where the product melted must be of exact analysis, where melting losses are to be avoided, or where special attention to the melting process is necessary. It is used to produce many grades of tool and alloy steels, to refine precious metals, to prepare special brasses and bronzes of frequently changed composition, to melt carbides of tungsten and other metals of high melting point, and to fuse refractory materials. Almost the entire production of chrome-nickel resistance alloys, the melting of most special magnetic alloys, and the remelting of stainless steels are done by induction. It is also employed for laboratory research in metallurgical melts, or for the study of metals melted under vacuum or special atmospheres. Castings made in centrifugal molds, or billets made of two or more different metals, are frequently prepared in induction furnaces.

Practically all ferrous metals are treated in direct induction furnaces, in which the charge is contained in a non-conducting lining or in a crucible, and the energy for melting is induced directly in the charge. The lining material varies with the operation of the furnace, but consists usually of a magnesia or silica mix. Nearly all linings comprise a sintered surface next to the metal, backed up with a tightly rammed powdered or granular material. In addition, the coil itself is covered with a hard, air-setting refractory material, molded against the inside of the coil and between its turns, and acting as a last defense in keeping molten metal from contact with the coil in case of a leaking lining. Channels are sometimes provided in the lower portions of the furnace structure, to allow leaking metal to escape in case of emergency. The largest single steel-melting furnace was installed at Aosta, Italy, in 1935. It is rated at 1750 kw and can hold and melt eight tons of steel in about three hours.

Non-ferrous metals are generally melted in conducting and semi-conducting crucibles that permit the heating to be rapid and efficient, and allow some energy for stirring the melt to pass through the crucible into the charge. Conducting crucibles are preferable for melting metals of low resistivity, and are of course necessary for heating electrically non-conducting substances. They are usually made of clay and graphite in proportions, depending upon the desired electrical conductivity, temperature, and resistance to oxidation. The more graphite in a crucible, the higher the electrical conductivity and the operating temperature permissible, but also the faster the rate at which the crucible can oxidize, and vice versa. Pure carbon or graphite crucibles backed with carbon heat insulation are used for almost all applications above 1600°C, at which temperature practically all oxide refractories react with carbon. Crucibles of platinum or other metals of high melting temperature backed with refractory oxides are sometimes used as indirect "muffles" for high-temperature work.

Nickel-chromium resistance alloys are prepared in this one-ton furnace of the Wilbur K. Driver Co., Newark, N.J.



Although conducting crucibles are self-supporting, they are usually backed with a refractory material, in the same manner as crucibles used in direct induction furnaces. The most commonly used backing material, except for high-temperature work, is silica sand held in place by a refractory cement topping, applied as a plastic and hardened in place.

Types of Furnaces

Both direct and indirect induction furnaces vary in the manner in which the charge is heated or poured. The tilting furnace, in which the melt is poured from the top, can be emptied at the point of melting or carried like a ladle to a distant point of use. Some steel-melting furnaces are bottom pouring, like cupola furnaces, with a tap hole in the bottom that can be opened and closed to pour all or part of the charge.

Furnaces for melting brass are frequently made with stationary crucibles but with coils that can be either lifted or dropped away. Usually two pedestals are provided on a movable truck. After the charge in one crucible has been melted, the coil is lifted (or dropped) and placed over the other crucible. The first charge can be lifted and poured into the mold. This type of furnace is convenient for quick melting and for quick changes in charge composition, but is not as efficient as the built-in crucible type because of poorer coupling between charge and coil and because of lack of heat insulation.

For some special applications there are vacuum furnaces, in which either the charge alone, or both charge and coil, are in a vacuum chamber. These are used in laboratories for exacting work in special atmospheres. Some converter-type vacuum furnaces are used for melting and gas-analysis work. Furnaces incorporating both melting chamber and mold are used for rapid centrifugal casting of a metal, to control the temperature of both charge and mold in casting metals of high melting temperature, or to control the rate of solidification of a charge after pouring.

Furnace Control

Control of Power—The rate of power application determines the speed of heating and the degree of superheating of the charge. Furthermore, the power requirements of a furnace vary through the heating cycle. If constant voltage is applied to the terminals of a furnace coil during the melting of an average steel charge, the power rises slightly as the charge warms up, then drops to as low as one-half the starting power as the charge becomes non-magnetic. As the steel begins to melt, the molten metal fills the crucible and improves the coupling between the coil and charge, thereby raising the power to its original amount. Means must therefore be provided to control the power supply under load.

In furnaces supplied by spark-gap oscillators, power varies with the length of the spark gap, which is readily changed under load. If the source of power is a motor-generator set, the most common method of control is changing the excitation. Voltage, and hence power, is thus easily varied from zero to full load. Automatic voltage regulators can be used to keep the power supply constant at any preferred setting.

Another way to control power is with taps on the furnace coil. By connecting the capacitors for power-factor correction across the whole coil, and

Induction Heating—The Past

The first practical use of high-frequency current for heating was made in 1916, when Dr. E. F. Northrup was asked by Dr. G. H. Clamer, now President of the Ajax Metal Company, to search for a method of heating by electricity that might have been overlooked at the time. Within the year, Dr. Northrup (co-founder of the Leeds & Northrup Company) developed the ground work of induction heating with high-frequency current. Subsequently the Ajax Electrothermic Corporation was organized to develop and exploit the invention, and sublicensees were set up to handle special applications for the foreign fields. Until his death in 1940, Dr. Northrup continued with the development of the furnace, and in the twenty-four years of his work took out the greater number of the 120 patents granted in the United States. Similar patents were granted throughout the world.

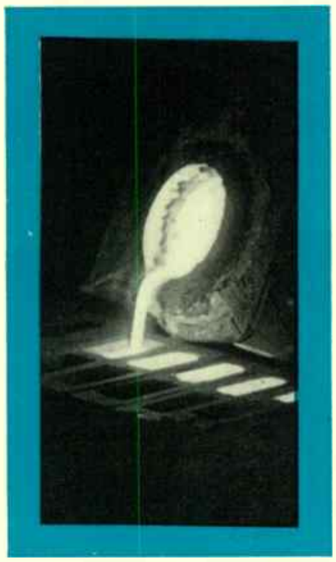
At first all induction furnaces were supplied with energy from the Tesla or spark-gap type of converter. Frequencies ranged roughly from 20 000 to 80 000 cycles. Power limitation of this type of converter restricted the furnace to laboratory or small scale production units for many years. When it was finally learned that intermediate frequencies of 1000 to 12000 cycles could be used for most commercial requirements, the spread of induction heating was assured. Although equipment was not then available, the electrical manufacturing companies began to supply ample generators and improved capacitors; power limitation was no longer a bar to progress.

Adoption of induction heating by industry was neither spontaneous nor general. Each furnace installed in the early days had to prove its worth in competition with other equipment. One or two of the larger companies foresaw the possibilities of induction heating and took out broad licenses for its use. Most customers were skeptical, and literally thousands of tests had to be made before they were convinced of the value of the new heating method.

---

the supply voltage across only part of the coil, the coil behaves like an autotransformer, and a voltage higher than that in the line is impressed on the capacitors. Using four taps and a constant generator voltage, the power can be varied from about half to full load or full-load and can be delivered to the charge at all times, in spite of large fluctuations caused by changing conditions such as variations in magnetism, coupling, and resistance. The tap switches must be interlocked so that when they are opened under load a high resistance is cut into the exciter field circuit to prevent switching surges caused by the collapse of the magnetic field.

Control of Power Factor—Induction furnaces inherently operate at low power factor and capacitors are used to raise the line power factor nearly to unity at all times. In addition, the power factor varies with the condition of the charge. At constant voltage, and with an average number of capacitors in the circuit, the power factor of a steel charge may vary, as the melt progresses, from about 0.40 lagging to 0.40 leading. Capacitors can be added to the circuit at full voltage, but it is necessary to insert a high resistance in the exciter field to prevent arcing as they are removed.



Control of Stirring—The amount of stirring in a furnace varies with the relative position of the charge and the coil. If little or no stirring is desired, the charge surface is kept close to the top turns of the furnace coil, and vice versa. The amount of stirring is a construction rather than an operating characteristic, and few attempts have been made to vary the stirring during operation by moving the coil or the charge, because a furnace with a movable coil is mechanically and electrically weaker than a built-in unit.

By far the best method of controlling stirring is to have currents of two frequencies flow in the same furnace coil. Stirring depends only upon the magnitude of the current, and not on the frequency. Adjustable low-frequency current can therefore be used to stir the charge, with little effect on the heating. A choke coil in the low-frequency mains and a capacitor in the high-frequency connections prevent interference between the two sources of supply. No change in the furnace itself is necessary.

Furnaces in Parallel—It is sometimes necessary to operate two or more furnaces in parallel from one source of power. This happens, for example, when a larger melt than usual is required for an oversize casting, and the metal has to be prepared simultaneously in two furnaces. Sometimes it is desirable to melt a charge and keep it molten for refining. A special holding tap that reduces the power is then used, and the remaining available power is released for another furnace in the plant.

Slag Control — Because of its rapid melting characteristic, the induction furnace is usually operated without slag. Whatever impurities are caused by an open pool are considered negligible in most alloy work. If slagging is required, however, the stirring of the metal causes it to come in intimate contact with the slag very quickly, and impurities are trapped as they rise to the surface and are skimmed out by the slag.

It should be remembered that the top of the charge in an induction furnace is not as hot as in a fuel-fired furnace. It is therefore advisable to use slags melting at low temperatures. If the furnace is arranged for high stirring at the surface, the molten charge has a high crown. If slags are to be used, it is advisable to use a furnace with a low crown or with little surface stirring, so that the slag is kept over the whole surface of the melt.

Safeguarding the Equipment—Almost every part of a coreless induction furnace is separately protected. Overload relays and oil switches protect the generator; fuses protect the capacitor units. The furnace coil and the capacitors are water cooled, and thermostats are sometimes inserted in the water lines to warn against insufficient flow or overheating of the cooling water.

Emergency dumps and passageways are provided in the furnace bottom and housing walls to permit safe emptying of the charge in case the lining breaks. Linings and other parts of the equipment are periodically inspected to anticipate mechanical and electrical faults.

Trends in Powerhouse Auxiliary Practice

Reliability of motors, control, and power supply for steam-power-plant auxiliaries has increased in importance with the trend toward high steam pressures, large boilers, and unit operation. Power-plant engineers have met this need in many different ways. In selecting drives there is an underlying preference for squirrel-cage motors and simplified control, but adjustable-speed motors are being given the test of operating experience in draft-fan and boiler-feed-pump service. Of equal moment is the reliability of the power supply, which is the principal reason for the constantly growing use of the secondary-network system in powerhouses.

J. C. CUNNINGHAM
Central-Station Engineer,
Westinghouse Electric & Mfg. Co.

WITHIN a minute or two after the induced-draft fan in a station has stopped, the turbo-generator can no longer supply its load. With a modern tendency toward larger individual generating units in central stations (50 000- and 100 000-kw units are now quite common), the serious consequences of an outage of a single unit make imperative the utmost reliability of the auxiliaries, of their driving motors, and of their power supply. A survey of auxiliary practice in central stations during the past six years shows how this prime requisite of reliability is incorporated in representative installations, and that the choice of drive, equipment, or control is governed by the desire to preclude failure of any essential auxiliary.

The survey in table I of the practice in 35 new stations or recent additions shows that steam turbines are rarely used except as stand-by units on boiler-feed pumps and in superposed-turbine installations, where additional low-pressure steam is needed for feed-water heating. Although it is likely that some of the electrically driven boiler-feed pumps that are part of additions to existing stations are backed up by older steam units in the same station, electric-motor drives are nevertheless depended on for the continuous operation of modern power stations. Failure of the electric supply to the auxiliaries means a major shutdown.

Typical auxiliaries in a modern power plant, and what they do.

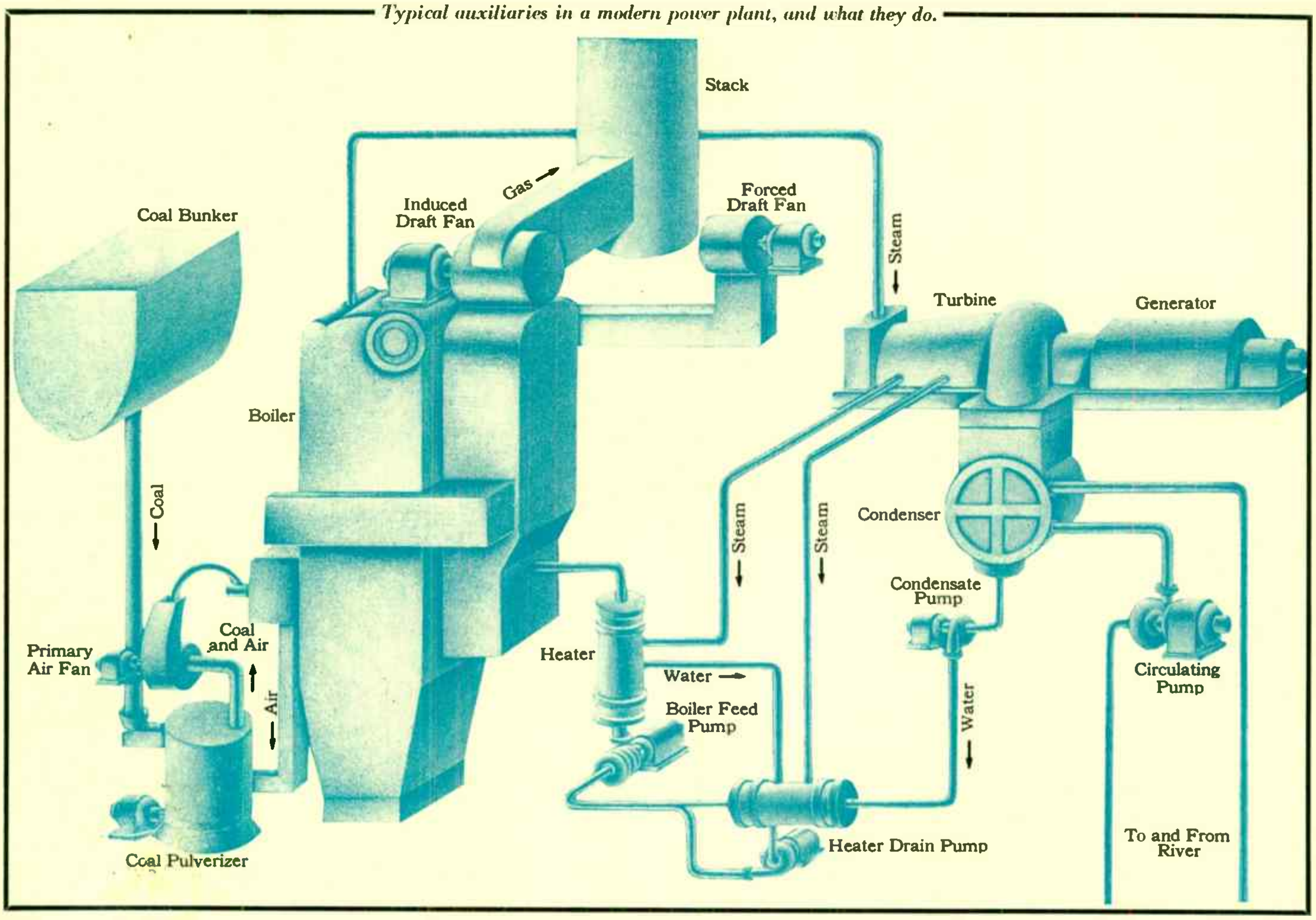


TABLE I—STEAM VS. ELECTRIC DRIVE IN 35 STATIONS

Driven Auxiliary	Number of Installations	Steam Turbine	Electric Motor	Combination Steam and Electric
Boiler-Feed Pump	35	6	14	15
Boiler-Feed Booster Pump	5	2	3	
Condensate Pump	21		19	2
Circulating Pump	21		20	1
Forced-Draft Fan	35		35	
Induced-Draft Fan	35	2	33	
Primary Air Fan (Separate)	15		15	
Pulverizer	30		30	
Stoker	5		5	

TABLE II—ELECTRICAL AUXILIARY DRIVES IN 35 RECENT STATIONS OR ADDITIONS

Motor	Squirrel Cage					Wound Rotor		Direct Current
Controlling Element	Damper	Inlet Vane	Hydraulic Coupling	Electric Coupling	Other	Drum	Liquid Rheostat	Field & Armature Res.
Boiler-Feed Pump			2		24	3		
Boiler-Feed Booster Pump			1				1	1
Condensate Pump			1		17	3		
Circulating Pump					19			2
Forced-Draft Fan	3	17	11	2				2
Induced-Draft Fan	2	12	12	2		1	2	2
Primary Air Fan	13			2				
Pulverizer					30			
Stoker					3			2

Types of Motors

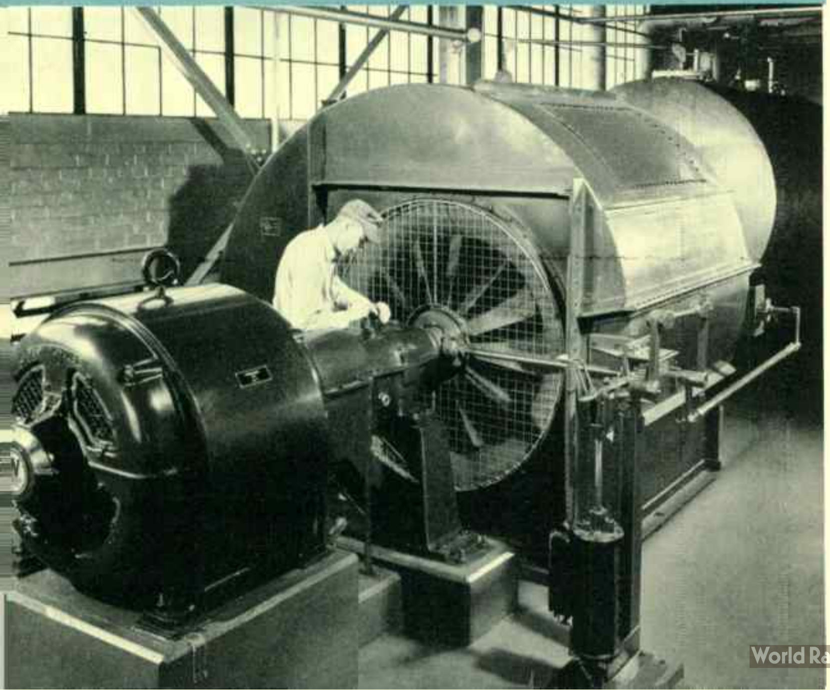
Squirrel-cage induction motors are by far the most frequent choice for general power-plant service. They are efficient, inexpensive, reliable, and they require a minimum of control and protective equipment. Although single-speed motors are used commonly, two, three, or four fixed speeds can be obtained with special stator windings and control. Whether the advantages of multi-speed operation are worth the higher cost and complexity of both motor and control depends upon the particular application.

Synchronous motors are generally more efficient than squirrel-cage motors and can also be used for power-factor correction. But the complication added by excitation supply and synchronizing control generally offsets their advantages, except for low-speed drives.

Where an adjustable-speed motor is essential, either a d-c or a wound-rotor a-c motor is used. A wound-rotor induction motor is fundamentally similar to a squirrel-cage motor; but because it is possible to control the rotor resistance, its speed is adjustable and it has higher starting torque. It can handle severe duty cycles, such as starting, inching, and reversing. Wound-rotor motors and their controls are more expensive and more complicated than squirrel-cage motors.

Direct-current motors have certain special uses in power plants because of their inherently accurate speed control with low regulation. The higher cost of d-c motors, the need for special generators, and the expense of maintaining commutators and brushes restrict their use.

The boiler-feed pump in a modern power plant is usually driven by the largest auxiliary motor in the station. The one shown here, located in the Toronto Station of the Ohio Edison Company, is a squirrel-cage motor rated at 800 hp. Units as large as 2000 hp are now being used.



Pump Drives

The largest single auxiliary motor in a power plant usually drives a boiler-feed pump. The total connected pump horsepower in a station may be 3 to 5 per cent of the station rating and 40 to 50 per cent of the auxiliary horsepower. As shown in table II, most pumps are driven by squirrel-cage motors. The output of circulating pumps and the miscellaneous medium and small pumps for feed-water and house service can be controlled easily and economically by valves instead of by speed variation. Variable-speed couplings and wound-rotor or d-c motors are used occasionally, but the general trend is toward squirrel-cage motor drive.

Throttling losses in valves for boiler-feed pumps operating under variable head become so large that it may be desirable to use a variable-speed motor. Even so, squirrel-cage motors are often preferred, particularly for high-pressure boiler-feed pumps designed for 3600-rpm operation. In modern stations these pumps may require 1000, 1500, or 2000 hp. Wound-rotor motors are available only up to 1250 hp; furthermore, the difference in cost between a squirrel-cage and a wound-rotor motor is greater for 3600 rpm than for lower speeds. The throttling losses with these large pumps are to some extent compensated by the higher efficiency of the driving squirrel-cage motors.

In these motors, the rotors are greatly strengthened by making the cage of trapezoidal bars fitted tightly in slots of similar shape. At high speeds these bars wedge themselves more tightly into the slots and form a rigid structure that does not distort under the high centrifugal stress. A retaining ring of high-strength non-magnetic steel limits thermal and centrifugal expansion of the rotor end rings. The usual radial rotor vents are eliminated to reduce windage and noise; rotor and stator are cooled by streams of air, passing through axial ducts formed by the rotor surface and the stator slots adjacent to the air gap, and escaping through radial vents in the stator. Longer motors have a special chamber that brings cool air to ducts at the center of the stator core, as in large turbo-generators. This provides a uniformly cool machine with a low noise level.

Draft-Fan Drives

The drives for forced- and induced-draft fans in a modern station should not require maintenance shutdowns, and at the same time should have a sensitive volume control. That there is no fixed rule for selection of the fan motor and its control is attested by the diversity of practice indicated in table II. Dampers, inlet vanes, variable-speed couplings, wound-rotor motors, and d-c motors all have their proponents. No one method can be named as best.

Fans driven by direct-coupled squirrel-cage motors, and with their output controlled by dampers or vanes, are simple to install and operate. But because fan blades are eroded in time by ash carried in the flue gas, and fan erosion depends on blade velocity, it is frequently desirable to reduce the speed of the fan at low loads. The added cost of a two-speed motor or of two motors in tandem is often justified by the reduced fan wear, and also by reduction in the power lost in the dampers or vanes.

Squirrel-cage motors for high-inertia fans must have rotor windings large enough to absorb the heat generated during the accelerating period. Another important feature in a thoroughly reliable fan motor is an air gap of sufficient size. Because of the greater amount of heat generated during acceleration, rotor expansion may be more than allowed for in other designs.

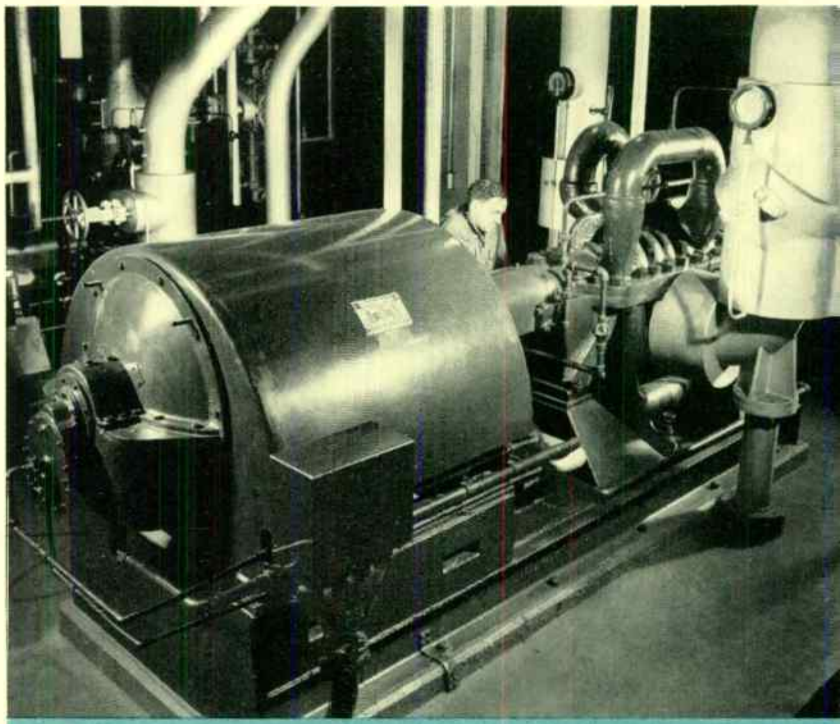
Variable-Speed Couplings

Continuous speed control can be had by using a single-speed squirrel-cage motor and an adjustable-speed hydraulic coupling. The motor shaft transmits torque to the fan shaft through an oil-filled coupling, in which the two members are not connected mechanically, but through an oil bath. The oil content of the coupling is adjustable and controls the slip between the two parts, and with it the speed of the driven fan. This combination reduces fan wear, but introduces an extra rotating device with bearings, oil seals, and an oil-cooling system.

Relatively new is an electric (or magnetic) slip coupling. The oil of the hydraulic coupling is replaced by the magnetic flux of a d-c magnet coupled to the fan shaft, dragged by an iron rotor connected to the motor shaft. The speed of the fan can be varied by controlling the excitation of the magnet. Here again reduced fan wear is obtained at the expense of an extra element and the addition of a d-c excitation supply.

Electric couplings can be used on draft fans and boiler-feed pumps, either with squirrel-cage or with synchronous driving motors. When a synchronous motor is used, a common exciter supplies both motor and coupling. However, it should be remembered that synchronizing control is required for the motor and that if synchronism is lost, the coupling excitation must be removed to prevent attempting to restart under load unless a synchronous motor with high pull-in torque is used.

Wound-rotor induction motors have been used for draft-fan drives for many years. The inherent mechanical simplicity of their speed control is extremely desirable. Thoroughly reliable cam-operated contactor controllers are available, normally with 13 or 20 balanced operating points of speed control. When the boiler operating duty calls for widely varying loads, it is frequently desirable to have smoother control than is offered by 20 operating points. This is furnished by adjustable-speed couplings, but a mechanically simpler speed device is preferable. A wound-rotor induction motor regulated by an up-to-date liquid rheostat in the secondary fills this need adequately.



Who said air was free? By the time the fixed and operating costs of this forced-draft fan are paid, the 130 000 cfm it delivers are worth a tidy sum. Air, although smaller in economic stature, is just as vital in the generation of power as the more glamorized steam and coal. In fact, for every pound of coal used, 10 pounds of air must be forced into the boiler to make combustion complete and utilize every available Btu.

Liquid Rheostats

Liquid rheostats, as built for many years, had several major faults. All the heat generated in the tank had to be dissipated by radiation, with a resulting overheating and evaporation of the electrolyte. The resistance was usually varied by changing the depth of the electrodes in the liquid, and at minimum immersion the current density at the surface of the electrode was enough to cause corrosion of the metal. It was also difficult to insulate the leads where they were brought out of the tank (in a rheostat for a large motor the potential may be as high as 1000 volts).

A design introduced in 1937 eliminates all these objections. The electrolyte is circulated through the rheostat and a heat exchanger; by this means it is kept at 65°C, a temperature too low to cause appreciable evaporation. Resistance is changed, not by partial immersion, but by variable separation of electrodes in an electrolyte column of constant area; the current is never allowed to reach a density harmful to the metal. A separate tank of impregnated transite is provided for each phase, and the high-voltage electrodes are bolted directly to the bronze plates that form the bottoms of the tanks. Each phase assembly is mounted on porcelain insulators, and the frame and moving electrodes are grounded. The whole unit is therefore well insulated.

Distribution and Power Supply for Auxiliaries

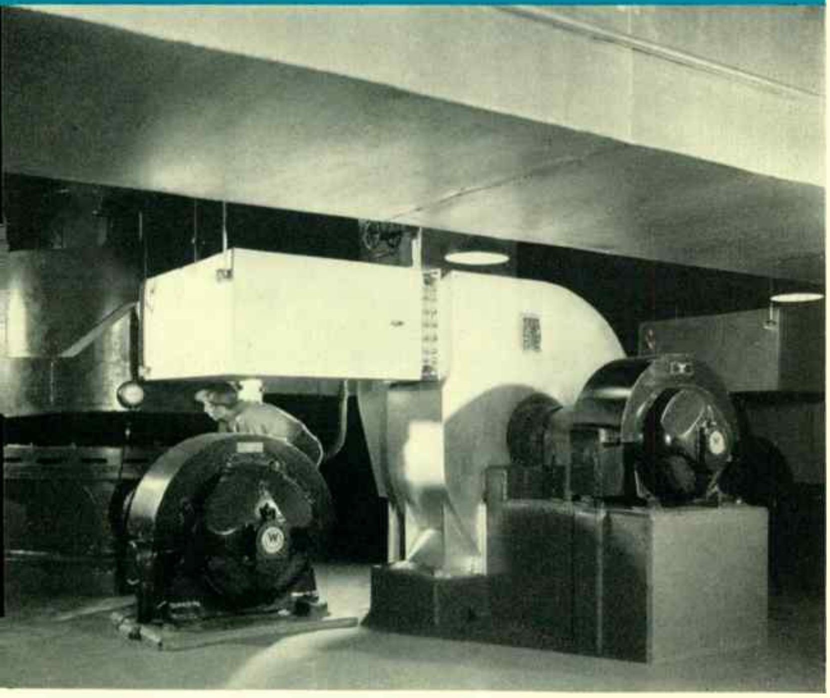
The need of a reliable source of auxiliary power is recognized easily; the length to which one may justifiably go in securing this reliability has never been clearly established. In the past ten years few separate generators have been installed for auxiliary service. The great majority of auxiliaries have been supplied through transformers connected to the main bus or to the generator leads. In the last year or two there has been some tendency to return to separate auxiliary generators, either driven by separate turbines or coupled to the main unit. This trend may have been due to recent system troubles in which the time of outage was lengthened by failure of the auxiliary supply.

At present auxiliaries are most commonly supplied through a single-bus radial-feeder system with sectionalized high- and low-voltage buses. Various switching arrangements are used to minimize the effect of a fault on any one part of the system, particularly those sections supplying essential motors.

The secondary network has been applied to power-plant auxiliary distribution* and is now being considered for several new stations. A network, although comparable in cost with the more dependable radial arrangements, offers greater reliability, improved regulation when starting large motors, and better flexibility of supply. Where there are motors larger than 1000 hp, it may be preferable to feed them from separate transformers at 2300 volts, and to supply the smaller auxiliaries from a 208- or 440-volt network system that is thus free from excessive voltage dips caused by starting large motors.

When a network distribution system is used, motors of as high as 600 hp can be supplied at the network voltage. This permits the use of lower-cost, low-voltage circuit breakers and may result in a single-voltage distribution system for stations of moderate size.

Pulverized coal is used to fire the boilers in this particular station: other plants use stoker-fired furnaces. Coal coming from a bunker is ground in the pulverizer at the left, then mixed with air and injected into the boiler. The primary air fan is at the right. Although mere dwarfs in comparison with other auxiliaries, these are just as essential.



Control and Protection of Auxiliaries

Control practice for powerhouse-auxiliary motors and circuits differs from industrial practice because greater continuity is required, and because fault currents are larger. When a fault occurs in a powerhouse, near the generator, there is less impedance to limit the short-circuit current than is present in an industrial plant, located away from the station, and separated from the generator by at least a transformer and a transmission line.

Primary Control Equipment—In most power stations (with radial distribution) motors up to 100 or 150 hp are supplied at 220, 440, or 550 volts. Magnetic starters and thermal circuit breakers are used where the calculated fault current does not exceed 10 000 amperes. Several related or non-essential motors may be grouped on a single feeder with a contactor for each motor and one circuit breaker of adequate interrupting capacity for the group. For motors of about 40 hp and larger and for all feeders where a fault at the motor terminals can exceed 10 000 amperes, the combined functions of motor starting and motor and circuit protection are performed by individual air circuit breakers designed for repetitive service.

Motors larger than 150 hp are usually supplied at 2300 volts from individual motor circuit breakers. In the last few years there has been a strong trend toward the use of metal-clad circuit breakers for this service, although oil breakers are also used.

Protection of Essential Auxiliaries—To minimize the possibility of even a few minutes' shutdown of any essential pump, fan, pulverizer, or stoker, motors are rated generously and the control is made as simple as possible. To eliminate interruptions caused by faulty or improperly applied relays, it is good practice to prevent these essential drives from being tripped automatically on overload. An alarm allows an operator to relieve the motor before it fails. In general, essential motors should not be allowed to lock out on low voltage. However, some means must be provided to prevent the introduction of pulverized fuel to the furnace after the fire has become unstable or gone out. This can be accomplished by a time-delay low-voltage relay that disconnects the pulverizers, primary air fans, and forced-draft fans, or else by relays operating on failure of draft or primary air pressure. Pumps and the induced-draft fans usually restart automatically on return of voltage because the motor feeder breakers are left closed or "latched-in" contactors are used. Short-circuit protection is provided by instantaneous trips on the feeder breakers and, on large motors, by differential relays.

Non-Essential Auxiliaries—On the essential drives, motor safety is sacrificed to achieve maximum continuity. On the other hand, protection of non-essential auxiliaries does not differ greatly from that of other industrial equipment, and a balance between continuity of service and protection of equipment is desired. Automatic overload and locked-rotor protection are usually provided by thermal relays which open the contactors or breakers. Undervoltage protection is desirable to prevent unsupervised restarting. Short-circuit protection is provided as on essential auxiliaries.

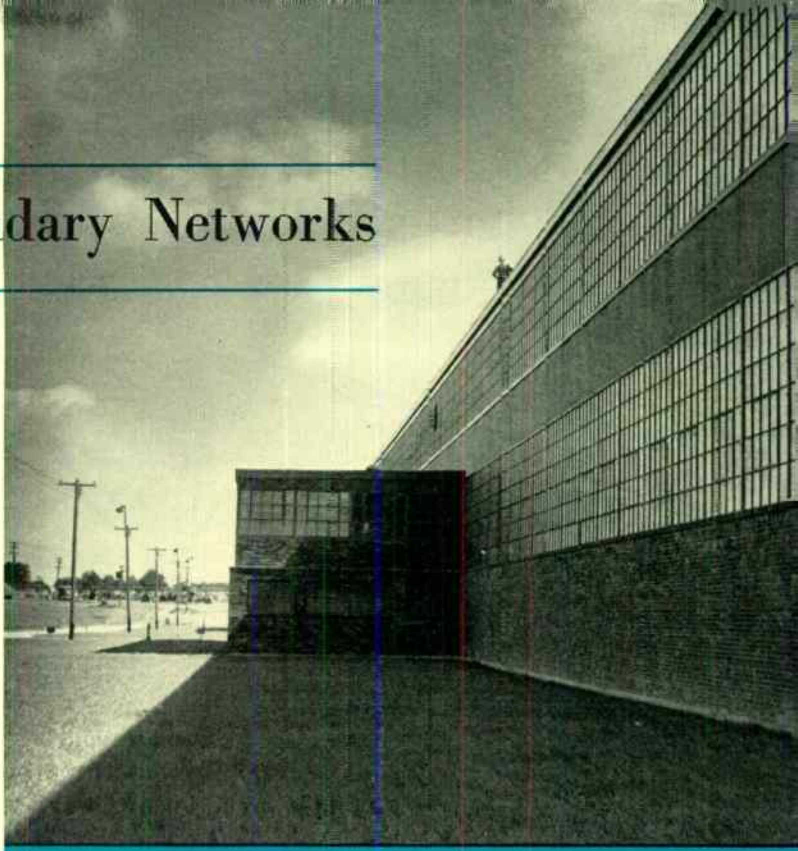
---

*"New Applications for Secondary Networks," John S. Parsons, *Westinghouse Engineer*, May, 1941, p. 24.

Industrial Plants Adopt Secondary Networks

Industrial plants have "discovered" the secondary network, used for twenty years with great success as the power-distribution system in large cities. The "discovery" could not have come at a more fortunate time, with the present emergency demanding extensions to old plants and new plants in which the power supply must have the utmost in reliability, be virtually sabotage proof, and be adaptable to changes. The secondary-network system readily fills these requirements.

JOHN S. PARSONS
Distribution Engineer,
Westinghouse
Elec. & Mfg. Co.



Power is distributed in the new naval ordnance plant at Canton, O., through a stoppage-proof secondary network.

THE a-c secondary network is the ideal type of distribution system for most industrial plants. Foremost among the merits that support this strong statement is the continuity of service inherent in the basic secondary network scheme. The network employs a common load circuit in the form of a grid or loop operating at utilization voltage, from which the loads are fed. This grid or loop is supplied over two or more primary feeders through network transformers, which are connected to the grid or loop through network protectors. The system is designed so that the entire load on the network can be carried with at least one primary feeder out of service. No single fault anywhere on the system, whether accidental or deliberate, will interrupt the service to more than a small part of the system load; most faults will be cleared without interrupting any load. In addition to service reliability, the secondary network system provides maximum flexibility that permits adapting the system to growing or changing load conditions at minimum cost and with minimum interference with the normal operation of the plant. It provides uniform and minimum voltage regulation that permits starting relatively large motors across the line at any point on the system, which often results in greater economy and simplification of motor controls. Its high efficiency materially reduces the cost of power losses in the lines.

Modifications Are Required for Industrial Use

The above advantages mean that the secondary network system gives the highest quality of service with a minimum of operating and maintenance expense. To make the initial investment in a network system compare favorably with that of competing systems used in industrial plants it is necessary to make certain modifications in the usual form of a-c secondary network. The network system as applied to metropolitan distribution for many years is designed so that peak load can be carried with at least one primary feeder out of service without overloading any part of the system. Since it is usually unnecessary and often impractical to have more than two primary feeders supply an industrial plant, one hundred per cent spare transformer capacity would be required if the usual form of secondary network were used. The investment in such a two-feeder network system would in most cases be out of proportion to the advantages derived and would be much greater than the investment in radial-feeder systems usually used in industrial plants.

To eliminate this excessive amount of spare transformer capacity and reduce its cost materially, the a-c secondary network system has been modified for industrial plant applications as shown in Fig. 1. A double-throw primary switch is used with each network transformer and the primary feeders are so arranged that any transformer can be connected to either of the two feeders. Normally half of the network transformers are connected to each feeder. When a fault occurs on one of the primary feeders the faulty feeder is automatically disconnected from the system, without any interruption to service, by the tripping of the circuit breaker at its supply end and by the tripping of all network protectors in the secondary leads of network transformers connected to the faulty feeder. This leaves the entire system load supplied over one primary feeder and through half the network transformers. Under this condition the regulation is about twice normal and the transformers remaining in service are loaded to nearly 200 per cent until the transformers associated with the faulty feeder are manually switched to the good feeder. It should be possible to complete this switching operation in 45 minutes or less. The inherent thermal capacity of network transformers is such that this is fast enough to prevent damaging the overloaded transformers. After this manual switching operation is completed, all transformers again carry normal load and almost normal voltage conditions are restored. This switching operation could be performed automatically as the result of loss of voltage at the primary switches. The thermal capacity of the network transformers makes automatic switching unnecessary, and the convenience resulting from its use does not justify the resulting complication and expense except in a few unusual cases.

When one primary feeder is out of service, the entire plant load is carried over the other primary feeder. Each feeder must have sufficient capacity to supply the peak load. After the fault has been located and repaired, the feeder can be put back into service by closing the circuit breaker at its supply end and by reconnecting the network transformers normally connected to it by manually operating the double-throw primary switches. To prevent these double-throw primary switches from opening load current, each switch is electrically interlocked with the associated network protector so that it cannot be operated unless the network protector is open. The switch must be capable of interrupting the exciting current of the transformer as the transformer is disconnected from its temporary feeder and returned to its normal feeder after the feeder has been out of service. Without such capacity the plant would have to be shut down after each such switching operation.

Obviously in large plants more than one primary feeder is required to carry the load and instead of having two feeders as shown in Fig. 1, the number of feeders required to carry the load plus one should be used. The additional feeder permits operation of the system without overloading the primary circuits when one feeder is out of service either because of a fault, for plant extension, or for maintenance. About the same transformer capacity should be connected to each feeder under both normal conditions and with one feeder disconnected. For example, in a system having three primary feeders, the normal supply should be feeder No. 1 for the first transformer, feeder No. 2 for the second, feeder No. 3 for the third, feeder No. 1 for the fourth, and so on. The emergency supply for the first transformer connected to feeder No. 1 should be feeder No. 2; for the second transformer connected to feeder No. 1 it should be feeder No. 3; etc. The larger the number of primary feeders used, the less the percentage of transformers that must be switched when a primary feeder is disconnected. Likewise, until the switching operation is completed, the per cent overload caused by the transformers connected to the feeders remaining in service decreases as the number of feeders increases. For example, with a three-feeder supply it is necessary to switch about one-third of the transformers when one of three feeders goes out of service, and the transformers normally connected to the good feeders carry about 150 per cent load until the switching operation is completed. With a four-feeder supply only about one-fourth of the transformers must be switched and the temporary load is only about 133 per cent.

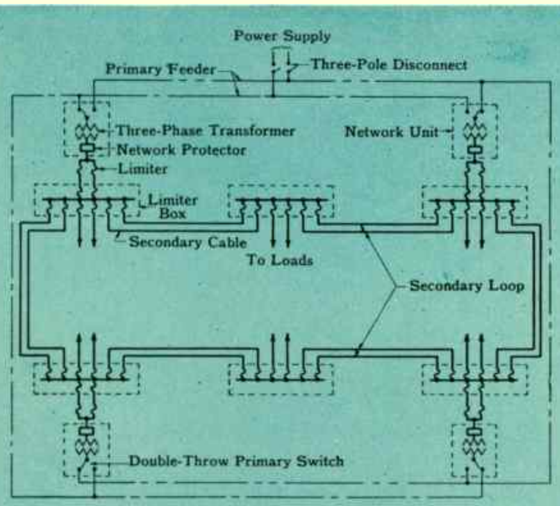


Fig. 1—*Single-line diagram of an industrial-plant network supplied by two primary feeders.*

In the secondary-network system for city distribution, the secondary circuits from which the loads are tapped usually form a grid or mesh with the cables surrounding each city block and tied together at each street intersection. For industrial-plant applications a loop secondary as shown in Fig. 1 is usually preferable. The use of a grid or of cross ties often causes one or two of the transformers to carry more overload than the others until the transformers associated with the faulty feeder can be switched to the one remaining in service. The most important reason for using a secondary loop, however, is to limit the short-circuit currents caused by faults on the secondary circuits, particularly where the load density is high. When the size and arrangement of the plant are such that one secondary loop is inadequate, several loops, all supplied over the same primary feeders, should be employed. In some cases it is possible to save sufficient transformer capacity to justify cable ties between loops. However, it is usually advisable to design the system with each secondary loop as an independent unit.

Limiters Provide Cable Protection

Faults on the cables of the secondary loop are cleared, without any interruption to service, by means of limiters located in each end of each secondary cable. Limiters are specially designed, completely enclosed copper fuses, having high interrupting capacity, and protect only against short-circuits. Limiters have been used for more than five years in the 120/208-volt secondary mains of a number of secondary-network systems; most city network systems, however, are designed to burn off secondary cable faults. Networks for industrial plants where the secondary voltage is 120/208 could also be designed without limiters. However, because of the disturbance that may result while some faults are burning clear, limiters should always be used if the network is located in a building, such as an industrial plant, to insure quick and complete clearing of all secondary cable faults with little or no disturbance. If the voltage of the secondary loop or grid is above 250, and a large number of industrial plants do use 460 volts, limiters are essential as faults at these higher voltages cannot be depended upon to burn clear.

The limiters in a faulty cable usually blow with so little disturbance that they give no indication that a fault has occurred. Increased voltage regulation at certain loads may indicate that a section of cable is out, but usually the voltage is not noticeably affected. An annual check of all cable sections in the loop with a clip-on or tong-type ammeter readily shows a cable that carries no current. If the corresponding cable in the parallel section of the loop carries current, this is an indication that the cable has failed and its limiters have blown. Occasionally voltage conditions are such that no cur-

The Battle of the Substitutes

The admonition, "accept no substitute," has for the duration gone by the board. The problem of the designer now is: what can be substituted for priority materials without affecting usefulness of the product? He defends first of all the quality of his creations, but he may have to give some ground on weight, cost, or looks. The experiences of the appliance engineer are typical because his problems run the gamut of strength, weight, appearance, and cost—and he has few priority ratings to help him.

W. M. LAYTON
Materials Engineer,
Appliance Division,
Westinghouse Elec. & Mfg. Co.

MANUFACTURERS of appliances for the home, not long ago the mainstay of the era of electrical living, find these times trying and difficult. Metals and materials are scarce. We are in for a period of production curtailment by government fiat. We have had to make frantic efforts to find substitutes for substitutes, to keep even the production we are permitted. Thus far well over a hundred substitutions have been or are being made in the Westinghouse plants manufacturing home appliances and air-conditioning equipment—and the end is not yet in view.

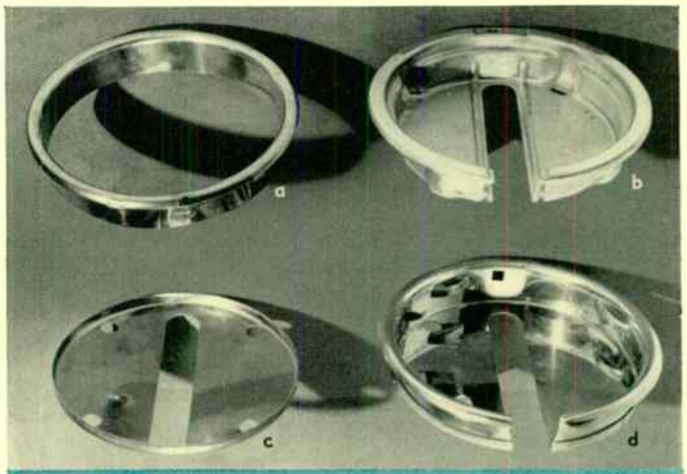
Headaches these are, to be sure, BUT—when we pause to consider the ultimate purpose of all these drastic steps to control and preserve our material resources, and we realize the mighty headache we, and all democracy, will have forced upon us if our materials for defense prove to be insufficient, our substitution troubles become insignificant.

Faced with the loss of a material, the engineer sometimes finds that his problem is simply one of using a substitute material with little or no change in design or manufacturing procedure. In some cases by a change in design or by dusting off an old construction technique, another material can be used with substantially similar results. Then occasionally the material can simply be omitted. For example, designs have been worked out for electric ranges, which have as usual the attractive chrome trim. However, if chromium becomes wholly unobtainable the bright metal can simply be left off. The recess it leaves can be easily enameled in a bright attractive color. There has been little, if any, sacrifice in appearance and none in the usefulness of the range, and because the change is anticipated the extra manufacturing cost is held in check. The engineer has devised many tricks of this sort but because the materials themselves are of greatest interest this discussion will be confined to substitution only.

Aluminum Has Been the Major Problem

The first request of O.P.M., when G.P.O. No. M-1 was issued, was for all manufacturers of mechanical refrigerators to supply only one aluminum ice-cube tray with a refrigerator, and to substitute some other more plentiful material for the others. Steps were immediately taken to substitute molded rubber trays for the prohibited aluminum ones. Rubber had already been proved a success in ice-tray application, so this change was made easily with little sacrifice, except possibly in life. Rubber, too, has been placed under full control by G.P.O. No. M-15 and may become too scarce for use as ice trays. Engineers are now working on a substitute for rubber and the early indications are that, should another change be necessary, it can be made without serious inconvenience to builder or user.

For roaster covers, an application requiring a material with non-corrosive, non-toxic properties and one remaining strong at high temperatures, the engineers first decided, after extensive tests, to substitute a chrome-plated steel containing 16 to 18 per cent chromium. However, feeling that chromium would more than likely go under full priority control at some future time, tests were made on covers of nickel- and chrome-plated red brass, which proved the suitability of the reserve substitution. Chromium, zinc, and copper are now under priority control, and nickel for plating is becoming scarce. The last resort is vitreous-enameled iron, a good substitute with the minor disadvantage of increased weight. Fortunately for the engineer in the present emergency, vitreous-enameled iron has greatly improved as a material in the last few years. Its resistance to chip has been greatly increased by improved processes, and its cost has been reduced by the use of ultra-modern manufacturing methods.



Substituting one material for another sometimes requires change in design, as for this broiler pan for an electric range. Instead of the pan deep drawn from aluminum as (b), it is made of two chrome-steel parts. A side ring (a) is rolled into shape and end-welded. It is then welded to the stamped bottom enclosure (c). The pan is placed in a die and the slot in the bottom extended through the side ring. The finished substitute for (a) is shown at (d).

It has been a life saver in this and many other appliance applications, because, where usable at all, it results in no depreciation in quality. Such reappearances of vitreous-enameled ware in place of aluminum include the broiler pan for electric ranges and the insert vessel in the deep-well cooker.

For waffle-iron grids, the only logical substitute is cast iron. Most people still remember the days of the cast-iron waffle grids when mothers baked waffles over wood- or coal-burning ranges. The irons used in those days were of cast iron, and although slightly heavier, the results, you will admit, were very satisfactory.

The manufacturers of molded materials have, for several years, worked on the development of a plastic suitable for application in the agitators of washing machines. Probably this was not done in anticipation of the present-day aluminum shortage; it has nevertheless relieved washing-machine manufacturers of one very serious problem, because a plastic is now available that offers a perfect substitute for the aluminum for agitators. Plastics also have been substituted for parts subjected to corrosion but not to high mechanical stresses, such as the pump body and the pump hub. Washing-machine engineers have their fingers crossed lest plastics become scarce.

Several substitute materials were considered for the die-cast aluminum parts used extensively in the mechanism of the automatic washing machine. Brass, cast in plaster-of-Paris molds, was adopted for those parts subjected to high mechanical stresses and to the corrosive action of the wash water. Among them are the attachment ring and ring gear.

Some substitutions have required redesign of the parts to some extent. In some instances complete redesigns were mandatory. The pump impeller, originally an aluminum die casting, has been redesigned to use sheet copper.

Substitutions Have Been Made for Zinc

Zinc die castings are commonly employed in the design of appliances for parts where stresses are not excessive and where the parts are not subjected to corrosive conditions. For the idler pulley and pump pulley of the automatic washer, pulleys machined from steel-bar stock have been substituted. The ring gear and shift ring will be made from brass, cast in plaster-of-Paris molds. The damper shoe will be molded in rubber, and the tub-door handle will become a plastic. Here again the changes have no bearing on the ability of the machine to do its job. They have meant some trifling weight additions and some greater manufacturing expense.

> *"The engineer has learned that to be prepared for any eventuality he must find a substitute, and then quickly develop a substitute for the substitute; also that there is no universal substitute for any material."*

Nickel, Chromium, and Nickel-Chromium Alloys Are Tough to Replace

Nickel or chromium, or both, are the main constituents of alloys used for high-temperature service, and are practically mandatory for applications where the temperature exceeds 1000°F. These two metals, because they impart strength to their alloys, are essential constituents of spring materials for applications at temperatures above 500°F.

It can readily be understood what a headache the electric-heating appliance engineer had when G.P.O. No. M-5, placing nickel on mandatory priority, was issued. And it can be even more readily perceived what a severe headache occurred when G.P.O. No. M-18, placing chromium in the same category, was issued.

The most important metals to the appliance engineer are the nickel-chromium and the nickel-chromium-iron alloys used for the resistance wires of the heating elements of appliances. The first named is composed of 80 per cent nickel and 20 per cent chromium, and is the highest-grade resistance alloy used for this application. It is absolutely essential for the reliable performance of those heating appliances with elements that operate at temperatures higher than 1700°F. There is no practical substitute for this grade of resistance alloy, and its non-availability would create an unsurmountable obstacle to the production of electric-heating appliances.

The second grade of resistance material is the 60 per cent nickel, 15 per cent chromium, 25 per cent iron alloy, used for certain heating appliances where the operating temperature does not exceed about 1600°F.

There are several other lower grades of resistance alloys, but they are relatively unimportant. There are no proved substitutes available for any of these materials.

Other nickel alloys extremely important to the electrical appliance industry include the nickel steels and the nickel-chromium steels used as the component parts of thermostatic metals. These so-called "bimetals" have played a great part in the convenience, reliability, and safety of the present-day household appliances, and their scarcity would greatly handicap the engineers in their endeavor to meet the needs of the modern housewife.

Nickel, or chromium, or both, are practically essential components of the alloys used in bimetals, because of the rather high temperature requirements, and, also, because they impart the proper thermal expansion properties to the alloys.

Another important application of nickel-chromium-iron alloys, such as the standard 18 per cent chromium, 8 per cent nickel steel (commonly called 18 and 8 stainless steel), is for springs that are, of necessity, stressed at operating temperatures above 400°F. There are several other less common high-temperature spring alloys, but all of them contain either nickel or chromium, or both.

An application for nickel-chromium-iron alloys that is also important, and which, in the past few years, has consumed a large amount of nickel and chromium is the top, or surface, heating unit of the electric range. The sheathing, or tubing, material of this unit attains a temperature as high as 1600°F under some operating conditions, and, therefore, must be made of a metal having good thermal conductivity, high strength and oxidation resistance at high temperatures, and rust resistance. The metal must also have good mechanical fabrication properties, first in the welding of the strip to form the tubing, and again in the swagging, bending and flattening of the tubing after the resistance coil and magnesium-oxide insulation have been placed in the tubes. The alloy best suited to this application is, essentially, a high-nickel stainless steel with silicon and columbium.

> *" . . . these drastic steps to control and preserve our material resources have caused many headaches, but when we realize the mighty headache we, and all democracy, will have forced upon us if our materials for defense prove to be insufficient, our substitution troubles become insignificant."*

When G.P.O. No. M-5, placing nickel under priority control, was announced, attention was turned to an investigation of the possibilities of substituting a steel alloyed only with chromium. Previous investigations, conducted when the tubular range unit was being developed, had indicated that a chrome steel with a chromium content above 20 per cent would be just as satisfactory, if not more so from a service standpoint, as the present nickel-steel alloy. The only difficulty experienced at that time was in the mechanical fabrication of the tubing, both at the time of welding the strip into a tube and during the processing of the tubing into the heating unit. Chrome steel does not have the welding properties or the ductility of the nickel-steel alloys.

With the issuance of G.P.O. No. M-18, placing chromium under priority control, the headaches have started all over again. However, after going through the trying experiences of finding substitutes for aluminum, zinc and nickel, the engineers are certain they can, in most cases, and especially in the case of range heating units, find a substitute for chromium. They are already well along in the development of electric-range units, in the manufacture of which little, if any, critical materials will be used.

An important adjunct to the tubular heating element described above is the metal pan that supports it and also acts as a drip tray. This pan, at the time previous to that of material scarcity, was made from 18 and 8 stainless steel, an ideal metal for this application. When nickel became scarce, the first consideration, as in the case of the heating-element sheath material, was directed toward chrome steel as a substitute.

Chrome steel of the 16–18 per cent grade had been investigated for the pan during the development of the tubular heating unit, but it was not sufficiently ductile to permit the severe deep-drawing operation necessary in forming the pan. The only recourse was a rather novel scheme in which the pan is made up of a welded assembly of two individually fabricated parts, neither one of which requires an extremely ductile material. This is shown on p. 91 and illustrates the radical changes that have been necessary in some cases. The substitute design obviously costs more but from the point of view of service is the equal of its predecessor.

When chrome steel becomes no longer available, the next substitute material for these heater pans will be, most probably, vitreous-enameled iron. This material has been used successfully for this part in years past.

Space does not permit details of possible substitutes for copper, brass, and other copper alloys. With aluminum, nickel and chromium practically out of the picture, the only possible substitute becomes iron or steel. Vitreous enamel will be used as a protective finish over the iron whenever possible. If copper becomes so scarce as to make necessary its elimination, it will be extremely difficult to maintain the present high quality of appliance attachment cords.

Some substitutions have already gone into effect, and others merely await the depletion of the stocks of the standard material. Some proposed substitutions may become ancient history overnight, because of the rapidly changing material situation. The engineer has learned that to be prepared for any eventuality he must first find a substitute and then quickly develop a substitute for the substitute; also, that there is no universal substitute for any material. In all cases the engineer's main objective has been throughout all these changes to uphold quality. It can be said at this point without fear of contradiction that there has been no lessening of the fundamental worth of the products; they do their work just as well and with the same saving of effort as before. In almost no case is appearance inferior. This much is certain, that, when the task of making this a world of free men is done, many of the lessons learned in these trying problems of materials will be put to good use to accelerate at even greater rate the development of more and better time- and labor-saving devices.

Auxiliaries at the Windsor station of the West Penn Power Company are controlled by this new 460-volt metal-enclosed switch-gear. Each of its three sections has a 4000-ampere main breaker, a 3000-ampere tie breaker, and twenty 1200-ampere feeder breakers.

What's New!

Boric-Acid Fuse Limits Short-Circuit Current

POTENTIAL-TRANSFORMER fuses should work in both directions—they should safeguard the system to which the transformer is connected, and they should protect the transformer itself. A new boric-acid De-ion fuse provides this complete protection by combining the functions of a fuse and a current-limiting resistor in a novel three-element device, obviating the use of a separate fuse with external resistors.

The new fuse clears a faulty transformer from the line in the shortest possible time; at the same time, the current input to the fault is limited, to reduce the violence of the fault and keep it from spreading to adjacent equipment. The current is limited also to prevent the relays connected to the bus from operating other protective devices unnecessarily. A major advantage of the new fuse is that it limits, during current interruption, the voltage surges caused by the release of magnetic energy stored in the circuit. In addition, the unique main fuse element does not blow on magnetizing inrush currents, but does blow rapidly enough to prevent a transformer with a short-circuited secondary or partial winding fault from producing an excessive amount of conducting and inflammable gases.

A new type boric-acid fuse eliminates the need for external current-limiting resistors, providing compact protection for potential transformers, especially in metal-clad switchgear.

The new fuse consists of three parts: (a) The main interrupting element operates in a small hole through solid boric acid. The arc caused by a short circuit dehydrates the boric acid and is extinguished by the steam thus generated. (b) The current-limiting element consists of a silver fuse wire spirally wound on a fibre tube. (c) The voltage-limiting element is a silicon-carbide rod in parallel with the current-limiting element. It acts as a lightning arrester to limit the surge in the current-limiting element to a voltage slightly higher than normal in the system.

The fuse has a continuous rating of 0.5 ampere at voltages between 2500 and 23 000. At 15 kv its current-interrupting capacity is 120 000 amperes, and interruption is complete within one-half cycle. Less space is required for the new fuse mounting than for the conventional fuse-resistor combination, because the external resistor is omitted; this advantage is useful in enclosed switchgear where space is limited. Emitting no flame, metallic parts, or ionized gases, the fuse is noiseless and smokeless in operation.

Thermoset, Tough Guy of Insulating Varnishes

A CAKE with icing illustrates the different effects that baking has on various insulation varnishes. Placed in a hot oven, the icing will melt, but the cake will harden. Thermoset, a new synthetic varnish that hardens by gelling, or heat reaction, is of the obviously superior "cake" type. This new varnish permits "all through" drying even in thick films and deep-seated parts of coils and windings. Once this varnish has set up, it does not resoften in service. Initial dips or impregnations need not be thoroughly dried out, as the final baking will complete the cure of the earlier treatments and at the same time complete the final treatment.

This curing characteristic is of great importance in the production of high-quality windings. It permits the use of partially cured coils so that they can be wound while in a flexible state. The complete cure of the varnish in the deep-seated parts of the winding can then be accomplished by the final bake when the last treatments are applied. Thermoset also affords excellent filling of insulation interstices and can therefore be used for impregnation under pressure and at low solvent content, thus accelerating the drying time.

The excellent interstice-filling and hardening characteristics of Thermoset varnish coupled with the good cementing power produce a sturdy, solid coil construction. This makes a stronger and more compact winding, thereby minimizing the destructive effect of vibration. It also allows better heat flow to the coil surface.

In addition to its filling and hardening characteristics, Thermoset surpasses most varnishes in resistance to effects of moisture, oil, and

Adjusting the filaments in a new 16-inch searchlight designed primarily for marine work and other long-range spotlighting.

corrosive atmospheres. A three-week shower bath, simulating several years' rainy-weather service, had little effect on the mechanical and dielectric strength of Thermoset-impregnated coils. Tests have also disclosed a high resistance to oil and to weak acid and alkalies—the most frequently found ingredients in the air of industrial areas. Finally, Thermoset hardens with a tough resilient surface film surrounding a softer internal structure, making it suitable for insulating coils that are subject to vibration and repeated expansion and contraction, as in machines with frequent and severe duty cycles.

New Sun Lamp with Built-in Reflector

A new sun lamp (Westinghouse Mazda RS) operates directly from an ordinary lighting circuit without an auxiliary transformer or ballast. It is completely self-contained, with a reflecting surface coated on the inside of the bulb where it is protected from corrosion and dust so that the lamp maintains a high output throughout life.

The conventional auxiliary ballast is replaced by a filament resistance mounted inside the glass bulb and a starting electrode in the inner quartz tube. The starting electrode is in series with the filament resistance. A thermal switch mounted next to the resistance filament allows the starting electrode in the quartz tube to heat. As soon as the filament and starting electrode are heated, the thermal switch opens and the mercury arc starts.

Use of the built-in resistance filament makes it possible for the lamp to produce infrared radiation as well as ultraviolet to approximate the quality of sunlight. Consuming 275 watts, its erythemal—or sun-tanning—energy is approximately 360 microwatts per second per square inch, if used at a distance of two feet. This means that a person "sun-bathing" two feet away from this lamp receives about three times the tanning energy afforded on a beach by the July sun.

Fan Supplies Air to Cool Own Motor

Exit another familiar figure on deck of ships—the blower motor. Instead of protruding from the end of the ventilator and occupying valuable deck space, a newly developed motor for axial-flow fans now fits inside the duct. Moreover, the very air displaced by the fan is passed over the motor to cool it, resulting in more efficient ventilation. Thus the motor used can be smaller than previously; without this cooling air flow the motor would have to be about three times larger.

The motor frame serves a double purpose. First, it supports and centers the motor in the duct. Second, the supports are shaped like air-foil vanes, straightening the air flow in the duct. This lessens the turbulence in the air, resulting in higher efficiency and quieter operation of the blower. In fact, the overall efficiency of the ventilating system is raised about one-sixth, and at the same time the noise level is reduced by about one-quarter. Further increase in efficiency is obtained by careful attention to details, such as bringing the motor leads and grease pipes through one of the vanes, thus eliminating an obstruction that often causes increased losses and excessive noise.

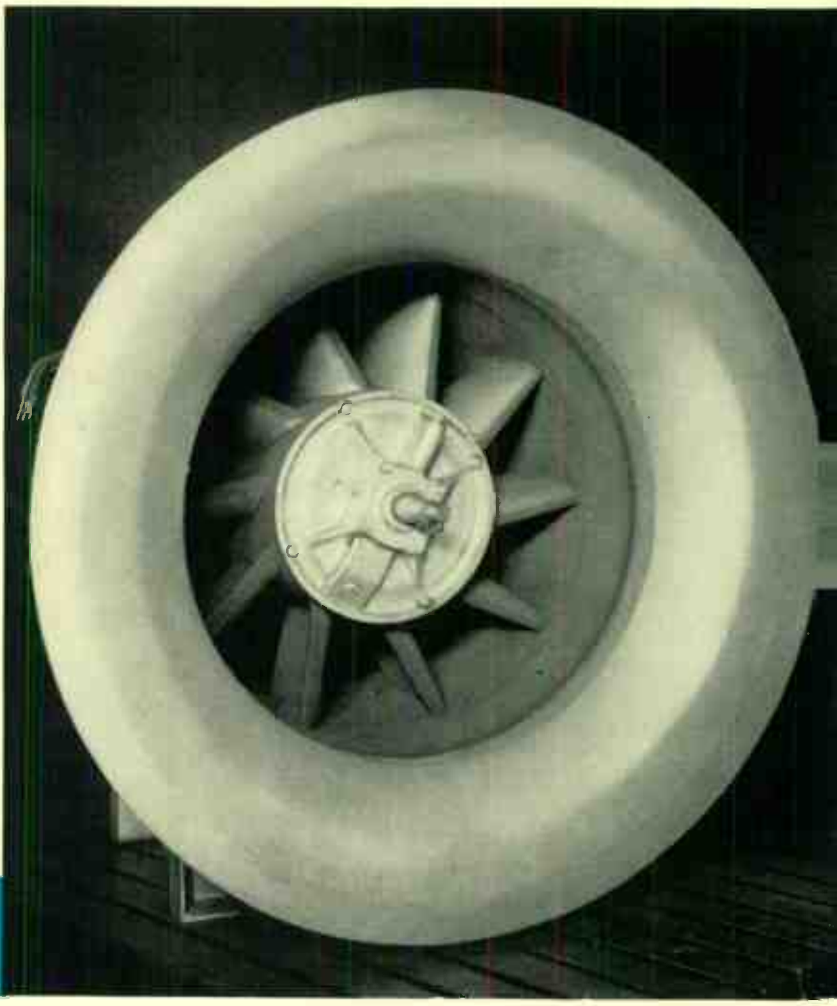
Dynamic Balancing at Low Speeds

The conventional equipment for balancing rotating machines in their own pedestals has been previously limited to equipment rotating at above 600 rpm. Yet many electrical machines, particularly water-wheel and Diesel-driven generators, operate at speeds as low as 100 rpm. These can now be balanced with standard portable balancing equipment (Westinghouse type HQ), by means of a new pick-up that extends the balancing range down to 100 rpm.

To balance rotating machines in their own mounting, and under operating conditions, it is customary to resort to a scheme in which a wattmeter is used to measure both the magnitude and the phase angle of the vibrations caused by unbalance in the rotor. A pick-up held against the frame of the machine translates the vibrations into voltages that are impressed on the potential coil of the wattmeter. The current coil is energized from a sine-wave generator coupled to the rotor being balanced. The phase angle between the current and the voltage in the wattmeter can be made to equal 90 degrees and its indication made to equal zero by rotating the stator of the sine-wave generator. This position is a measure of the phase angle of the unbalance vibration. Shifting the phase of the generator 90 degrees from this zero position gives a maximum reading in the wattmeter. This reading is a measure of the amplitude of the vibrations. With the magnitude and phase angle of the unbalance vibration known, it is relatively easy to compute the proper balancing weights.

The difficulty with low-speed balancing has been that a pick-up capable of measuring vibrations of low frequencies must have much lower natural frequencies than the vibrations measured. To furnish correct indication, a vibration pick-up and its mounting should have a natural frequency of no more than one-half the frequency of vibration of the machine to be balanced. Thus for a 100-rpm generator, for example, the natural frequency of the pick-up must be not more than 50 cycles per minute. To get a body with such a low frequency has heretofore meant the use of large masses, making the instrument unwieldy.

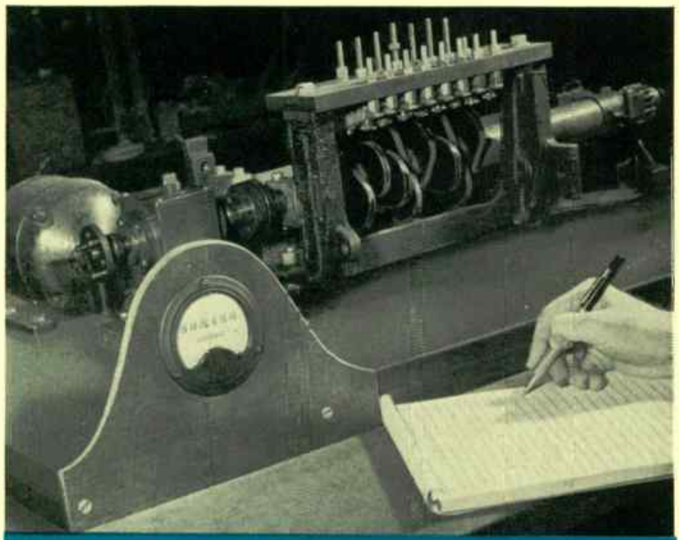
The new pick-up employs something like an inverted pendulum. The frequency of an ordinary pendulum, operated by gravity, can be lowered by lengthening its arm—the way a grandfather's clock is regulated. Similarly, the natural frequency of an inverted pendulum can be made extremely low by weakening the restoring springs so that it is barely stable in a vertical position. To permit the use of this pick-up in all directions, the effect of gravity has been eliminated by



"If you can't beat them, join them." The temperature rise in a fan motor cannot be prevented, but the air displaced by the fan can be drawn over the motor and made to carry the heat away.

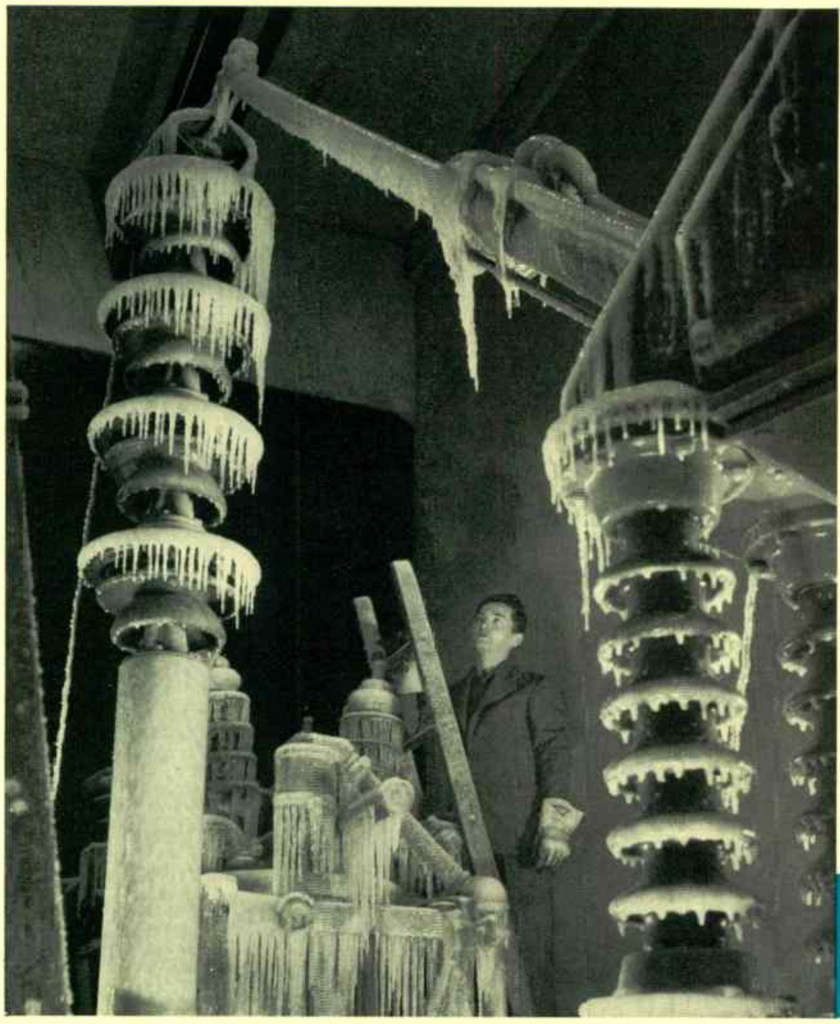
laying the pendulum on its side, and the force previously supplied by gravity is furnished by a toggle-like spring mechanism.

Used in connection with a conventional sine-wave generator and portable balancing equipment, the pick-up readily indicates vibrations of double amplitude as low as 0.003 inch at 100 rpm.



The small dial in the foreground is that of a new total hour meter that shows elapsed time up to 100 000 hours (more than eleven years) in 0.1-hour steps. It consists of a small synchronous clock geared to a cyclometer dial, and can be used for a large variety of life tests of many machines and parts.

Vibration pick-up for balancing low-speed rotors.



A compressed-air circuit breaker being tested at –10 deg. F.

Tests at Subzero Temperatures

THE New York blizzard of 1888 would have been an excellent occasion to test circuit breakers for satisfactory sub-zero operation—but it is not advisable to depend on the weatherman in even less important matters. To make sure that circuit breakers and other outdoor equipment will operate when all else freezes over, a new refrigerated laboratory at the Westinghouse East Pittsburgh Works permits mid-summer testing at temperatures as low as —20°F. In it can be tested not only the effects of cold weather on the oil, lubricants, and stiffness of the mechanical linkages, but also on the ability of the operating mechanism to break a heavy coating of ice.

To insulate this laboratory, which has a floor area 12 by 30 feet and is 25 feet high, the sides, top, and bottom are lined with 6 inches of cork. The floor is also lined with cork, but to support the devices tested, the cork is covered with three inches of concrete. The room has what are probably the largest refrigerator doors in existence, each measuring 25 by 6 feet. Two small doors, which latch from the inside only, are also provided so that a person cannot accidentally shut himself inside.

A railroad track runs into the room so that large circuit breakers may be taken directly to the test floor and unloaded by a crane from the car. To operate the circuit breakers under load, the room is equipped with high-voltage terminals. Three openings in the side of the room are fitted with insulated doors through which heavy leads for testing high-current apparatus may be brought in.

The room is cooled by means of an ammonia refrigerator that has a capacity of eight tons at room temperature and three tons at −20°F. Usually 36 hours are required for the room to undergo the large temperature drop from the high summer eighties of the outside air to the test temperature of 20°F below zero.

PERSONALITY PROFILES

For a man who has lived and worked 400 miles from salt water, *J. C. FINK* has had a lot to do with ships, both naval and merchant marine, that ply the oceans. In the thirteen years he has been with Westinghouse since he graduated from Penn State he has helped apply electrical equipment on dozens of new vessels. In addition to several battlewagons for Uncle Sam and a number of Coast Guard vessels, the list runs the gamut from ocean greyhounds like the Coolidge, the Washington, and the Manhattan, to ships requiring very special drive and auxiliaries, such as the Tuna Clipper and ice breakers. At first glance this might seem like strange qualification for one writing on wind-tunnel drives, but this is more apparent than real, for his marine work has taken him into the complexities of transient conditions in maneuvering vessels and in the associated propeller characteristics. Ship propellers and fans differ in what they displace, not in fundamental characteristics. Actually, his wind-tunnel experience has been varied. He has assisted with the drives for the 2000-hp tunnel at Langley Field, the one at Washington University, the Wright Field tunnel, and the one still on the drafting boards for Ames Laboratory, California Fink, when he can find any time for relaxation in these days of rush, loses himself in his excellent library of symphonic and classical records or whips out a mean concerto on the violin himself.

L. A. KILGORE is building motors to make winds that put even a tornado of his native Nebraska to shame. As head of the Westinghouse engineering section that designs large alternating-current motors he has had much experience building drives for wind tunnels —but the present 40 000-hp motor for Wright Field tops them all. His first degree, B.S. in Electrical Engineering, was obtained from the University of Nebraska in 1927. He has since added an M.S. from University of Pittsburgh, and an E.E. from his alma mater. He has been concerned with building "big stuff" ever since he finished his student apprenticeship at Westinghouse in 1928: big turbine-generators, rectifiers, electric couplings, and now large motors. The intricacies of the many machine reactances hold no terror for him; in fact he has presented various papers on this subject, calculation of reactance, effects of saturation, etc., to the profession. In his time off he takes a busman's holiday by teaching design courses in the University of Pittsburgh graduate school.

FRANK T. CHESNUT refers to himself as a "degenerate engineer"; possibly he was so dubbed by some lawyer, who had every reason to object to an engineer becoming a patent attorney without the benefit of the usual law courses. For the secretary and patent attorney of the Ajax Electrothermic Corporation is not merely a graduate EE (Maryland '24—Princeton '26), but has also acquired a rich engineering and research background before coming, in 1928, to assist Dr. Northrup with his induction furnaces. He has been a commercial radio operator, has done radium research for the U. S. Bureau of Standards, has held a Munn Fellowship at Princeton studying electron theory under K. T. Compton—he's been around. In 1930 he installed the first commercial coreless induction furnace in Japan, and judging from the quality of the Japanese landscape photographs that adorn the walls of his office, he is a pronounced success in his hobby, too.

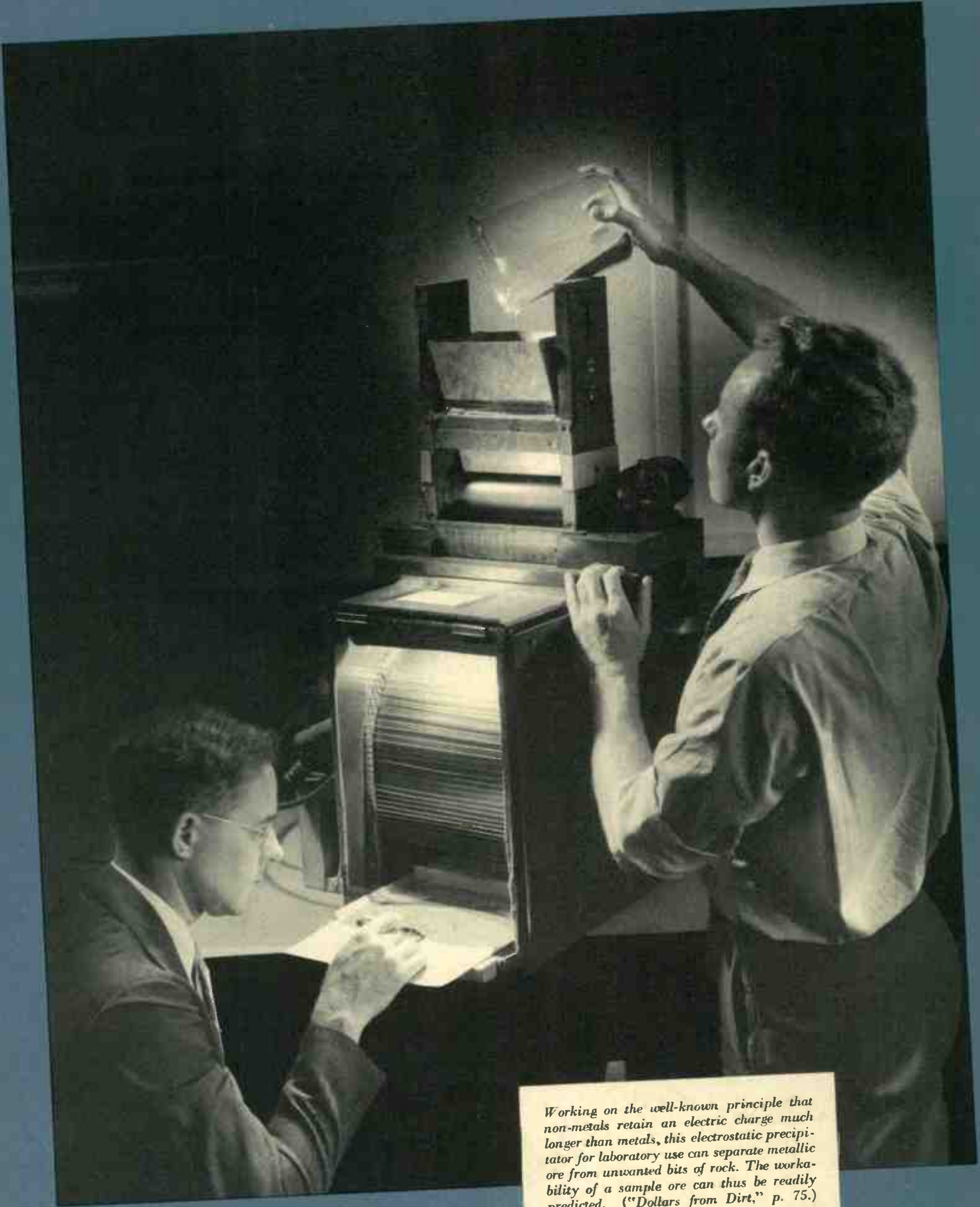
W. M. LAYTON has made it his business for years to know engineering materials. Even before the era of priorities, this has been absorbing work because of the rapid development of wholly new materials. A student of electrical engineering at the University of South Carolina, from which he was graduated in 1917, Layton joined Westinghouse and studied under B. G. Lamme in the Westinghouse engineering school. He then began to specialize in materials and manufacturing processes and is now head of that engineering group at the Appliance Division. There he not only is concerned with the materials of which electrical appliances are made, but also must keep close tab on all patents that are granted on the subject, and study the kindred work done in other lands. Although he is reticent as to his extracurricular activities, his friends report he has a fine collection of symphonic recordings, and indulges in amateur dramatics.

J. R. McCLAIN is Materials and Process Engineer at the Sharon Works of the Westinghouse Company. In this position he is charged with developing new processes or modifying old ones in the manufacture and improvement of the plant's product—mostly transformers and their component parts. Although he completed the Westinghouse Engineering Training Course after Carnegie Tech granted him his E.E. degree in 1910, his experience in materials and processes was not confined to that one company, as he also held engineering posts with the New York State Railway of Rochester and the Pittsburgh Testing Laboratories. And that he—like almost everybody described on this page—could not go through life without obtaining several patents and writing a few technical articles should be taken for granted.

Webster defines "auxiliary" as "conferring aid or help," and for the past two years *J. C. CUNNINGHAM* has been taking this definition seriously. His job is to confer with construction engineers and to aid them in the selection of motors and controls for their power-plant auxiliaries. He began to learn all about his work in 1935, when he entered the Motor Division, shortly after coming to the Westinghouse Student Course from Purdue. Four years later he was transferred to his present position in the Central Station Engineering Department. His duties require extensive travel, preparation of voluminous reports, and frequent lectures. He is not, however, like a postman on his day off—there is no auxiliary motor on the canoe he sails in his spare time.

DR. F. L. WATTENDORF has had long experience with wind tunnels before his intimate association with the planning of the new tunnel at Wright Field, Dayton. For example, in 1937 he designed and supervised the erection of a 15-foot wind tunnel at Tsing Hua, China (which, unfortunately, made too conspicuous a target for a bomb from a Japanese plane). Dr. Wattendorf is the author of many articles on the more technical phases of aerodynamics . . . *S. PAUL JOHNSTON* prior to becoming Coordinator of Research of the National Advisory Committee for Aeronautics was for several years editor of *Aviation*. His extremely broad experience with the art of flying has enabled him to write authoritatively on many aspects of aviation . . . *JOHN S. PARSONS* is in charge of the engineering of secondary-network systems for Westinghouse, having been instrumental in the establishment of the idea in the early '20s and in the application of the system to most of our large cities. More was written about him in the "Personality Profiles" of the May, 1941, issue.

New tasks FOR ELECTRICITY



Working on the well-known principle that non-metals retain an electric charge much longer than metals, this electrostatic precipitator for laboratory use can separate metallic ore from unwanted bits of rock. The workability of a sample ore can thus be readily predicted. ("Dollars from Dirt," p. 75.)