WESTINGHOUSE
Engineer

JULY 1950

Various Paths to Rail Electrification

Transportation engineers have long sought the best method of using central-station electric power to haul trains. Announcement of the construction of two large ignitron-rectifier locomotives brings to mind the other routes taken to that objective. The announcement points up, also, the twofold nature of the engineering problem. One basic consideration in electrification has to do with the power-supply system by which current is brought to the locomotive. The second equally important aspect is a suitable drive on the locomotive. And—as always—economics stands as final arbiter to the success of any electrification system.

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The problem of an ideal electrification system has been approached principally by two main routes—via alternating current and direct current—although a combination route has also been used. By nature the a-c system meets well the power-supply requirement, but has more difficulty with the motor problem. On the other hand, direct current has superb driving characteristics but has a transmission-voltage handicap. Neither alternating current nor direct current alone has been able to score practical perfection on both counts.

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A-c rail electrification, in the U.S., had its beginnings almost exactly a half century ago. Its "angel" was, as one would readily guess, B. G. Lamme, of Westinghouse, a staunch advocate and outstanding genius in the field of alternating-current electric power.

The a-c traction system got its start when it was discovered that a single-phase, series (i.e., commutator) motor has unidirectional torque with alternating voltage and current applied. Lamme, in his "Autobiography," speaks of building in 1897 several 60-cycle, series-wound, single-phase motors for application in a packing house. He adds ". . . these machines were really the predecessors of the single-phase, commutator-type railway motors, brought out some three or four years later."

This type of motor was historically significant in that it introduced to rail electrification the famous Lamme resistance-lead principle. Commutation by an a-c motor is more difficult than on d-c motors because the a-c field creates, by transformer action, a circulating current in the coil being short-circuited by a brush. This circulating current adds to the load current and hence increases the total to be commutated.

This condition was alleviated by the insertion of a small resistance between each commutator bar and the armature coil connected to it. This effectively reduces the a-c circulating currents. This principle has had great significance in the long history of a-c electrification.

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The series motor has since been used on several electrifications—beginning with the New York, New Haven, and Hartford in 1907. The Pennsylvania main-line electrification is 11-kv, 25-cycle, single-phase and employs the series commutating motor exclusively. In these the basic principle of the a-c series motor has been employed, although the different combinations of resistance leads, interpoles, and compensated-field poles have been numerous. The 1901 motors used resistance leads and compensated main-field poles, but no interpoles. Later, use of interpoles and no resistance leads came into favor. Now the trend has returned to emphasis on the resistance-lead feature—with interpoles—particularly for freight service.

While the series motor has dominated the a-c locomotive field, other types of a-c motors have been used. One of the early trunk-line electrifications was the Norfolk & Western in 1914. It used the split-phase system, in which each locomotive carried a rotating induction machine (phase converter) that, with Scott-connected transformers, converted the single-phase supply to three-phase for the motors. These were two-speed, wound-rotor motors, which avoided the commutation problem present with the series motor when starting very heavy trains from standstill. These locomotives have the merit of using simple, low-cost motors and provide the ability to brake by regenerating power at constant speed and returning it to the line—which is important to the Norfolk & Western in hauling heavy coal trains down the eastern slopes of the Appalachians. But they have disadvantages too—the inflexibility of two speeds, 14 and 28 miles per hour, and high energy losses at starting. The original Virginian electrification, in 1923, was a similar system.

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In 1915 the doubly fed series motor appeared on the Pennsylvania multiple-unit car electrification to Paoli (many of these cars are still in service). The object again was to improve commutation during heavy-current starting. Part of the power is fed to the armature winding by transformer action, i.e., in effect making it unnecessary for all the current to pass through the commutator. At very low speeds the armature and series fields can be reconnected for operation as a repulsion motor and thus further reduce the duty on the commutator.

Even three-phase trolley power has been tried to permit direct use of simple, low-cost, wound-rotor motors. But it has never become popular. The Cascade Tunnel of the Great Northern was so equipped.

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Meanwhile, d-c systems have undergone a parallel evolution. It is generally agreed that there is nothing wrong with low-voltage d-c motor locomotives that a higher voltage power supply won't fix. (A d-c transformer would come in mighty handy here.) The speed characteristics of a d-c series motor leave little to be desired. But the inflexibility of the supply voltage handicaps it. High-voltage transmission is desirable on two counts: because of the inexorable laws of I^2R, and IR drop, and because only about so many amperes—around 500—can be picked off a trolley wire by single sliding contact (each pantograph has two in parallel at, say, 90 mph.).

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The solutions to the transmission problem for d-c electrifications have been several. One has been the direct approach, i.e., to raise the d-c trolley voltage. The Long Island Railroad began electrified d-c service in 1905 with 650 volts. The Piedmont and Northern was electrified in 1911 with a 1500-volt system, which is used more extensively in Europe and South America. The Chicago, Milwaukee, and St. Paul electrified system in the Rocky Mountains began in 1915, using 3000 volts and a regenerative-braking system. Even a 5000-volt system has been tried. This was the 12-mile Grass Lakes interurban line of the Michigan United Traction Company in 1915. Although operation was satisfactory (experiments had been conducted even up to 7000 trolley volts at East Pittsburgh) the 5000-volt system was never considered competitive because of the difficulty with the motor insulation and the problems of high-voltage d-c control.

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One approach to the transmission-voltage problem is the use of an a-c trolley and motor-generator sets on the locomotives to supply the low-voltage d-c motors. The Great Northern was electrified on this basis in 1927. Recently some Virginian motor-generator locomotives were built.

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These several systems have been practical ones but they all fall short of reaching the ideal. Perhaps the ignitron-rectifier locomotive will be the "short-cut" by which the better sections of both the a-c and d-c roads to electrification can be joined to build a far superior route.

WESTINGHOUSE Engineer

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On the Side

The Cover—To portray the idea of the stoker's fundamental operation, Cushing & Nevell, industrial artists of New York, figuratively speaking, climbed inside the furnace. The result is a realistic depiction of the Westinghouse spreader stoker, the Centrafire (see p. 171).

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For the Philadelphia Electric Co., Westinghouse will build a 3600-rpm, 125 000-kw turbine generator. The large reheat-cycle turbine will operate with initial steam conditions of 1800 psig and 1000 degrees F, reheated to 1000 degrees F; generator output will be 147 059 kva (0.85 pf). This unit will have the largest output of any two-pole machine operating at 0.5-pound hydrogen pressure.

In This Issue

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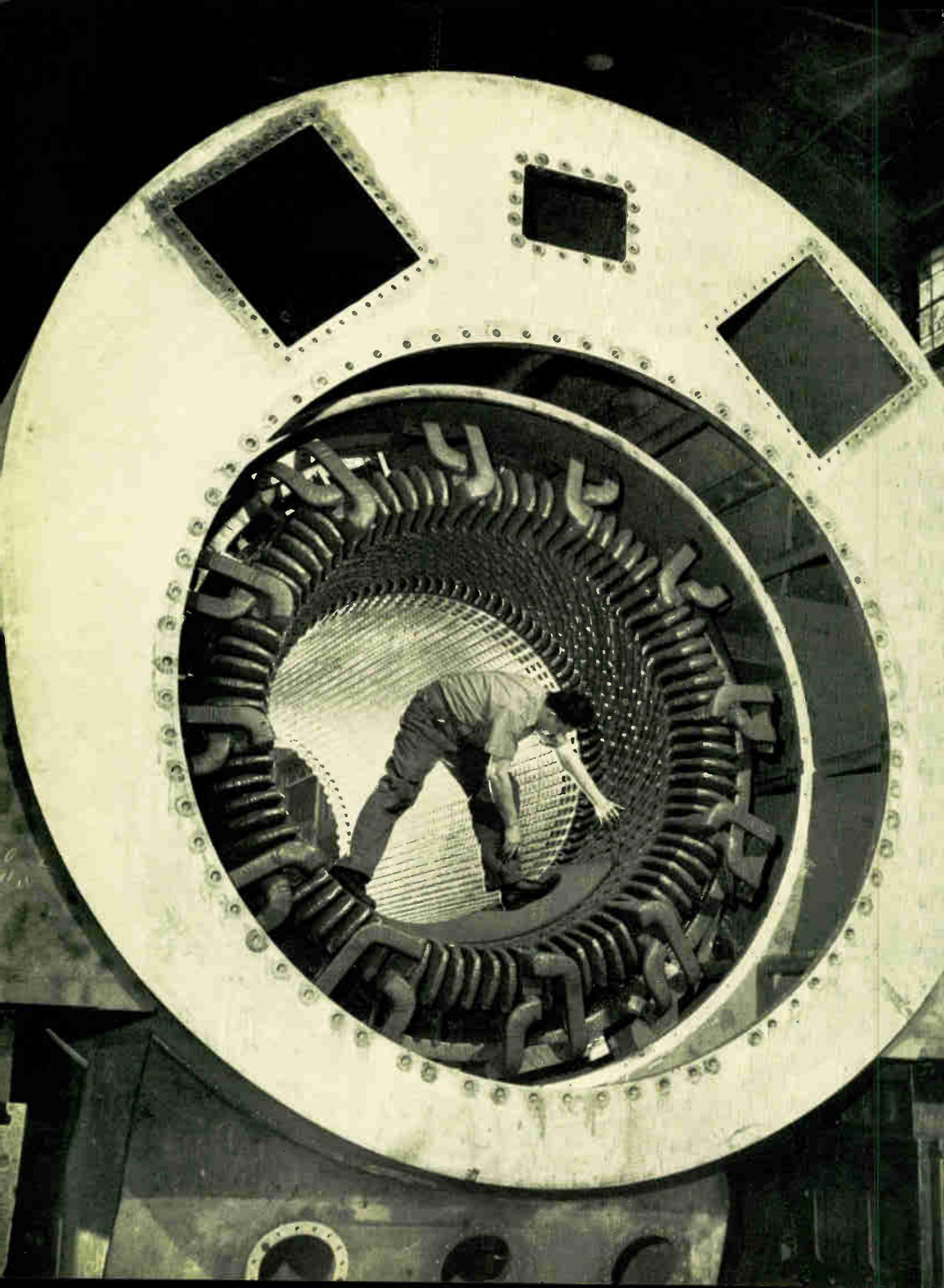


Thermalastic Insulation—

Improves High-Voltage Generator Coils

The perfect insulator, like the perfect conductor, will always remain a goal, not an accomplishment. Nevertheless, progress toward it is continual, sometimes by small increments, occasionally by giant steps. This year marks one of the major steps—a vastly superior material for the stator coils of high-voltage generators, christened Thermalastic insulation.

GRAHAM LEE MOSES, *Manager, Development Insulation Sec., Westinghouse Elec. Corp., East Pittsburgh, Pennsylvania*

RADICALLY new and unusual electrical insulations, like new modes of transportation, appear only a few times in a century. In fact, until now there have been but two major developments in high-voltage generator insulation since this century began—the mica-folium insulation introduced in 1911, and the asphalt-impregnated, continuous mica tape insulation of about 1930. This year marks the development of the third major high-voltage material of the century—Thermalastic insulation—which had its beginnings in the Research Laboratories more than ten years ago.

This new insulation is designed primarily for high-voltage machines and is now being applied to large steam-turbine generators. Extensive tests reveal that, compared to conventional insulations, it has an unusually high degree of resiliency—an extremely important factor as generators increase in size. Also the dielectric power factor is drastically decreased, and dielectric strength shows a significant increase. The voltage endurance, i.e., the time to failure at a fixed voltage, is increased by many times. In fact, Thermalastic insulation is superior, in nearly every physical, chemical, and electrical respect, to previous materials.

The mica-folium and asphalt-impregnated insulations both utilized the unusual electrical properties of mica. So does the new insulation. The basic difference lies in the bond used for mica flakes. Coils of early machines used shellac as a mica binder, forming a rigid and brittle insulation. But machines were small in size, especially in length, so the insulation proved highly satisfactory for many years. Then in the middle 20's, as the ratings of generators grew, and thus cores became longer, thermal expansion of the coils necessitated a new and more flexible insulation, and an asphalt bond replaced the shellac. This has proved highly satisfactory.

But generator ratings are still growing, with the result that coils are becoming longer and longer. This emphasizes and exaggerates an old problem associated with thermal expansion. Differential expansion of copper, iron, and insulation, which has been readily taken care of in smaller machines by existing insulations, increases in importance as the coil length increases, and eventually reaches a point where the insulation expands, but does not again resume its original position when the coil cools. This is called tape migration. Thus, with machine sizes ever on the increase, a new insulation is now necessary, preferably one with sufficient resiliency to contract as well as expand with the coil, plus physical strength to withstand the expansion forces. Such is Thermalastic insulation, which consists essentially of mica flakes bonded with a strong, resilient synthetic resin.

The Components of Thermalastic Insulation

To understand the reason for the unusual properties of Thermalastic insulation, it is necessary to compare its components and the method of their application with previous insulation. The new insulation is similar to asphalt-bond insulation in one respect, and different in three. Its common feature is the use of mica flakes as a basic insulating barrier; different is the tape in which these flakes are distributed, the bonding substance, and the method of applying them.

Mica Tape

The new mica tape is machine-made with good quality muscovite mica splittings. The major part of the tape is built on a thin, strong, fibrous backing, with a second layer of backing applied to the top side after the mica splittings are laid. New and unusual is the bonding agent that binds the mica flakes to the tape—it is a synthetic resin that is compatible with the solventless varnish used for impregnating the finished coils. This agent has a low electrical loss and contributes to the low power factor and high dielectric strength of the composite insulation. The result is a strong, dry tape, easily applied and with a high tensile strength that permits tight application without breaks.

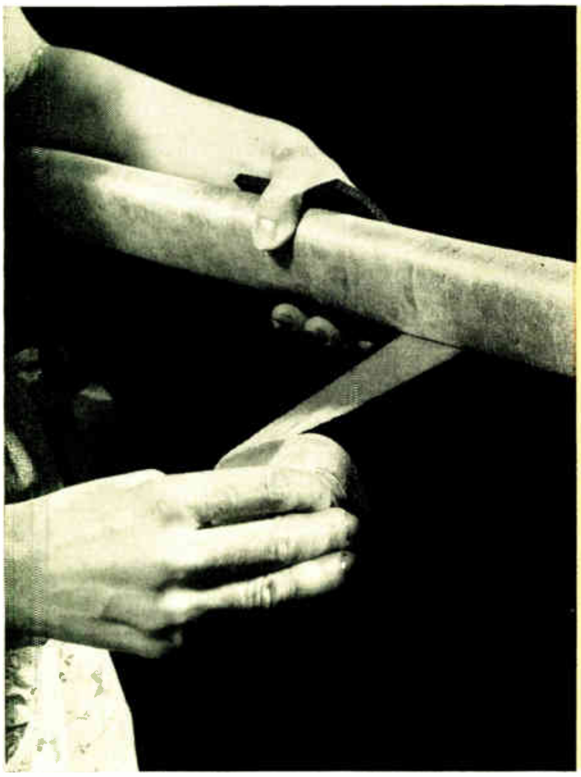
The Impregnant

The previous impregnant, an asphalt bonding material, is a brittle solid at room temperature. Since asphalt is permanently thermoplastic (not thermosetting), it becomes a semiliquid at operating temperatures. The new impregnant, a solventless varnish, is a low-viscosity liquid and is therefore easily handled at room temperature (and below). Chemically it is a copolymer polyester, a varnish in which one or more resins are dissolved in the monomer of another resin.

When heated in the presence of a catalyst the complete varnish structure reacts to form a permanently thermoset material, which does not again liquefy unless heated to destruction. The resin can also be reacted at lower temperatures than normal by the addition of other types of chemical activators, or catalysts.

The chemical reaction does not result in by-products, such as water or volatile gases. Because it is solventless, nothing

At left, a huge 100 000-kw generator in final stages of construction. Coils of this new machine are insulated with Thermalastic.



At left, layers of the new mica tape are applied. After sufficient thickness has been built up, the coil is wrapped with fiber glass tape, as at right. Then the whole coil is impregnated with the new resilient solventless resin.

is given off during the reaction or curing. By the same token then no voids are created. This is important because it produces many desirable characteristics. When the reaction takes place under properly controlled conditions, the material becomes a solid, bubble-free mass that essentially fills the space it occupied in liquid form. The reaction is rapid and exothermic, for there is no stable intermediate stage of these resins. Once the reaction starts, the resin is quickly converted from the liquid into the final infusible solid phase.

The new resin itself has many outstanding properties. For example, it has excellent moisture resistance. It has a low power factor and dielectric loss. Its dielectric strength is equal or better than conventional bonds, but lends itself to processing into composites of far greater dielectric strength, possibly up to 50 percent. Its physical strength, coupled with good elastic properties, is the key to the answer to insulation-migration problems. It has a high thermal conductivity, and outstanding thermal endurance in the field of organic compounds. These qualities all lead to an improved insulation.

How the Insulation Is Applied

Fortunately, Thermalastic insulation is not only a far better insulating material, but is considerably simpler to apply. Previous coils were wound by wrapping a few layers of the old-type mica tape, vacuum impregnating the whole coil with asphalt material, then returning the coil for the application of more layers of mica tape, impregnating again, and so on until the requisite thickness was built up. Then the whole coil was wrapped with a fiber-glass tape, and painted with finishing compound. This was because the asphalt impregnant, being a heavy-molecule or viscous material, even though processed at high pressures and temperatures, cannot be relied on to penetrate all the layers of mica tape required to provide the insulation for the high voltages involved.

The coils thus far insulated with Thermalastic insulation are of the half-coil (one half of the full-coil loop found in small generators) construction, as are most large turbine-generator coils. All strands of each conductor are individually insulated with fiber glass. The assembled strands are bonded solidly in the portion to be embedded in the slot. This ensures a strong, rigid, straight part and consolidates the strands to a controlled size and shape.

The coils are insulated from ground by multiple layers of the new mica tape, but unlike asphalt-bonded coils, all tape is wound—layer after layer until the desired number of layers is in place—before any impregnation occurs. Then the coil is taped overall with a fiber-glass tape for structural support and finishing. Eliminated completely are the multiple, intermediate impregnations!

Taped coils—still with no impregnant—are then heated and treated at high vacuum to remove moisture, solvents, and gases. Then they are impregnated under pressure with the new resin varnish.

This varnish accomplishes two significant results—it provides a bond between mica flakes, which permits elastic deformation—both contraction and expansion—during cyclic movement of the coil, and also fills the voids in the mica insulation wall. Reducing the number and size of voids between mica flakes results in a great improvement in dielectric strength and voltage endurance obtained from the same mica flakes used in conventional insulations.

After impregnation, the resin is cured by heating in a conventional oven while there is physical restraint of the insulation, both on the straight portion and on the end winding. Since the resin is cured at the temperature at which the machine operates, the bonds between mica flakes are not stressed at this temperature. When coils are cold these bonds are actually in compression. The resultant composite insulation is a tough, yet flexible, dielectric barrier, with unusual electrical and physical properties.

The use of a solid bond as an impregnant precludes any serious deformation of Thermalastic-insulated coils during winding. Thus the manufacturer must produce coils, cores, and supports that fit each other reasonably well. Therefore, a characteristic that was the major problem with asphalt-bonded insulation—its plastic state when hot—was actually an advantage during winding. Any deformations incurred in manufacture could be corrected by heating the coil until the insulation was in a plastic state and forming it to shape. However, serious deformation of any coil, even in the plastic state, is undesirable, since the results are unpredictable. One thing is obvious—such deformation never improved the electrical characteristics of any coil.

The problem of shape and size control was recognized early in the development of Thermalastic insulation. It was solved by the use of mobile presses for curing the resin-bonded insulation while it is restrained and supported to the proper size and shape.

After vacuum-pressure impregnation, coils are placed in the presses. Clamps hold the slot portion of the coil, ensuring maintenance of the proper size. Shaped rubber pads are taped to the flat portion of the coil ends to obtain light physical pressure evenly on all surfaces. Support blocks hold the coil ends while curing to ensure that all coils are the same and will fit the core and coil supports. The mobile presses, with coils in place, are moved into an oven and the impregnating resin cured with the coil positively held in place.

After coils are removed from the mobile presses, they are checked in temporary models (replicas of core and coil supports) to make sure that each coil will fit the coil supports, and that top and bottom halves mate.

Properties of Thermalastic Insulation

The high degree of fill and the characteristics of the resin impregnant are reflected in superior electrical and physical properties. For example, the insulation power factor of Thermalastic insulation is decreased by one half to two thirds at operating temperatures and rated operating voltage as compared to the asphalt-bonded insulation. Moreover, the power-factor voltage curve is flatter and the value lower at every point. The dielectric strength per unit thickness is at least 20 percent greater than that of the asphalt bond. Tests indicate that far greater values are probable. The voltage endurance (time to failure at a fixed voltage) is increased by a factor of more than ten times!

The physical properties of Thermalastic insulation are no less impressive. Tests on various insulations indicate that this material has 30 times the tensile strength of conventional types at operating temperatures of 100 degrees C! The elastic nature of the bond overcomes the physical limitations experienced with thermoplastic asphalt bonds on very long machines. Thermal cycling tests on a variety of models have demonstrated the freedom of Thermalastic insulation from migration. The thermosetting nature of the resin provides a solid but elastic bond between mica flakes, which results in a high physical strength to resist tape migration and rupture of the insulation.

The thermal coefficient of expansion of Thermalastic insulation is only one fourth that of asphalt-bonded mica in the dimension perpendicular to the mica laminae. In other dimensions, it is, of course, determined by the expansion of the mica itself. Thus the excessive self-tightening of coils in the slots, due to expansion of the insulation wall, is eliminated by Thermalastic insulation.

The resilient nature of the resin bond permits elastic cyclic displacement of adjacent mica flakes and provides restoring forces within the insulation wall. Thus the composite insulation is capable of elastic deformation, but the thermoset nature of the bond prevents insulation creep, such as occurs with the thermoplastic asphalt bonds.

Conclusions

The outstanding characteristics of Thermalastic insulation have led to its adoption as the standard insulation for all Westinghouse high-voltage turbine-generator stator windings employing half-coil construction, which includes those rated at 12 500 kva and larger. This new insulation is also applicable to rewinds for older generators, where the electrical design is such that half coils can be used.

The major problems stimulating the development of this new insulation exist particularly in large machines with long cores, which all employ half-coil construction. In this field Thermalastic insulation has already proved so satisfactory that it now takes its place as the third major insulation development of the 20th century.

Work is proceeding in commercially adapting full coils embodying Thermalastic insulation to other types of electrical machines. There are such wide differences in the shapes of full coils and methods of winding them into the cores that each different application involving a full coil must be studied and solved individually. In some cases it has been found to be quite simple to substitute Thermalastic insulation for asphalt- or resin-bonded insulation with good results.

Operating experience with all types of high-voltage generator insulation has been excellent, and trouble has occurred only in isolated instances. Thus, in providing a new insulation with such outstanding properties, Westinghouse offers windings with even greater reliability and many highly valuable physical, thermal, and electrical characteristics. This paves the way for further advances in generator design.

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Stronger Power-Transformer Radiators

What a difference another seam makes. The air-expanded radiators for power transformers, introduced by Westinghouse in the middle 20's, consisted of two flat metal sheets placed face to face, seam welded along their outer edges and down the middle. Then the welded unit was expanded by inflation with air under pressure, forming a fairly thin member, consisting of two parallel lobes that serve as oil ducts. Witness to the success of this idea has been its use for over 20 years, during which time tens of thousands have been made for large power transformers.

Now transformer engineers find that a simple change from one seam down the middle to two equally spaced seams, forming three lobes instead of two, results in great improvement with no loss whatever in heat-exchange efficiency. Most of the gain comes about from a vastly improved mechanical strength.

The new radiator is pressure tested at more than three times the pressure applied to the two-lobe construction. This pressure better discloses any welding weaknesses and potential leaks. The higher pressure also assures more uniform contours of the oil lobes. Greater rigidity is obtained with the result that radiators are less subject to failure due to vibration, will stand the shocks of shipment, and are less likely to distort by rough handling.

The human coal heaver has long since been replaced as the primary means of conducting coal on its "last mile" —into the roaring furnace itself. In part this has been because he is too puny for modern boilers. But more particularly, the application of coal to a fire bed is more than the simple mechanical transportation of solid coal the necessary few feet, it is a precise operation involving coordination of many factors. The modern stoker, from crude beginnings, has become a precision instrument.

The Story of the Stoker

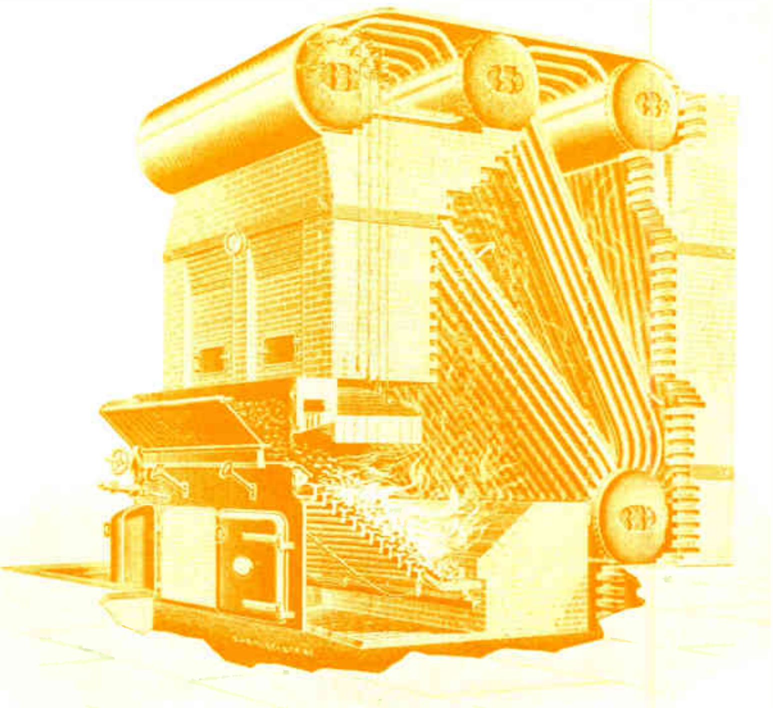


Fig. 1—An early Roney stoker under a 200-hp Stirling boiler. (Sketch is taken from a pamphlet dated 1893.)

James Watt raised steam for his first steam engine in a boiler fed by a hand-operated feed screw, but during the following century hand firing of boilers remained the universal practice. In all phases of the Industrial Revolution, the new machines were applied only to those intricate or power-demanding tasks that human muscles were not capable of fulfilling—the steam engine for pumping, the large weaving loom, or the gin for separating cotton and seed. Where man could successfully do the job, he was not replaced until it became economically necessary to change. Power was not applied to the intricate operations of loom or gin until man could no longer turn them economically. Such was the case with the stoker; the intricate functions of maintaining the proper rate of fuel entering the furnace, of maintaining a maximum release of heat energy, and of removing the ash so as not to interfere seriously with heat release became too much for the human. Eventually the time came when the job could be done more economically by a machine.

Without these machines, these modern fuel-burning equipments, our industrial scene would be vastly different. Industry's ever-increasing appetite for steam for industrial processes, for heating, for electric-power generation, and for many other uses, could not be satisfied. Of all these fuel-burning tools, the most universal, by far, is the mechanical stoker; in number of installations and in pounds of steam generated, it far exceeds other types of equipment.

Stoker Beginnings

In the 1880's, stoker development had only begun; the steam plants then in existence—a few industrial and reciprocating-engine electric plants—were of small capacity because steam and power requirements were low. The hand-fired boilers of a few hundred boiler horsepower were adequate. These boilers were attended by more-or-less skilled individuals who shoveled in coal, raked and sliced the fire bed, and removed the ash. Depending on their experience, knowledge, and skill, they obtained various degrees of success at releasing heat energy. But efficiency of heat release, as we now regard it, was generally low. Although hand firing was wasteful and far from satisfactory, human diligence could produce results of a sort; there was not a demand for change, as yet.

Around 1890, under the impetus to reduce steam costs, the trend toward stoker firing was definitely under way. Expansion of boiler plants and design of boilers of greater capacity was the order of the times, and human coal heavers, no matter how energetic or skillful, could not keep pace. The early stokers burned poorer quality coals and required less manual labor in their operation. These considerations in lowering steam costs initiated the demand for stokers. But combustion was little understood and the concept of a combustion process under precise control that gave a steady release of heat was unknown. The stoker's ability to maintain uniform heat release and to liberate more energy from a given quantity of coal was not recognized.

The Roney Stoker

The stoker in production by Westinghouse at the turn of the century was the Roney. The manufacturing rights to this stoker had been obtained in 1888 by the Westinghouse Church Kerr Company, who had built about 1650 before manufacture was taken over by the Westinghouse Machine Company in 1898. The Roney was an inclined-grate. natural-draft stoker, of a type that became known as the overfeed stoker, in which fresh coal was applied to the fire bed from above. A pioneer in the field of overfeed equipments, it burned poorer quality coals with fewer of the troubles encountered on hand-fired grates. Small enough for installation under almost any boiler setting designed for hand firing, it could burn enough fuel to accommodate the steam demands of the then larger boilers.

Written by Robert S. Giles of the Westinghouse Engineer staff, based on information furnished by members of the engineering and sales staffs of the Westinghouse Stoker Department.

The basic element of the Roney stoker was a rocking grate that agitated the fire bed to prevent caking of the fuel. This permitted a freer passage of air and resulted in greater heat release. The grate was formed of several cast-iron plates that extended from one side of the furnace to the other and were stepped from front to rear (Fig. 1). Fuel was fed, by pushers, onto the grate from a hopper on the front of the furnace. As the main grate opened and closed, the fuel moved slowly from hopper to dump grates over the ash pit at the rear of the furnace. Coincident with this movement of fuel from front to rear, the fuel passed through the successive stages of burning, incombustible ash making up the major portion of the material discharged into the ash pit.

The fuel-burning processes on early stokers, of which the Roney was representative, were the first steps toward today's highly efficient and more nearly complete combustion. In distinct contrast to the results obtained with manual firing, these stokers introduced, for the first time, some measure of combustion continuity—steady, controlled movement of the fuel into and through the furnace to give relatively uniform release of heat. However, some manual working of the fire bed and close operating attention were necessary. Compared to modern stokers, the Roney was difficult to operate and its ability to convert the latent Btu's in coal to heat energy was poor. Because natural draft air was used for combustion, the stoker's capacity was limited by the feasible height of chimneys. The low air volumes and velocities of chimney draft permitted excessive grate temperatures, causing rapid burning of parts, which resulted in high maintenance costs.

Nevertheless, the Roney was one of the best early stokers. New installations were made under small boilers until 1928. Testifying to its durability are several hundred installed before 1910 that are still in regular service.

Basic Factors in Development

Steam-generating capacity began its tremendous growth in the first years of the 20th century. The increasing appetite of industrial plants for steam and the application of the steam turbine to electric-power generation required ever greater quantities of steam. The steam turbine, in addition to accelerating the growth of boiler sizes, introduced another requirement—flexibility. Electric power, which must be generated as it is consumed, requires that the rate of steam generation—and rate of heat release—be coordinated with power demands. Added to the stoker engineer's problems of obtaining wide ranges in rates of firing was the necessity for changing these rates with the least practicable disturbance to the burning process.

During this period of tremendous expansion, stoker development consisted of more than just building bigger stokers to meet the growing steam demands. Other factors began to be important. Because of the almost infinite variations in chemical and physical properties of coal, the stoker never can be a completely automatic machine that can be turned on and operated without attention or adjustment. There arose the concept of the stoker as a machine tool used in producing another commodity—in this instance, steam—and like any machine tool, it requires the guiding hand of an operator. The skill of the operator largely determines the results obtained with the stoker. The stoker engineer's objective should be to build a machine that is readily responsive to adjustment and manipulation by the operator. Hand in hand with equipment improvements was the evolution of proper methods of operation and the development of instruments for measuring those factors, such as air pressures, airflow, and gas temperatures, that guide the operator in obtaining results.

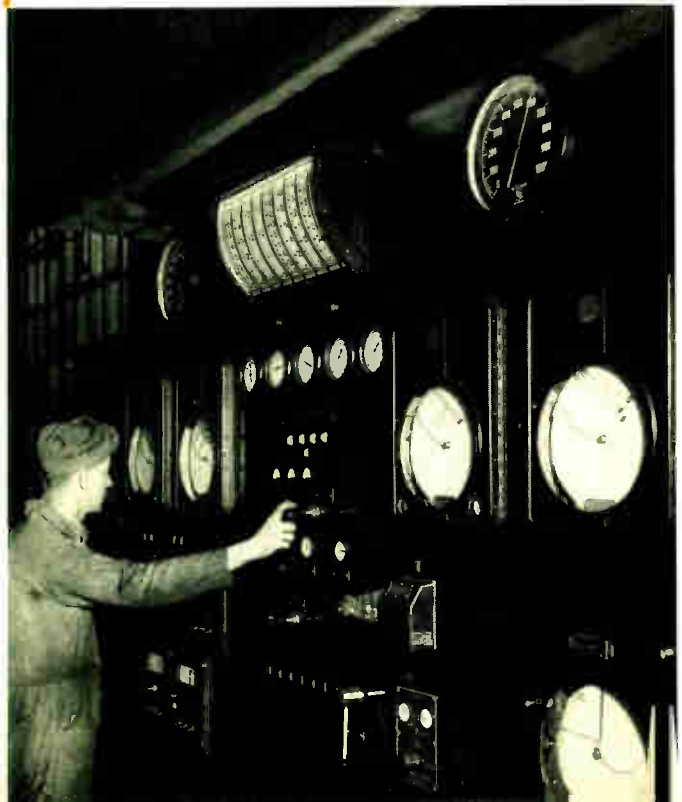
Engineers also saw that to raise stoker capability and efficiency, coal combustion and its relationship to other factors, such as the method of its introduction into the furnace and the conditions within the furnace, must be better understood. Coal, regardless of size or shape, can burn in only one way, but between initial ignition and final reduction to ash, conditions external to its composition can cause a wide variety of intermediate circumstances. For instance, there are two general methods of getting coal into the fire. In the first the coal is introduced en masse, and in the other coal is spread thinly over the entire fire bed. For each, the combustion reaction differs greatly.

For all bituminous coals, combustion proceeds through the distillation and oxidation of the volatiles, oxidation of the residual fixed carbon, and partial or complete melting of the ash. Where coal is brought to the fire en masse, distillation of the volatiles causes the tar in the coal to form a plastic mass and large numbers of particles become cemented together to form a relatively much bigger piece. This burns the same as a single piece of fresh coal would burn by itself. But when coal is introduced in this way, it is necessary to have a thick fire bed of these larger pieces so that sufficient surface is presented to the combustion air. Thus, an economical minimum of air is required to burn this coal, which presents relatively little surface area in proportion to mass.

On the other hand, when each individual piece is deposited on the hot fire bed and is isolated from other pieces of fresh coal, it usually passes through the plastic or sticky state before the arrival of another piece. Thus the small particles retain their original size and burn more rapidly because more surface area in relation to particle mass is exposed to the combustion air.

Understanding of the true nature of coal burning and the concept of the stoker as a machine tool has been developing throughout the last 50 years. With each idea or discovery,

Fig. 2—The modern controls and indicators that aid today's boiler-operating personnel are a distinct contrast to the early stokers, such as in Fig. 1, where only a few basic rods and levers were used to control combustion.



further modifications, trials, failures, and successes have been made to improve stoker performance and promote the reduction of steam costs and increased capacity.

The Chain-Grate Stoker

To meet growing steam requirements, Westinghouse, in 1910, introduced a stoker to augment the Roney. Like its predecessor, it was used in furnaces having natural draft. This stoker used the chain-grate principle in which an endless chain-type conveyor received coal from the hopper, carried it into the furnace where it burned, and discharged the ash to a pit at the rear. Combustion was accomplished by passing air through the grate and fire bed from below.

Although the chain-grate stoker was capable of burning the lower grade, cheaper coals fairly efficiently, with good continuity, many problems in design of structural members and in obtaining an adequate air flow with sufficient control handicapped its development. (Forced draft, which increased capacity and reduced temperatures of operating parts, was only beginning to be applied to boiler firing.) Also, the chain-grate provided only limited flexibility and inadequate control of the fuel bed.

The Roney and chain-grate stokers, although improvements over hand firing, were limited in the amount of fuel they could burn on each square foot of grate area. Because there was a practical height and size to which chimneys could be built, the draft resistance (resistance to air flow) of the fire bed could not exceed certain limits. Therefore, the thickness of the coal bed was limited. Basically, then, chain-grate firing as originally introduced was not the solution to the increased demand of steam plants. And although forced draft was subsequently applied successfully to chain-grate firing, and is still used, Westinghouse stoker engineers believed that a newer principle of firing was a more promising development. Thus, in 1917, after about 50 chain-grate stokers had been built, manufacture was discontinued in favor of the underfeed type.

The Underfeed Stoker

Following the application of forced draft to furnaces, a radically different and more effective stoker was developed. This was the underfeed type in which fuel was forced into the fire bed from below. The greater volumes of air that could be passed through grate and fuel bed with forced draft permitted the use of a thicker and more dense fuel bed. Thus more coal could be burned on each square foot of grate area. A definite increase in firing capacities resulted from the development of this stoker. In addition to burning larger quantities of coal, more heat was released from each pound of coal, combustion was steadier, and a new degree of flexibility was obtained.

The first Westinghouse underfeed stoker was a multiple-retort unit. It consisted of three or more channels, called retorts, through which coal was forced into the furnace by reciprocating rams. Adjacent to each retort was a tuyere box—an iron casting supporting the "tuyeres" through which the air entered the fuel bed. On this first underfeed stoker a manually operated dump grate released the accumulation of ash. The stoker could be applied to boilers of various capacities and sizes by using different numbers of retorts.

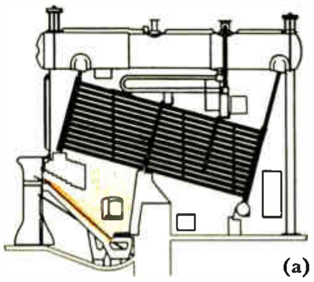
Only after this stoker was firmly established did engineers begin to understand clearly the complicated actions occurring on the underfeed grate. The movement of fuel in a multiple-retort stoker is positive and continual. Coal, entering through the retort, is forced upward and outward by the continual push of additional entering fuel and the motion of secondary rams moving back and forth in the lower portion of the retorts. Combined with this upward and outward motion is a general movement of the entire fuel bed toward the rear of the furnace. The air forced through the tuyeres passes through the fuel over them, burning this fuel in intensely hot zones called "burning lanes." Actually the fire bed is a series of these burning lanes (Fig. 4) and, although some combustion does take place in the bed above the retorts, the major portion of the heat is released in these burning lanes.

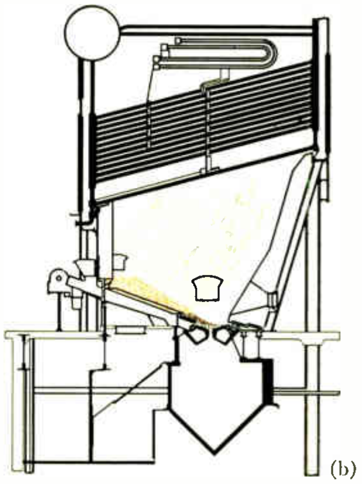
Combustion in these lanes creates temperatures much higher than the fusing temperature of the ash. The high-velocity stream of burning gases leaving the lanes draws off the gases distilled from the fuel over the retorts. These gases burn with a short, smokeless flame leaving the remainder of the fuel in the free-burning, highly combustible carbon form mixed with a relatively small amount of incombustible ash. When this portion of the fuel is forced into the burning lanes, most of the ash melts. As it drips toward the cooler tuyeres it chills and forms small globules. This incombustible solid is swept down the inclined tuyere rows by the general movement of the fire bed.

On the first underfeed stokers, ash disposal was accomplished by a dump grate attached to the rear of the multiple-

Steam Generators—Old and New

Fig. 3—Although boiler sizes and capacities have grown tremendously in the past 50 years, it is the stoker's reliability and efficiency, as well as its ability to burn more coal per square foot of grate area per unit time, that has permitted this growth, rather than a comparable increase in stoker size. A comparison of boilers over a period of more than 50 years shows this growth graphically and gives a good comparison of boiler and stoker sizes. (a) —Typical installation of the Roney stoker under a straight-tube boiler having a capacity of 12 000 pounds of steam per hour. Furnace area: 11 feet by 7 feet 8 inches. Boiler thermal efficiency is 65 percent. (b)—An early cast-tuyere-box type multiple-retort, underfeed stoker under a straight-tube boiler, having a capacity of 125 000 pounds of steam per hour. Furnace area: 24 feet 8 inches by 10 feet. Boiler thermal efficiency is 75 percent. (c)—Unit-retort type, multiple-retort, underfeed stoker with Link Grate and clinker grinder, installed under a 350 000-pound central-station boiler. Furnace area: 31 feet 11 inches by 22 feet 11 inches. Boiler thermal efficiency is 85 percent. (d)—A projected 350 000-pound-per-hour boiler using a Centrafire-with-traveling-grate, spreader-type stoker. Furnace area: 32 feet 3 inches by 20 feet 3 inches. Thermal efficiency of 85 percent expected, with almost completely automatic combustion control.


(a)


(b)

retort section. This dump grate was operated periodically to drop the ash into the pit below. This exerted a disruptive influence upon combustion. Although the material deposited on the dump grate was largely ash, some combustible material was carried down and continued to burn, fusing the ash into large clinkers. On early improved versions of this stoker various devices were provided to obtain more complete burning of the fuel and to provide for adequate and less disruptive removal of the increasingly larger quantities of ash that were accumulated. These devices were "overfeed" or "extension" grates between the ends of the retorts and dump grates.

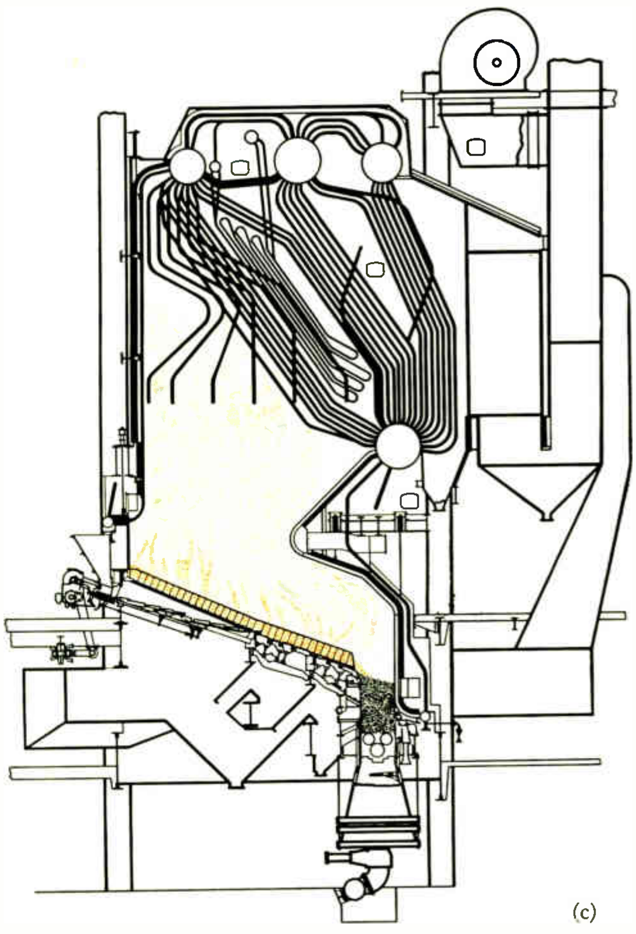
Skill and attention were required to manipulate distribution of fuel and discharge of ash without undue loss. Hence, considerable manual labor and skilled attention were necessary to achieve best results with this unit. The advantages of the underfeed stoker far outweighed the disadvantages; and development of the stoker, together with continued development of the boiler, increased boiler unit efficiencies 10 percent.

The Clinker-Grinder Stoker

The underfeed stoker was the first major change in the development of stokers, but its initial form did not long remain static. As in any new development, immediate and continual modifications were made to improve performance. To obtain higher efficiencies, coal must be burned more completely, reducing discharge of combustible material to the ash pit. At the same time the fire bed must carry the ash to the brink of the ash pit. The ideal would be to have the fire bed burn completely to ash as it reached the pit, but obviously this is impossible. To reduce loss of unburned fuel and eliminate the disruptive periodic dumping of the ash, the clinker grinder was added to the underfeed stoker.

The clinker grinder consists of a pair of rolls, each carrying rows of cutters to grind the refuse. Dump grates are eliminated and replaced by a relatively deep cavity, called the clinker-grinder pit, into which ash moves from the grate. Refuse fills this pit to the level of the overfeed section and the clinker grinder disposes of the ash at the rate it is deposited, maintaining a constant level. The combination of the overfeed section and constant level in the clinker-grinder pit permits burning most of the combustible material accompanying the ash. The clinker grinder eliminated the periodic dumping of the ash and handled large volumes of refuse.

During and following the first World War, the growing capacities of steam plants, and central stations particularly, made necessary further increases in stoker capacity. Also the increasing variety of boiler types and sizes being built required that a multiplicity of stoker grate sizes be supplied. Thus, the unit-retort construction was adopted to accommodate this need. The former construction of the cast tuyere boxes with the retort mechanism supported between two tuyere boxes, required a different size tuyere-box casting for each grate length installed. In the newer construction each retort is supported by structural members, various lengths of which can be used. Short side-plate sections serve as retort walls. These sections are attached to the structural members vertically and sides of adjacent retorts provide support for the tuyeres. The first installation of a Westinghouse unit-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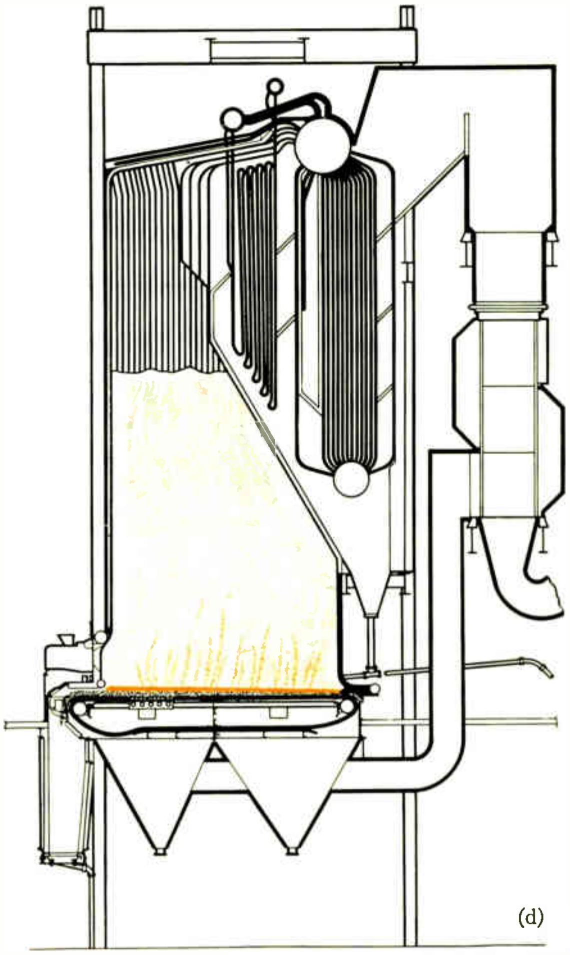

(d)

retort stoker was made in 1920 for the Street Railway System, Minneapolis, Minnesota.

The Single-Retort Link-Grate Stoker

Attention was turned in the early 20's to the development of a unit for the smaller capacity boilers. A forced-draft stoker to replace the low-capacity Roney and to reduce steam costs on the smaller boilers was needed. Thus a new single-retort underfeed stoker, called the Link Grate, was developed and the first installation was made in 1925 at the Patchogue, Long Island, Electric Light Company.

The single retort of this stoker was similar to that of the multiple-retort unit, but it extended horizontally into the furnace. On either side of this retort, the Link-Grate mechanism, which was unique in the field, extended outward and downward toward the furnace side walls. The Link Grate consisted of several rows of iron links, parallel to the retorts and pivoted on arms, through which a continuous undulating motion was transmitted to the fire bed. This motion kept the bed agitated and in continual movement, causing the fuel as it burned to travel from the retort toward the dump grate at either side. Combustion progressed as the fuel moved from the retort and was completed when it passed onto the dump grates. This Link-Grate stoker brought higher efficiencies and lower steam costs to small boilers of up to 35 000 pounds-per-hour capacity. Improved and developed, it continues to be used in considerable numbers of new installations.

The Multiple-Retort Link-Grate Stoker

As boilers grew, calling for larger capacities, it was possible, within limits, to raise capacity by using longer retorts and tuyere rows. However, greater quantities of ash had to be disposed of and more and more unburned fuel was needed to move the accumulated ash to the point of discharge. The overfeed section between the retorts and ash pit was required to burn more fuel. But on the larger capacity boilers more material was being forced onto this section than could be burned on it and losses of combustible material to the ash pit increased as retort length increased.

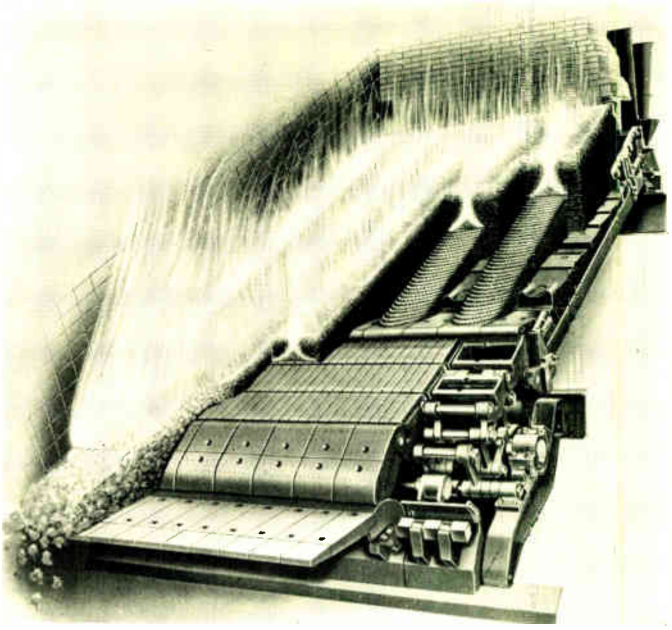
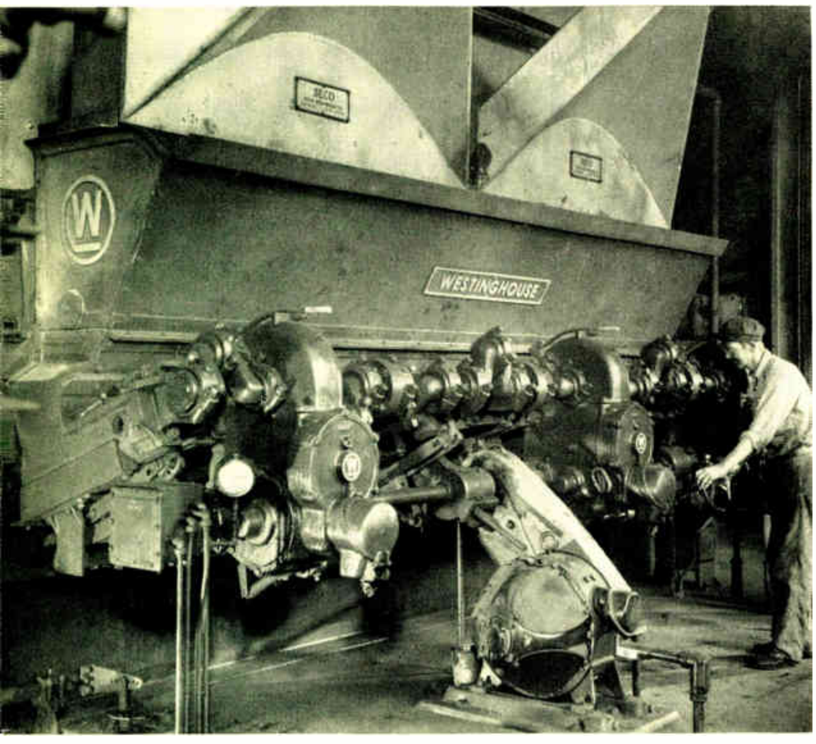


Fig. 4—A sectional sketch of the fire bed on a continuous-ash-discharge, multiple-retort underfeed stoker. The step-like series of plates beneath the burning lanes are the tuyeres, through which air enters the furnace. The depressed sections between the rows of tuyeres are the retorts where coal enters; the secondary rams are in the bottom of each retort. In the foreground are shown the Link-Grate section and adjustable ash-discharge platform mechanisms.

To minimize this loss, a much longer overfeed section was developed in 1928, employing the principle of the Link Grate, which had been so successful on the single-retort stoker. The large quantities of coal and ash moving down from the underfeed section, passed onto the Link Grate and were burned more thoroughly than previously. The undulating motion of this grate agitated the fire bed, permitting the combustion air to mix intimately with the overriding combustible material. Therefore, combustion of fuel was brought under much better control and the fire bed was allowed to extend over the grinder pit only to the extent required to prevent passage of excess air through the ash to the furnace. The clinker-grinder pit then was made deep and narrow. The application of the link grate measurably improved the efficiencies of boiler units. With proper skill and supervision, the multiple-retort stoker, with Link Grate and clinker grinder, was capable of giving higher sustained capacity and combustion efficiency than any other type of underfeed stoker.

Stoker improvements, like most any phase of engineering work, are not accomplished through theorizing and calculations alone. Trial and error, building and testing modifications to see whether or not they work must follow any logical engineering analysis. In the narrow, deep, clinker-grinder pits, for example, large cavities within the refuse of the pit were being formed. And as the grinder drew down more ash, these cavities would suddenly fill with combustible matter and ash. This waste had to be eliminated, but logical engineering thought availed nothing. An engineer studied the unit and noticed that the finer particles in the pit sifted from around the clinkers and dropped through between the rolls and the pit walls. When a partially enclosing plate around the rolls was attached to prevent fine ash from passing anywhere but between the rolls, the trouble disappeared.

Fig. 5—A nine-retort underfeed stoker under a boiler having a capacity of 80 000 pounds of steam per hour.



Continuous-Ash-Discharge Link-Grate Stoker

Further improvements of the small- and medium-size multiple-retort units were made in 1931 with the installation of a continuous-ash-discharge underfeed stoker. The application of the Link-Grate section to the multiple-retort underfeed stoker brought a reduction in the amount of combustible material discharged to the clinker-grinder pit. A high percentage of all coal was being burned completely on the grates. The next and logical step was to omit the clinker grinder. An adjustable platform over which the Link Grate could push the ash to a pit was provided, and, at a suitable distance above this platform, a water-cooled wall was provided to prevent coked fuel from rolling into the pit. This wall also redirected into the fire any air leaking through the burned-out ash. Thus, stoker engineers, in going one step further and eliminating the clinker grinder, reduced the installation and maintenance cost of underfeed stokers. The performance of the continuous-ash-discharge stoker is comparable in efficiency and reliability to that of the clinker-grinder stoker with Link Grate.

Trends in Stoker Use

The single- and multiple-retort underfeed stokers offered a wide range of fuel-burning capacities—from a few thousand pounds of steam per hour to a top of about 500 000. Although stokers were once thought capable of meeting the highest demand for capacity, eventually engineers realized that boilers to meet most central-station requirements called for more Btu's in one furnace than could be obtained by stoker firing on a practical and economic basis. In this period, roughly 1930 to 1935, central stations turned to other types of firing, such as pulverizers, for boilers of the 1 000 000-pound class. Utility use of stokers has, therefore, decreased in the last 15 years. But expanding industry has increased its use of steam; ever larger numbers of these plants utilize greater quantities of steam in their operations. Thus the field of stoker application, rather than diminishing, is continually expanding.

The Spreader Stoker—An Old Idea Modernized

A fresh start toward solving a given problem, based on a reappraisal of all influencing factors, oftentimes leads to a surprisingly successful solution. Such was the case with the spreader stoker. Its development was retarded by obstacles once considered insurmountable. Analyzing the limitations of other fuel-burning equipment and studying them with a new understanding of the coal-burning process produced the modern stoker.

D. J. Mosshart, *Engineering Manager, Stoker Dept., Westinghouse Electric Corp., South Philadelphia, Pa.*

The great number of sizes and types of boilers to fit a multiplicity of operating conditions indicates that it is impractical to build a fuel-burning equipment that is universally applicable. The influencing factors of each specific installation—location, economics of the fuel and labor supply, and others—affect the choice of a coal-burning equipment to give the most desirable performance. Also, whether to invest heavily in the equipment—machinery, auxiliaries, and automatic controls—or to use a simpler type that requires more attention and gives lower thermal efficiencies and possibly higher maintenance, is a decision that must be reached. Thus, the choice of each type and the field of its application varies. At times this results in rather sharp differences of opinion.

At present, coal burning on the grates of mechanical stokers is generally favored for the lower and medium-capacity units, but with upper limits of 300 000 to 350 000 pounds of steam per hour. The higher capacities, from about 200 000 pounds up, at the present time, are generally fired by pulverized-coal apparatus or the cyclone furnace.

The underfeed and chain- or traveling-grate equipments, although extensively developed in the past 50 years, still have some inherent limitations. They cannot handle some varieties of coal; they require a fair amount of skill and diligence in their manipulation and, under some conditions of operation, regular maintenance in the replacement of grate elements is necessary at intervals of 3 to 12 months. On the credit side, however, these equipments, if properly applied and properly handled, are the easiest to operate smokelessly and, compared to other fuel-burning equipments, discharge less fly ash.

These characteristics result from the use of a thick fire bed that burns relatively slowly. With this type of fire bed, proper fuel movement into areas of combustion requires knowledge and skill in manipulation of the equipment, because all phases of the combustion are linked together by the closely integrated functions the stoker must perform. It must, simultaneously, transport coal into the furnace, provide a platform for the fire bed, and remove ash from the burning area. Thus, adjustments of secondary ram travel, Link-Grate motion, and the ash-discharge mechanism alter the conditions within the furnace; resistance of the fuel bed to air flow, rate of ash removal, and the air-fuel ratio are all affected.

On these stokers, there is always a bed of fuel in various stages of combustion, and the volatile constituents of the coal are released from this bed at a relatively uniform rate so that they burn with minimum smoke. When heated in a thick bed, bituminous coals tend to fuse and large quantities of the smaller particles are not carried away in the combustion gases, which minimizes fly ash. Thus, stack discharge with these equipments is low. However, the large coal mass in contact with certain sections of the grate over which the coal initially travels, has no insulating ash beneath it to protect the grate elements. Cooling of these sections by flow of combustion air does not always prevent some gradual burning. Hence, there is a necessity for regular maintenance.

Other factors have been at work in recent years to change again the trends in stoker development. Increased use of coal up to the end of the last war made it difficult to obtain the

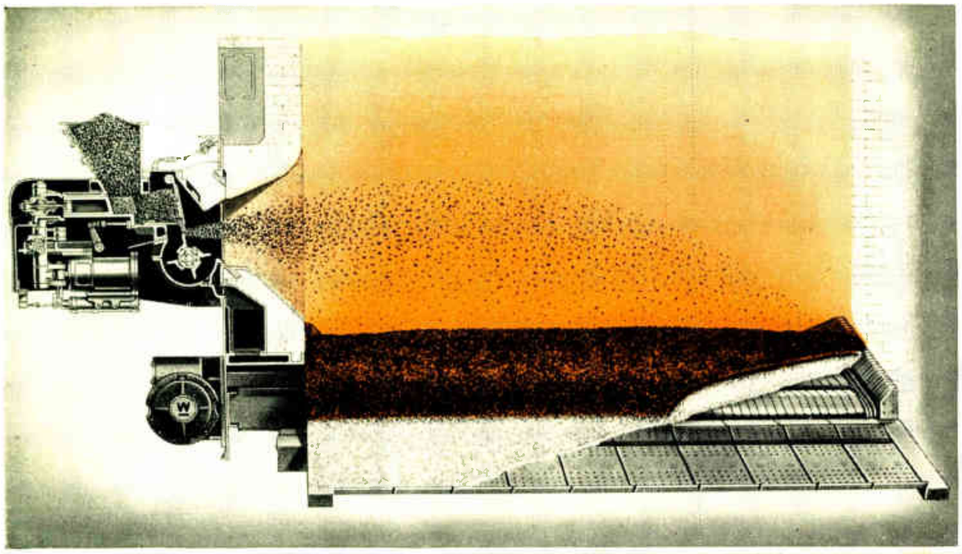


Fig. 1—For steam rates from 20 000 to 50 000 pounds per hour, the Centrafire-with-Link-Grate stoker is used. Feed and distributing mechanisms are at left; a portion of one of the side-dump grates and a part of the Link Grate are shown by the cutaway view.

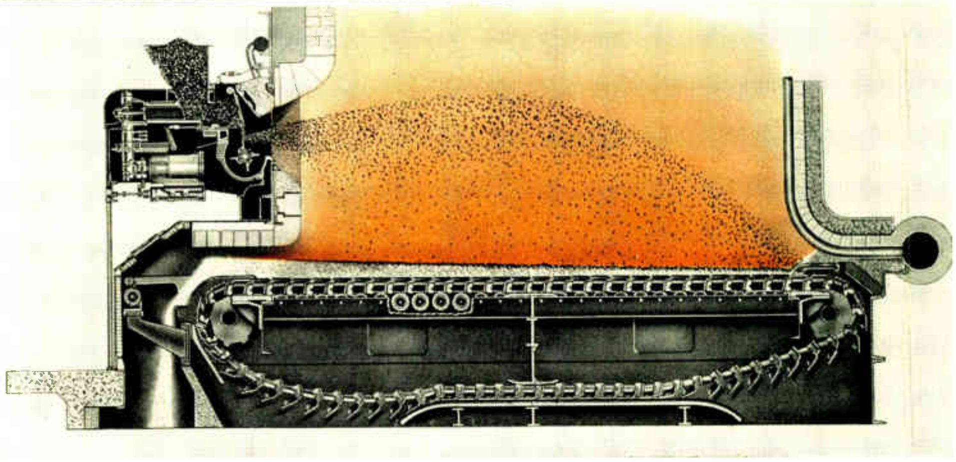


Fig. 2—The Centrafire-with-traveling-grate stoker, used on boilers having steam rates from 30 000 to 350 000 pounds per hour, is physically larger than the Link-Grate-type spreader stoker. Sketch shows coal distribution and continuous discharge of ash over the reciprocating air-seal member.

normal quality coals formerly used for underfeed and pulverized fuel firing. Also wartime experience showed that under emergency conditions of constant high demand with a shortage of skilled operating personnel, difficulties arose in maintaining output in many existing plants. A stoker was needed that could burn almost any coal and one that did not require highly skilled attendants. All this has turned attention again to the spreader stoker, which has been undergoing extensive engineering development for several years.

The Spreader Stoker

In the spreader stoker the grate structure does not transport fuel into the furnace and to the fire. It merely supports a bed of ash, which in turn supports the fire bed, and moves the ash out of the furnace. A simple and positively controllable mechanism projects fuel through the furnace atmosphere to fall in a controlled pattern on the fire bed where it burns completely within a few seconds. For this reason proper combustion requires precise control of air flow, rate of fuel feed, and fuel distribution within the furnace.

Fuel feed is isolated from actual combustion and ash removal because the fuel is distributed by a mechanism separate from the grate. Therefore, the skill and diligence required of the operator are considerably less than when all functions are combined into one integrated mechanism. Also the hazards of damage to the grate are slight, as the entire grate is covered with some ash in addition to being uniformly cooled by the combustion air. These features are largely responsible for the rapid rise in popularity of the spreader-type stoker.

A situation of excessive stack discharge is caused by two conditions that contribute to the carrying away of considerable amounts of carbon and ash in the combustion gases. When the fuel passes through the furnace atmosphere, the finer particles are caught and carried away, and carbon and ash are removed from the fuel bed itself because the fuel is burned in an extremely thin and non-fusing layer. A large, high furnace is required to burn effectively this fuel carried in suspension. Until recent years the requirement of precise control for high efficiencies and the tendency toward excessive stack discharges virtually excluded the spreader stoker from those installations where these conditions were critical.

The development of efficient mechanical dust collectors, the adoption of the large, high furnace, and the development of sensitive and accurate automatic combustion control, have provided means for overcoming these limitations of the spreader stoker. This is especially true of dust-collecting apparatus that enables recovery and return to the furnace of the partially burned fuel carried away, and reduces to a tolerable value the discharge of solids from the stack. The increased demand for the spreader stoker brought about further improvements and refinements to the components and to the system as a complete unit.

The Centrafire

The Centrafire, the Westinghouse spreader stoker, was first placed in regular service in 1944. In development, certain specific principles were made paramount. These units were built for efficiency and reliability primarily; they were built as "machine tools" to enable the operator to maintain capacity and efficiency despite wide variations in quality and sizing of coal. The controls for their operation were to be automatic to the greatest extent practicable. Also, the economic relationship between steam-power-plant product and plant equipment was a basic consideration.

The initial cost of fuel-burning equipment amounts to only 15 percent of the total capital investment in a steam generating plant. Its importance in establishing surety of the total investment and in reducing operating costs is much greater than this percentage indicates. To illustrate the relative value of the product, in one year at only 50-percent annual load factor, coal costs approximate the total investment in the entire steam-generating unit. An additional investment in fuel-burning equipment to obtain an increment of higher operating efficiency and greater reliability is readily justifiable. The prevention of a serious loss of production would easily make up for considerable additional initial expense in fuel-burning equipment to obtain this prevention.

Two basic equipments for two ranges of capacity were developed. The first, with capacities from 20 000 to 50 000 pounds of steam per hour, discharges ash from the furnace intermittently. It is designated as the Centrafire with Link Grate. The larger unit, with capacities from 30 000 to 350 000 pounds per hour, discharges ash continuously and is designated Centrafire with traveling grate.

In the spreader principle of firing employed in the Centrafire, one or more feeder units supplies fuel to the furnace and distributes it evenly over the grate. These feeding and distributing mechanisms meet extreme requirements. To achieve a uniform lateral distribution they feed the fuel positively and at a uniform rate in terms of pounds each second—this, as against a rate of hundreds or thousands of pounds per hour on underfeed stoker. The force required to throw solid matter a given distance varies considerably with particle size, thus compensation for this variation is made to obtain an even distribution in the longitudinal direction.

Wet or dry coal is fed equally well by relatively large, positive-displacement, slow-speed reciprocating rams. These rams push coal through restraining and shredding devices (called feed equalizers), from where it drops in a steady stream onto rotating blades that propel the coal into the furnace.

Direction of throw is established by the shape of the blades and is adjustable to some extent by manual positioning of a "spill plate" that controls the point of impact between coal and rotating blades. Distance of throw is controlled by varying the speed of the rotor. One setting of the spill plate and constant speed of the rotor give even distribution when the various particle sizes are in about equal proportions. If any one size predominates, there is a tendency to deposit this size in excess at one point on the grate. To correct this condition a control is provided that changes the speed of the rotor several times each minute to maintain uniform distribution of the fuel.

Centrafire with Link Grate

In the smaller unit, Centrafire with Link Grate (Fig. 1), coal is spread on a grate of articulated links, positioned midway between the furnace sidewalls and which occupies approximately two-thirds of the furnace area. Fuel is burned on this grate with a minimum amount of air. Necessary excess air is passed through the ash-discharging grates at the sides of the furnace and is caused to mix with the combustible gases by high-velocity air jets from the side walls. Ash is discharged intermittently by opening the side grates from where it drops into the ash pits. This is accomplished without reduction in boiler load, because nearly all of the fuel is burned on the central Link Grate, and with no reduction in the supply of fuel to the furnace while ash is being discharged.

This equipment is unique among spreader-type stokers; all others employ a flat grate, upon which coal is burned more or less uniformly throughout the furnace area and with excess air through all the fire bed. Those that do employ intermittent ash discharge, do so by burning out a section of the fire bed at intervals and dumping the ash from the burned-out section; thus a recurring temporary reduction in capacity necessarily accompanies this intermittent operation.

Two other principal features of the Centrafire are important. By limiting air flow through the portion of the fire beneath the entering coal stream, fewer particles are entrained in the combustion gases and dust discharges from the stack are reduced. The relatively short travel of the ash and the slight undulation provided by the Link-Grate mechanism permits the use of high fire-bed temperatures. This results in a certain amount of fusion of the ash to form friable, porous clinker and inhibits the carrying away of fine ash.

Centrafire with Traveling Grate

On the larger units a traveling grate (Fig. 2) moves from rear to front of the furnace, discharging ash continuously to the ash pit below the feeders. This grate is a series of flat plates supported on and carried by conveyor chains running over rollers. To utilize preheated air of maximum practical temperature, the grate members are separated slightly, the gap between them being closed by floating seals that allow ample freedom for expansion. The grates are thus relieved of all stresses that might accompany their propulsion on skids or sliding members.

At the discharge end of the grate, an unconventional system of sealing is employed to prevent leakage of air to the ash pit. An airtight curved structure encloses the end of the grate and the inner edge of this enclosure rests and slides on the flat portion of the grate surface. It reciprocates as the grate travels beneath it and scrapes the ash from the grate and discharges it to the ash pit. Close-fitting members or

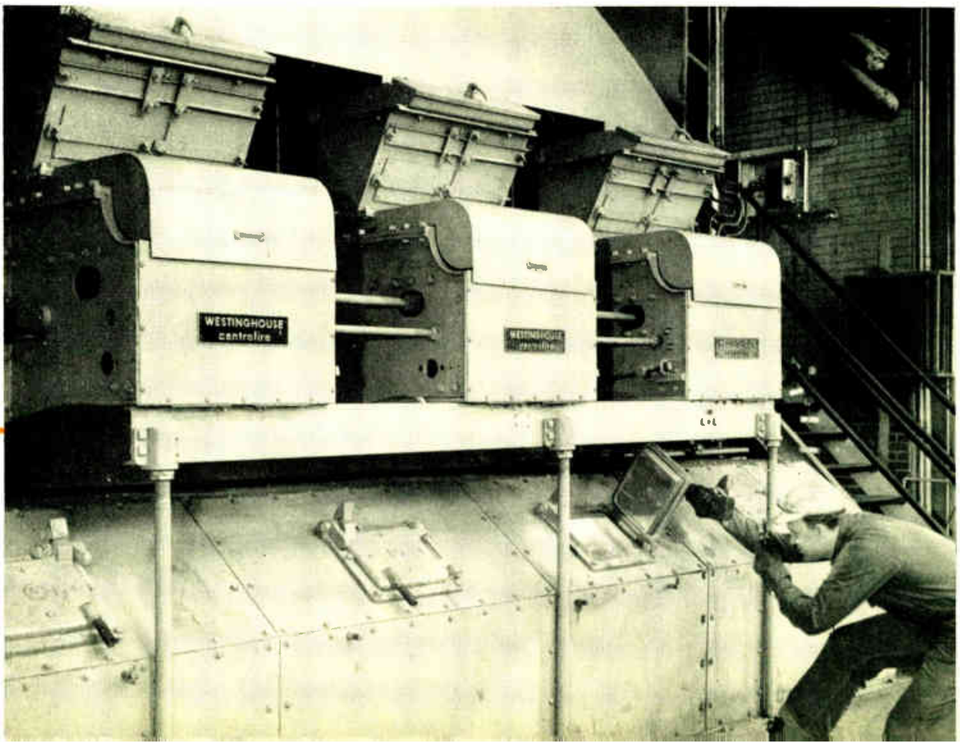


Fig. 3—The Centrafire pictured at right, under a boiler having a capacity of 85 000 pounds of steam per hour, is the initial installation of the Centrafire-with-Traveling-Grate Stoker.

flexible sliding seals are not used in the grate assembly. Because the grates need not seal tightly around the chains to provide an adequate air seal, they may expand freely without affecting the alignment of chains and sprockets.

Even distribution of coal becomes an increasingly important factor as grate size is increased. Although manual adjustment of spill plate and rotor speed produces the desired results, it is at the expense of increased attention. To reduce the manual adjustment required, an automatic control is provided. The windbox, which supplies air to the grate, is divided into two chambers, one beneath the rear half of the grate and one beneath the front half. A partition divides the space between upper and lower grate-runs into two corresponding halves. Flow of air to each half of the grate is measured by pressure drop through an orifice in the duct supplying each windbox. A variation in the flow of air through the two sections indicates a variation in the amount of fuel deposited on the two halves of the grate. These pressure variations react on sensitive control mechanisms that vary the speed of the distributing rotors to maintain even and proper distribution of coal to both halves of the grate.

Drive and Control

Both Centrafire units are driven hydraulically; the integrated hydraulic system, receiving oil from a gear pump at 75 to 150 psi, includes flow-controlling devices for each driving element. This provides accurate adjustment of each element. Positive metering and automatic control of the rate of fuel feed, automatic control of rotor speed, and automatic control providing a wide range of adjustment of grate travel are obtained in the control system. Reduction gearing, variable-speed transmissions, and chain or belt drives of primary elements are eliminated.

Operating Experience

Experience with these stokers with a fair cross section of the coals normally used for steam generation covers a wide range of conditions. It includes operation with air preheated to approximately 400 degrees F, coals having an ash content of from 6 to 30 percent and ash-fusing temperatures from 1900 to 2700 degrees. Combustion rates up to 900 000 Btu per square foot of grate per hour have been maintained.

Dust Abatement

One of the principal problems in the use of spreader stokers is that of dust emission from the stack. High-efficiency dust collectors are usually applied, and, if the collected dust is discarded, emission is within tolerable limits. However, in many cases the collected dust contains sufficient carbon to represent a substantial loss of fuel. This dust can be returned to the furnace where it re-enters the gas stream. As the dust is again carried through the furnace, part of the carbon content is burned. The remainder will be carried through the boiler to re-enter the collector, be caught, and again returned to the furnace. Although some of the returned solids do fall to the grate and combine with the ash bed, most recirculate through the boiler and collector. Eventually, the particles become so small that the collector is no longer able to separate them from the gas stream and the stack discharge exceeds tolerable limits. Constant recirculation of this material imposes severe conditions on the dust-handling system, and increases maintenance requirements.

Best results should be obtained by adoption of a compromise system between the extremes of total rejection and total recirculation of collected dust. This can be done by installing dust-storage hoppers in parallel with the dust-recirculating system. Automatically operated dust valves, arranged to function in sequence, can return all collected material for a specified interval (ten minutes) and then, for a shorter interval (thirty seconds), the collected dust can be diverted to the storage hopper for rejection. This operating cycle can readily be adjusted to maintain sufficiently high percentage of collection with but slight loss of unburned carbon in the rejected material.

Conclusions

Coal-burning equipments and the fields of application of each are not yet stable and probably never will be. All manufacturers are constantly developing or improving equipment and its application. The spreader stoker is firmly established in the field; its present popularity largely stems from the fact that it is almost foolproof. It will maintain boiler output with a wider variation in fuel and quality of operating attention than any other equipment. But, like any other coal-burning equipment, this stoker is still a tool and not a completely automatic self-sufficient machine.

The entire stoker industry guarantees thermal performance of its equipment based on certain specific operating conditions. These guarantees of performance are made in good faith, but are based on operation of the equipment under test conditions and supervised by the manufacturer's representative. Under such conditions, with necessary attention to readjustment of controls affecting all the various functions, predicted or guaranteed performance will normally be obtained.

If, in daily operation, the same conditions are maintained, and the same attention and skill are applied, performance will equal that obtained on test. This relationship between test and daily performance is rarely encountered. Efficient, low-cost daily operation of a stoker equipped with suitable and effective means of adjustment results only from proper handling of the equipment, and is not determined by guarantees or prediction of performance. The Centrafire equipment provides the operator with a versatile, responsive tool that enables him to achieve low operating costs with minimum effort.

More Power for More Paper

A modernization of a South Carolina paper mill now underway well illustrates three things: how rapidly production techniques and machinery improve, the trend for industry to raise production levels, and that, in so doing, the quantity of electrical energy required per unit of production rises.

The present drive in this mill was installed only 13 years ago and was fully modern at the time. It permitted operation of a 240-inch-wide kraft paper machine at 1400 feet per minute. Power for this operation was provided by a 1000-kw generator and a total of 1560 hp in motors ranging in size from 30 to 300 hp. The machine is now being rebuilt to increase output at the original speed (although a future increase in speed is contemplated). To achieve this, another 1000-kw generator is being installed and the drives for several sections are being increased in rating—up to a maximum of 500 hp. The total motor horsepower will be increased to 1910 hp. In addition to increasing machine output the addition of a second 1000-kw power supply will permit savings in renewal parts and allow operation of the machine at reduced capacity on only one generator when output requirements or servicing needs make it desirable.

Stories of RESEARCH

Vitamins for the Mercury-Vapor Lamp

What vitamins are to humans, phosphors are to light sources. Gaseous-discharge lamps, in particular, are prone to deficiencies in color output, some of which can be corrected by fluorescent bulb coatings. For example, the mercury-vapor lamp inherently is deficient in both the red and blue-green ends of the color spectrum. As the gas pressure and temperature of the lamp are increased, the output not only increases, i.e., becomes more efficient, but also shifts from the ultraviolet toward the visible. Over the past few decades lamp engineers have succeeded in pushing the pressure and temperature to sufficient heights to provide a highly efficient high-pressure lamp. However, ordinary mercury-vapor lamps are still not rich enough in the red and blue-green regions to satisfy more exacting color requirements.

Although several promising methods of color correction (such as the addition of small amounts of cadmium to the mercury vapor) were then being investigated, the Westinghouse Lamp Division decided in 1946 to look also into a less-apparent means—that of correction with phosphors capable of operating at high temperature. Although this seems an obvious choice in view of the success along these lines with the fluorescent lamp, little was known at that time about the reactions of phosphors, either as to chemical stability or efficiency, under conditions well above room temperature. A young research engineer named Luke Thorington was assigned to investigate the dependence of phosphors on temperature, under the direction of Dr. Rudolph Nagy.

Thorington first checked the characteristics of known phosphors, picked more or less at random. Most showed a definite tendency to be most efficient within a specific range of temperatures, and to be less efficient at either higher or lower temperatures. Although most phosphors reached their maximum efficiency at relatively low temperature, or were chemically unstable at higher temperatures, a few gave definite promise of both chemical stability and high efficiency at the elevated temperatures of the high-pressure mercury-vapor lamp, i.e., upwards of 100 degrees C.

Thus encouraged, Thorington next investigated phosphors that could provide the necessary color correction. Among the many studied was magnesium germanate, which was known to fluoresce a weak red under ultraviolet light of 3650 Angstroms. But although the color was obviously a step in the right direction, nothing was known as to its temperature dependence. Experiments showed that it was not as satisfactory as desired.

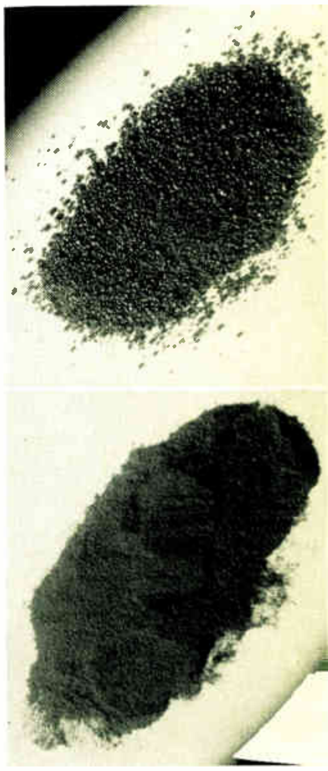
However, remembering a fact that he had noted in his many experiments with phosphors, namely, that as elements with lower atomic number (in a given atomic group) are chemically combined with a given phosphor the temperature of peak efficiency increases, Thorington tried several substitutions in the compound. Especially successful was the element of fluorine, which effected a twofold increase in overall efficiency both at room and at elevated temperatures. An experimental mercury-vapor lamp with its outer envelope coated with the new phosphor, magnesium fluorogermanate, showed a 700 percent increase in the red output of the lamp without a serious absorption of visible light. Moreover, the phosphor was most efficient at about 350 degrees C!

Although successful in finding a suitable high-temperature phosphor, Thorington is by no means convinced that the possibilities have been exhausted. His experiments indicate a strong likelihood of phosphors that are chemically stable and most efficient at even greater temperatures. If Thorington's expectations are borne out, several interesting prospects give promise. If a phosphor that is sufficiently stable and efficient can be found, it might well be coated directly on the arc tube, rather than on the envelope. This would mean smaller, more compact lamps.

Ductile Vanadium Comes of Age

To achieve ductile forms of some metals, metallurgists often attempt a "great trees from little acorns" process, in which a finely powdered pure metal is compressed and sintered into a large solid mass. Engineers of the Lamp Research Department have now developed a new process for making powdery fine vanadium, which makes possible for the first time the production of this metal in any shape or size.

Many of the rare metals, such as vanadium, are extremely hard and brittle when prepared by older methods. They are therefore extremely difficult to work by conventional methods. These same metals, when the oxides and other impurities are removed, assume desirable characteristics. Pure vanadium, for example, is ductile, only moderately hard, and has high tensile strength. But the trick lies in obtaining the metal in pure form. Because its high melting point (about 1700 degrees C) and susceptibility to oxidation complicate any melting process, such as is used for iron, pure vanadium is usually made by chemically reducing its oxides with a reagent, which can later be separated from the solid metal. The familiar Marden and Rich process, with subsequent improvements, has been the generally accepted method for about 20 years, but its product is a fine bead-like vanadium, which is not adaptable to large-scale processes. Though relatively tiny (see upper sample in picture), these beads are large enough that they cannot be successfully combined by compression and sintering, possibly because the areas in contact are not sufficiently large to allow good adhesion between particles.



The new Westinghouse process, developed primarily through the efforts of research engineers Edward Gregory, W. C. Lilliendahl, and Donald Wroughton, results in a fine, powdered metal, scarcely more coarse than talcum powder (see lower sample in picture). Essentially this process consists of reducing the starting product of vanadium pentoxide (V_2O_5) to the trioxide by reaction with hydrogen, and then completing the reduction with metallic calcium and calcium chloride. The product is pure vanadium, which can be formed into ductile wire or sheet by conventional powder metallurgy and rolling operations.

The advantages of the process are considerable. Not only is there a marked reduction in the quantity of reducing agent required, as compared to the Marden-Rich process, but the end product is much more versatile. Because the fine powder can easily be compressed and sintered into any shape, pieces of pure ductile vanadium of any size and shape are now possible. With the bead-type metal, the largest piece possible was a small rod, less than one-quarter inch in diameter.

The relative importance of this new process is as yet difficult to evaluate. However certain facts are known. Vanadium is an abundant element, ranking eighth among structural metals, sandwiched in between magnesium and nickel. Due to its excellent physical properties, it will likely prove valuable as an alloying agent. For example, alloyed with increasingly common titanium and zirconium, it makes possible hardening of these metals by heat treatment. Uses for the pure metal may also be uncovered.

For Safer Shipme

Last year about 25 million dollars' worth of home appliances and allied metal-finished products were damaged in shipment between factory and user. This meant 25 million dollars' worth of headaches, delays, disappointments, waste, and, inevitably, a cost of household appliances that was higher than necessary.

About 1930, Ralph F. Bisbee, Manager of Quality Control, Westinghouse Appliance Division, pondered the staggering annual national loss and decided that something should be done about it. Rolling a package down a flight of stairs, dropping it to a hard floor, or even making a round-trip test shipment, while helpful, did not seem to Bisbee to be a scientific approach to the problem. He began some research—to find out exactly what happens to a packaged product after it leaves the company shipping department. First, obviously, was to learn exactly what happens to packages in transit. To obtain this data several test round-trip shipments were made of normally packaged products to which shock recorders were affixed. These are clock-driven devices that record on chart paper the time and severity of shocks.

Shipments of various sizes and weights of appliances were made: electric ranges, roasters, refrigerators, etc. Shipments were made by all commercial forms of transportation: rail freight, express, truck, air. In some cases, the packages with their "clocks"—as the recorders are sometimes called by transportation workers, who can occasionally hear the relentless ticking—made their circuitous trips unaccompanied. In other tests, an observer went with the shipment to gather information on the treatment accorded the package in addition to that provided the vibration and shock recorders, such as the time and kind of physical handling given the shipment when being moved from one vehicle to another.

The findings were surprising. The shocks that packaged products receive far exceeded what transportation people believed normal. In almost every case the package was subjected at some point in transit to shocks of zone-5 magnitude (above 8 g). Sometimes these occurred in rail shipments when the freight car was bumped hard—mostly the severest shocks were registered as the package was being handled, as to and from a truck or when unloaded from a plane. For example, shock-recorder tests showed that, when a packaged product weighing 300 pounds is dropped on one end no more than 10 inches—a very common occurrence in unloading from a car, truck, or hand truck—the shocks are equivalent to those received in a freight car traveling at 11 miles per hour at impact. And the railroads consider that any impact above six miles per hour is bad handling.

The data accumulated with these "ride" recorders resulted in the creation of two standard shock tests. For packages of between 100 and 1000 pounds, an incline-plane shock stand is used. The packaged product on a car rides down this incline a prescribed distance and smacks into an abutment. The relationship of the shocks thus received to those actually incurred in normal transit is known. The second shock test, for lighter packages, is the simple one of dropping them from a bottom-opening platform a prescribed height above a solid floor. These are repeated for different package conditions.

So much for shock. Then came the war. The enormous experience gained in building all sorts of war materials, shipping them to all parts of the world, and using them under war conditions taught another thing—the importance of vibration. The ability of a package to withstand shock is not the whole story. If shock is preceded by prolonged vibration, the package is far more likely to be damaged than if subjected to

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Prepared by Charles A. Scarlott, based on information provided by the Quality Control Department, Westinghouse Appliance Division, Mansfield, Ohio.

Two types of standardized pre-shipment tests give quite accurate information as to what damage a packaged product will meet in transit: vibration (left) and shock (center).

A ride-recorder mounted for test shipment.

The most critical period in the life of a household appliance is that between factory door and customer's door. "Damaged in transit" happens too often to products, a fate that nullifies the finest of engineering, manufacturing, and quality-control skills. Something, fortunately, is being done to reduce damage to goods en route.

shock alone. Parts are loosened or weakened by vibration, thus allowing a blow to cause injury. This led, since the war, to vibration studies in all sorts of transit.

As a result, two tests have been devised by which the shipability of a packaged product is determined: one is vibration, the other shock. Furthermore, these tests are now nationally accepted standards and have resulted in the formation of a National Safe Transit Committee, participated in by shippers, transportation companies, and packaging companies. This group is working to increase acceptance of the standard preshipment test procedures, to improve packaging techniques, and to reduce hazards in transit.

At Westinghouse the lessons of Bisbee's research are applied in several ways. A new appliance at the time of its original design—even while in the planning stage—is examined from the standpoint of shipability. When prototypes of the new appliance are available, the packaging experts go to work. The appliance and its package are studied as a unit from all angles. Sometimes shipability is improved by changing or strengthening the container; sometimes by altering the product itself. In the case of one electric range design, certain braces costing a dollar were removed from the range itself while the container was strengthened at a cost of fifty cents. Thus there was a net saving of fifty cents at the same time that the damage in shipment on this range was very significantly reduced.

In the case of a new design of the automatic washing machine, the preshipment tests indicated that a high percentage would be received at their destination with the motor out of position, enough that they would be inoperative. A re-examination of the design showed that this was due to a mounting-bolt construction that would not always hold the motor in place after vibration and handling shocks. This was changed and subsequent field reports indicated negligible shipping damage from this cause.

A similar situation developed with a new design of rigid-mount automatic washing machine. Shipping difficulty was predicted by the preshipment tests because of a structural weakness due to welding and support bolts. After a change was made, large-scale shipment began with no significant reports of damage in transit.

Such episodes have been numerous. The object always is to secure a product and its container of least weight, least package cost, and with the least prospect of damage in shipment.

The results! The worst product from a shipment standpoint in the appliance field is one that includes both porcelain and glass. At Westinghouse this is the electric range. In 1930, the ranges damaged to various degrees in shipment ran to 18 percent. After the lessons of the shock-test data were placed in practice, the shipping damage dropped to one percent. That was in 1941. This represented a whopping big improvement that should satisfy anyone. But not Bisbee and his crew. Since the war, and with the results of both the vibration and shock tests, Westinghouse range damage is down to 0.6 percent. The national average for some manufacturers who are not yet participating in this program still runs around 12 percent. By applying the Safe Transit Committee tests to Westinghouse electric ranges a direct saving of almost $21 000 was effected—in addition to the reduction in inconveniences and improvement in customer good will.

In short, a scientific approach is being taken to reduce the annual toll of damage to products in shipment—a movement destined to benefit everyone from designer to eventual user. It is hoped that this program will be adopted by manufacturers generally because shipping rates reflect the national average experience. They are not based on the performance of a few. Enormous national economies are potential.

When a packaged product successfully passes the two pre-shipment tests it is entitled to a label to that effect. Damage to a package so labeled is accepted as caused by abnormally rough handling.

A chart being removed from a ride recorder.
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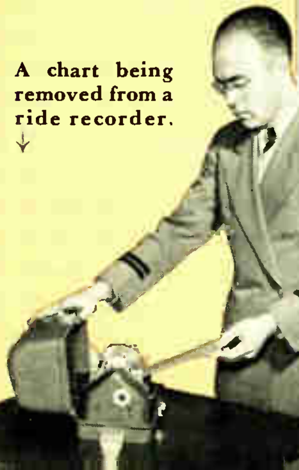


Resistance Welding—An Expanding Field

The principle that describes resistance welding is quite simple—if enough current is passed through a metal-to-metal joint, the temperature reaches sufficient magnitude to fuse the two. The earliest resistance welding was based on this limited knowledge, largely because no one knew what factors affected the soundness of welds. All control was vested in an operator's judgment. Now, however, resistance welding is a specialized science, with split-second timing and accurate control of all the variables, producing consistent, sound results.

C. B. STADUM, *Electronic Control Engineering, Westinghouse Electric Corporation, Buffalo, New York*

THE FIRST resistance weld was made probably by a man who accidentally short circuited the terminals of a battery. Innumerable others have accidentally made spot welds by putting screwdrivers into lamp sockets to see if they were "hot." However, spot welding has grown from a haphazard short-circuiting of batteries and unthinking wielding of screwdrivers to a highly specialized science.

Resistance welding is a process wherein a high current is passed through two metals to be joined. The electrodes are applied to the work with high pressure, thereby localizing the current path and creating a weld in the desired position only. This high pressure prevents the too frequent "spitting" or sputtering around the electrodes. A welding transformer supplies the extremely low secondary voltage (about 1 to 15 volts) that is used to drive the current through the electrodes and the two pieces to be joined.

Early Controls

The first control equipment (used about 1890) was undoubtedly either a pushbutton or a knife switch. The electrodes were clamped on the metals to be welded and the switch closed until the experimenter decided that enough heat had been generated to create a weld. Like the welding machine of 1890, present-day machines have a control mechanism to start and stop the current; however, control mechanisms have been refined to such a point that precision amounts of current and time, and current wave shape are controlled by the operator of the welding machine.

Until the 1920's, the resistance-welding process was largely a novelty rather than a commercial practicality. Because the currents of welding machines were so high, it was difficult to obtain control equipment to switch them on and off. The magnetic contactor, with its higher current-carrying capacity, superseded the pushbutton and knife switch and is still used extensively on small welding machines. Since welding current of hundreds or thousands of amperes exists for a fraction of a second, the duty imposed upon a magnetic contactor is extremely severe. The destructive hammering of contactors prevents their use on high-current and rapid-fire applications.

With the invention of the thyratron tube, another step was taken in the evolution of welding—electronic control. The first tube control was the "series transformer" system. A transformer was placed in series with the power line and the primary of the welding transformer. During standby conditions the secondary of the series transformer was left open. Because of the high impedance of the series transformer, little current existed in its windings and, consequently, only small currents in the welding transformer. When current was de-

Fundamentals of Resistance Welding

Resistance welding is essentially a process in which enough localized heating is produced by the passage of electric current through the parts and the electrodes to fuse two metals. The heat generated in these pieces is a function of the current through the weld, the resistance, and the time ($W = I^2Rt$). Not all the heat, of course, is used in producing the weld—some is carried away by the electrodes, which are usually water cooled, and some by the metal itself.

Each of these variables—current, resistance, and time—must be carefully judged in making a sound resistance weld. In general, any two metals can be joined by resistance welding, but unless these three factors are carefully considered the resultant "weld" will not be satisfactory. Welds between two dissimilar metals that do not alloy are particularly difficult, and the bond produced is not as strong as that attained with two similar metals. Also the best welds are made with two metals of approximately the same shape and thickness, the same resistance and melting point.

In spot welding, a definite sequence of events must be accurately timed. To begin with, full pressure is applied to the work by the electrodes while the current is off. This consumes from 3 to 60 cycles, depending upon the welding conditions desired, and is called the *squeeze time*. Next, with full electrode pressure, current is applied for a duration of 3 to 30 cycles, known as the *weld time*. After the current is shut off, the pressure is still maintained for a period of from 3 to 60 cycles—called the *hold time*—while the metals cool to a point where they regain most of their strength. This is followed by a removal of pressure, separation of electrodes, and movement of the work to the next weld position—all this being known as the *off time*, and consuming from 3 to 60 cycles. This series of events is then repeated. Automatic sequencing devices now time all of these events precisely so that a sound weld is obtained.

In some instances, particularly where thick materials are involved, the weld time is divided into heating and cooling intervals, to allow thorough and uniform heating. This method is called *pulsation timing*.

Welding controls, in general, perform four functions: (1) they stop and start the welding current, (2) control the amount of current, (3) time the welding current, and (4) time the sequence of events.

The point on the voltage wave at which the current is switched on has a marked effect on the weld. If the circuit is energized at the wrong point on the voltage wave (i.e., at the wrong power-factor angle) transients occur, distorting the current wave shape, and causing inconsistent welds. Since the duration of these transients is short, their effect on weld currents of long duration is hardly noticeable; however, where the duration of current is short the effect of these transients on the weld is noticeable. Controls that start the welding current at random points on the voltage wave are called *asynchronous*, or non-synchronous; those that initiate current at the proper power-factor angle are called *synchronous* controls.

sired in the welding transformer, the secondary of the series transformer was short circuited with a pair of thyratrons. This changed the overall impedance of the series transformer and allowed a considerable current in the primary of the welding transformer. The series transformer used two thyratrons operated at extremely high voltage (2000–3000 volts). This high voltage was necessary to handle the kva demanded by the welding machine—a high voltage and the normally low currents handled by the thyratrons gave the necessary power. Such a system had applications for seam welding where weld times are a few cycles "on" and a few "off." Such precision timing is easily handled by thyratrons. However, these tubes are limited by the amount of current they can carry.

Another disadvantage of the series-transformer system was the use of relatively high voltages in the control circuits. These voltages caused considerable trouble due to breakdown of component parts.

Still another disadvantage was that the current could not be shut off entirely; this resulted in a small amount of sparking at the electrodes whenever the electrodes came in contact with or left the work. Sparking results in surface markings, both of the work and the electrodes. This difficulty was overcome only by adding a contactor to open the power circuit between each welding operation.

Advent of Ignitron Welding Controls

The year 1932 marked the birth of resistance-welding equipment as it is known today, for then the ignitron rectifier was invented. The ignitron, with its virtually unlimited current-carrying capacity, fits perfectly into a welding system. The first ignitron welding control was designed in 1932 and built in the early part of 1933. It consisted of two glass ignitrons in inverse parallel, or back-to-back arrangement, in series with the primary of the welding transformer. The timing circuit for this first spot timer consisted of a synchronously driven motor with a cam switch to stop and start the ignitrons.

In the following three years, further improvements were made in the design of glass ignitrons and great strides were made in increasing the ignitron's capacity. Later, completely electronic timers were developed. Because the ignitron rapidly proved a very useful tool for resistance welding, designers were encouraged to increase size and ratings of ignitrons and progress to the next logical step—manufacture of steel-jacketed, water-cooled ignitrons. The first metal-tube applications appeared in 1935, when they were used in the fabrication of railroad cars. Between 1935 and 1937 the ratings of these tubes increased while their size decreased. Also, additional laboratory work was being done to eliminate pumping equipment required to keep a vacuum in the tube. About 1937 the

Fig. 1

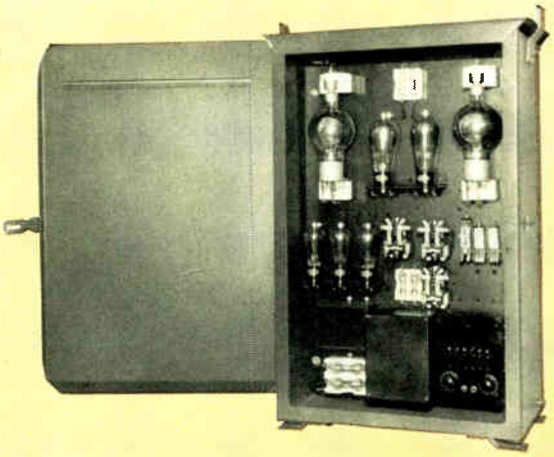


Fig. 1—An early ignitron spot-welding control, built in 1933. The ignitrons are the larger tubes in the upper corners of the cabinet. Fig. 2—One of the first applications of water-cooled ignitrons on a seam-welding control. Fig. 3—A spot welder of about 1942. Note the small sequence panel shown in upper left corner.

Fig. 2

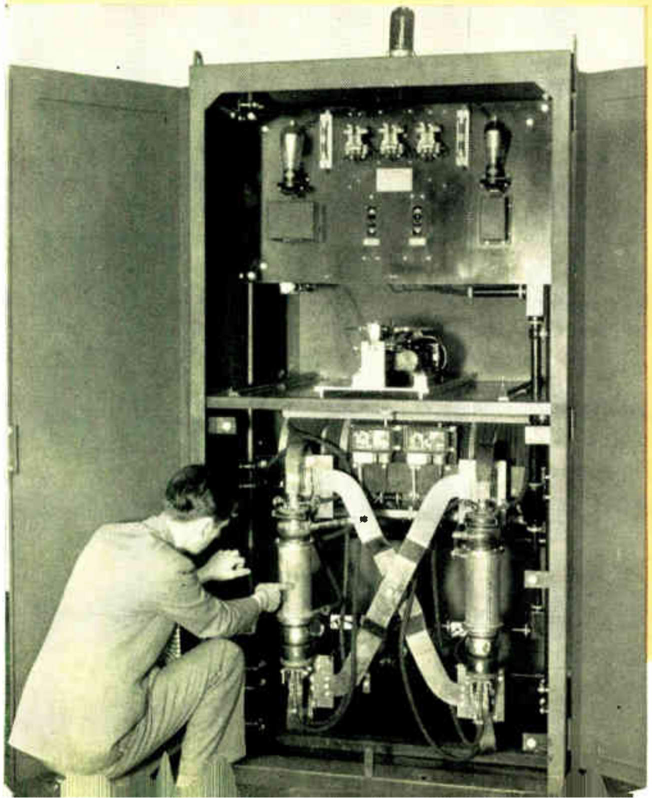
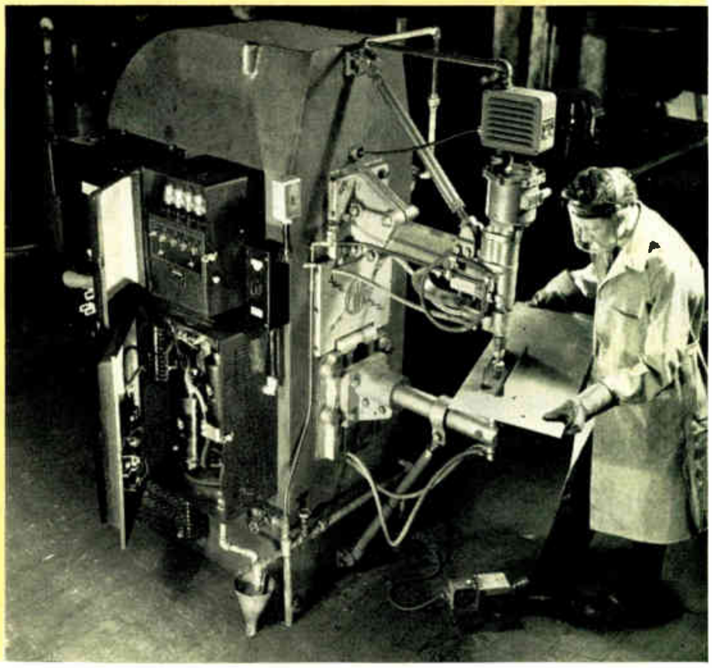


Fig. 3



first application of the "sealed-off" ignitron in a welding control was developed, further simplifying equipment needs.

New Welding Systems Appear

In the middle 1930's only the simpler type of welding control systems was used. Little attention was given to the investigation and development of the various timing and heating cycles needed to achieve sound welding results. The simple spot- and seam-type sequences were known, but refinements did not occur for some time. The sequence panel, a device that coordinates the electrical action of the welding control and the mechanical action of the welding machine, was an extremely crude, exceptionally large device. Built along the same lines as large motor controls, it differed markedly from the small, packaged timing units of today.

After the ignitron had been developed to the point where it was a reliable power switch, engineers had an opportunity to investigate the effect of different welding systems and timing patterns, and to make refinements on existing timing patterns. The period of 1937 to 1945 introduced several new types of welding systems.

It became apparent in the 1930's that the power demand created by a single-phase welding control system operating for such a short period of time would cause high demands on the power lines. This, of course, resulted in excess voltage drop, with accompanying light flicker. Methods were soon devised to reduce this high demand and spread the reduced demand over three phases. One of the first systems was the magnetic energy-storage system. Here ignitrons were used to create a d-c bias in a large reactor or welding transformer, then the current was ruptured rapidly. The rupture of so much energy resulted in a high current surge in the secondary of the welding transformer, and this surge was used for welding. Many installations of this type were made in the aircraft industry to weld aluminum. Its advantages were that the demand was spread over three lines, and the inherently brief current, which was useful for spot welding aluminum. Its limitations were that the short-duration current could not be used successfully for welding mild steel, which generally demands low current and long time.

Types of Resistance Welding

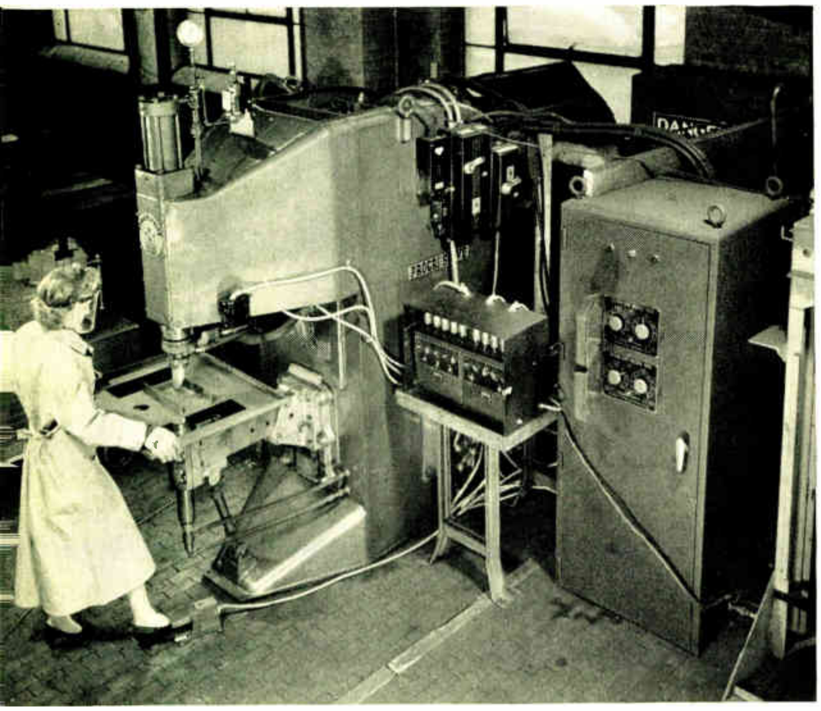
Spot welding, as its name implies, is a method of joining two or more metals by concentrating welding current and pressure on a relatively small area, using small electrodes. Such welding can be accomplished with portable tools, such as the *gun welder*, in which the electrodes, arms, and means of applying pressure are connected to the welding transformer by heavy cables, and thus can be moved independently of heavier equipment such as transformers and controls.

Other spot-welding equipment, such as the *rocker-arm* welder, is not portable. Here the work is moved into alignment by an operator (or by a mechanical feeding device) and must be repositioned for each separate weld. The *multispot*, or *hydromatic* welder is usually built for a specific welding operation, and has a number of electrodes that operate in sequence to weld a complete assembly.

Seam welding is similar to spot welding except that wheels replace the spot type of electrodes. The rate of welding speed with this welding method usually varies from 2 to 100 feet per minute. The usual seam weld is one in which two pieces are overlapped for joining, although some special machines make butt seams, such as in welding tubes, or pipe.

A third type of resistance welding is the *projection* method. This is of two general kinds—*butt* and *flash* welding. In butt welding, the two pieces to be joined are held together firmly and current passed through the joint. When sufficiently heated the two are forced together under high pressure, giving a solid joint. In flash welding, the pieces are held together only lightly while current is passed through them. Due to irregularities of the metal surfaces, considerable flashing occurs and the surfaces are "burned" smooth, as well as heated. They are then joined under high pressure.

Fig. 4—This spot-welding control is typical of the many diversified models built during the period from 1937 to 1945.



Another system developed to reduce kva demand was the capacitor-type energy-storage system. A combination of thyratrons and ignitrons was used to charge a capacitor bank to a high voltage. This charging action was slow and the kva demand was low. When a weld was to be made the energy in the capacitor bank was "dumped" through the primary of the welding transformer, which resulted in a high current surge through the primary and secondary of the welding transformer. This scheme had the lowest kva demand of any system, but it also had the disadvantage of having extremely short time duration, which is not suitable for welding ferrous metals. Both the magnetic- and the capacitor-type systems were known before the start of World War II, were used during the war years, and were valuable in the manufacture of aluminum and stainless-steel airplane parts.

A further modification of the single-phase system—the series-capacitor method—was also applied before and during the war. The power factor of the single-phase system is generally low, averaging around 40 percent, in some cases being as low as 20 percent. To correct for this low power factor and reduce the demand on the line, capacitors are placed in series with welding transformers, which corrects the power factor to 100 percent and accordingly lowers the demand on the power line. During the 1937–1944 period, several applications of this type were made for both aluminum and steel spot welding. These generally found use in steel welding where long times were necessary, and where high demand currents could not be tolerated.

This period was also characterized by refinement and decrease in size of controls. The sequence panel, for example, decreased in size from a six-foot monstrosity to a 15-inch midget. This was made possible by the development of small electron tubes and judicious choice of parts. Work was done on increasing the voltages at which ignitrons and welding controls operated. The first 2300-volt installations were made. Power was doubled by paralleling large ignitrons.

Bench-welding timers also made their debut. To weld jewelry, vacuum tubes, etc., precise welding controls are required. In general these consist of controls whose main switching devices are thyratrons rather than ignitrons. Various midget models were made available. Some would pass only a half cycle of welding current; others would pass welding current from one to ten cycles.

During the war years the basis of scientific production of spot welds was made. Many research laboratories, educational institutions, and aircraft companies did basic work on the requirements to make a weld. This work was necessary to discover means of producing consistently good welds for aircraft work. Welding schedules for stainless steel, aluminum, magnesium, Monel, Inconnell, and many other metals and alloys, were established during this period.

Consolidation of Welding Control Design

Prior to 1945, whenever a new control function was desired, a whole new welding control was developed specifically for this application. As the number of functions increased, it became obvious that consolidation of designs was necessary. Many welding controls whose functions were similar had nothing in common with one another—circuits were different, size was different, and method of construction was different. In 1945, control engineers made the first steps in obtaining unified or "functionalized" design. The required functions were physically separated from one another in design and construction. Each electrical function was separated from others and made into a panel entity. In other words, each main function like spot timing, pulsation timing, heat control, current regulation, etc., was put on an individual panel capable of being slid into a cubicle. By combining various types of panels, virtually any type of sequencing, regulation, or timing system could be achieved from a few panels.

Up to the present time there have been two basic lines of welding control—synchronous and non-synchronous. The non-synchronous has been the more common "workhorse," while the synchronous has been the precision control used on the most difficult welding jobs. Today the two types have been consolidated into a single welding control. In addition, the size has been reduced. The height of the new units, the floor space required, and the area taken by electrical components have been reduced to about half that required by older units. Also, virtually all parts that wear (such as relays) have been eliminated in favor of electronic tubes. The precision and speed of the most inexpensive 1950-model welding control exceed those of the highest priced 1940 models.

The Low-Frequency Converter System

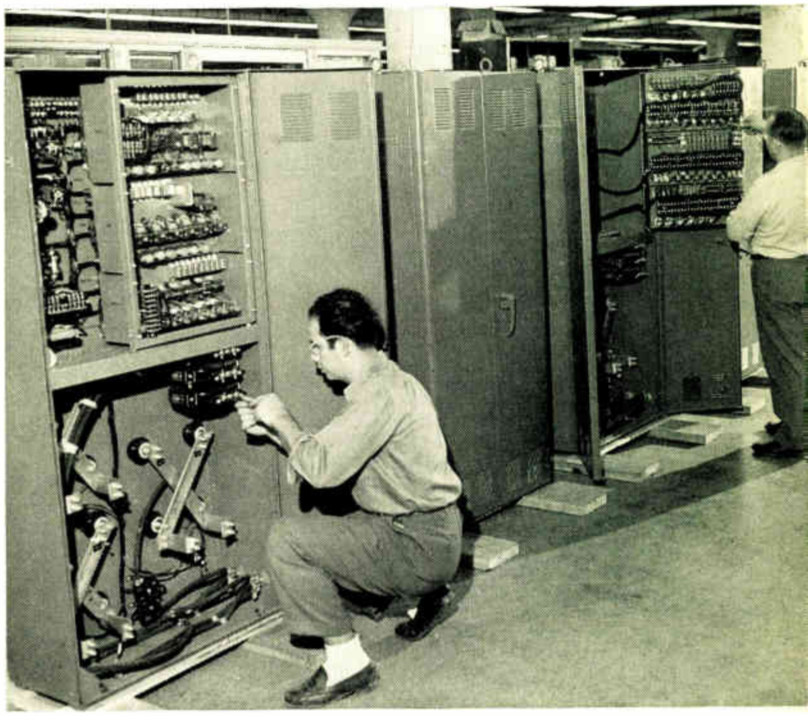
The present stage of control development has also produced another type of welding system—the low-frequency converter. Here three-phase or single-phase power at line frequency is converted electronically into a low-frequency single-phase source, which is fed into the secondary of the welding machine. At low frequency (between 5 and 12 cycles per second) the reactive effect of the welding transformer is nullified and consequently the kva demand reduced. If the converter is a three-phase control, it is, of course, possible to spread this reduced demand over three phases.

In a low-frequency system, the secondary current wave shape is not the customary sine wave, but has a slowly rising characteristic. The odd secondary current wave shape obtained in the low-frequency system has brought to light the most important realization of recent years—the effect of wave shape on welding conditions. During the war, work on magnetic and energy-storage systems showed that the wave shape of the current had an effect on weldability of metals. It affects the amount of "spitting" at the electrodes of a machine; it affects the amount of material "pick-up" that occurs on the electrodes, and it affects the amount of cracking or voids in the nugget of the weld. Especially are these factors true on hard-to-weld metals like aluminum and magnesium. The three-phase system, which has a low rate of current rise, enables the electrodes to become securely embedded in the surface of the work before the high currents are applied. This results in low heating at the junction of the electrode and the work piece. High localized heating, normally found in other types of welding control, causes pick-up of aluminum by the electrodes, and "spitting" at the work surface. Since the low-frequency system has a slow rate of rise of current, aluminum welding is greatly facilitated by this type of control. This has resulted in the re-examination of the single-phase welding control, which is by far the most popular. "Slope controls" are now being used on single-phase systems to vary the rate of current rise and give all the welding advantages inherent in a frequency-converting system.

Other Recent Developments

Such remarkable improvement has been made by varying the rate of rise of welding current that additional examination has been made of the influence of varying the rate of current decay. It was found that by continuing to apply a reduced current after the weld had been made, violent cooling or quenching at the weld could be stopped. This in turn has made welds more ductile, or has prevented crack formation in the welds. Such improvements in weld quality have been made possible by the recently developed automatic heat-con-

Fig. 5—A recently developed three-phase to single-phase, low-frequency converter. This is especially useful in welding aluminum.



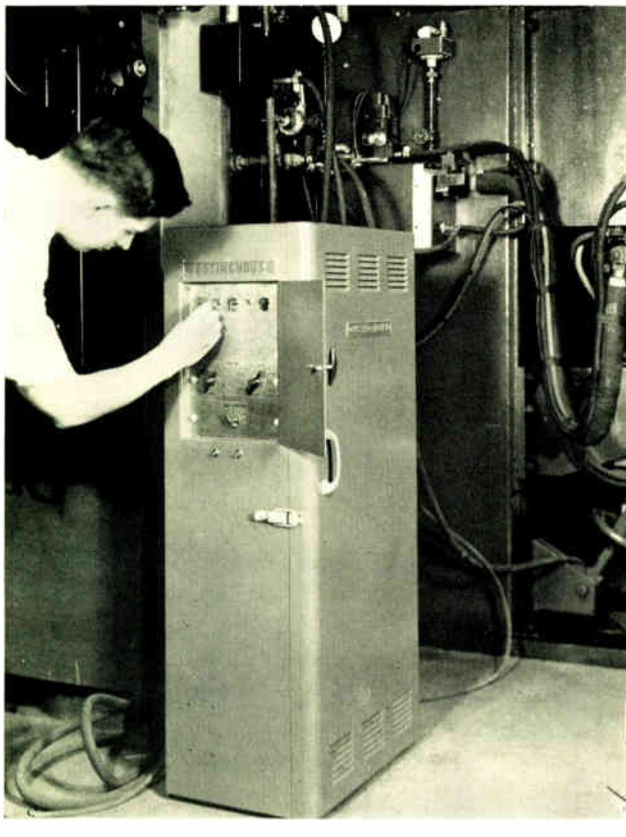
trol circuits, and fully electronic timing circuits included in the latest consolidated resistance-welding controls.

In recent years multi-electrode welding machines have found wide use. Several electrodes (sometimes over 100) are built into a single welding machine. These electrodes carry current from several welding transformers whose primaries are distributed over three phases. This provides equal distribution of kva over the three lines. The purpose of a machine of this type is to eliminate handling of the work. Large sections, such as the floor pans of an automobile, are fed into one of these machines, together with several small parts to be fastened to the floor pan. When all pieces are in place, a complete set of electrodes of the combination welding machine are lowered, and current is passed through each of them. Thus, it is possible to make 100 or 200 welds in a fraction of a second. Naturally this reduces cost, since each weld would otherwise have to be made by a single welding machine and a single operator. This single-purpose type of welding machine has been used chiefly in the automotive field. The controls built for these installations are three phase, which have built-in timing and coordinating circuits that intermittently control the mechanical actions of the machine and electrical operation of the hundreds of electrodes.

In the last few years welding speeds, especially in the gun-welding field, have increased tremendously. During the war the maximum speed of spot welders was roughly 120 spots per minute. For the gun welder, the speeds ranged up to 200 spots per minute—but with very poor results. In the fall of 1947 a new type of high-speed voltage control was demonstrated at 450 individual spots per minute. In November, 1949 new improvements were made in this type of welding machine, and on a demonstration a gun welder was run at 720 spots per minute! This is equivalent to running 12 complete and individual spots per second, or one weld every five cycles. Four different timing functions are completed during these five cycles—the head of the welding machine is allowed to come down, the weld is made, the head is kept on the work until it is cooled, and then is raised and lowered to start a second weld. Each of these four functions is electronically timed in a total of five cycles. In general this speed is probably far in excess of normal requirements, but the trend is to obtain extremely high-speed welding controls—much higher than required—to ensure satisfactory operation at normal high speeds of 300 to 360 spots per minute. Controls of the type used at these high speeds are called "automotive specials," since they have been built to obtain not only the high speeds required by the automotive industry, but have other features needed to withstand this severe duty. Power disconnecting means have been built into automotive specials to disconnect rapidly any control from the line. Ability to remove any panel or function that fails during operation and to insert a standby panel is another feature of the automotive units. If a standby panel is readily available, the defective unit can be removed, a new one inserted, and the machine can be back in operation in less than one minute!

The use of resistance-welding machines will undoubtedly increase far more in the 1950's than it has in the last decade. For example, in 1938 approximately four million dollars' worth of resistance-welding equipment, including machines, controls, electrodes, etc., was shipped by various manufacturers. In 1941 the figure had tripled, to 11 million, and by 1946 the yearly shipments were valued at 28 million dollars.

From a welding standpoint, progress can be made in perfecting techniques already known. The importance of wave shape on weld quality has just become apparent, and in the next five or ten years considerable work will undoubtedly be done in this field to determine the optimum current wave shape to produce welds free from voids and cracks. Further advances will also be made in welding the so-called hard-to-weld metals. This is expected to take the form of various heat-treating processes carried on while the nugget is being formed in the welding machine. Regardless of the technical advances, the increased future growth of resistance welding is assured, since it is easily the fastest and most inexpensive way to join two similar metals.



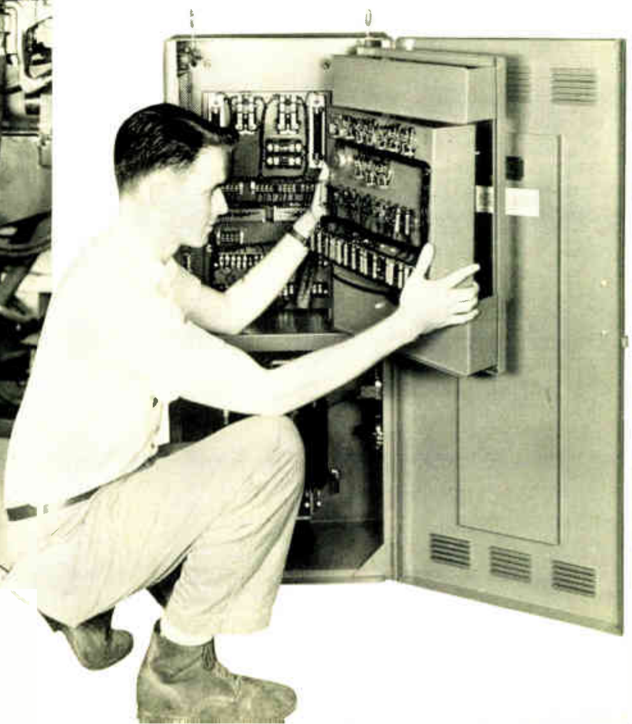


Fig. 6, at left, shows an exterior view of the 1950 welding control. Fig. 7, at right, shows the interior. Contrast these small, compact units with the earlier models shown in Fig. 1.

Semiconductors—

New Vigor in an Old Field

Semiconductors are a curious breed of materials—neither conductors nor insulators, but halfway between. This and other unusual characteristics makes them highly useful, even though the complete theory of their singular behavior is not yet understood.

DR. STEPHEN J. ANGELLO, *Research Laboratories, Westinghouse Elec. Corp., East Pittsburgh, Pennsylvania*

RECENT discovery of the transistor principle, which makes possible a subminiature amplifier element without filament supply or vacuum envelope, has quickened interest in a field that has plodded slowly for more than fifty years—the study of semiconducting materials.

Perhaps the first widely known phenomenon characteristic of semiconductors was the unidirectional current-carrying property of a metal point contact to poorly conducting materials, such as galena, pyrites, and carborundum. These contacts were used extensively in early radio circuits to rectify high-frequency waves. The galena crystal of 40 years ago was an erratic, temperamental device, but served until tube rectifiers appeared. How it worked was not understood then; it is not fully understood now. Knowledge of the physics of semiconducting materials was not far enough advanced then for any significant improvement to be possible; thus these units were deservedly displaced by the vacuum tube.

A new stimulus for development came when it was discovered that point contacts were not necessary for rectification, but that the phenomenon occurred at the junction of large areas of copper and copper-oxide, or cadmium and selenium. Large area meant high current-carrying capacity and many applications were found. Since the discovery of the so-called copper-oxide rectifier by L. O. Grondahl of the Union Switch and Signal Company in 1920, and its subsequent development as the Rectox rectifier by Westinghouse, literally millions have been built. Photoelectric effects in these devices also enhanced the interest in them.

During the last war, radar requirements[1] made necessary radio transmission and reception in a frequency range inaccessible to the vacuum-tube detector. Semiconductor rectifiers were again pressed into service. This time, advances in the theory of conduction in solids had an influence that culminated in the hyperfrequency (centimeter-wave region) silicon detector and the high-reverse-voltage germanium diode. Studies of the germanium diode led to the discovery of the transistor principle by Bell Laboratory engineers.

Among various other applications of semiconductors studied are the igniter of the ignitron and the porous block of the Autovalve lightning arrester. The importance of semiconductors to modern electrical devices cannot be overstated.

Basic Principles of Semiconductors

One usually thinks of a metal as behaving normally as a conductor of electricity. The resistivity of pure metals falls in the range of 10^{-6} to 10^{-4} ohm-cm at room temperature and increases slowly and regularly with rising temperature. Conversely, resistivity decreases to very low values as temperatures approaching absolute zero are attained. Hardly any other physical influence makes an appreciable change in conductivity of more than a few tenths of a percent. These characteristics for antimony alloyed with tin are shown in Fig. 1.

A semiconductor contrasts markedly with a metal. It is not just a high-resistance metal. It is a basically different material. In the first place, resistivity ranges from about 10^{2} ohm-cm to 10^{9} ohm-cm. Beyond the latter figure the material is an insulator. In fact, the name "semiconductor" means "half-conductor," i.e., a conductor whose resistivity ranges between those of metals and insulators. The resistivity of semiconductors is sensitive to temperature change, but in exactly opposite direction from metals. Increase in tempera-

Figure 1

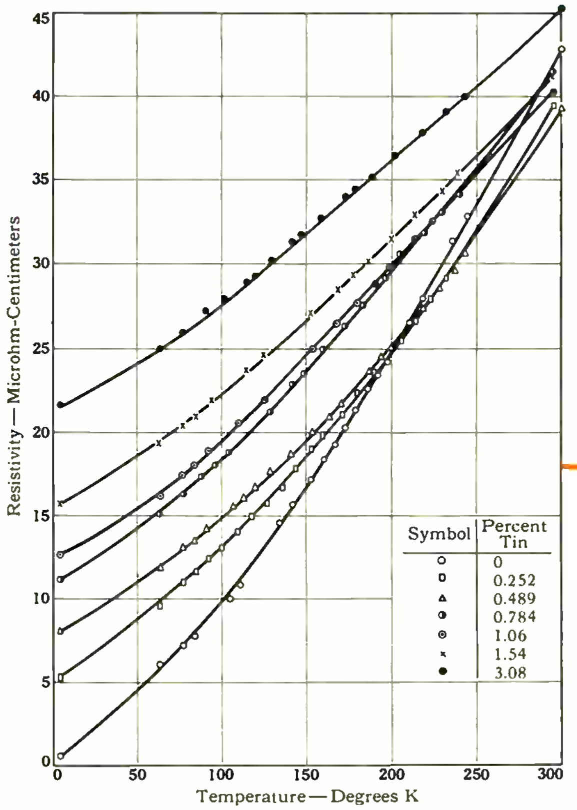


Fig. 1—Resistivity of antimony-tin single crystals from 4.2 degrees K to about room temperature. Note the large increase in resistivity with small amounts of tin added.

Courtesy *Physical Review*

ture lowers resistivity; decrease toward absolute zero causes a rapid approach to insulator properties—which gives a fine and exact criterion for deciding whether or not a substance is a semiconductor.

Physical influences can be brought to bear that change the resistivity of semiconductors by considerable magnitude—for example, annealing and quenching. Also, metals are influenced by impurities, as shown in Fig. 1, but not as much as semiconductors. The behavior of silicon as a function of temperature for different boron content is shown in Fig. 2.

The current carriers in metallic conductors are electrons. In semiconducting materials ion current is possible, i.e., a migration of charged atoms, especially at high temperatures. However, ion current is an extraneous property so far as semiconductivity is concerned. A true semiconductor must be predominantly electronic, that is, a conductor of electrons.

Probably the basic difference between a metal and a semiconductor (from the point of view of electrical properties) concerns the number of electrons participating in conductivity. In metals this number is essentially constant—about 10^{22} per cubic centimeter. Changes in conductivity brought about by impurities, cold working, and the like, alter the mobility of electrons in a metal. Mobility is conceived as an average electron velocity per unit of electric field intensity within the body. In semiconductors the number of electrons is very much less (by a factor of from 10 000 to a hundred million million) and is not constant, but ranges from, say, 10^{18} to 10^8 per cubic centimeter. More important is the fact that the number is not constant even in a given material. Temperature variations and other physical changes can alter the quantity considerably.

A glimpse of the reason that semiconductors are interesting to the physicist is apparent at this point. The possibilities for changing carrier density by heat treatment, addition of impurities, and other procedures permit a degree of freedom for control not possible in metals; moreover, a "diluted metal" is at hand, i.e., a substance that has many of the properties of a metal up to a certain degree. If any metallic property is influenced by the fact that there are large numbers of electrons present (and there are such properties), a study of a "diluted metal" will illuminate these phenomena.

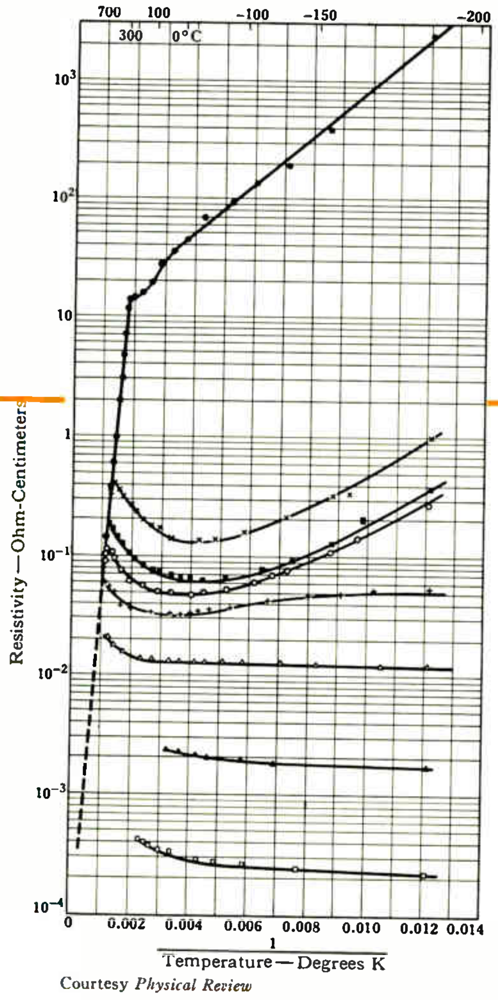
Types of Semiconductors

Two major classes of semiconductors are apparent—elements and compounds. The members of the elemental class (germanium, selenium, silicon, and tellurium) are few in number, but are already quite important. Germanium is utilized in the transistor and high back-voltage diode, silicon makes excellent hyperfrequency detectors and superheterodyne mixers, and selenium is used extensively in large-area power rectifiers and photocells. Tellurium has not yet found important uses as a semiconductor. The resistivity of these materials is governed entirely by chemical and physical purity. For example, pure germanium has a room-temperature resistivity of about 60 ohm-cm. This can be reduced to 10^{-2} ohm-cm by the addition of only a few tenths percent of tin. Physical purity in this case refers to crystal perfection. Selenium, for example, can be frozen from a melt into a glassy state having about 10^{13} ohm-cm resistivity; this can be brought to 10^2 ohm-cm by thermal crystallization below the melting point. In general, all semiconductors are sensitive to impurity content and crystal perfection, although those in the compound class have additional possibilities for carrier-density control. The effect of impurities on the resistivity of silicon and germanium is shown in Fig. 3.

Many compounds are semiconductors. A few important ones are cuprous oxide, titanium dioxide, cuprous sulphide, zinc oxide, cuprous iodide, magnetite, lead sulphide, and cadmium sulphide.

Cuprous oxide, used in the copper-cuprous-oxide rectifier, is an example of a semiconductor that is affected by annealing and quenching. Cuprous oxide has appreciable con-

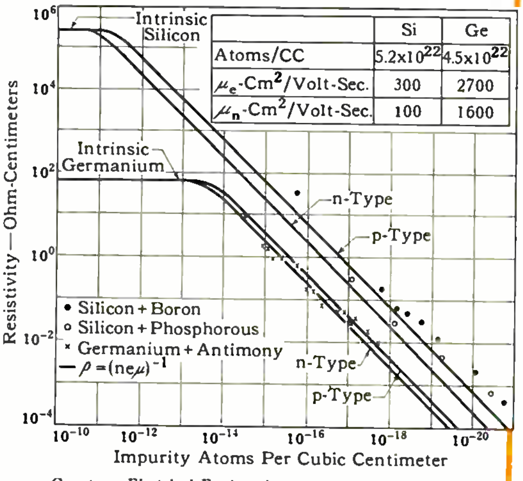
Figure 2



Courtesy *Physical Review*

Fig. 2—At left, the resistivity of silicon-boron alloys as a function of inverse absolute temperature. Lower curve is almost pure silicon; top curve shows a one-percent boron composition.

Figure 3

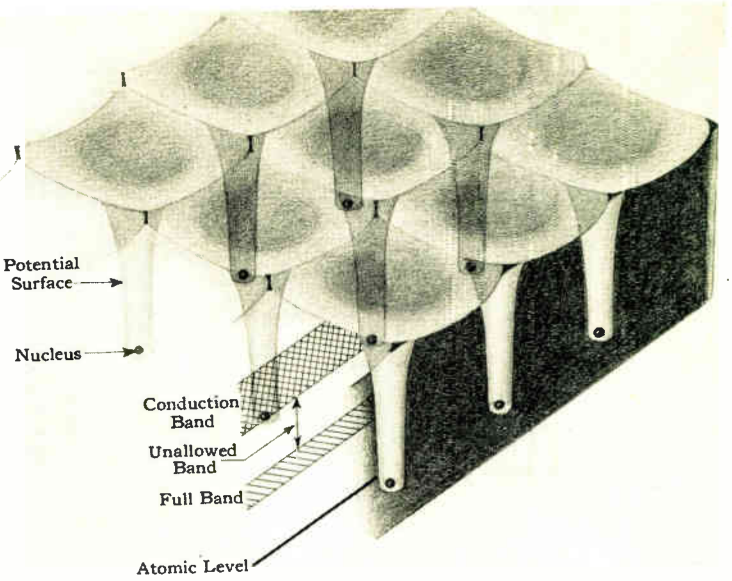


Courtesy *Electrical Engineering*

Fig. 3—Dependence of resistivity (at 300 degrees K) upon the impurity content of silicon and germanium alloys.

Figure 4

Fig. 4—An artist's conception of a three-dimensional periodic lattice potential, a fusion of the separate atomic potentials forming a three-dimensional grid structure in which electrons move. Electrons, having wave-like properties, are freely passed, or totally blocked by the periodic potential grating, depending upon their kinetic energy. The effect is an energy spectrum, which consists of allowed bands, separated by unallowed bands. Electrical conduction occurs in the conduction band; the full band is a reservoir for electrons, which sometimes can be excited into the conduction band region.



ductivity even though free of impurities. This conductivity is due to an excess of oxygen above that necessary to form a complete Cu_2O crystal. This substance is an example of a subclass of compound semiconductors called "oxidation semiconductors." The term "oxidation" probably arose from the fact that Cu_2O must be annealed in an oxygen atmosphere to obtain the effect. The term has been generalized to include any process that tends to raise the metal valence, whether by oxygen or not. Cuprous sulphide, the important part of another well-known power rectifier, is an additional example.

Zinc oxide also shows some conductivity when free of impurities, but in this case the carrier density (i.e., the density of current-carrying particles) is controlled by excess zinc in the crystal, which, for example, can be obtained by heating in an atmosphere of hydrogen. This is in a second subclass called "reduction semiconductors."

The Band Structure

To understand the electrical properties of semiconductors, an explanation of their sensitivity to temperature changes and illumination with light is necessary.

Considering a single, free atom, the outer electrons are not randomly distributed, but are organized into a definite energy-level structure. When atoms are arranged in the regular array of crystalline solids, some outer electrons may no longer be restricted to any particular atom, but become free to wander through the crystal. An electron belonging to an isolated atom has only one nucleus to attract it. Thus, it remains in its correct position. However, the nuclei of atoms in a crystalline solid are close enough together so that an outer electron of one atom can be attracted by several near neighbors. Thus it is possible to have electrons in a solid that do not belong to any definite nucleus. These electrons are not entirely free to move, i.e., they are restricted in the values of energy they can acquire. The reason for the restriction is found in the periodic structure of the lattice potential (see Fig. 4). Electrons are not merely small charged spheres; they often exhibit wave-like properties. For example, electrons can be selectively reflected from a crystal face (electron diffraction) in much the same way that x-rays are selectively bent by a crystal (x-ray diffraction). Electrons moving in a periodic potential can be likened to a telephone signal being propagated down a transmission line that contains a band-pass filter. Only signals with a definite frequency range can pass; others are rejected. The crystal lattice acts as a filter for electrons—only those electrons possessing energies in certain ranges or bands can pass.

In metals a definite number of electrons are free to move under the influence of an electric field, thus producing current. In semiconductors the energy region for free wandering (the conduction band) exists, but in a perfect crystal at low temperature, there are no electrons with energies in this region; thus no current is possible. As the temperature of a semiconductor increases, impurity atoms and excess negative ions act as electron-donating agents to the conduction region. At higher temperatures a more copious supply of electrons is released from the semiconductor itself (the so-called full band), rather than from impurities, and conduction increases very rapidly, i.e., resistivity decreases rapidly.

The Rectifier Effect

The most extensive uses for semiconductors at the present time involve the phenomenon of asymmetrical conductivity at metal-semiconductor junctions[2]. Not all junctions rectify, but only those that fulfill certain conditions. These are best illustrated by the analogy of a lake confined by a dam, leading into a stream at a lower water level. Water in the lake (electrons in the semiconductor) can flow freely over the dam (junction) into the stream (electrons in the metal) but the stream cannot flow easily into the lake. The height of the dam might be likened to the resistivity of the boundary region, i.e., the higher the dam, the more difficult it would be to force the stream to flow back over the dam into the lake, if such a thing were possible. This analogy is oversimplified but graphic. Two metals cannot perform this function because the reverse current in a rectifier must be low in absolute value, not merely less than the forward current. This necessitates a high-resistance element in the assembly. A rectifying junction can be attained between two metals if a thin film of a proper insulator is provided. Such junctions have so far been impractical.

The Transistor Effect

For many years inventors have tried to control electron flow in a rectifier by means of a grid structure sandwiched in the rectifying junction. About three years ago Brattain and Bardeen of the Bell Telephone Laboratories discovered that a potential applied to a second probe point placed near

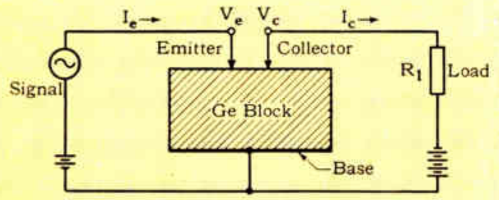


Fig. 5—A schematic diagram of a semiconductor triode. A germanium block is the semiconductor. (Courtesy *Physical Review*)

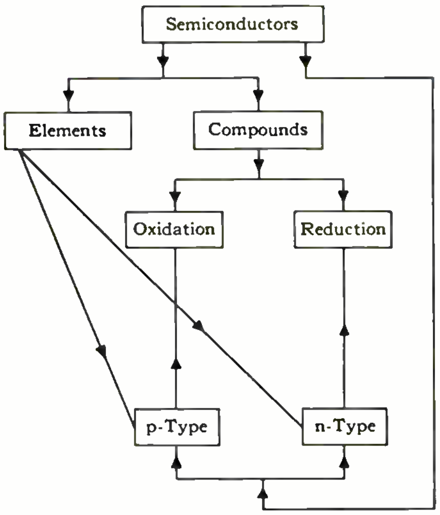


Fig. 6—A chart showing the various means by which semiconductors can be classified.

(within 0.005 inch) the contact of a common germanium-diode rectifier could be used to control the current in the diode circuit (see Fig. 5). This second probe acts much like the grid of a three-element tube. The application of a few tenths of a volt in the low-resistance emitter circuit can control many volts in the high-impedance collector circuit. The collector circuit is operated with d-c voltage in the high-resistance direction. A-c voltages up to about ten megacycles can be amplified much as in a three-electrode tube[3].

To avoid confusion, another possible division of all semiconductors has not been mentioned. This division—into two major classes—is based on the predominant type of current carrier. In one type the carriers are the familiar negative electrons. Until now it has been implied that these are the only types of carriers. However, in the section entitled "Band Structure" was mentioned an energy region of the crystal full of electrons that cannot be influenced by an electric field. If for some reason electrons leave the full band, we can think of the places previously occupied by electrons as "holes." These holes can move and act like positively charged electrons. The full band of electrons has been likened to a parking garage entirely full of cars. No cars can move because there is no room to move. Extracting one or more cars leaves vacancies that permit the remaining cars to be moved around in the garage. If a car (representing an electron) is moved in one direction, in a sense the hole moves in the opposite direction. For rather complex reasons, the hole in the nearly full band is important for conduction. Since it moves in an electric field in a direction opposite to an electron, it acts like a positive charge.

Agents that can extract electrons from the full band are visual radiation, x-rays, and temperature. In order for low temperature to be an agent there must be impurity atoms available in the crystal that can accept and retain electrons from the full band. It is possible that full-band electrons can be released directly at high temperatures.

The electron type of conduction is called "*n*-type" for negative charge, and the hole type is called "*p*-type" for positive charge. Both can exist in a single semiconductor under the proper circumstances. A summary of the various semiconductor classes in chart form is shown in Fig. 6.

The discussion above is necessary because a new principle has recently been discovered[4]. It is possible to inject into a semiconductor carriers of sign opposite to those normally present in the semiconductor. The injecting agent is a point contact biased with a sign opposite to the conductivity type. For example, holes can be injected into *n*-type semiconductors by a positively biased probe. Such a probe is called an "emitter" of holes. Holes, once injected, can travel like a cloud under the influence of an electric field until they are annihilated by combining with electrons. In *n*-type germanium the cloud of holes influences the current in the diode circuit part of a transistor. Here a negatively biased probe, called a "collector," collects the holes.

Western Electric has already demonstrated that these units can be made into a small line amplifier for telephone service. The transistor is too new to define its uses, but certainly they will be extensive and important.

The Future

Undoubtedly the most extensive development work in the near future will concern the transistor. This device will probably not replace vacuum tubes extensively, but it has unique qualities that will result in new applications.

Another field under development concerns photo-resistors. For brevity, the details of photoconductivity[5] have not been discussed, although the fact that light can change the number of current carriers was mentioned. The effect is pronounced in some cases, notably cadmium sulphide and lead sulphide, which is being developed as an infra-red detector.

Germanium diodes are finding increasing application in radio receivers. Development will continue, aimed at increasing stability and uniformity of characteristics.

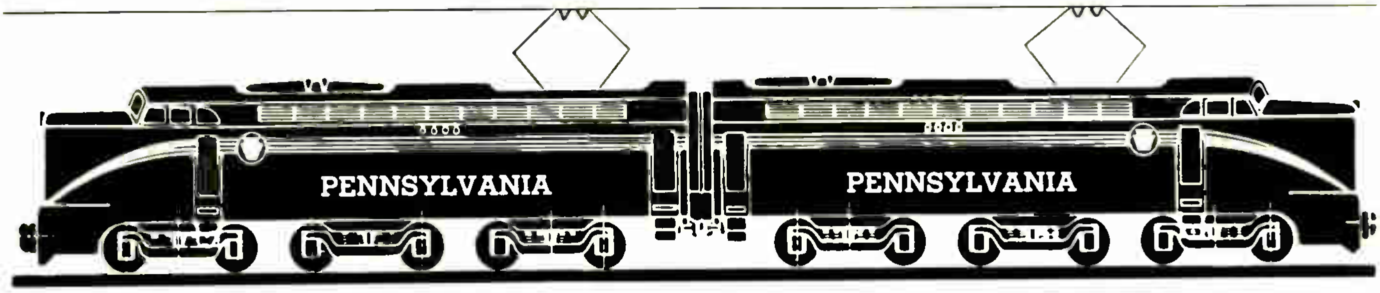
At the end of the last war, silicon crystal rectifiers were operated in the millimeter-wave region. Further development will be aimed at increasing sensitivity, for vacuum tubes are not likely to replace crystals in the near future.

Recently K. Lark-Horovitz discovered that deuteron bombardment and intense neutron bombardment in the nuclear pile can cause profound changes in semiconductors. The effects are caused mainly by physical changes, which, perhaps, can be produced in no other way.

The interest aroused by the transistor has produced increased activity in the field of semiconductors and will surely result in great advances in the future.

REFERENCES

1. "Radar Receivers and Crystal Rectifiers," by S. J. Angello, *Westinghouse* ENGINEER, March, 1947, pp. 54–56.
2. "Semiconductor Rectifiers," by S. J. Angello, *Electrical Engineering*, Vol. 68, No. 10, October, 1949, pp. 865–72.
3. "Some Circuit Aspects of the Transistor," by R. M. Ryder and R. J. Kircher, *Bell System Technical Journal*, Vol. 28, No. 3, July, 1949, pp. 367–400.
4. "Hole Injection in Germanium—Quantitative Studies and Filamentary Transistors," by W. Shockley, G. L. Pearson, and J. R. Haynes, *Bell System Technical Journal*, Vol. 28, No. 3, July, 1949, pp. 344–66.
5. "Photoeffects in Semiconductors," by J. A. Becker, *Electrical Engineering*, Vol. 68, No. 11, November, 1949, pp. 937–42.



The Ignitron Locomotive and Its Effect on Electrification

A new chapter is to be added in the story of the endless search for better, cheaper ways to haul trains. It is to be centered around a locomotive that uses d-c motors but operates on a-c power supply, with ignitron rectifiers on the locomotive itself providing the conversion link. This new type of locomotive, two of which are now being built, gives hope of being not just a superior locomotive but of having other characteristics that might make it the key to much wider use of railroad electrification.

The idea of alternating-current power supply, ignitron rectifiers, and direct-current driving motors has worked so well in experimental rail-car service* that it is being carried to the next logical step—to full-size locomotives. Two 6000-hp, rectifier-type locomotives are being constructed by Baldwin Locomotive Works and Westinghouse for freight service on the Pennsylvania Railroad.

Each locomotive, consisting of two 3000-hp units, produces a maximum tractive effort of 165 000 pounds. The total weight of 660 000 pounds is carried on 12 axles, all of which are drivers. They will be the most powerful 12-axle electric locomotives ever produced.

Locomotives have been produced with direct-current motors operating from an alternating-current trolley supply. One type of locomotive, introduced in the 1920's, used motor-generator sets to convert the alternating current to direct current. These were good locomotives—most of them are still in service—but motor-generator sets are expensive, bulky, and rather inefficient.

The weight and space advantages gained by using ignitron rectifiers, rather than motor-generator sets, to effect the combination of d-c driving motors with an a-c power supply are dramatically demonstrated by the fact that motor-generator equipment for a 6000-hp locomotive weighs four times as much as the rectifiers and associated apparatus needed to do the same job. Furthermore, the motor generators require longer and heavier locomotive bodies and running gear to house and carry them. Finally, this heavier and larger motor-generator locomotive operates with an efficiency about five percent below that of the rectifier type.

The fundamental operation of the rectifier locomotive is quite simple. Alternating current from the trolley is collected by a pantograph in the normal fashion, then transformed to low voltage by a transformer on the locomotive. Between the transformer and motors are located the rectifier tubes that convert a-c into d-c power. Speed of the locomotive is controlled by varying the output voltage, by selecting proper taps on the tap-changing transformer.

The Merits of the Rectifier Scheme

Why add another distinctly different locomotive to the already large number of railroad motive-power types, comprising the conventional steam, several steam-turbine types, diesel-electric, full electric, and a newcomer—the gas turbine? What can the rectifier locomotive hope to add in the way of improved and lower cost railroad operation? Several advantages immediately come into view. Some are startling.

Tractive Effort—The payoff for any locomotive is tractive effort. While not the whole story, pulling power is an important segment of it. What the rectifier locomotive promises in this regard can best be obtained by stacking it against a similar, modern electric locomotive. Such a comparison is afforded by a recent design of a locomotive of similar mechanical arrangement but using a-c series traction motors similar to those employed on the Pennsylvania Railroad and New

Proof of the Ignitron in Rail Service

The modern guinea pig for the idea of a mercury-rectifier link for d-c motors and a-c supply for locomotives has been a rail car operating on the electrified system of the Pennsylvania Railroad since last October. The original object was severalfold, but principally to determine how well ignitrons operate in such mobile service and whether there would be interference with communication service. In both regards the performance has proved entirely groundless all fears of defect in either regard. Interruption of power because of arc-backs has proved to be no problem and interference negligible. By the first of May the car had covered about 32 000 miles in everyday routine service and continues to add mileage at about 1100 miles per week. While the tests have been concluded, the car continues in use.

This article is based on a paper presented by A. C. Monteith, Vice President in Charge of Engineering, Westinghouse Electric Corporation, before the New York Railroad Club, March 16, 1950.

*Described in "The Rectifier Railway Car—A-C Supplied, D-C Driven," *Westinghouse* ENGINEER November, 1949, p. 179-80.

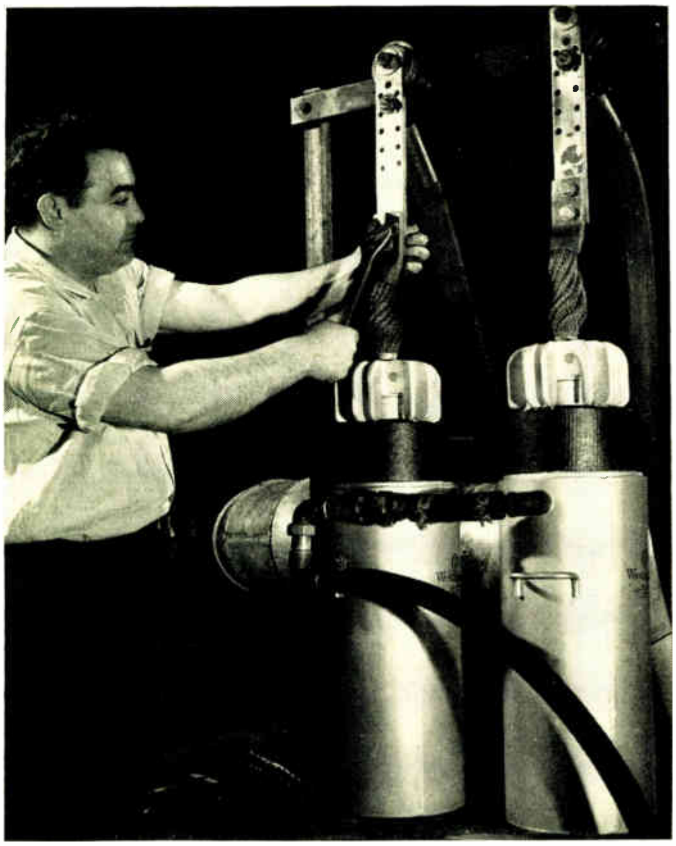
Haven electrifications. The weights and dimensions of this new a-c locomotive and the ignitron locomotive are essentially identical. The conventional a-c locomotive was designed to develop 5625 hp continuously, a little less than the 6000 hp of the rectifier locomotives. However, the continuous tractive effort of the rectifier locomotive will be about 50 percent greater at speeds from starting to about 17 mph. At about 40 mph the continuous tractive efforts of the a-c and rectifier locomotives are approximately equal. Above this speed the a-c locomotive displays a modest but not significant advantage. In other words, the rectifier locomotive is better suited to heavy-drag service than is the a-c locomotive. At 17 mph the rectifier locomotive could haul a 14 000-ton train on a typical ruling grade while the equivalent a-c locomotive would be limited to a continuous load of 9000 tons. At 40 mph, the comparative figures are 4600 and 4700, respectively.

The lower tractive effort of the a-c locomotive at low speeds is due to the inability of its single-phase, a-c series motors to develop full horsepower in this speed range. Because of inductive effects, commutation of the high currents equivalent to full horsepower at low speed becomes difficult for an a-c motor.

Efficiency and Power Factor—The rectifier locomotive is expected to be appreciably better in overall efficiency than the a-c locomotive. As to power factor, it should be a few percentage points better.

Cost—While rectifier locomotive initial costs are still not clear, certain factors weigh heavily in its favor by comparison with the a-c unit. Most of these stem from the fact that the rectifier locomotive will use standardized d-c motors, already well developed and—by comparison with a-c equipments—produced in relatively large quantities for diesel-electric locomotives. As on diesel-electric locomotives, the d-c motors will be operated ungrounded, which reduces the total insulation requirement. The rectifier tubes have been in quantity production for some time and are used for a variety of industrial purposes. The simpler direct gear and pinion drive can be used instead of the flexible drive required with the a-c motor with its torque pulsations.

Ignitrons such as these will be used in the rectifier locomotive.



Maintenance—Two factors make it appear that the rectifier locomotive will require less maintenance. The d-c motor naturally requires less maintenance expense than the single-phase a-c motor, largely because of the easier commutating conditions and because the more uniform torque flow lessens the mechanical stresses on bearings and other components.

Also, the motors are the same as those in extensive use on diesel electrics. Hence railroad shops are better equipped to service them and maintenance crews are already well experienced in taking care of problems arising with them.

Power-Supply Advantages—The story of the rectifier locomotive is not completely told with an enumeration of its promises for lower initial cost, higher tractive effort, greater efficiency, and reduced maintenance. The rectifier idea sets off a chain of events that may have even greater significance to railroad managements. In fact, it is quite possible that this new type of locomotive may be the key device by which the field of electrification will be widened to include many lines that cannot now economically justify it.

The overall costs of railroad electrification may be significantly reduced as a consequence of another quality of the rectifier locomotive. This conclusion of vast implications arises primarily out of the fact that the rectifier locomotive can free electrifications from the necessity of using 25-cycle power supplies. The a-c series motor—used on most a-c electrifications—operates on 25 cycles, instead of the universal central-station frequencies of 60 or 50 cycles. While series a-c motors have been built, particularly in Europe, for higher frequencies, this type is better suited to lower frequency. In fact, a-c electrifications in the United States have been established at 25 cycles largely for this reason. This necessitates frequency conversion from 60 or 50 cycles to 25. This means large and expensive rotating converter stations.

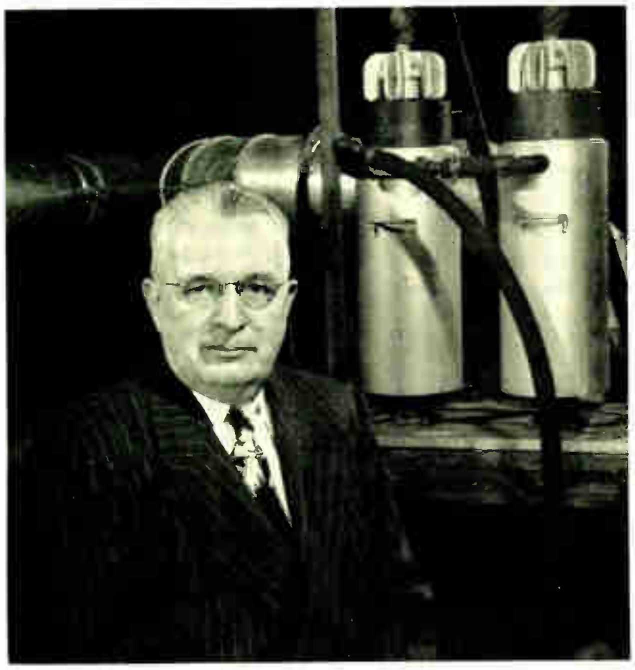
The rectifier system eliminates right-of-way conversion stations. Ignitron rectifiers operate as well on 60 cycles as on 25. In fact the supporting transformers are only about two thirds as large and as heavy.

Another power-supply simplification is touched off by the rectifier system. If commercial frequencies can be used, then it becomes advantageous to employ commercial voltages. Trolley voltages can be increased several times, if desired, over the 11 kv commonly used. Essentially this means reducing the number of substations along the right-of-way compatible with maintaining continuity of service. Also, another factor in the resulting economies is that 60-cycle power-distribution apparatus is standard and is built in relatively large quantities—with consequent cost advantages. In short, the ignitron-rectifier locomotive may strongly affect the whole power-supply economics for railroad electrifications. By making available central-station produced power at lower cost, the rectifier locomotive may be the factor that will expand the field where electrification becomes economically attractive.

Certainly the idea of the rectifier locomotive and its possible wide-scale effects on the nation's rail transportation systems are attractive enough in theory to warrant great interest in the actual performance of the two prototypes now under construction. It speaks well for the ingenuity and initiative of designers of transportation equipment and for the readiness of railroads to seek new facilities by which service can be improved and costs lowered.

Personalities IN ENGINEERING

Editor's note: *Engineering developments are seldom, if ever, the result of one man's efforts. Inevitably, however, there is someone with foresight involved, a man who lends a guiding hand to untie the more knotty problems, and promote the development. Such is the case with Lloyd J. Hibbard, who was a central figure in the ignitron-locomotive development.*



Four seemingly unrelated things—a tornado, a large tract of land in western Texas, railroads, and an electronic tube—have played successively important roles in Lloyd J. Hibbard's life. And, though dissimilar in nature, all these factors form a closely woven pattern of events.

The tornado, which whirled destructively through Hibbard's home town of Snyder, Oklahoma, in 1905, deprived him of his parents. Thus at the age of twelve, Hibbard was placed in the care of a guardian, a successful local businessman. The guardian had acquired, some years previous, several thousand acres of semi-wilderness in western Texas. Being a man of imagination he often "dreamed out loud" to young Hibbard of building a private railroad across the tract. To a lad in his teens, this was a fascinating thought; it aroused Hibbard's interest. Here the tornado re-enters the picture, although in a less important role, for it had destroyed the local high school, necessitating many round trips by train to prep school on the campus of the University of Oklahoma. This gave Hibbard a chance to examine railroads more carefully, which evolved into a desire to know more about them. So, logically enough, Hibbard eventually enrolled in the university for engineering training.

Hibbard admits that during the ensuing four years, his desire wavered ever so slightly. He spent many interesting hours hunting rock specimens with friends studying geology, a subject that also fascinated him. Engineering eventually won a clean-cut decision, and Hibbard has never been sorry.

Hibbard was fortunate, when he came to Westinghouse, to come under the guiding influence of B. G. Lamme in the Company's Engineering School in 1914. Here he became one of a group familiarly, though not disparagingly, called "Lamminations"—a group of bright young men who had been chosen for further engineering training. Here Hibbard absorbed much valuable engineering lore that was to stand him in good stead.

Here, too, Hibbard heard for the first time of a unique experiment then being conducted with a multiple-unit railway car. This car was powered by d-c motors, supplied by an a-c trolley through mercury-arc rectifiers. Although it aroused little more than his passing interest at the time, this idea was to become one of his most engaging activities.

After completing the initial training course, Hibbard went on to learn more about the idiosyncrasies of a-c and d-c machines, as well as transformers, at the Electrical Design School. His formal training complete, Hibbard then embarked on an interesting and assorted variety of engineering experiences, most of which concerned railway equipment.

One of Hibbard's proudest moments came when he and Lamme were awarded one of the basic patents on a motor-generator locomotive. Even today, Hibbard is not quite sure which gave him the most personal satisfaction—the idea itself, or the distinction of being associated with Lamme as a co-worker and joint patent holder. Hibbard followed through on this idea by taking charge of the design and manufacture—and later the assembly and testing—of the first m-g locomotive.

When the Pennsylvania Railroad decided to electrify from New York westward to Harrisburg and southward to Washington, Hibbard jumped at the chance to take a leading part in this tremendous undertaking. Here Hibbard's genial manner and sound engineering skill helped smooth out many of the unavoidable difficulties that arise in such a joint operation by many companies.

During this first half of his career, Hibbard, like most railway engineers, formed some pretty definite personal opinions as to the best form of railroad motive power. To him, electric locomotives were the ultimate in traction units (in fact this opinion is still as strong as ever). Also, he joined the group favoring a-c transmission with d-c motive power, if it could be achieved. The m-g locomotive, in which development he had played a major part, was a solution—but Hibbard was still bothered by the several separate losses involved in this system.

This eventually led Hibbard to thinking of means of eliminating some of these elements. Fortunately his thoughts turned back to the rectifier multiple-unit car that he had observed while still in training school. And here enters the fourth influential factor in Hibbard's career—an electronic tube. For with the development of the ignitron, new life was breathed into the idea of a rectifier traction unit. And Hibbard was largely responsible for the resuscitation. Campaigning with all the vigor of an experienced salesman Hibbard successfully put over his ideas. The result—after preliminary tests on a multiple-unit car—is that two ignitron freight locomotives are now to be built (see page 187).

Hibbard's experience with the rectifier principle points to some personal characteristics that have had a great deal to do with his success as an engineer. In talking with him, you get the distinct impression that Hibbard believes that a person can do what he wants if he has the "will." Looking back at his record, perhaps that is true—certainly the perseverance he displayed in promoting the rectifier principle is evidence. However, in Hibbard's case, as in that of any engineer, "will" is only a part of the story; it must be accompanied by a strong measure of ability, and in many cases, a touch of salesmanship—both of which Hibbard has in greater than normal quantity.

What's NEW!

Precision Welding for Miniature Parts

Resistance welding is not always confined to large, glamorous assemblies such as airplanes and automobiles. It also has an important role in more mundane matters—like fastening the opening key to the top of a coffee can. Controls for the resistance welding of small items—the internal elements of vacuum tubes, costume jewelry, and kitchen utensils—require the same precision needed in welding larger components. For this purpose a new family of electronic controls has been created.

Typical of these new controls is one designated as the S1-15, designed for use with small bench-welding machines of up to five-kva rating, with maximum current of 20 amperes at 25-percent duty cycle.

To obtain sound and consistent welds on delicate parts the timing of welding current must be precise. A special electronic circuit, in lieu of the usual relay-type circuit, provides accurate weld times of one to ten cycles over a wide variation in supply voltage. Adjustment of this weld time—the only manipulation required of the operator—is accomplished with a single dial mounted on the front of the cabinet.

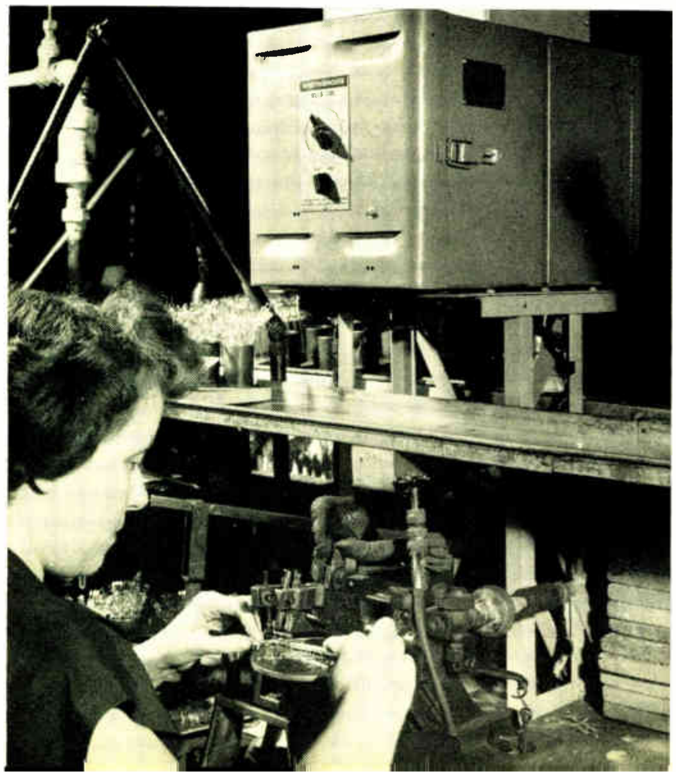
Only about the size of a small table-model radio, the new control has a four-tube circuit, which uses only two different types of tubes. Circuit components are mounted on a swinging panel for easy access.

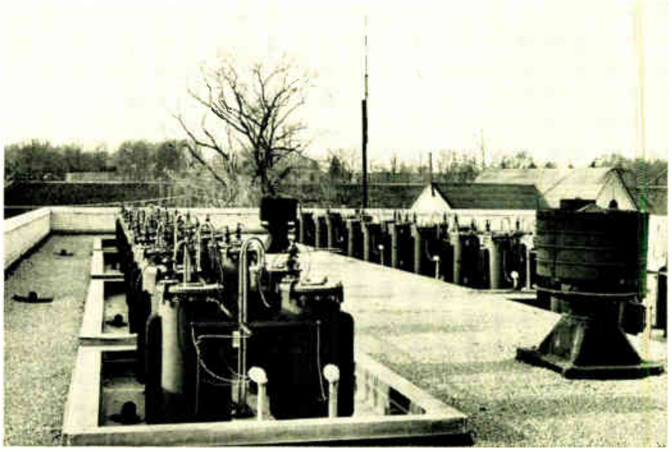
A companion to this new control is the S1-25, a heavy-duty version. For application where currents as high as 50 amperes at a 25-percent duty cycle are required, this control provides precise timing over a range of 1 to 30 cycles.

Ozonation Plant for Philadelphia

A perennial complaint of city dwellers is the taste of their drinking water. Although all city water is bacteriologically safe, little effort is made in many locales to make it more palatable, but with the completion of the world's largest ozonation plant, residents of West Philadelphia are assured they can open their faucets and get water free of objectionable taste or odor.

The new synchronous bench-welding timer being used in the spot welding of automobile-headlight parts.





The fifty transformers that supply Belmont's ozone generators.

Like many another industrial city, Philadelphia is forced to draw raw water from an industrialized river, in this case the Schuylkill, and treat it to destroy harmful bacteria. But even when the water is safe to drink, many compounds remain to give it an unpleasant taste. However, passing ozone, which is oxygen in a very active form, through the water destroys the taste-producing compounds.

In the new Belmont Filtration Plant, the results of a long investigation by the City of Philadelphia and the Welsbach Corporation of Philadelphia have paid off with immediate results in improved taste and odor.

The plant is completely electrified. The ozonation process consists essentially of cleaning, filtering, and drying a mass of air, converting a small amount of the oxygen to ozone by passing the air through a corona-generator, and then bubbling the ozonated air up through the water to literally "burn out" the oxidizable material.

Fifty ozone generators are supplied with power by an equal number of Westinghouse 460/15 000-volt transformers. Corona is formed in annular openings in a boiler-shaped vessel with 85 graphite-lined, tubular glass electrodes within stainless steel tubes. Circuits to individual generators are metered and controlled through a control panel. Pushbutton stations and contactors furnish the control for individual ozone generators. Control point is at the individual generator, and red and green indicator lights show which units are in operation.

Three single-phase circuits for the generators are provided in three wall-mounted cabinets. Two cabinets contain 16 switches, the other 18, each switch controlling an individual generator circuit. From these cabinets individual circuits go to the contactors, and thence to the 25-kva transformers on the roof; the high-voltage side of each of these transformers is connected to the corresponding ozone generator.

In effect the ozone generators are capacitors and produce a leading power factor. This is partially balanced by other equipment, with fifty 10-kva reactors, one for each unit, bringing the power factor almost to unity.

The Belmont Filtration Plant is currently treating about 36 million gallons of water per day with ozone, and uses about 200 kwhrs per million gallons when treating at a rate of 20 pounds of ozone per million gallons of water.

New Tools for Photochemistry

The sun has been in the photochemistry business ever since the universe was organized. Only lately has man tried his hand at it, and as yet he understands it very little. But he is learning—and using it—fast.

Most industrial photochemical processes utilize the wavelengths near 3650 Angstroms—just below the visible. At this wavelength, for example, the chemical activity of chlorine increases markedly, and it combines easily with various other chemical compounds. A new 3-kw photochemical lamp, the C-H9, produces approximately 50 percent more ultraviolet than its predecessor (the 3-kw B-H9) at about 3650 Angstroms. Most of this gain is accomplished through the use of a special glass, which not only passes a greater portion of the ultraviolet, including the shorter wavelengths, but is also more heat resistant. The C-H9 has a rated average life of 2000 hours at five hours or more per start, is 56 inches long overall, and burns in any position. It operates at 535 volts and 6.1 amps, and requires a starting current of 9.3 amps. The maximum temperature limit of the bulb has been raised to 650 degrees C through the use of the new glass, a gain of about a hundred degrees, which simplifies cooling in enclosed equipment. The C-H9 is interchangeable with the B-H9 by a slight adjustment of the lampholders.

A smaller version of the C-H9 is the new A-H14. This is a 940-watt lamp, with a maximum overall length of slightly over 21 inches. Its starting current is 9 amps, and the lamp operates at 4.2 amps at 250 volts. Rated life is the same as its larger companion, the C-H9.

Another photochemical lamp now available is the A-H13, a 1200-watt lamp that operates at 10.5 amperes and 125 volts. Its rated average life is 1000 hours at five hours per start, and the bulb temperature limit is 550 degrees C.

These new lamps are suitable for many types of photochemical applications, such as the chlorination of hydrocarbons (an integral part of many chemical manufacturing processes), polymerization, bromination, and for high-speed automatic "blueprinting" machines and other applications.

Phos-Copper Strip for Better Brazing

A beginner in the art of brazing could easily make a natural mistake. Anxious to secure a good bond between two metals, he might purposely use a large quantity of the brazing alloy. Actually the more alloy he succeeded in putting into the joint the weaker the bond. Metallurgists have found that the best brazing results, i.e., the strongest joints, are obtained where the thickness of the joint is between one and two thousandths inch thick.

Obtaining uniform joints of close to this thickness has been somewhat of a stumbling block. The brittle nature of inexpensive, silver-free brazing alloys complicates any cold-rolling process, and hot rolling is also difficult because of the problem of keeping the thin strip heated uniformly until it is rolled. Thin strips of Phos-Copper, a well-known brazing alloy, have previously been rolled down to about 0.015 inch.

Using a new hot-rolling method, Westinghouse engineers have now succeeded in rolling Phos-Copper to a thickness of but 0.005 inch and less. This process also yields a more ductile alloy strip, thus facilitating handling and use.

Essentially the problem in hot-rolling brittle strip is the fact that if the thin metal is heated in an oven it cools before it reaches the rolls. Moving the furnace closer to the rolls only complicates matters by getting both rolls and guides too hot. In the new process, the strip is heated by the resistance method. Electric current is passed through the strip, using the strip coil as one contact and the rolls as the other. No arcing occurs. This method assures that the coil is hottest as it reaches the rolls, since they are one contact. Because the current can be regulated to give the necessary heat, the rolling speed of the process can be much higher than previous hot-rolling methods.

The success of this new process has added another size and shape to the previously available Phos-Copper ribbon, rods, and powder. The strip alloy has a 5-percent phosphorus, 95-percent copper composition, and a melting range between 1305 and 1600 degrees F. The alloy is fluid at about 1425 degrees, the temperature at which the best joints can be made.

The coefficient of expansion of Phos-Copper matches both brass and pure copper closely, so that it is suitable for joining either of these metals. Because of the small amount of Phos-Copper necessary to make a properly designed joint, conductors so joined exhibit at least 98 percent of the conductivity of a solid copper conductor. A joint in which the overlap of pieces is three times the cross section of the conductor is more than sufficient to compensate for the joint resistance.

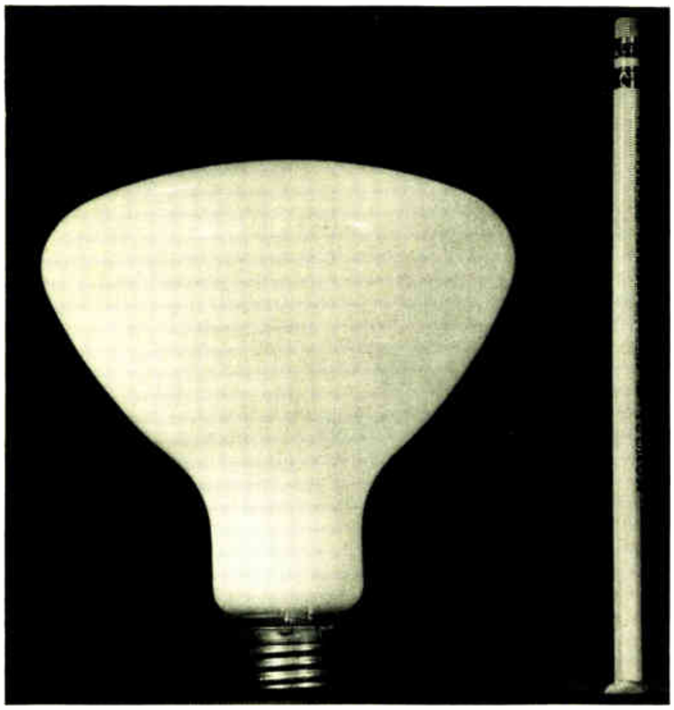
The average tensile strength of the Phos-Copper alloys is about 90 000 psi. The strength of the brazed joint, of course, depends upon several factors, such as the design of the joint, its thickness; but almost without exception the strength of the bond is greater than the metal itself.

How to Assemble a Meter

Once a week, at an opportune time, many of the top industrial managers of Westinghouse push their stacks of papers to one side, clear a small working space on their desks, pull out a small black box, and become engrossed in its contents for a few minutes. The reason for this seemingly strange conduct—a unique plan to illustrate the simple design and precise manufacture of the single-phase, type CS watthour meter. The plan goes something like this: Each week one production-line part of a watthour meter is mailed to each manager. First installment is a carrying case, containing the meter base and its cover, plus the one tool needed to assemble the meter—a small screwdriver. Next follow the electromagnet, then the mounting frame, and so on, until at the end of several weeks all parts have been received. After the final piece has been installed, the meter is ready for service, except for calibration, in exactly the same manner as one coming off the assembly line.

None of the parts have ever been assembled previously—all are taken at random off the assembly line at the Meter Division. However, each piece is so well designed and accurately made that all go together in proper relationship without further adjustment. Proof indeed that watthour meters—for all their being precision instruments—are simple and well-made devices!

R. C. Bergvall, Engineering Manager, Industrial Products, takes "time out" to insert a newly arrived part in his watthour meter.



The new 150-watt indirect lamp. Initial lumen output is 2100.

A New Look in Lamps

A RECENTLY developed 150-watt indirect-light lamp introduces a "new look" in home lighting. For several decades incandescent lamp bulbs have changed little in shape or appearance, despite numerous improvements, but the new indirect lamp presents something new in design. In physical contour it resembles the standard reflector flood lamp, but instead of the inside reflector it has a special inside silica coating designed to give greater diffusion to the lamp's rays. In order to give more diffusion downward, minimizing direct or reflected glare, the coating on the side of the bulb is more dense than that on the bowl. The initial light output of the lamp is approximately 2100 lumens.

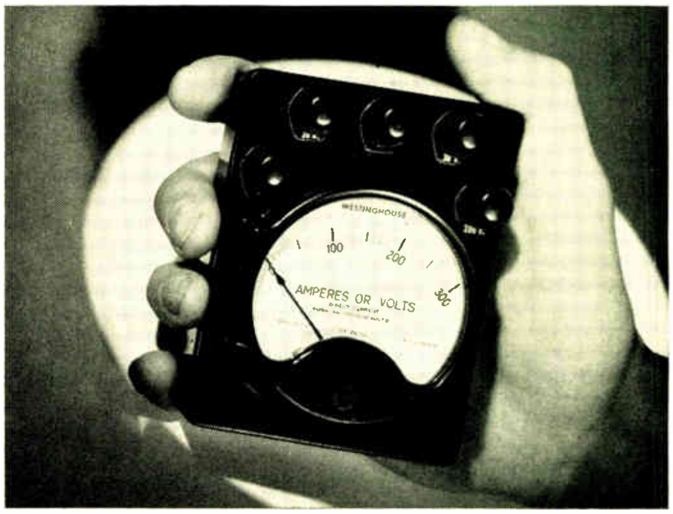
This indirect lamp fits any standard socket, and can convert almost any portable household lamp to higher illumination.

A young admirer exhibits the latest in Christmas-tree bulbs.

Tricolored Christmas-Tree Bulb

ANYONE who has mixed paints of two different colors has been aware of the attractive, swirling, marble-like design produced when the two are first stirred together. Recently a ceramic engineer at the Westinghouse Lamp Division, mixing various hues of a new, permanent enamel, wondered why this design wouldn't look equally attractive on a bulb. Several different designs were flowed onto Christmas-tree bulbs by hand, and the result was a highly attractive lamp. Convinced that they had something, lamp engineers went ahead and tackled the obviously difficult problem of making a multicolored bulb with mass production lamp-making machinery. Five months and 50 000 bulbs later they had the answer, with the result that Christmas trees this year will display tricolored bulbs of red, green and white—these three colors having been decided upon as the best of 50 different color combinations.

The new enamel that suggested the idea of the tricolored bulb will be used on regular-size, multiple-type bulbs of all colors—the red, blue, green, orange and white, as well as the tricolored. A combination of color pigments and a ground-glass mixture, the enamel is sprayed onto the tricolored bulb through jets, then baked in a 1200-degree F oven. The result is a colored finish that is more uniform and lustrous, and far more resistant to fading than previous Christmas-tree bulbs. Also it is scratch-proof and chip-proof. Unlike usual bulbs of this type, the new lamp is suitable for use in outdoor equipment. Heretofore only larger colored bulbs, sprayed inside, have been practical outdoors.



A d-c version of the new P-12 pocket-sized portable instruments.

Pocket-Sized Portable Instruments

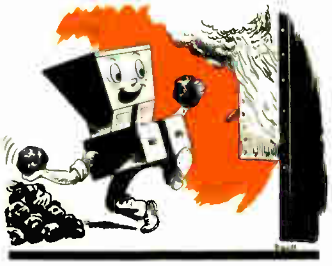
UTILITY and industrial service men no longer need carry around heavy, bulky equipment to get accurate test readings. Instead they can make use of a new group of pocket-sized portable instruments (designated P-12's), which have an accuracy in the two-percent class. The d-c version of this instrument is but 4¼ inches long, 3¼ wide and 1¾ deep; the a-c type is similar, except for a half inch greater depth.

Various models of these new instruments have different current ranges from a few microamperes up to 50 amperes, and voltage ranges from a few millivolts up to 800 volts. Both the a-c and d-c versions will be built in single-range models, and with multiple ranges up to four.

Unusual in an instrument of this size is its magnetic shielding, designed to protect against any external field disturbances. Other nearby instruments or steel table tops do not affect its readings.

This miniature portable employs the elements, coils and dials normally used in slightly larger standard instruments, but arrangement of components enables a considerably smaller and more compact design.

Personality Profiles



When *D. J. Mosshart* first came to Westinghouse in 1921, he intended to get a couple of years field experience and then settle down to a nice desk (he calls it executive) job somewhere. But after spending more than 29 years studying combustion processes and stoker engineering, he says that he is still getting experience and still largely in the field. He has a firm belief that theory is fine, but that personal contact with everyday operations leads to a quicker and better solution of engineering problems. Consequently, Mosshart has spent a great deal of his time "dispelling illusions" of the theorists that try to solve problems from behind a desk.

Mosshart joined Westinghouse, South Philadelphia, as a technical apprentice after graduating from Kansas State College with a B.S. in Mechanical Engineering. In 1926 he was appointed Assistant Chief Engineer of the Stoker Department, and in 1945, Engineering Manager.

Outside of his intense interest in engineering problems concerned with combustion processes, Mosshart studies guns and gunnery with the same thoroughness. The Centrafire Stoker has, however, been his consuming interest for recent years.

• • •

Quiet, studious research engineer *Stephen J. Angello* has packed a lot of experience into his eight-year career, and all on the same general subject that he describes in this issue—semiconductors. Angello came to the Westinghouse Research Laboratories in 1942, after receiving a Ph.D degree from the University of Pennsylvania. He soon developed a highly successful synthetic-crystal rectifier that was hailed as an outstanding development in the field of radar.

In 1946 Angello returned to the University of Pennsylvania, where he taught electrical engineering for a year, as an assistant professor. The following year, however, he returned to the Research Laboratories, and again delved into the field of semiconductors, this time selenium and copper-oxide rectifiers. Since then he has made various studies in the wide field of semiconductors, including a preliminary study of the transistor. Angello is now a research engineer in the Physics Section of the laboratories.

• • •

C. B. Stadum disregarded Horace Greeley's proverbial advice and came East as a young man. Up until the time when he graduated from California Institute of Technology (B.S. in Engineering) in 1941 and came to Westinghouse, he had never been east of Chicago.

During the period spent on the Student Training Course, Stadum spent some time at the Electronics Department of the company's Lamp Division, and also a few months in the Electronics Section in the Industrial Control Division. The latter proved to be his niche. At the completion of the course he remained there, and since has devoted most of his time to resistance-welding problems. In 1947, his ability was rewarded when he was made Manager of the Resistance Welding Control Section. Stadum is a member of the AIEE and the American Welding Society, and is active in the AIEE Subcommittee on Resistance Welding.

Stadum professes to no particular hobbies, but admits that he spends much of his off time "building something—garden furniture, house furniture, a den, radios, picture frames, or anything else that strikes my fancy." No hobbies, he says! We also happen to know that one of Stadum's life-long ambitions has been to invent a new implement that every housewife could use, but that would cost under 50 cents. Says it would make a fortune. We wish him luck.

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Something new has been added to the *Westinghouse* ENGINEER—the title of Managing Editor. This is in recognition of the fact that the publication is now in its tenth year and that the editor's duties have expanded materially. While the role is a new one the incumbent is no stranger to the readers of the publication. *Richard W. Dodge* has "by-lined" several feature articles and has prepared feature pieces opposite the Table of Contents in several issues, in addition to many short items.

Dick was born and raised in Maine and graduated from the University of Maine with a B.S. in E.E. in 1948. He forthwith joined the editorial staff of the *Westinghouse* ENGINEER. He displays the economy of speech for which New Englanders are noted, but when he coils his long legs around his typewriter stand and hammers away for a while, the result is smooth indeed, and shows outstanding skill with the English language.

His college career was interrupted by the fracas in the Pacific. A captain in the Army, he went from island to island hot after the retreating Japanese army. He still shudders to think that he was scheduled to be in the first wave of troops to assault the Japanese mainland. Dick understandably, feels kindly toward the Manhattan Project.

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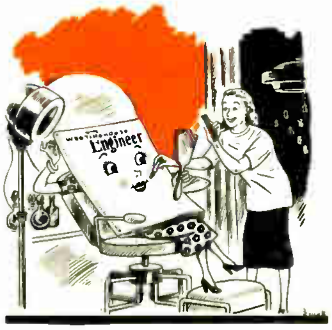
The Editor of the *Westinghouse* ENGINEER is so frequently asked "Who is responsible for the attractive appearance of the *Westinghouse* ENGINEER?" that he sometimes wonders if the looks of the magazine is not getting the lion's share of the attention. He firmly believes, of course, that appearance is of as much importance as the words that go into the magazine. The credit for the inviting appearance of this magazine goes to *Miss Emma Weaver*. She also handles the arrangements for its physical production, scheduling, handling of engravings, and herding the proofs through the proofreading gantlet. She is responsible for the layout and mechanical production of the two Latin editions, *El Ingeniero Westinghouse* and *O Engenheiro Westinghouse* (Spanish and Portuguese editions respectively).



Her experience with publishing procedures and techniques began with *The Electric Journal*, predecessor of the *Westinghouse* ENGINEER. Her artistic skill, a fine sense of color and harmony of design, largely of native origin, are given free rein in the *Westinghouse* ENGINEER.

Lighting a baseball stadium is no haphazard procedure. Each fixture must be aimed at a certain predetermined spot on the playing surface, so that lighting is uniform overall. Above, a workman adjusts one of the 1318 new floodlights installed in Cleveland's baseball stadium. Numbered discs on the field indicate the targets for correspondingly numbered fixtures.