BELL LABORATORIES RECORD

SYNTHESIZING SPEECH
HOMER DUDLEY

THE TONLAR
L. G. ABRAHAM

VACUUM TUBE RELAY IN SUBSCRIBER SET
L. J. STACY
S. B. INGRAM

DECEMBER 1936 Vol. XV No. 4

BELL LABORATORIES RECORD

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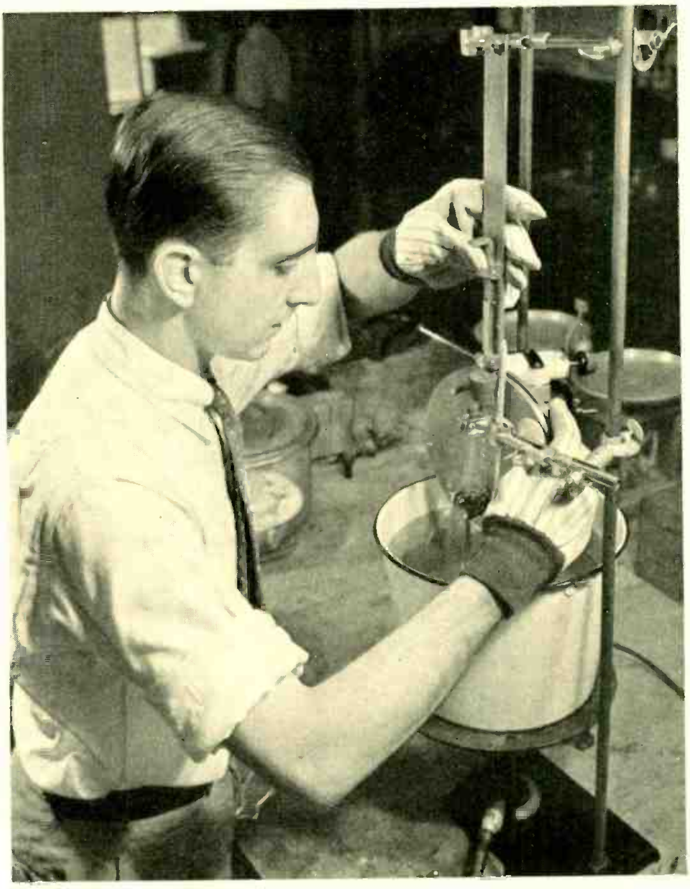


Measuring the viscosity of shellac to predict its plastic flow when used as a solid insulating material

DECEMBER, 1936

VOLUME FIFTEEN—NUMBER FOUR

Synthesizing Speech

By HOMER DUDLEY
Wire Transmission Research

A demonstration by the author of a speech-synthesizing system accompanied Dr. F. B. Jewett's address at a session of the Harvard Tercentenary Conference on Arts and Sciences, Sanders Hall, Cambridge, September 11, 1936.

THE synthesizing of speech, demonstrated at Harvard University, involved an instantaneous analysis of speech and then, upon the basis of that information, a synthesis which reconstructed the speech. It was a case of doing electrically what one does in mimicking when he listens to speech sounds with his ear and immediately reproduces them with his own vocal system. In this process three operations may be distinguished: first, the aural perception and analysis of the sound; second, the passage of neural impulses for the control of the vocal organs, and third, the reproduction of the sound. In the system which was demonstrated these operations were electrical or electro-acoustical.

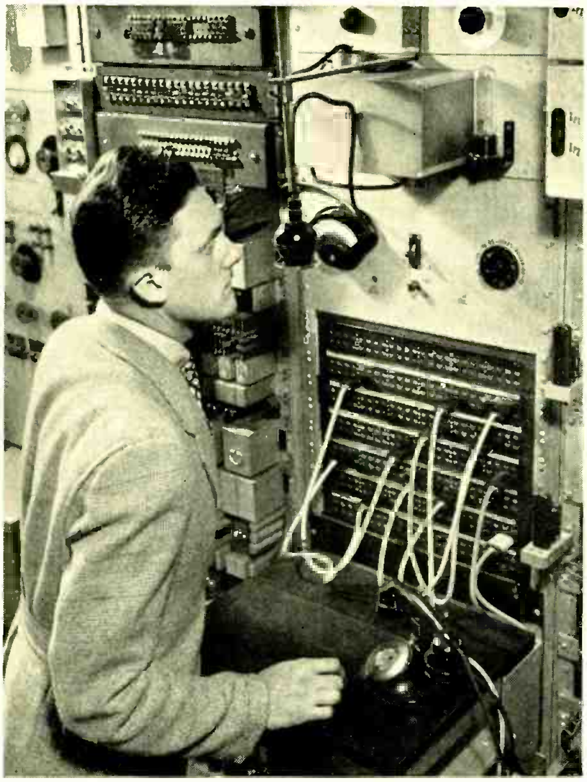


Fig. 1—*C. W. Vadersen speaking into the microphone of the speech-synthesizing apparatus*

These operations are to be distinguished from those of ordinary telephony. In telephony there is no analysis of the sound nor is there any synthesis of it. Instead a listening device, the telephone transmitter, picks up the speech sounds and translates them into current variations; a complex alternating current, with components corresponding to those of the sound wave, is then transmitted to the other terminal; and there a reproducing, or talking, device in the form of a telephone receiver reproduces the speech. In ordinary telephony we move a sound wave electrically from one point to another by direct transmission but in the syn-

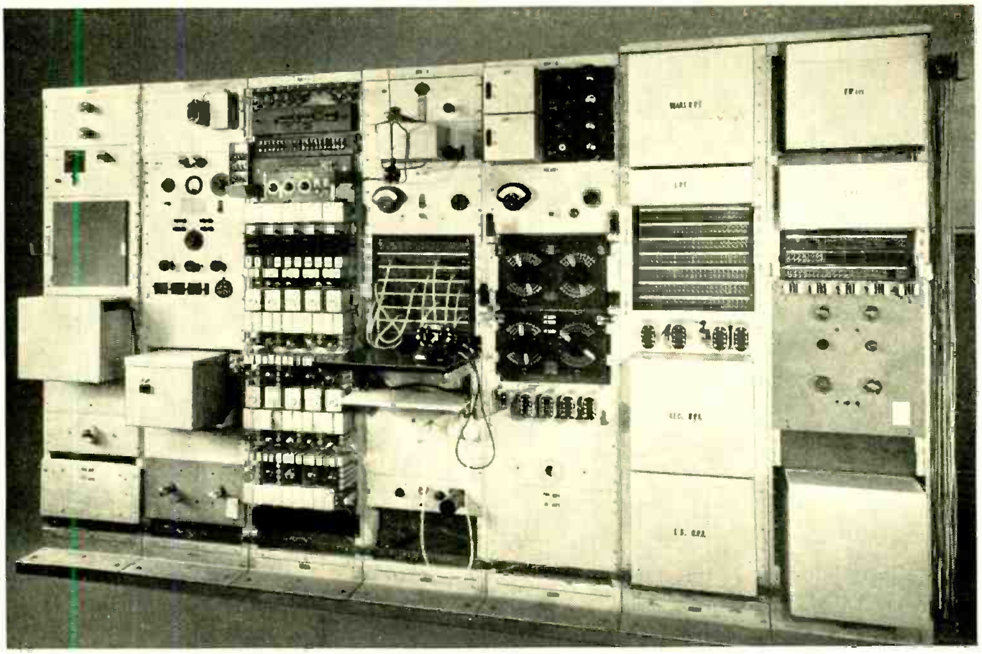


Fig. 2—Laboratory arrangement of the speech-synthesis system

thesizing process, only the specifications for reconstructing the sound wave are directly transmitted.

Synthesizing speech is another step in our studies of speech. Speech is the subject of continuous investigation because it is the basic material which telephony handles. To be able to build an electro-mechanical system for producing speech artificially is a step towards a fuller understanding of the physiological mechanism and of its acoustic output.

Such an artificial system is not easy to build; and the present system is not perfect although it will produce easily intelligible speech with the usual variations of pitch and loudness. It required first, the construction of an instantaneous analyzing device. In most of the other investigations of speech characteristics the analysis has been for the purpose of obtaining statistical information. Sounds have been analyzed in terms of energy levels and of frequency components as a function of time with various speakers. In some of these studies, currents derived from analyzing equipment have been used to operate recording meters of various types. In the present system such currents are used to control the elements of the synthesizing device.

What may be considered the first important step toward speech producing was the development of the artificial larynx.* An important organ of speech production, the vocal cords, was approximately simulated by a mechanical element. The artificial larynx, for example, varies its pitch with the sound pressure applied thus limiting its volume range. The device is entirely mechanical and produces a complex sound wave by an operation basically similar to that of the vocal cords. In the present system the ele-

* R. R. Riesz "Restoring Speech," RECORD, *Vol. VIII, p.* 64.

ment equivalent to the vocal cords is entirely electrical, and produces an electrical current. The present development also goes further in that all of the important elements of the vocal system have electrical equivalents. The resulting current when supplied to a telephone receiver or loudspeaker then produces the characteristic sounds of speech.

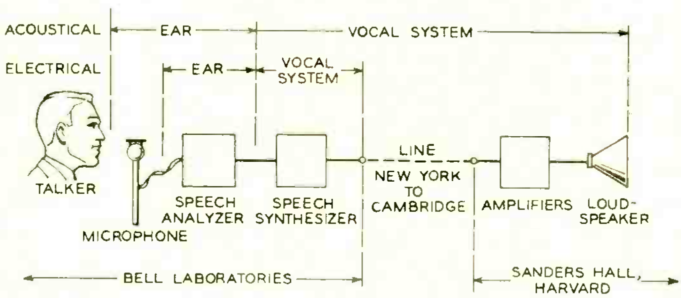


Fig. 3—Circuit arrangement for the demonstration at the Harvard Tercentenary Conference

The electrical equipment occupies enormously more space than the ear and vocal organs which it simulates, as may be seen from Figure 2, which shows the apparatus mounted in its room in a Transmission Research laboratory.

The circuit arrangement for the demonstration is shown schematically in Figure 3. Speech originating in the laboratory in New York was picked up by a moving-coil microphone; it was analyzed for the three fundamental characteristics of speech sounds, namely, pitch, resonant frequency regions, and loudness; control currents were then passed to the speech synthesizer; in this a new current was produced, manufactured according to the specification of the speech analyzer; and this current was transmitted to the distant auditorium in Sanders Theatre where it was converted into acoustical speech waves by means of a public-address system.

Figure 3 has also been labelled in accordance with the earlier analogy in which the complete analyzing-synthesizing system was compared to a person mimicking instantaneously the sounds he hears from another speaker. The system proper does not analyze a sound to produce another directly, but instead analyzes a sound-bearing electrical current and synthesizes a mimicking electrical current. On this basis the analyzing device is the artificial ear of the mimicker and the synthesizing device is the artificial vocal system as shown on the lower added line at the top. On the other hand if we think of an artificial ear as a device for analyzing an acoustic speech wave, then the microphone must be added. Likewise from the acoustic standpoint the artificial vocal system contains the loudspeaker. This is shown by the top line.

Of the two basic elements, the analyzer and the synthesizer, the analyzer is like the ear in that it analyzes speech sounds to determine their previously mentioned basic characteristics of pitch, resonant frequency regions and loudness. The ear mechanism for doing this is not entirely understood, so no direct comparison is practicable between its elements and those of the electrical analyzer.

The processes of the vocal system are better understood. The three fundamental steps in producing speech sounds are: (1) provision of an energy source, (2) modulating energy from this source so that it will contain vibrations in the frequency range audible to the ear, and (3) selecting from these audible vibrations by resonance to get the various speech sounds.

The energy source is provided by the pressure on the air in the lungs as it is being exhaled. In a normal exhalation this flow of air is not audible. It is made audible by forming a partial closure and forcing the air through under pressure. The air particles which get through then vibrate in rapid complex motions at frequencies that are audible to the ear. For voiced sounds, this partial closure is at the vocal cords which then vibrate at their natural periodic rate, depending on the tension the talker places on them. For unvoiced sounds the closure is in the mouth passage. Thus "s" is formed by placing the tongue against the hard palate and forcing the air through the narrow opening between them. After these audible vibrations are set up it is still necessary to provide means for differentiating the various sounds from one another. This is done by shaping the mouth to form resonant air chambers which favor certain frequencies but discriminate against others. It is in this way that "ah" differs from "ee" although in both cases the vocal cords are vibrating.

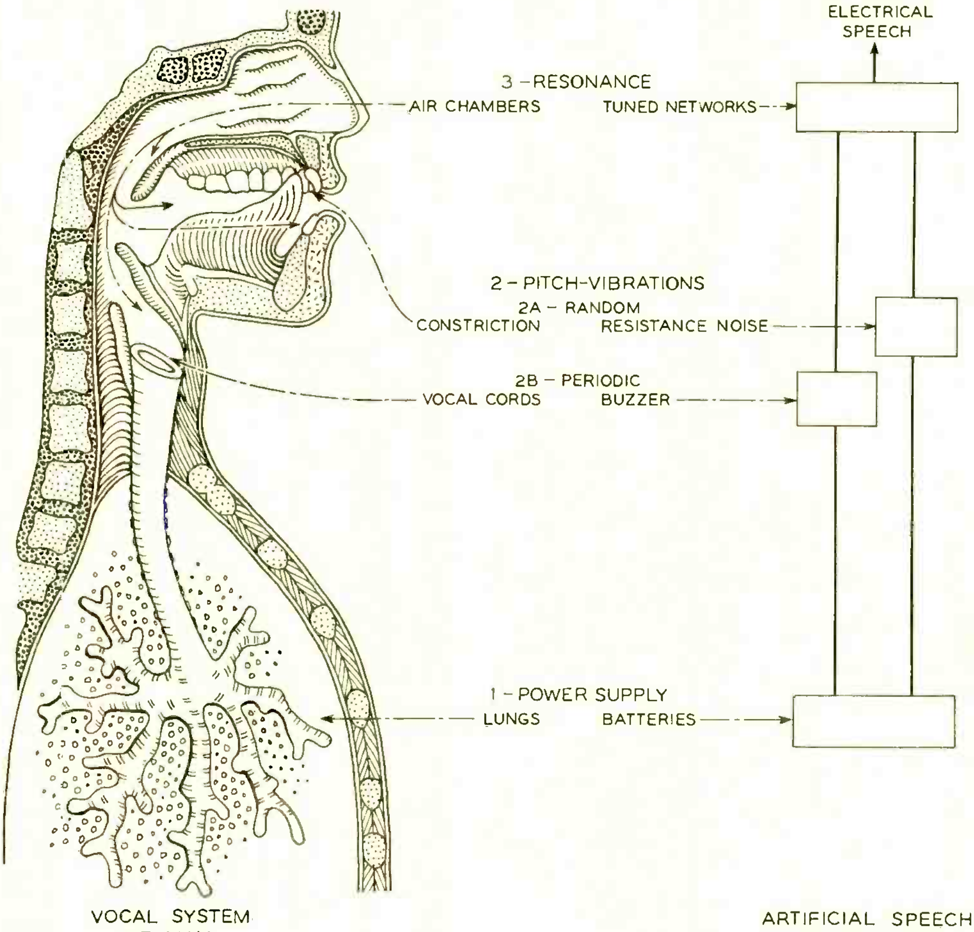


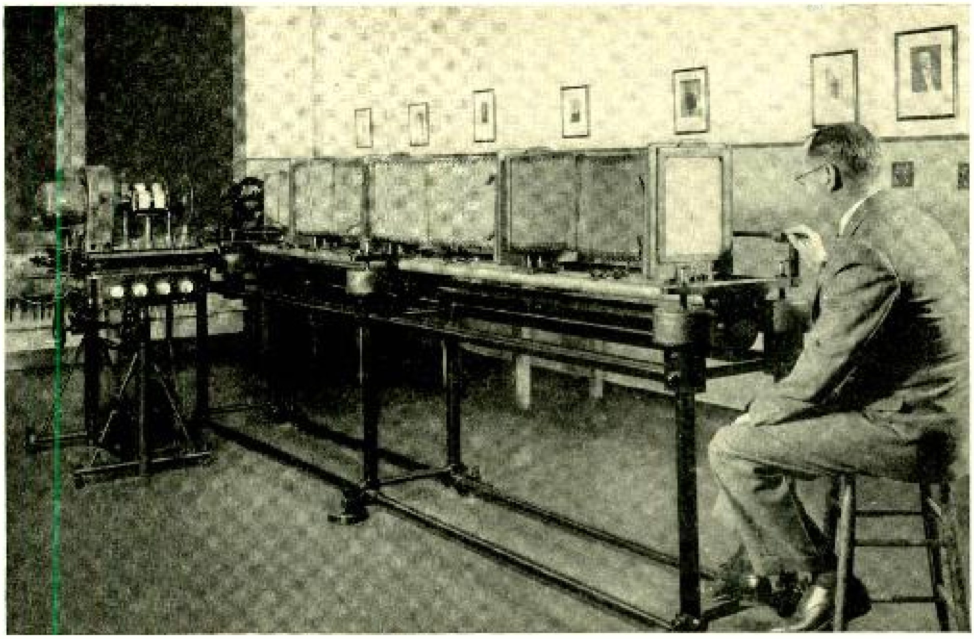
Fig. 4—A comparison of human and electrical systems for speech

Starting from the lungs and going out to the mouth there are indicated in Figure 4, (1) the steady power source in the lungs, (2) the vibration producers in the form of the vocal cords for the voiced sounds and the constrictions in the mouth passage for the unvoiced sounds and (3) the resonance elements in the form of resonant air chambers.

The box schematic of the artificial speech synthesizer in Figure 4 shows its correspondence with the vocal system. The steady power supply is essentially from batteries instead of compressed air in the lungs. The vibrating elements are a buzzer-sounding relaxation oscillator for the vocal cords and a resistance noise for the unvoiced sounds produced at the constriction in the mouth. Resonance, which determines the frequency components to be favored and those to be discriminated against, is provided by tuned electrical networks instead of air chambers as in the mouth. The output, of course, is an electrical, instead of an acoustic wave.

When a speech signal is analyzed by the artificial ear it is resolved into simple speech-defining signals or control currents. These currents, however, can be modified by introducing circuit elements in their paths. It is, therefore, possible in the laboratory to modify the manufactured speech so that it differs in almost any prescribed manner from the original speech. Thus the pitch may be raised or lowered or kept fixed—each producing an interesting modification of the original voice while preserving the same sense. The pitch of the synthesized speech can be varied independently of the vocal-cord pitch by manipulating a manually operated dial. Also the artificial voice may be used together with the original voice to produce a duet from a single voice. And the harmony is almost perfect!

This voice-controlled voice is seen to manufacture speech in such a way as to give important information about the basic character of speech production. In particular it will permit experiments in which the ear evaluates the effect of various modifications in the character of speech sounds. It provides a new tool for the Laboratories' continuing studies.



A Metallographic Microscope of Exceptional Power

By F. F. LUCAS
Telephone Apparatus Development

FIFTEEN years ago most photomicrographs were made at magnifications of from 100 to 500 diameters and one was seldom encountered which exceeded a magnification of 1000; moreover the results showed much poorer resolution than calculations indicated lens systems then available were capable of giving. Evidently something had been overlooked although the statement was not infrequently made that the ultimate in resolving power had been attained. As a result of studies begun in the Laboratories at that time the useful range of microscopic vision was increased to 3500 diameters with existing equipment by refinements in technique. This work, which extended over a period of several years, made it apparent that an increase in both resolving and magnifying power could be attained by the design of more stable equipment and the use of a lens system, developed years ago by Abbe, which was particularly well suited for the study of metal structure. As this required important constructional changes in the apparatus, the design of new equipment was undertaken. This involved conferences by the present writer at the Zeiss Works at Jena where the apparatus was constructed. As a result of these efforts the most powerful metallographic microscope thus far attained was produced. It gives excellent definition at 5000 diameters and has an ultimate

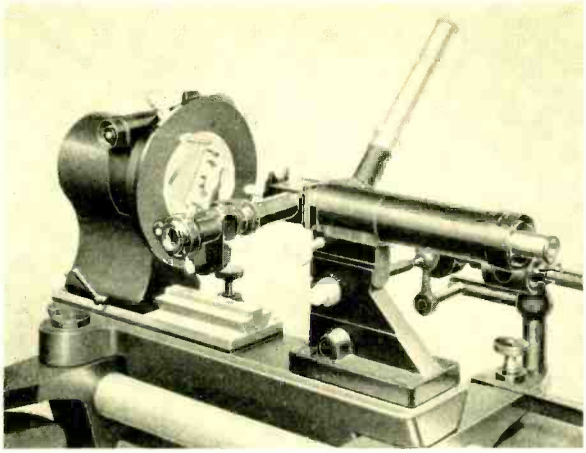


Fig. 1—The specimen which is mounted on the stage at the left is illuminated by light brought in from the side of the microscope

the camera were therefore mounted on a stand with six supports, each provided with a levelling screw and insulated from the floor by a sponge rubber pad. The main horizontal support consists of three large steel tubes joined at their ends and at two intermediate points by massive yokes. The camera is in four sections so that different lengths of bellows can be used. Photographic plates up to 24 x 30 centimeters can be accommodated. As assembled for operation the complete apparatus is twelve feet long and ten feet wide.

limit of approximately 7000 diameters.

In many respects the new microscope is quite similar to instruments of much lower power. Mechanically, however, its appearance is quite different. In the earlier investigation it had been found that high resolution was most effectively secured by using a low power projection lens with the photographic plate a long way from the lens system rather than a high power projecting lens and a short bellows. This meant an extensive system of bars and couplings to keep the plate rigid with respect to the lens as well as vibration-absorbing supports. These conditions required for convenience of use that the microscope be mounted in a horizontal position.

The microscope and

The microscope proper is shown in Figure 1 and its principal parts are given diagrammatically in Figure 2. Since metallographic specimens are opaque they have to be illuminated from the front. This is done by bring-

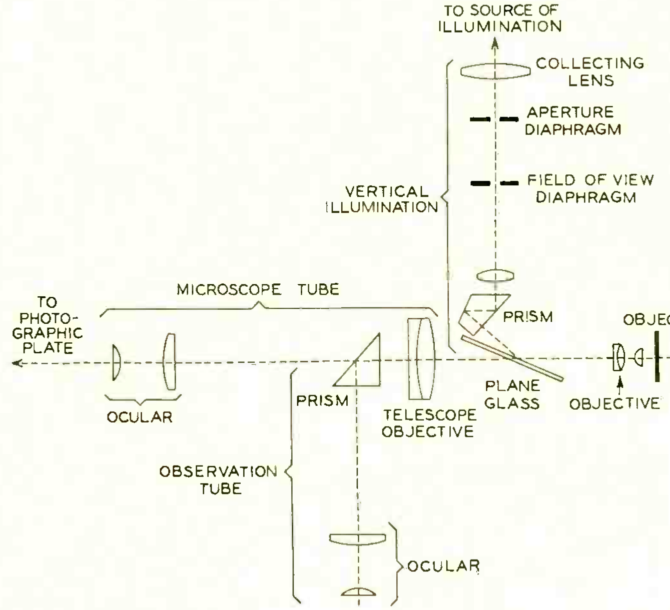


Fig. 2—A simplified diagram of the optical system of the new metallographic microscope

ing light in from the side through a lens system and then reflecting it from the surface of an inclined plane glass directly onto the specimen. Light from the specimen passes back through this glass plate to the camera. Some of the light is lost in this beam splitting arrangement but enough is left to make high power photographs in from one to five minutes.

Another interesting feature is the immersion objective. The front lens of the microscope is set within less than a millimeter of the specimen and the space between is filled with a drop of monochlornaphthalene. An objective of this type increases the light gathering power and the resolution and is generally used when very high magnifications are required.

The horizontal assembly of the microscope also made it convenient to

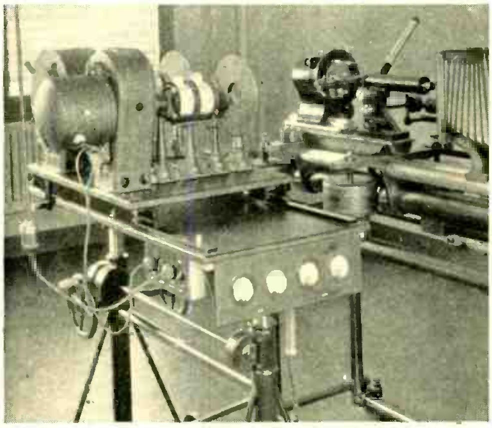


Fig. 3—The illuminator for arc and mercury vapor lamp illumination

illuminate the specimen from the side and to mount the light sources on separate floor stands which can be brought up to the microscope and adjusted. There are two such illuminators provided: one equipped with carbon and mercury arc lamps and the other with a spark generator. The

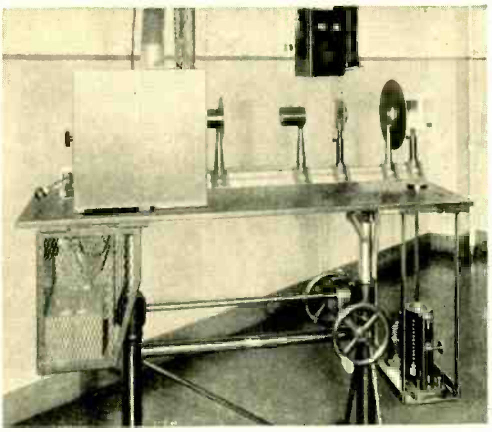


Fig. 4—The monochromator illuminates the specimen with light of a single wavelength

arc lamp is the most intense source available and is generally used in conjunction with filters to limit the frequency band. The mercury vapor lamp gives approximately monochromatic light when suitably filtered. The assembly for the spark source has a prism which spreads the light into a spectrum so that light of a single wavelength can be selected for illumination. The spark source is generated between flat metal strips of the appropriate metal to give illumination of the desired wavelength. These strips are mounted in holders which are enclosed in a wooden box lined with sheet metal and heavy felt to deaden the noise of the spark. The box is connected by a flexible hose to an exhaust fan and flue to remove fumes caused by the discharge.

Focussing the specimen where such high magnifications are involved is a complicated task. At the side of the microscope is an observation tube which can be pushed in and made to reflect light from the specimen into the observing eyepiece. This is used for preliminary adjustment. More careful focussing is obtained by observing the image on the ground glass at the far end of the bellows. This distant focussing is made possible by controls which extend along the side of the camera back to the microscope proper. Finally a clear glass is substituted for the ground glass and the image is examined with a magnifying eyepiece to assure the best possible focus. A photographic plate is then mounted in exactly the same position which was occupied by the clear glass.

Some idea of the increase in magnification obtained with the new equipment as compared with that previously attained is given by the accompanying series of photomicrographs of a high carbon tool steel specimen. The photograph shown in Figure 5 was taken at a magnification of 200 diameters and represents a high

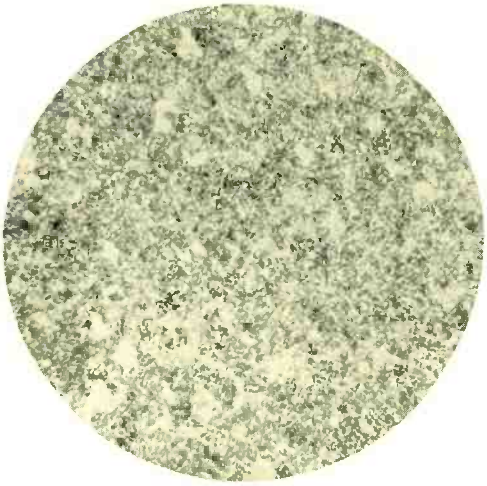


Fig. 5—A photomicrograph of high carbon steel at a magnification of 200 *diameters*

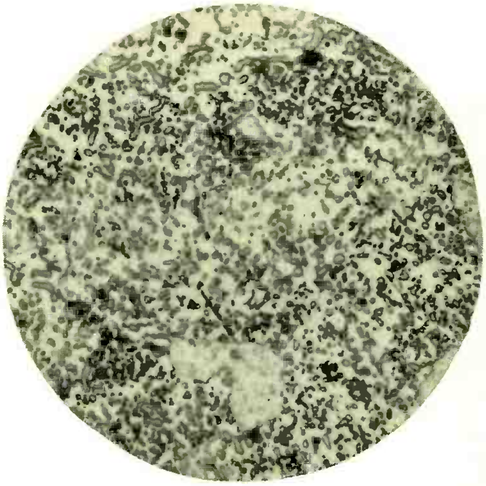


Fig. 6—At 1000 *diameters globular particles of iron carbide become visible*

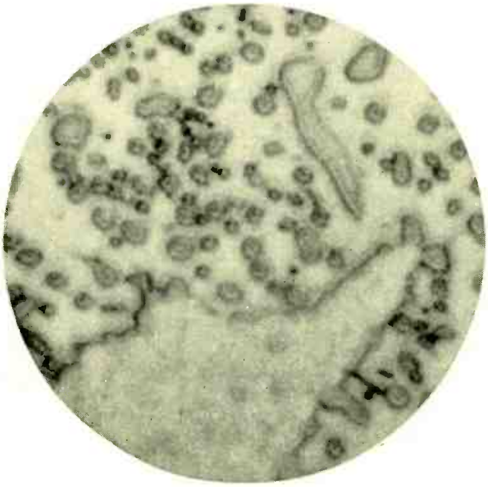


Fig. 7—When a magnification of 4000 *diameters is employed the small individual particles of iron carbide are clearly visible*

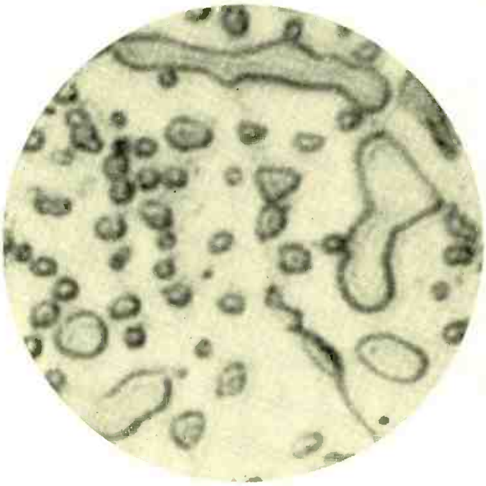


Fig. 8—Magnification to 6500 *diameters shows a clear image with the iron carbide particles embedded in the iron matrix*

resolving power for a micrograph made prior to the studies reported here. In this specimen the carbon is present as carbide which is suggested by the mottled appearance but the magnification is not high enough to resolve the particles. In Figure 6 the same specimen is shown magnified to 1000 diameters. The larger particles of carbide show here quite clearly in globular form. The photograph of Figure 7 was taken with a high resolving power lens system at 4000 diameters. Finally Figure 8 shows the particles enlarged to 6500 diameters without serious breakdown of the image. The matrix of iron in which the particles are embedded appears clear and structureless and the carbide particles stand out distinctly against the background. The increase of resolution, as distinguished from magnification, attainable with the new microscope is brought out by comparing the micrographs of chrome-iron shown at 1000 diameters in Figure 9 and at 4000 diameters in Figure 10. Extremely fine structural details are clearly shown at the higher magnification.

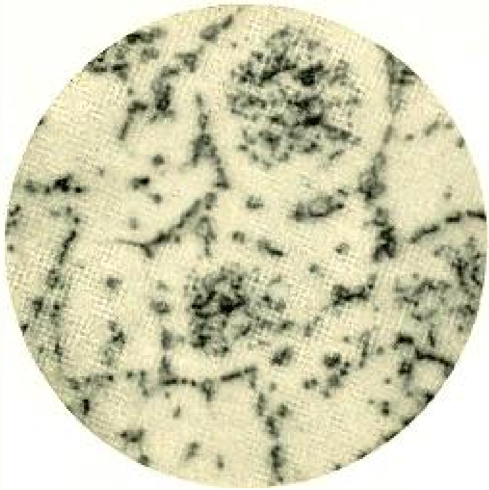


Fig. 10—*Increased resolution is shown at* 4000 *diameters*

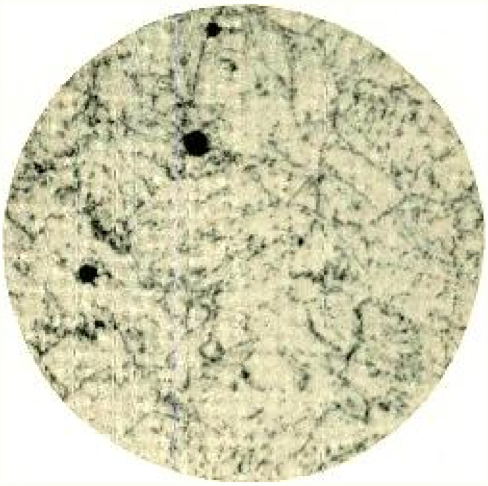


Fig. 9—*Chrome-iron specimen magnified to* 1000 *diameters*

Another factor which has contributed to the successful use of such high magnifications is the improvement which has been made here at the Laboratories in the preparation of metallographic samples.* Specimens similar to those shown in the accompanying photographs would formerly have appeared rough and scratched and the carbide particles would have been surrounded by halos and diffraction bands at the magnifications used here. The methods of illuminating the specimen at that time were also unsatisfactory and would have made the particles appear much larger than their actual size.

These attending difficulties emphasize the fact that success in extending the useful range in high power metallography has depended not only on increasing the magnification but also upon taking extreme care to control the many other factors involved such as mechanical stability, freedom from outside disturbances, illumination of the specimens and preparation of the specimen itself.

*Record, *December,* 1935, *p.* 116.

Impact Tester for Organic Finishes

By H. G. ARLT
Chemical Laboratories

ORGANIC finishes are now made which are so hard and adhere so firmly that a nail coated with them can be driven into hard wood without appreciably damaging the finish. With this surprising degree of toughness attainable the importance of making tests to determine the impact resisting qualities of different finishes, so that good finishes can be distinguished from poor ones, is evident. Such impact tests give information regarding the adherence characteristics of a finish to its base material and the deformability under impact stress of the organic coating—qualities which measure the ability of the finish to withstand the handling incident to assembly and subsequent use in the field. To carry out tests of this character more effectively, a new impact machine has recently been developed by the Laboratories.

The earliest type of impact test was of a qualitative nature and consisted of striking the finish under test with the rounded end of a hammer. The next development was to make the test quantitative by dropping the head of the hammer from definite heights. This type of test is also made by using hardened steel balls as the impact device. Tests made in this fashion can be used to measure the resistance of a finish to a single blow of selected energy value or to repeated blows of either the same or different energy levels.

To obtain better control and to simulate the battering action to which a switchboard keyshelf is subjected by falling plugs the so-called "Woodpecker machine" was developed. With this device, the blows are delivered by a spherical hammer located at the end of a cam-actuated lever arm and the intensity of blow is controlled by a coiled spring. Testing machines of this type have been constructed in the Laboratories to deliver a series of blows of constant energy either at a single spot, or on a small area over which the blows are evenly distributed by providing a mechanism to move the specimen. These devices have been used for testing keyshelf facings and similar materials as well as for testing finishes.

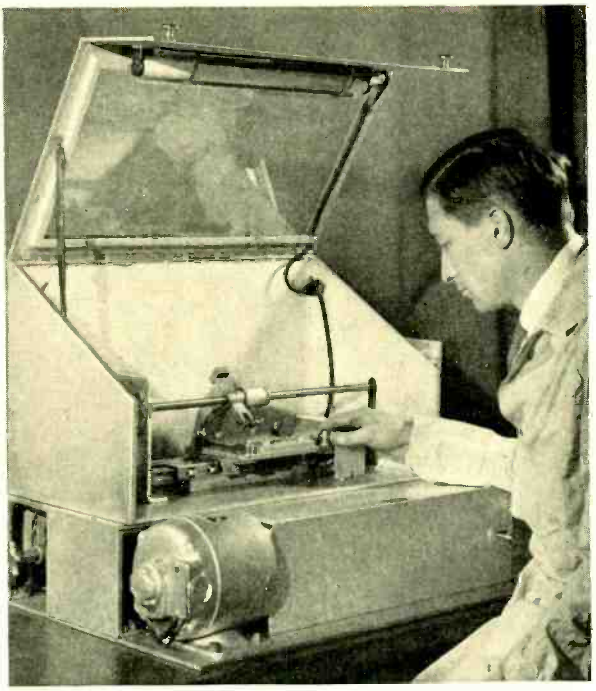


Fig. 1—Finishes are tested by striking them glancing blows with a rotating hammer. H. C. Theuerer is conducting the test

More recently, the impact resistance of finishes has been tested by another type of apparatus in which the blow is delivered by a hammer loosely pivoted on a rotating shaft in such a fashion as to scuff the surface while subjecting it to a glancing blow, thus removing any loosened particles of finish. The first device of this type was arranged to deliver repeated impact blows of uniform intensity uniformly over a small area. It soon became apparent, however, that the information needed was not so much the number of blows of a given intensity which a finish can withstand as how hard a single blow a finish will resist. To meet this requirement the early design was modified to provide a constantly increasing speed of rotation of the shaft controlling the energy level of impact while the base panel was moved so that each new blow would strike a fresh but closely adjoining area.

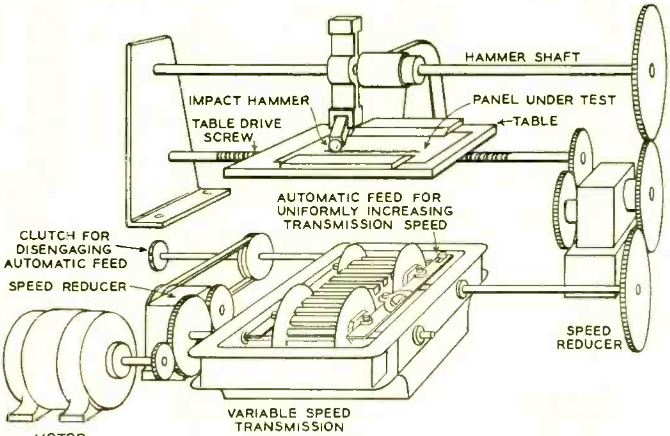


Fig. 2—The hammer and test panel are motor driven through a variable speed transmission which can be set to automatically increase the blow delivered by the hammer

Since it has been found necessary to determine the resistance of finishes to both constant and increasing impact, an apparatus has been developed in which both of these features are combined. In this new machine the panel is moved longitudinally past the rotating hammer in such a manner that the finish under test is either subjected to a number of impacts of uniform intensity on the same area or to a series of blows of gradually increasing intensity, where each blow strikes a different spot on the finish.

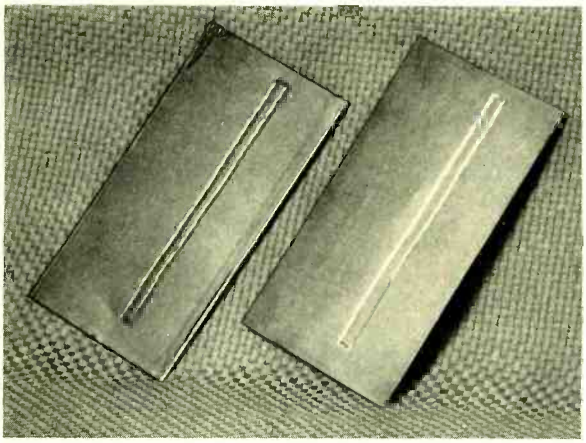
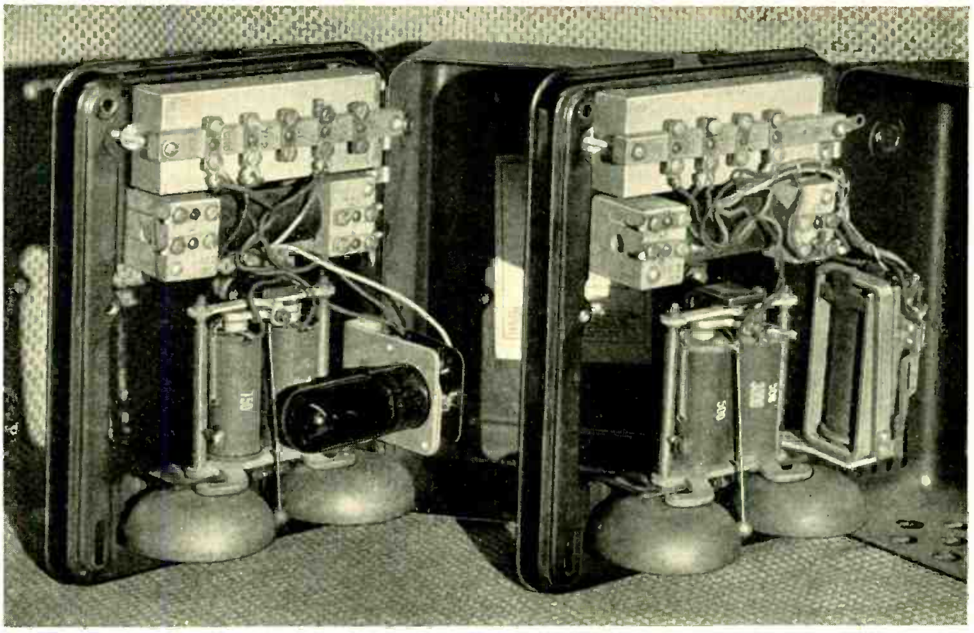


Fig. 3—The left panel was struck a series of blows of constant intensity. Breakdown under blows of increasing severity is shown by the change of color in the path of the hammer on the right panel

In the new apparatus the specimen is clamped to a carriage which moves in a horizontal plane under a rotating hammer so that the finished surface receives a glancing blow each time the hammer revolves. The intensity of the blow delivered can be controlled by varying the speed of rotation. The hammer and carriage are driven in synchronism by a motor which advances the specimen two one-hundredths of an inch for each revolution of the hammer, thus presenting a fresh portion of the finish for each blow. The variable hammer speed is obtained by a double set of belt-driven cone pulleys which are located between the motor and the hammer shaft. By spreading one pair of these cones and bringing the other pair together the effective speed ratio of the pulleys can be changed. The spreading is controlled by a drive screw attached to the motor which moves the specimen so that the speed of the hammer automatically increases as the specimen advances. When blows of constant intensity are required the screw is advanced to the point which gives the desired hammer speed and disengaged. The speed of rotation then remains constant as the specimen advances. The impact hammer is enclosed under a cover equipped with a double layer of safety glass through which the action on the finish may be safely observed while the test is being made. The appearance of the test specimen is shown in the accompanying illustration. When blows of constant intensity are delivered the specimen is moved back and forth under the hammer until the finish is destroyed and the number of repetitions is taken as a gauge of impact resistance. With blows of increasing intensity the test is continued through one complete cycle of hammer blows, in which case the intensity required for destruction by a single blow is taken as the measure of resistance. The rate of the hammer in r.p.m. at the point of failure can be found from a previous determination of the speed corresponding to different positions of the specimen.

The new impactometer permits rapid and economical impact testing of finishes over a wider range of impact values than have previously been available with this type of device.



Vacuum Tube Improves Selective Ringing

By L. J. STACY
Systems Development

THE standard subscriber set used in the Bell System for four-party selective ringing employs a relay as well as a polarized ringer at each station. The arrangement of such a circuit is indicated in Figure 1, which shows the connections at the four subscriber stations on a full-selective circuit. Superimposed ringing current is employed, which uses an alternating current superimposed on either a positive or negative direct current. Ringing is applied across the line, and one side of the line is grounded. At the subscriber stations, the relays are all connected across the line through condensers, and all four relays operate whenever ringing is applied, and connect their respective ringers to ground. The ringers, however, are divided; half of them are connected to one side of the line and the other half to the other. While all of the relays operate for all calls, current will flow through only the two ringers connected to the side of the line not grounded during the application of ringing. The ringers are of the polarized type, however, and the two connected to the same side of the line are oppositely poled so that one will ring only with a positive superimposed current and the other only on a negative superimposed current. In this way only one bell will ring for any one call.

Recent improvements in the neon tube suggested that it might be used at the subscriber station to take the place of both the relay and the condenser in the subset, and at the same time to give better operating conditions with a lower original cost and decreased maintenance expense. With this in view, the 313A vacuum tube (described in the following article) was developed. This is a three-element tube with two control electrodes, either of which may be used as an anode or cathode, and an operating anode. As used in the new subscriber set one of the control electrodes is always used as a cathode, and the other is used as a control anode to secure breakdown or ionization of the tube at a potential of about 70 volts. A resistance of 100,000 ohms is connected in series with this control anode to limit the current in the control gap to a value sufficient only to ionize the gas so as to allow current to flow in the main gap.

The connection of the tube at the four stations of a full-selective line is shown in Figure 2. When station 1 is to be rung, "negative" ringing current is applied to the "ring" side of the line, and the "tip" side of the line is grounded. Control gaps of tubes at stations 1 and 3 break down, but since "positive" current can flow only from the anode to cathode, the tube at station 1 alone will pass current enough to ring its bell. To ring station 3, "positive" current is applied to the ring side, and as the anode at the tube is connected to that side of the line, current will flow to operate the ringer. Stations 2 and 4 respond in like manner to ringing current flowing through the tip side. The tube set will operate on the same type of ringing and requires even less current than the relay set, so that no change is required in the central-office ringing supply. It will also operate on the same line with relay sets.

Several advantages arise from the use of this new tube. With the relay-type subscriber set, current flowed through two ringers and four relays at each call, while with the vacuum-tube set, because of the asymmetry of the tube, which makes it conductive to current passing in one direction only, current flows only in one ringer for each call. This reduces the voltage drop due to line resistance, and permits a longer ringing range for four-party service.

The tripping relay at the central office, whose function is to open the ringing circuit when the subscriber answers, must be adjusted not to operate on the ringing current, but to operate promptly on the small additional current that flows when the subscriber lifts his receiver from the hook. Since, with the vacuum-tube set, current flows through only one ringer at any one time, the amount of ringing current is less, and as a result the adjustment of the tripping relay is simplified.

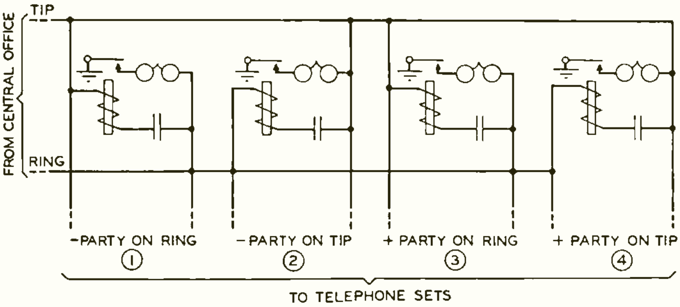


Fig. 1—Substation connections for a four-party full-selective circuit using relay-type subscriber sets

The new circuit completely eliminates bell tapping and false ringing sometimes caused by dialing or switching operations on the line. Another advantage of the tube is that it can be mounted in any position, and requires no adjustment. The relay, on the other hand, has to be mounted vertically to insure proper action, and in addition a certain amount of adjustment is required to insure its proper functioning.

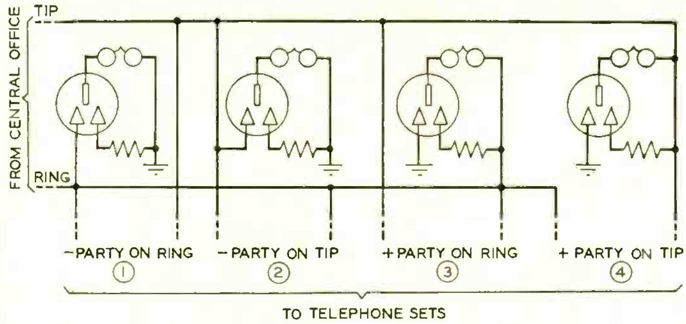


Fig. 2—Connections for the vacuum-tube subscriber set for a four-party full-selective circuit

Several years ago, an eight-party semi-selective ringing system was adopted using relay sets and superimposed ringing current. One of the essential differences between the eight-party semi-selective relay sets and the four-party full-selective relay sets is that higher impedance relays and ringers are used for the eight-party set. These impedance requirements were imposed partly by the adjustment requirements for the tripping relay, and partly by the necessity for high impedance to noise induction, such as from power lines. Since the use of the tube set leaves the connection to ground at the subscriber station open to normal voltages, no noise induction results even with the use of low impedance ringers, and since as previously pointed out, the tripping conditions for the tube set are considerably less severe than with the relay set, the vacuum tube subscriber set gives appreciable improvement for eight-party semi-selective service as well as for four-party full-selective service.

Another application of the vacuum-tube subscriber set is in areas where relay sets are now used on two-party lines to avoid interference from foreign a-c. earth potentials or induction. Since the vacuum tube is open-circuited except for the duration of the ringing, the new sets put the subscriber's station on the same footing as in individual line service, so far as noise is concerned. Also, in two-party service, the new sets avoid false ringing from foreign voltages up to the breakdown voltage of the main gap, which is of the order of 175 volts peak. In four-party service protection against false ringing extends to the breakdown voltage of the control gap, about 70 volts peak.

The 313A tube can be provided more cheaply than the relay now used, and since it requires no adjustment, considerable savings both in first cost and maintenance of subscriber sets will result from its use. Accelerated life tests on the 313A tubes have indicated that the tubes will permit satisfactory ringing service for at least 300 hours actual operation. Average station traffic requires the tube to conduct current for only about 6 hours per year of service. After long usage or excessive current flow, both breakdown and sustaining voltages of the tubes rise, thus reducing the current through the ringer. So far no tubes have been destroyed during test except by mechanical breakage.

The 313A Vacuum Tube

By S. B. INGRAM
Vacuum Tube Development

COLD-CATHODE gas-filled tubes are well known as sources of illumination for special purposes. The two-watt neon-filled lamps, which operate in standard lighting circuits, are commonly used as indicator lights because of their low power consumption. These glow lamps have only two electrodes, but by the addition of a third electrode, and by properly controlling the tube geometry and gas filling, tubes may be produced which have many interesting properties as circuit elements. A program for the development of such tubes has been undertaken in the vacuum-tube development department, and parallel investigations of their circuit possibilities have been in progress in several different parts of the laboratories. A number of applications have been made, but by far the most important to date is in the four-party selective-ringing circuit described in the previous article. In this circuit the tube operates in the subscriber set, a fact of considerable interest since this is the first time that vacuum tubes have found general application in that part of the telephone plant which is located on the subscriber's premises.

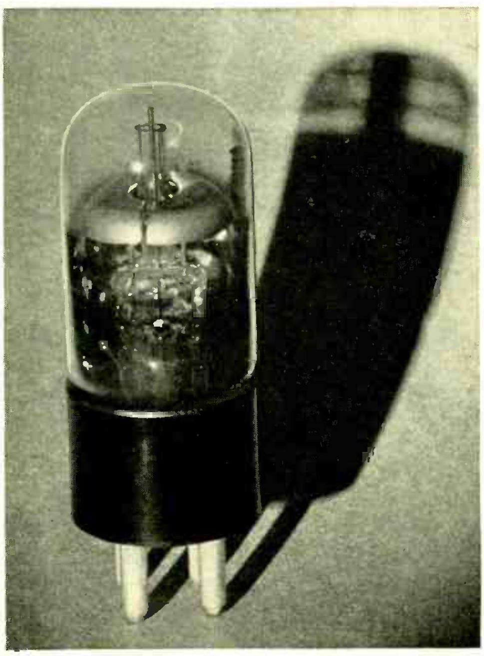


Fig. 1—The 313A cold cathode gas-filled tube

The overall appearance of the 313A tube is shown in Figure 1. In finished tubes the entire glass bulb is covered with a coat of black enamel to render the glow invisible, but in the photograph the enamel has been left off so that the elements may be seen. The two semi-circular discs are known as the control electrodes. The small nickel wire projecting above the glass sleeve is the anode. The two control electrodes are coated with an activated surface of barium and the envelope is filled to a pressure of several centimeters of mercury with a mixture of the rare gases, neon being the principal constituent. The physical properties of the barium surface together with the nature of the gas filling combine to produce a discharge device that operates on a low voltage. The sustaining voltage—that is, the potential drop between one of the control electrodes and the anode when the tube is conducting—is about 75 volts. This compares with drops of two or three hundred volts in structures of similar geometry but with unactivated electrodes and other gas fillings.

As a circuit element, the 313A tube may be used to perform as a relay, as

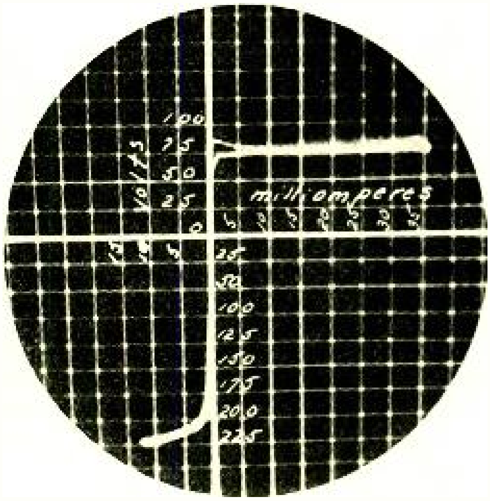


Fig. 2—Current-voltage characteristic of the main gap is asymmetrical and exhibits a constant voltage for all positive currents

a voltage regulator, or as a rectifier. Within the tube there are two conduction paths, one between the two control electrodes, known as the control gap, and the other between one of the control electrodes and the anode, known as the main gap. Each gap is characterized by a breakdown voltage and a sustaining voltage. In the main gap, as a result of the wide spacing of the electrodes, these values are quite widely different, about 175 volts and 75 volts respectively. In the control gap, where the electrode spacing is small, the corresponding values are about 70 and 60 volts. This difference in breakdown voltage of the two gaps enables the tube to act as a relay.

The current-voltage characteristic of the main gap, taken on a cathode-ray oscillograph by G. H. Rockwood, is shown in Figure 2. To obtain these characteristics the tube was connected in a circuit as shown in Figure 3, where the control gap—in series with a high resistance—is used to obtain a low breakdown voltage. Two features of this characteristic are of particular importance. One is the flatness of the voltage curve for positive currents, which makes the tube suitable for voltage regulation, and the other is the lack of symmetry in voltage for positive and negative currents, which allows the tube to act as a rectifier. With positive current, the potential remains essentially constant at about 75 volts for all values of current, while with negative current, practically no current flows at all until the potential reaches 150 volts, and then the voltage rises rapidly with an increasing negative current. This asymmetry of current-voltage characteristic is caused by the difference between the large activated surface of the control electrode and the small unactivated surface of the wire electrode. With the latter positive, large discharge currents may flow, but with either of the semi-circular electrodes

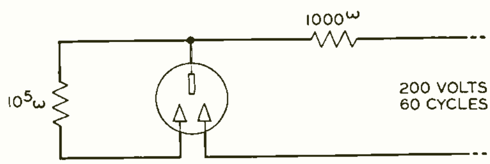


Fig. 3—This typical rectifier circuit was employed to obtain the current-voltage characteristic of the main gap

positive, much higher voltages are required to produce the same current. The characteristic for the control gap is similar except that the sustaining voltage is lower because of the narrower gap, and that the current-voltage relationship is symmetrical because of the similarity in size and shape of the two control electrodes.

A typical relay circuit for the 313A tube is shown in Figure 4. A biasing voltage of somewhat less than the control-gap sustaining voltage is impressed on the control gap. If now a

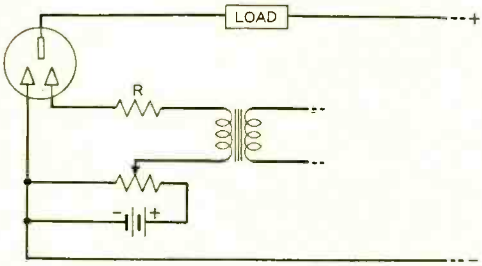


Fig. 4—A typical relay circuit utilizing the 313A vacuum tube

signal voltage large enough to raise the control-gap voltage above breakdown is applied in series with this biasing voltage, the current that flows between the control electrodes will produce sufficient ionization to break down the main gap. The amount of current required is of the order of one microampere. Load currents up to 30 milliamperes, the peak current rating of the tube, may then be safely drawn in the load circuit. Removal of the signal voltage will have no effect on the current in the load circuit, which must be interrupted to restore the tube to the non-conducting condition.

To obtain regulating action, the tube could be connected into a circuit as shown in Figure 5. The control gap alone is used because of its low breakdown voltage, and it regulates at about 60 volts. A d-c supply of varying potential greater than 60 volts is connected to the terminals at the left of the diagram. The control gap at once breaks down and forms a shunt path across the load. Because of the characteristics of the tube, however, the voltage across this gap, and hence across the load, remains constant at 60 volts regardless of the supply voltage or the load current.

The asymmetrical characteristic of the tube, as already mentioned, enables it to act as a rectifier, since it will readily pass current in one direction and not the other. Because of the high breakdown voltage of the main gap, however, it is best to use the tube as a combination of relay and rectifier, employing the control gap to start the flow of current at a much lower voltage. Such relay-rectification could be obtained with a tube arranged as in Figure 3, where the 1000-ohm resistance represents the load.

If this circuit were supplied from a 110-volt 60-cycle source, no appreciable current would flow during the negative half of the cycle, because as is evident from Figure 2, no current will flow even at the peak negative

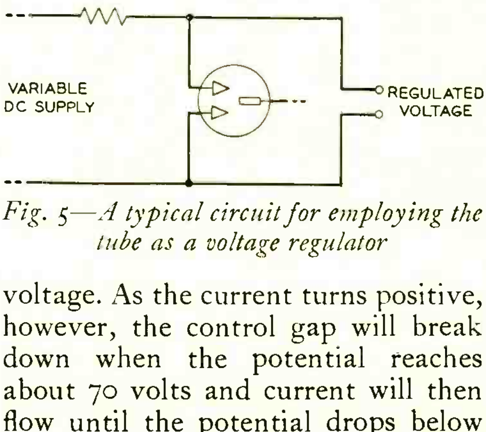


Fig. 5—A typical circuit for employing the tube as a voltage regulator

voltage. As the current turns positive, however, the control gap will break down when the potential reaches about 70 volts and current will then flow until the potential drops below 60 volts, toward the end of the positive half-cycle. This action will repeat for each cycle, but for potentials less than 70 volts the tube is open-circuited—no current will flow in either direction. It is this action that is employed for four-party selective ringing already referred to. A number of other possible applications will suggest themselves to those familiar with the technical phases of the telephone plant.

I

Tonlar bay at the New York Long Lines building. The Tonlar is described on page 117 of this issue.

II

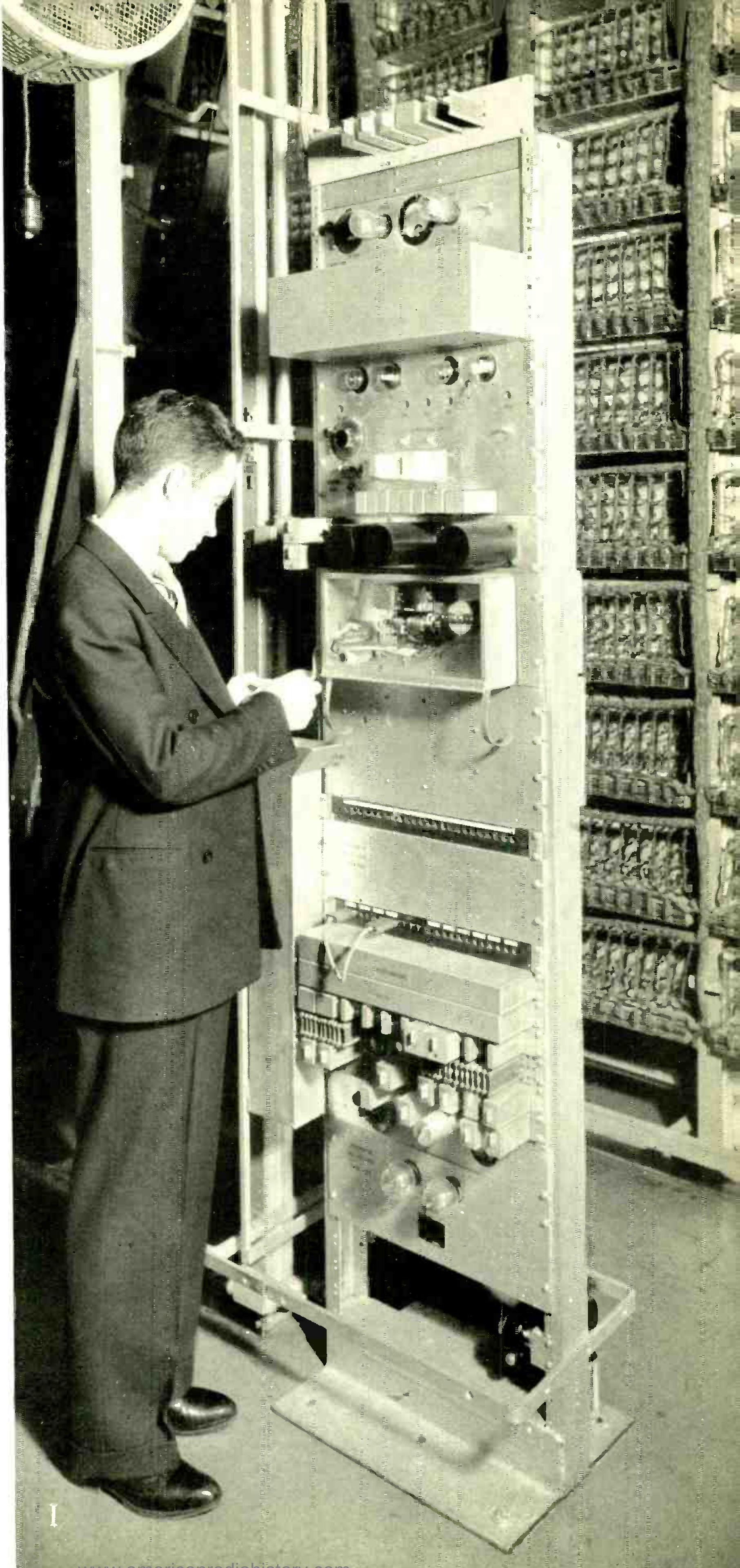
In the Development Shop, standard relay parts are assembled into new combinations for use in experimental circuits.

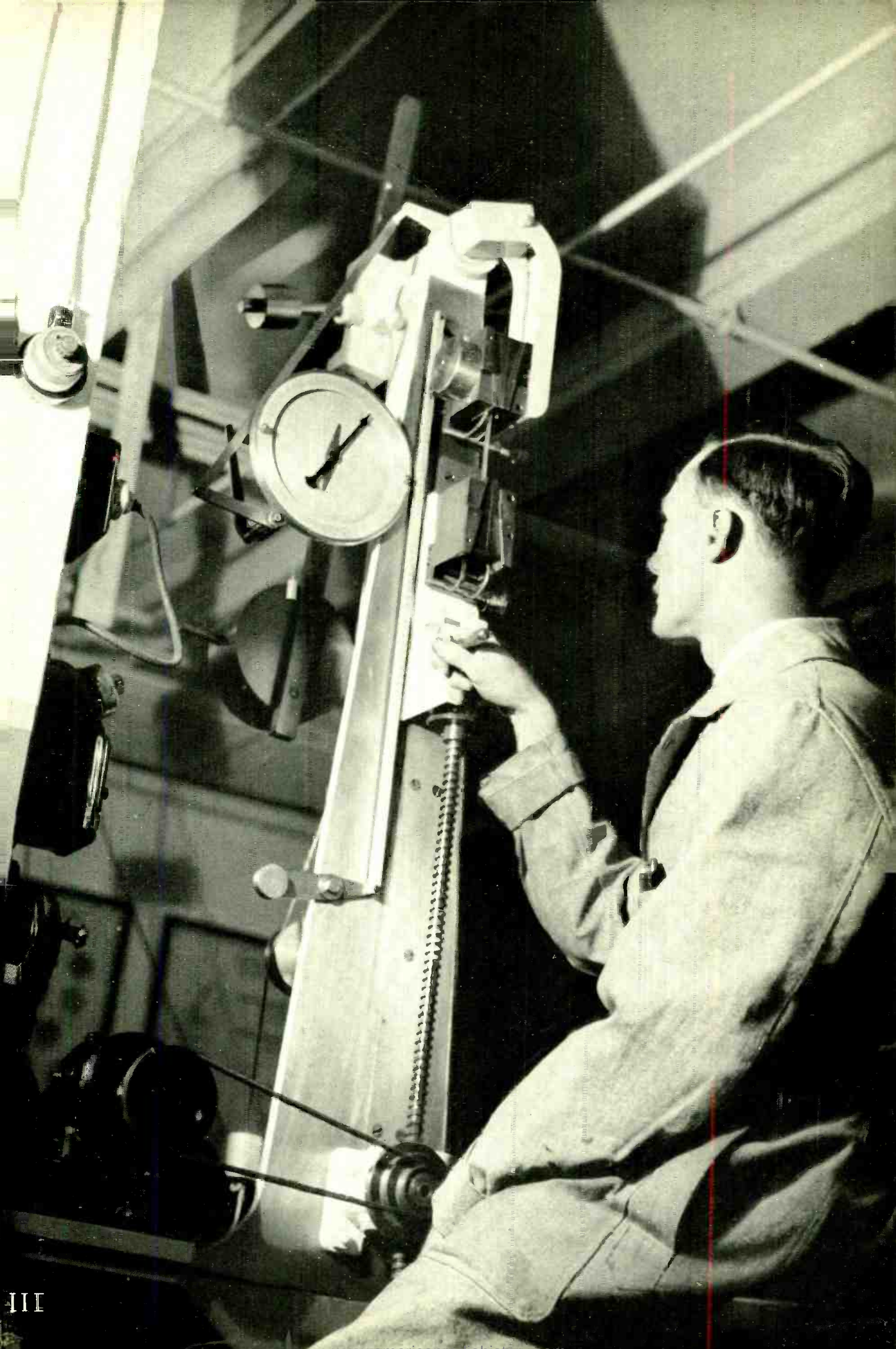
III

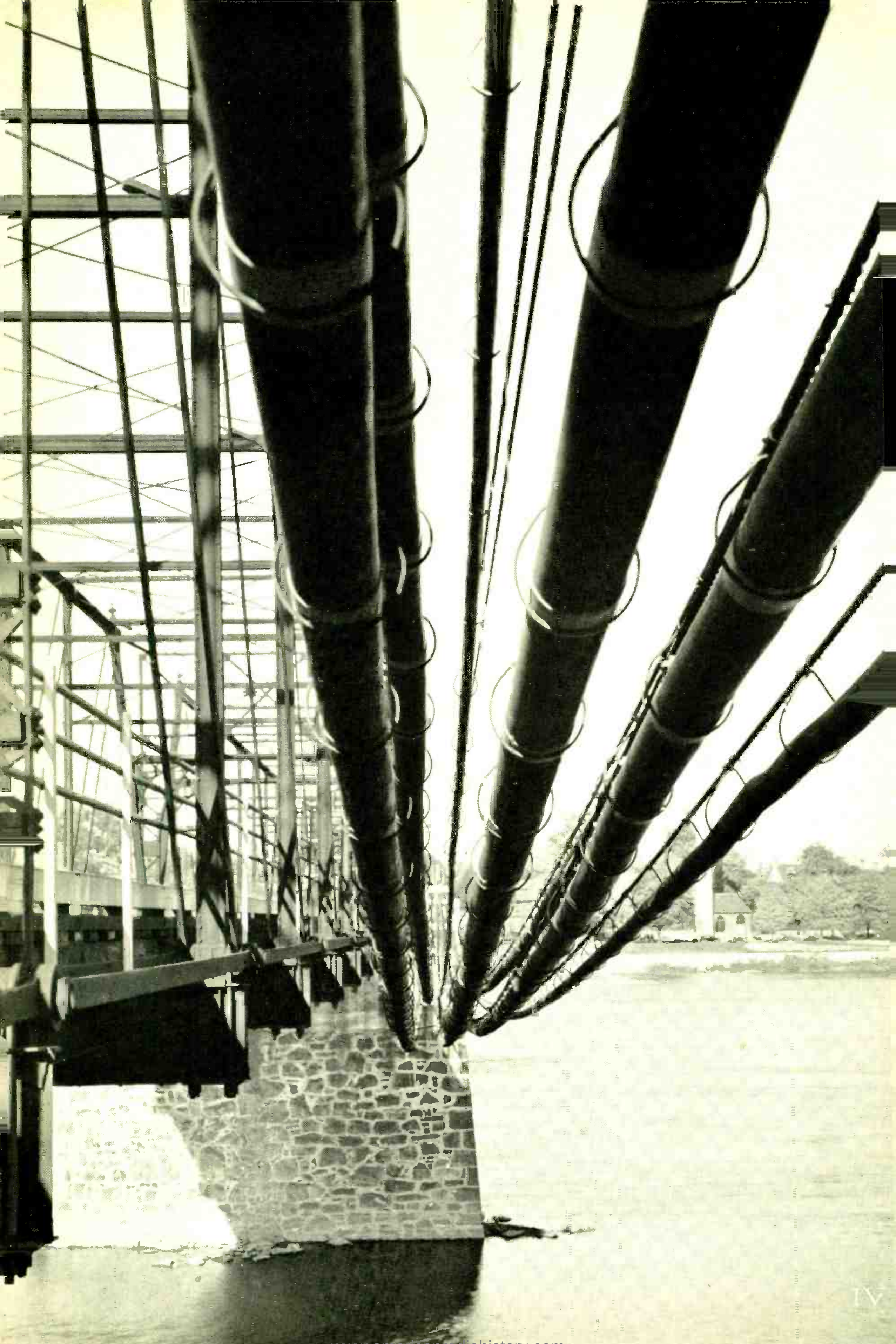
Measuring tensile strength with a 600 pound Amsler testing machine.

IV

Crossing the Delaware at Trenton: the coaxial cable is dwarfed by the standard telephone cables in service between New York and Philadelphia.







IV

Tonlars

By L. G. ABRAHAM
Toll Transmission Development

WHEN Napoleon first came into power, he found certain semaphore stations in operation for the transmission of messages. For long-distance transmission these were unreliable because some of the stations were poorly manned and there were gaps which could only be covered under favorable weather conditions. By adding a few new stations at strategic points and improving the facilities, personnel, and maintenance at existing stations, Napoleon established a system which permitted messages to be transmitted over great distances with remarkable speed and accuracy for those days. Even with this system when messages were transmitted over long distances there were occasional mistakes and failures to complete messages due to residual imperfections in the system, and therefore a mounted courier was occasionally dispatched with a copy of a test message, which was checked eventually against the message received over the semaphore circuit. If the two copies did not agree, suitable adjustments were made along the line, perhaps by liquidating part of the personnel, until a satisfactory test message could be obtained.

With modern telephone circuits there is an analogy to the courier-borne test message in the "lining-up" measurements of the circuit, which are made usually in the early hours of the morning. A testing current of known magnitude is impressed at one end of the circuit and a measurement made of the amount received at the other end. If this received amount deviates too much from the normal for the circuit, necessary tests and adjustments are made to restore the performance to the proper value. In a long and complex circuit, however, there are many elements which may

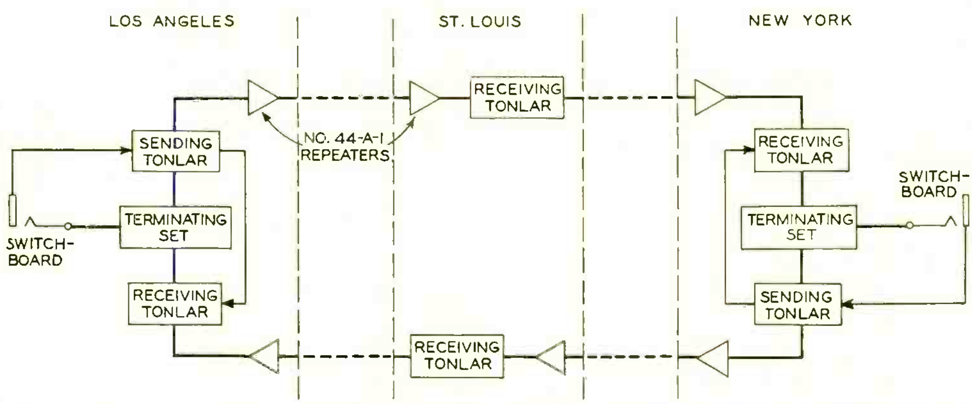


Fig. 1—In a circuit from New York to Los Angeles, sending tonlars would be used at both terminals, and receiving tonlars at the terminals and at St. Louis

give rise to small residual variations despite the use of pilot wire regulators, pilot channel regulators, battery regulators and other such apparatus for maintaining the loss at a constant value. During the period between "lining-up" measurements, therefore, the circuit may wander from its nominal loss, even though it might start with the best possible adjustment. To investigate the benefits of occasionally compensating for these variations, an experimental tonlar has been developed by the Laboratories.

The tonlar, deriving its name from the initial letters of the phrase "Tone Operated Net Loss Adjuster Receiving," is essentially a device that will dispatch a "test message" just prior to each regular message, and, at the distant end, compare the amount of test current received with the desired amount at that point. If the amount received differs from the desired amount, an adjustment in the circuit net loss will be made automatically, and left there until the next test message is sent. The improvement due to tonlar operation will be small compared to the improvements made possible by pilot wire regulators, pilot channel regulators, battery regulators, and circuit maintenance, but will be large compared to the residual variations caused by slight imperfections in these devices.

Figure 1 is a schematic diagram showing the application of the tonlar system to a circuit connecting New York and Los Angeles, on which a commercial trial is being made. Each receiving tonlar is essentially an adjustable gain repeater. When the circuit is picked up by the operator, say at New York, the sending tonlar is actuated, the operator is cut off from the toll circuit for a short interval, and a specified amount of 800-cycle power is sent into the transmitting repeater. This power passes through the four-wire circuit to St. Louis, where it enters the receiving tonlar. The receiving tonlar adjusts its gain until a given predetermined output is obtained from it. At the same time, the 800-cycle power has been transmitted over the line to Los Angeles, and the receiving tonlar at this point also adjusts its gain to obtain the desired output power, subject to the changes made at St. Louis. The net result is that the overall circuit net loss at 800 cycles is adjusted to a given predetermined value immediately after the operator picks up the circuit.

In the model at present on trial, the receiving tonlar at Los Angeles also fulfills other functions, one of which is to actuate the sending tonlar at Los Angeles so that a test is also made in the other direction. Arrangements are also incorporated in the present model for periodic tests, which occur at approximately thirty-minute intervals from each end of the circuit, and adjust the net loss of each direction of transmission. The purpose of these periodic

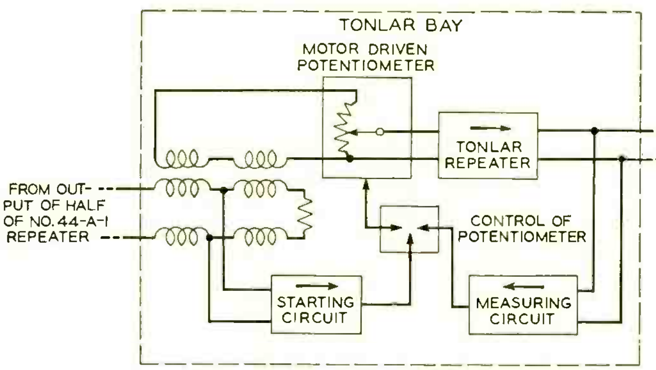


Fig. 2—Simplified schematic of the receiving tonlar

tests is to detect circuit trouble which occurs during times when the circuit is idle.

Figure 2 shows a schematic diagram of the receiving tonlar. The circuit involved is looped at the output of the 44-A-1 repeater through the tonlar bay. The receiving tonlar may be divided into the motor-driven potentiometer, the tonlar repeater, the starting circuit, and the measuring circuit. The tonlar repeater consists of a one-tube amplifier with sufficient gain to make the overall loss of the receiving tonlar to through transmission equal to zero on the average. This repeater has the same overload characteristics as the 44-A-1 repeater, so that it does not introduce appreciable distortion. In tandem with this repeater is the motor-driven potentiometer, by means of which the overall loss of the receiving tonlar is adjusted.

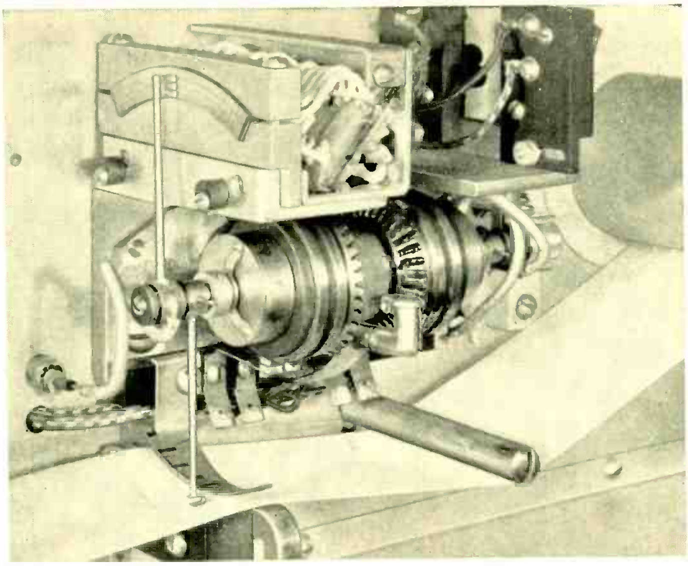


Fig. 3—Motor-driven potentiometer of the experimental receiving tonlar showing the tape on which a continuous record of the adjustments is made

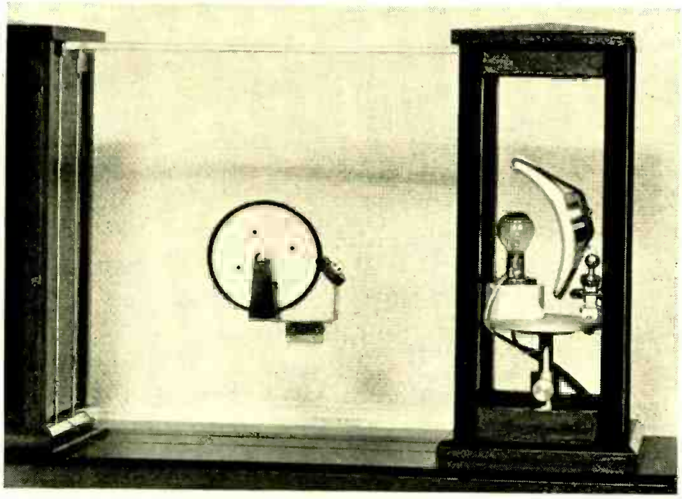
The starting circuit consists of an amplifier-detector with tuned circuits so arranged that power of 800 cycles tends to operate the start relay, while currents of other frequencies tend to prevent this operation. When the start relay has operated, a ground is placed on the adjusting circuit, which permits the motor-driven potentiometer to operate should an adjustment be necessary.

The measuring circuit consists of an amplifier-detector circuit which, if the start relay is operated, causes the motor-driven potentiometer to adjust the tonlar repeater gain until the output that is desired is obtained.

The potentiometer, shown in Figure 3, consists of thirty-three segments, each step producing a change of approximately .3 db, thus giving a total range of 10 db, or ± 5 db from an average gain of zero. The brush of the potentiometer is mounted at the end of a hollow nickel tube in the form of a truncated cone. This is of very little weight and can start, cover the entire range, and come to rest in less than 0.4 second. A wax paper record, which moves continuously, is marked by a stylus at the opposite end of the brush arm, thus making a continuous record of the tonlar settings.

When the potentiometer reaches either end of its available range, it mechanically interrupts the circuit that controls the electromagnetic clutches, and thus prevents damage due to over-shooting. In addition, it sounds an alarm which calls an attendant to find the cause of the trouble on the circuit.

The present model seems to be substantially satisfactory from a transmission standpoint, although considerable simplification is desirable. The principal field of use is expected to be the longer voice frequency and carrier circuits. With this system, the nominal variations of the circuit net loss of the longer circuits are reduced from about ±4 db to about ±1 db, and this change makes it possible to increase the echo suppressor sensitivity about 2 db without increased danger of noise operation. Taking advantage both of the increased echo suppressor sensitivity and the reduced overall circuit variations, the working net loss of the circuit may be reduced from about 11 db ±4 db to about 7 db ±1 db, where the circuit is not switched to another toll office at either end. The tonlar is believed to have similar advantages on "via connections," where the main line under tonlar control is extended to outlying offices at one or both ends.



Visitors to the Bell Telephone Laboratories' exhibit at the convention of the American Institute of Physics were intrigued by the continuous rotation of a small disk, supported by glass so that no mechanical or electrical power could reach it. The facts that the black rim of the disk was embraced by a small piece of steel shaped like a magnet, and that a nearby box was quite warm, suggested to some of the physicists that the trick was based on the loss of permeability by iron when heated to a temperature called "the Curie point."

To create the exhibition model a thin strip of permalloy was welded into a ring and fastened around the periphery of a glass disk which was set in bearings so that it could rotate. Light from an automobile headlight bulb was filtered so that only its invisible heat waves were focussed on a small section of the permalloy ring and the heat sharply reduced the permeability. Close to this point the ring was subject to attraction by a permanent magnet and as the mechanical force was greater for the cold part, the resulting unbalance of forces caused the ring to rotate about twenty times a minute.

A Wide-Range Oscillator for the Higher Frequencies

By L. ARMITAGE
Telephone Apparatus Development

THE recent increase in importance of impedance and transmission measurements at high frequencies has required the development of special measuring equipment. To provide a source of power at these frequencies, an oscillator has been developed which covers the frequency range from about 50 to 5000 kc.

A balanced push-pull circuit was chosen as is shown in simplified form in Figure 1. Such a circuit has the advantage of lending itself to a symmetry in the arrangement of its physical elements that is nearly as great as that indicated in the schematic. The wire connections can be made very short, and because of the very complete balancing, parasitic oscillations are greatly reduced. The circuit consists of a push-pull oscillator loosely coupled through small-capacity condensers to a push-pull amplifier, which in turn feeds the output transformer through a potentiometer across the high impedance. Pentode tubes, with indirectly heated cathodes, are used for both oscillator and amplifier.

Besides the electrical requirements of stability and precision of setting, simplicity in design and control was felt to be of considerable importance. The output frequency is set by two decade condenser units and a vernier air condenser, but one of six plug-in coils must be selected depending on the portion of the frequency range being used. These coils are inserted through a small door in the front of the oscillator as shown in the photograph at the head of this article. The complete oscillator is housed in a metal box which may be placed on a table or mounted on a relay rack. A small plate power supply unit has been provided in addition to make the oscillator completely a-c operated. This, together with a box for holding the spare plug-in coils, is shown mounted in the center directly above the oscillator in Figure 2.

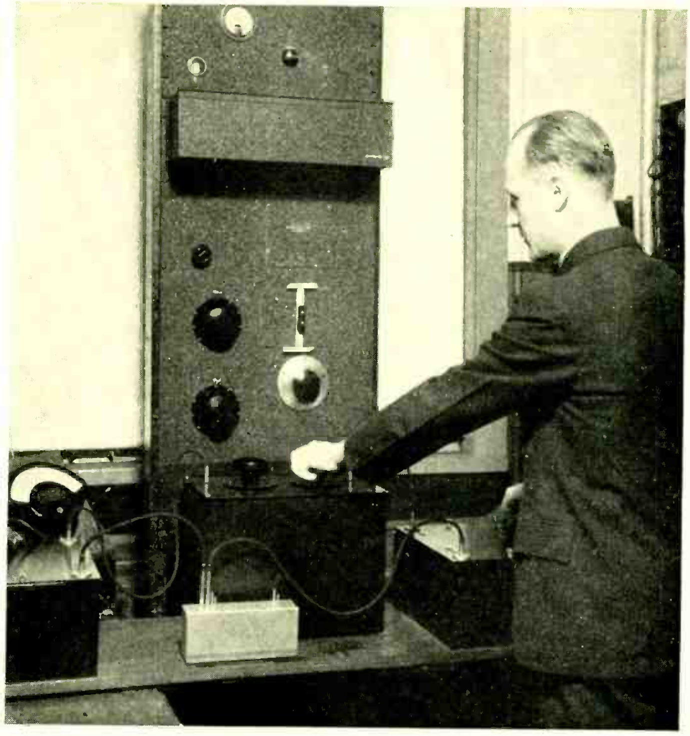


Fig. 2—Two dials for the decade condensers, at the left, the vernier air condenser dial, at the lower right, and the output potentiometer knob, above the condenser decades, are the only controls employed in the operation of the new oscillator

Between the oscillator and amplifier tubes on Figure 1 are shown the plug-in coil and the tuning condenser. This latter really consists of three units: two decades of mica condensers, and an air condenser operated by a

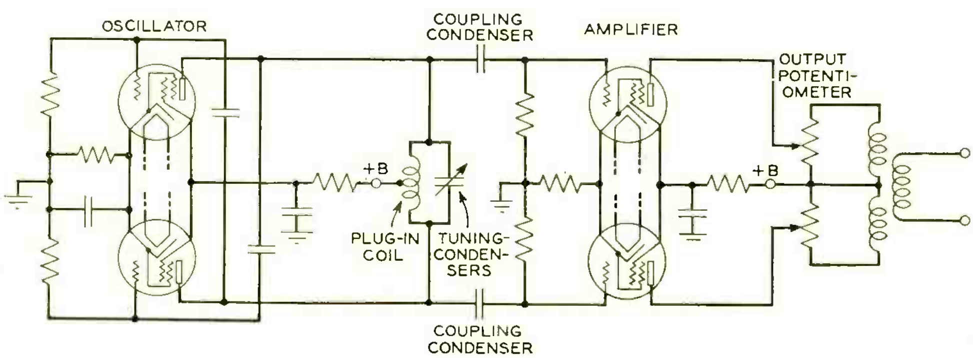


Fig. 1—Simplified schematic of the oscillator

vernier dial. The decades are arranged so that there is only one condenser of each decade in the circuit at any one time. This construction, which has already been described in the RECORD* as applied to a resistance standard, has considerably less stray capacitance and inductance than the commutating type. The air condenser is turned by a commercial micrometer-type dial through a worm gear drive. The dial is marked with fifty divisions and makes ten turns for one rotation of the condenser, so that 500 divisions are passed over for one revolution of the condenser. Since the dial may be readily set to one-fifth of a division, extreme precision in the setting may be obtained with little trouble.

The plug-in coils are wound on Isolantite forms two inches in diameter and four inches long. Four of them have single-layer windings of bare tinned copper wire, while the other two—used for the lower frequencies—have layered windings of insulated wire. The windings are put on under tension so that as the temperature rises there will be a reduction in the tension in the wire rather than a change in its length or position on the form. This reduces the effects of changes in temperature on the constants of the coil, which might otherwise be objectionable. Since the coils are of the solenoid type, their inductance will be affected by the configuration of nearby metal parts. Special precautions were taken therefore in designing the door on the front of the oscillator cabinet, through which the plug-in coils are changed, so that the inductance of the coils would not be changed by differences in contact between the door and cabinet as it was successively opened and closed.

A single output transformer is used over the full frequency range of 50 to 5000 kc. to couple the output amplifier to the load. Although tuned output transformers would give a uniformly greater output over this frequency range, tuning of the transformers would react upon the oscillator circuit and result in poorer frequency stability. Also in the interest of frequency stability, it was found advisable to control the output on the plate side of the output tubes rather than the grid side. In addition to this, the wave form of the oscillator was

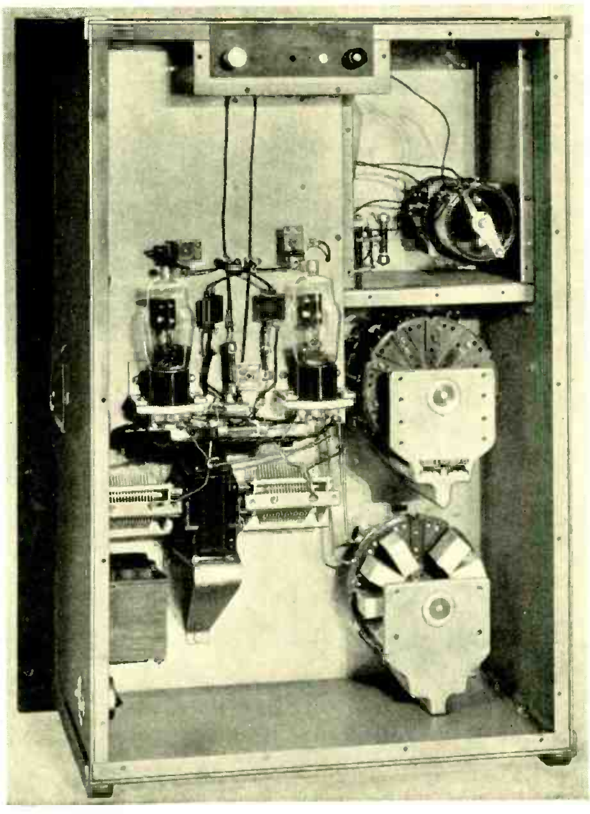


Fig. 3—Rear view of oscillator with cover removed, showing the arrangement of apparatus

*RECORD, *January*, 1935, *p.* 136.

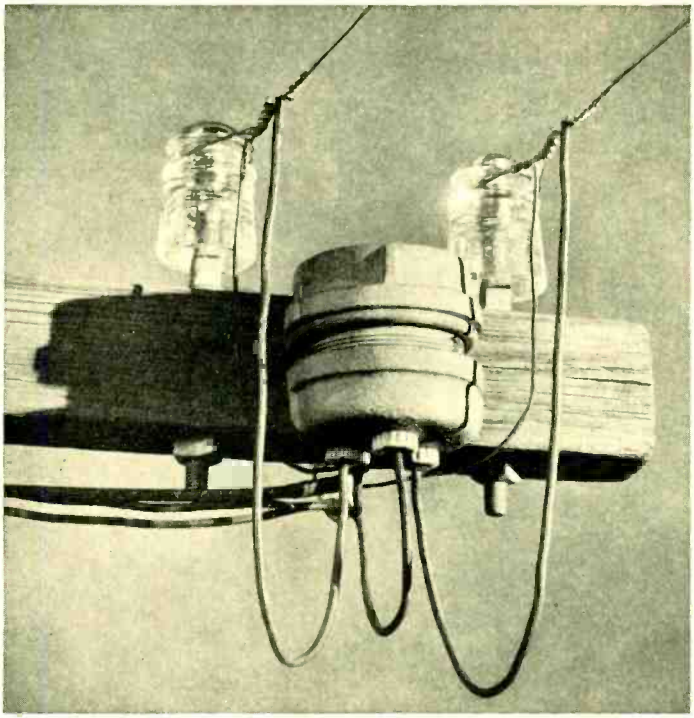
considerably improved by stabilizing the output impedance at a relatively low value by means of a resistance across the high side of the output coil. By making this resistance in the form of a potentiometer it is made to function also as an output control. This arrangement works well over the entire frequency range without greatly affecting the oscillator frequency when changing its output. An output of at least 100 milliwatts into 100 ohms may be obtained over the entire rated frequency range. The frequency change of the oscillator when the load impedance is changed from open to short circuit is only about 5 cycles in one megacycle. Although the normal frequency range of the oscillator with 6 plug-in coils is 50 to 5000 kc., the high frequency coil may be used as high as 10 megacycles with some sacrifice in output and stability.

The arrangement of the apparatus in the cabinet is shown in Figure 3. At the left center are the two oscillator tubes while at the other side of the shielding partition behind them are the two output tubes. Directly beneath the oscillator tubes are the air condensers with the vernier gear drive between them. At the right are the two decade condenser units, and at the upper right are the output potentiometers, mounted tandem and controlled from a single dial on the front. At the extreme lower left-hand side of the illustration is shown the transformer used for supplying filament current.

The maximum temperature rise inside the oscillator is only about 11 degrees Fahrenheit. Temperature saturation is practically reached, however, in about an hour, and for most purposes the oscillator may be considered stable in half an hour. The maximum change in frequency of the oscillator during the warming up period is of the order of 100 cycles in one megacycle or about 0.01 per cent.

The frequency change of the oscillator for one volt change in the plate power supply is of the order of one cycle at one megacycle, and automatic regulation is incorporated in the plate power supply unit to maintain the plate potential constant to within one volt for variations in the line voltage of $\pm$ 10 per cent. Some change in frequency due to variations in line voltage is also caused by changes in the filament supply voltage, but the overall frequency change resulting from variations in line voltage of as much as $\pm$ 10 per cent is only of the order of ten cycles at one megacycle, or about 0.001 per cent. Radio-frequency energy radiated by the power supply unit and its associated supply line is negligible.

As a result of this development there is now available a wide-range oscillator for the higher frequencies, which is simple to operate and has high frequency stability. By the use of six plug-in coils the frequency range from 50 to 5000 kc. may be covered with high precision of setting.



Protection Against Lightning Interference

By C. C. CASH
Protection Development

DIRECT lightning strokes on communication lines rarely occur but disturbances may result from inductive effects caused by thunderstorms, sometimes many miles away, unless these disturbances are effectively guarded against. On open-wire lines which are well transposed and well balanced, the voltages developed directly in the telephone circuits during storms are relatively small but high voltages to ground are induced which appear in substantially the same magnitude on both wires of a pair. Protectors are provided at the ends of the line to relieve these high voltages by discharging them through suitable ground connections.

There is always a certain amount of dissymmetry between the two protectors on a pair of wires, either in the initial breakdown or discharge characteristics or in both. In view of these dissymmetries, when the lightning currents discharge through the protectors, a pulse appears in the circuit whose magnitude depends upon the size of the voltage induced by the lightning and the dissymmetry between the two protectors. These surges produce "hits" on carrier telegraph instruments and clicks in telephone circuits. Much effort has been expended to develop protector blocks to operate in pairs without unsymmetrical characteristics, but it has not been found possible to accomplish this without impairing their ability to protect the plant.

To minimize these surges, it is necessary either to prevent the protector blocks from breaking down or to apply circuits which force them to operate in a symmetrical manner.

One such method involves the use of drainage coils to prevent protector breakdown. In this arrangement, Figure 1, there is a coil bridged across each end of the open-wire line at the cable pole with the center tap connected to the cable sheath. This sheath must be continuous to the underground cable or to the central office or repeater station and connected there to the protection ground. In most cases drainage coils at the cable poles are sufficient to conduct the discharges to ground and to prevent breakdown of the protectors at the office. In some cases, however, particularly where the entrance cables are rather long, so that the resistance of the cable sheath from the central office to the cable pole becomes appreciable, or if electrical reflections may occur, drainage coils are necessary in the office as well as at the cable pole. On lines which include intermediate cables such as may be used at a river crossing, it is necessary to install drainage coils at both ends of the cable, where the protector blocks are located. Experience has indicated that it is necessary to drain only the circuits upon which the interference is to be minimized and not the whole line.

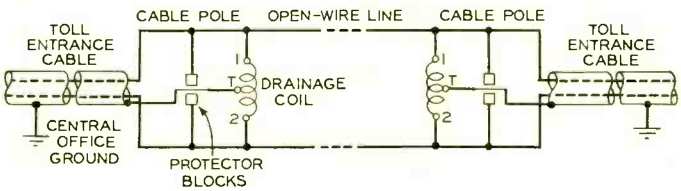


Fig. 1—Drainage coils are bridged across each end of an open-wire line to prevent protectors from breaking down

Field tests made during the summers of 1933 and 1934 indicate that such coils drain the lightning surges off to ground and prevent nearly all protector operation. In the case of carrier transposed circuits the interference to carrier telegraph due to lightning and static is reduced to only a few per cent of that on circuits without drainage. The data were obtained on an idle carrier telegraph channel with a recorder arranged to indicate the number of times the tongue of the receiving relay was moved off contact. Teletypewriter tests were also made over the test circuits.

The drainage coil, which was designed by the Apparatus Development Department, is shown in the headpiece. It consists of a single winding (1-T-2), T being the center tap, and is potted in a weatherproof case suitable for outdoor mounting. A U-bolt encircles the case for securing it to a telephone crossarm.

The coil has a low impedance to ground for current induced simultaneously in the same direction in both wires of the circuit, which is a necessary condition for a good drainage coil, and at the same time a high bridging impedance for voice and carrier currents. The modulation, noise, crosstalk and attenuation effects in the voice and carrier ranges are practically negligible.

The action of the coil in reducing lightning interference in a carrier telegraph circuit is shown by the accompanying oscillograph record of Figure 2 where records of currents observed in an undrained and a drained circuit

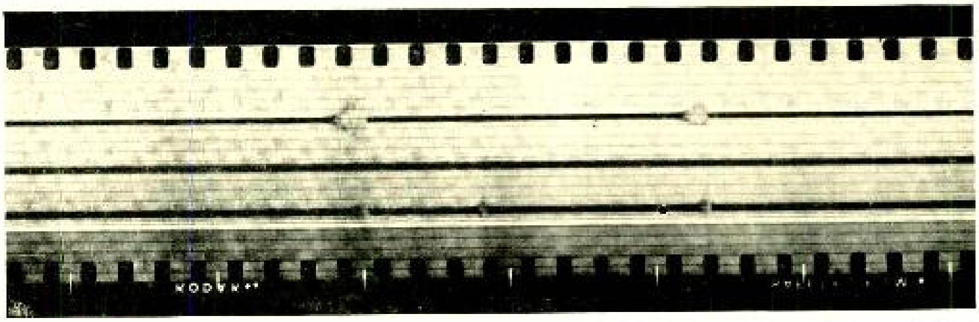


Fig. 2—Oscillograms show that induced currents of measurable value are recorded on an undrained circuit (top and bottom lines) when they are not obtained on a drained circuit (middle line)

during a lightning storm are given. Induced currents of substantial value were obtained in the undrained circuit while none were recorded in the drained circuit. Other data indicate that disturbances which are large enough to affect both the drained and undrained circuits are very few compared with the total number of disturbances and that when such disturbances do appear they are much smaller in magnitude and shorter in duration in the drained than in the undrained circuit.

While the direct use of drainage coils provides a large measure of relief, it has definite disadvantages in that the low impedance to ground which is so necessary for satisfactory drainage of lightning currents prevents the proper operation of grounded telegraph system and the usual direct-current testing of the wires.

These disadvantages may be obviated with some reduction in effectiveness by an arrangement which consists of protector gaps in series with the drainage coil. This keeps the drainage coil off the circuit until a surge has broken down the protector blocks. In this arrangement, low voltage breakdown protector blocks are connected between the coil winding and the line wires with the center tap of the coil grounded, Figure 3. The voltage across the circuit is minimized by the balancing action of the coil, which tends to counter-balance dissymmetry in the breakdown and discharge characteristics of the protectors. When the protector gap associated with one-half of the coil dis-

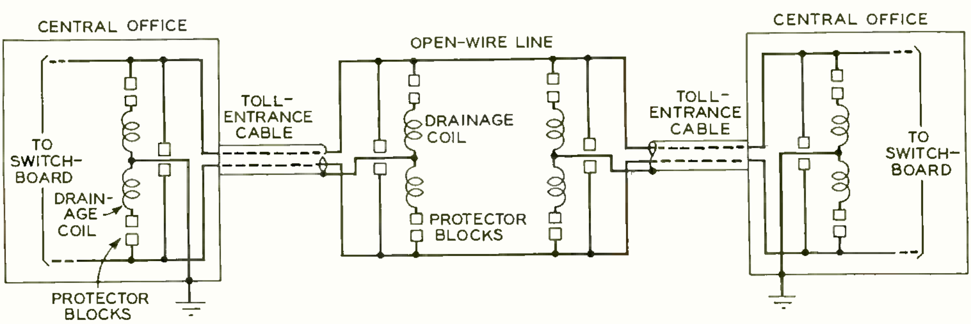


Fig. 3—Low voltage protector blocks are sometimes connected in series with drainage coils to prevent grounding the line except when a discharge takes place

charges more rapidly than that associated with the other half, a voltage is induced in this second half which strengthens the weaker discharge and hastens the breakdown of the protector on the weaker side. The above arrangement of protector blocks with retardation coil should be placed at every entrance cable pole, at both sides of any intermediate cables and in offices where the lines terminate.

The benefits of this protector drainage arrangement are large, since as noted it saves the grounded telegraph circuits, and the direct-current testing methods. Furthermore, on picture-transmission circuits it permits using the wire for direct-current control which would not be possible without the series protector blocks to prevent short-circuiting the control current.

Protector drainage is now being used quite extensively on open wire pairs employed for the transmission of voice-frequency carrier telegraph superposed on carrier telephone for high-frequency telegraph and for picture transmission. Further tests are being made to determine more completely the effectiveness of protector drainage and direct drainage and the fields of application for each method.

"A few years from now the pendulum clock itself may be obsolete. At the Bell Telephone Laboratories in New York City, a young physicist, Dr. W. A. Marrison, has invented a totally new form of clock. For the first time since 1673, he has dispensed with the pendulum itself in a highly accurate timepiece. Primarily Dr. Marrison was interested in a standard of frequency rather than of time, but, as a by-product his work has produced a clock that, without a pendulum, keeps time of an accuracy comparable to that kept by the most accurate clock of a few years ago. So far, the Shortt clock has some advantage on the Marrison device in point of precision. However, great superiority of Dr. Marrison's invention comes from the fact that, not using a pendulum, it does not require as stable a support as the older clocks. The latter must be kept on firm piers of brick or concrete, preferably in an underground chamber, away from vibration. The Marrison clock can be used in a tall office building, on board ship, or even in an airplane if necessary, so that it will do the work of a chronometer, but with far greater precision. . . ."

From "Stars and Telescopes," by James Stokley, Harper and Brothers.

Laminated Phenolic Insulating Materials

By J. J. MARTIN
Insulation Materials Engineering

LAMINATED phenolic insulating materials are used extensively in telephone apparatus. They are made by impregnating sheets of paper, fabric or asbestos with condensation products of the phenol formaldehyde type and bonding a number of such sheets together by heat and pressure. A very dense, strong material of uniform structure is thus obtained which embodies such characteristics as good electrical properties, hardness, toughness, heat resistance, low water absorption, high dielectric strength and chemical resistance. These qualities, and other primary properties, such as resilience, easy fabrication and lightness make it adaptable to many different uses.

Laminated products are made only in the form of sheets, rods, tubes, and a few other shapes of simple contour because they cannot be molded in intricate form. The range of uses to which they have been found suited, however, is so large that a number of grades of phenolic laminated materials are now made by the Western Electric Company under the designations of phenol fibre and phenol fabric. The resin content of the product is the factor which primarily determines its

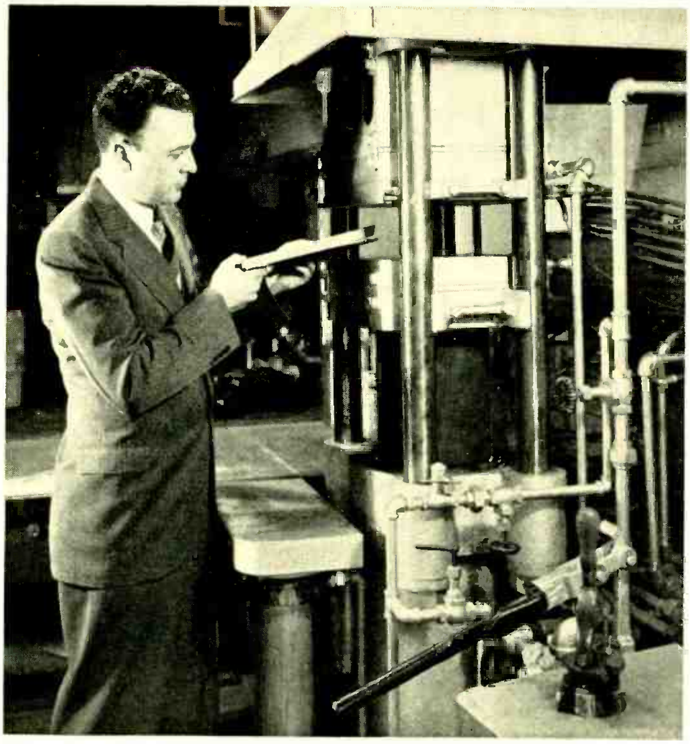


Fig. 1—J. J. Martin demonstrating with an experimental stack-up how laminated phenolic materials are made. Pressures of about one ton per square inch and a temperature of about 350 degrees Fahrenheit are used

Laminated tubes are made by two methods. The pre-cured material may be rolled on an unheated steel mandrel of the desired inside diameter and then placed between the halves of a semi-circular steel mold for final processing under heat and pressure, or the mandrel itself may be heated and paper or fabric compressed by a second heated roll. In this case the processing takes place as the mandrel is slowly revolved. The first method gives what is known as a molded tube and the second forms a so-called rolled tube. In some cases, the tube is placed in an oven immediately after the wrapping operation to complete the polymerization of the resin. In general, molded tubes are more homogeneous than rolled tubes and consequently have greater resistance to moisture and higher electrical insulating properties. Rolled tubes, on the other hand, show better mechanical properties.

In the manufacture of rods, the impregnated paper or fabric is wound on a mandrel of very small diameter, which is withdrawn after the winding is completed. The tube is then subjected to heat and pressure in the same type of mold as is used for the molded tube. This pressure closes the hole from which the mandrel was taken and makes a solid rod.

Since laminated products which have a high resin content, in general,

insulating properties. This varies in the different grades from thirty to seventy per cent. The phenol fibres are distinguished from the phenol fabrics in that the former are made with paper and the latter with cloth.

Laminated sheet material is built up of plies, or laminae, of paper, fabric or asbestos, which have been passed through a bath consisting of phenol resinoid in solution and then pre-cured in a long, heated dryer. The requisite number of plies for the desired thickness are weighed out and placed between metal plates. If a polished surface is desired, metal plates that have been highly burnished are required, but where the finish is immaterial an unpolished plate is used.

have good insulating properties, they are extensively used for electrical apparatus where exposure to severe atmospheric conditions is experienced. Those made with less resin find application primarily where high electrical resistance is not demanded and for various mechanical purposes.

Laminated phenolic materials were first used by the Bell System in 1913 as a substitute for red fibre in the front spools of relays to prevent corrosion of contact springs and windings. Their use was later extended to keys, jacks, lamp sockets and other applications in manual apparatus. With the development of machine switching apparatus, a high electrical grade of material having a minimum amount of shrinkage and cold-flow for the pileup insulators of closely adjusted relays was required and also a material which offered resistance to arcing for the sequence switch cam insulators. These results were attained by using a phenol fibre having a high resin content to prevent the absorption of moisture with consequent changes of dimensions in the one case and by the use of a special plasticized phenol fibre to prevent arcing in the other.

Another phenol fibre was recently developed in connection with spoolheads for relays. This material has good electrical properties under high humidities and can also be used for punched parts. It changes less in linear dimension, with changes in atmospheric humidity, than any other grade of phenol fibre which makes it particularly well adapted for use in the construction of relays with a short armature travel. A mahogany-type surface finish is provided to designate the direction of grain which in turn is also the dimension of least change.

Phenol fabric as distinguished from phenol fibre is made in grades which differ principally in the closeness of weave of the cotton fabric. The finer weaves are known commercially as "linen" while the coarser weaves are designated as duck or canvas. The finer weave material, because of the closely woven and uniform structure of the fabric layers, is especially adapted to applications where an unusually dense, tough, close-grained product is desired. The linen stock is particularly suitable for punched parts since its fine texture insures clean-cut, smooth edges. It is also especially adapted to the cutting of gears of small face dimensions. The duck and canvas base materials are used where mechanical requirements are important.

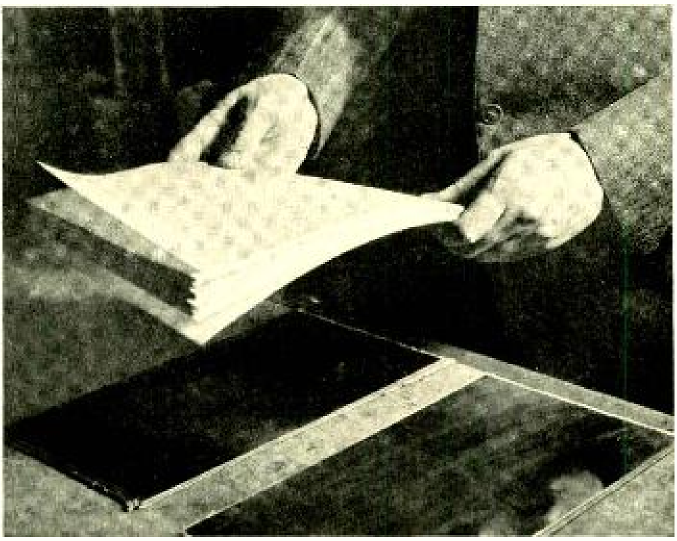
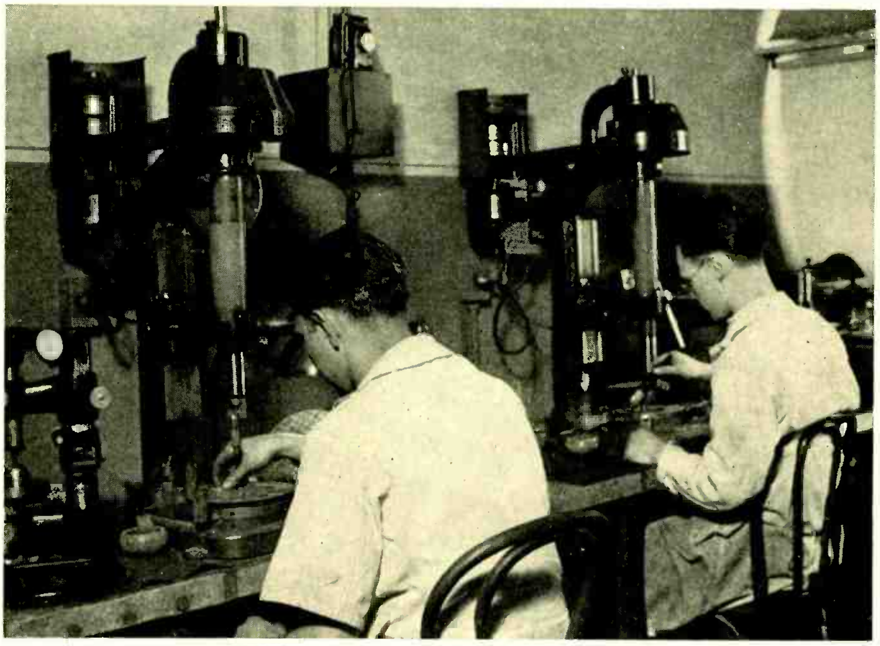


Fig. 2—The stack-up of pre-cured paper is placed between polished metal plates to give a smooth-finished product

The electrical grade of phenol fabric is made from a fine weave fabric. It must meet the standard of insulation resistance required for the electrical grades of phenol fibre, although the fibre, in general, is a better insulating material. Because of its toughness and resistance to cracking this grade of phenol fabric is used for terminal plates in constructions where hollow rivets or eyelets are used and where transmission losses must be kept low.

The mechanical grade finds application where physical properties, particularly toughness, are of prime importance, but where electrical properties are secondary. It is made with a canvas base and is used extensively in the construction of terminal plates for power transformers; also as a material for tool handles. Another grade of phenol fabric is also available of the same type as the electrical grade except that the electrical requirement is waived. It is used in mechanical applications where the fine weave is necessary to insure good appearance after machining, such as for small gears and in tool construction.

Phenol fibres and phenol fabrics have become an indispensable insulating material in the construction of telephone apparatus. Their use in this field has grown rapidly during the last few years and the many applications in which these laminated insulating materials are found particularly suitable are continually increasing.



Grinding and polishing quartz-crystal plates in the crystal laboratory

"The Renaissance of Physics"

"EVER since the turn of the century physics has been enjoying a veritable renaissance, fairly to be likened with that splendid flowering of the arts and humane letters four hundred years ago to which the name of Renaissance was first applied." So writes Dr. K. K. Darrow in a new book entitled "The Renaissance of Physics," and recently published by Macmillan. In emphasizing the recency of physics, he writes further: "Many of its heroes are still living and still young, many more are vividly remembered by the living; and of the rest, all but a few have lived within the last two centuries."

Karl K. Darrow

After discussing the small particles or corpuscles composing material bodies, and the various wave phenomena grouped under the generic name of light, which until the present century might have been considered the non-material element of physics, he faces the fact that corpuscles have wave aspects, and waves have corpuscle aspects, and states the rules of correlation. He points out, however, that the problem of how "to make sense of the Rules of Correlation . . . has proved to be a very tough one. So tough it is, that physicists have been driven to all manner of singular mental devices. It is the origin of most, if not of all, of the amazing and baffling assertions which have crept even into popular literature—sources of grief to those who expect a classic sobriety of statement from the scientist and of malicious joy to those who like to see unsettlement and incoherence invading an authoritative science." He then regretfully adds that "perhaps there will have to be an esoteric doctrine for those who wish to master the processes of physics, and an exoteric doctrine for those who merely wish to use it or to read about it."

"The fixity of the chemical elements," Dr. Darrow points out in his concluding paragraph, "has vanished, for we are able to convert their substance from the form of one into the form of another. The fixity of matter itself has vanished, for we are able to convert its substance from the form of electrical particles into the form of light. No element, nor matter itself, nor light itself, is permanent. All that is perpetual is something of which they all are made, incarnating itself in all of them by turn, and passing unimpaired from form to form. . . . The belief that all things are made of a single substance is old as thought itself; but ours is the generation which, first of all in history, is able to receive the unity of Nature not as a baseless dogma or a hopeless aspiration, but a principle of science based on proof as sharp and clear as anything which is known."

Contributors to This Issue

L. G. Abraham received the degrees of B.S. and M.S. in electrical engineering from the University of Illinois in 1922 and 1923, respectively. In July of the latter year he joined the Department of Development and Research of the American Telephone and Telegraph Company as a member of the Transmission Development Department and was transferred to the Laboratories in 1934. His work has been chiefly in connection with toll circuits, and he has devoted most of his time to securing optimum overall performance of message circuits.

Homer Dudley has been a member of the Research Department since his graduation from Penn State where he received the degree of B.S. in Electrical Engineering in 1921. His first work related to the transmission features of local telephone systems. Then for several years he supervised work on voice-operated circuits for transatlantic radio, long lines and submarine telephone cables.

In 1930 his activities were diverted to research and development problems on coaxial-conductor systems. For the past two years he has been engaged in the design and construction of the speech analyzing and synthesizing circuits which are described in this issue of the Record. He received the degree of M.A. in Physics from Columbia in 1924.

For the past twenty years F. F. Lucas has been engaged at the Laboratories in metallographic investigations which have not only extended our knowledge of the microstructure of materials used in telephone construction but have also led to the development of a powerful microscope which has greatly increased the range of microscopic vision.

Dr. Lucas received an honorary Sc.D. degree from Lehigh University in 1931. He has also been awarded four medals for outstanding contributions to the field of photomicrography. In 1933 he was awarded a diploma for exceptional photographic art by A Century of Progress, Chicago.

In 1929 he was invited by the Japanese to participate in the World Engineering Congress held in Tokio and was made a chairman of the Metals Section. While in

L. G. Abraham

Homer Dudley

F. F. Lucas

H. G. Arlt

L. J. Stacy

L. Armitage

Japan he was invited to lecture at the Imperial Universities of Tokio, Kyoto and Sendai. In 1927 and again in 1931 he was a delegate of the State Department to International Congresses held in Amsterdam and in Zurich where he presented reports of his work. Dr. Lucas has been invited to present a report on metallography before the International Congress to be held in London during April, 1937.

H. G. Arlt received the degree of M.E. in 1923 from Stevens Institute of Technology. He joined the Laboratories that year and was assigned to preparing apparatus specifications. Two years later he transferred to the physical laboratory where he has specialized in the engineering of finishes. He is now in charge of the work on finishes and of that on the chemical requirements of various organic materials.

L. J. Stacy received the A.B. degree from St. Lawrence University in 1909. After six years of school teaching, he entered the University of Chicago for two years of graduate study in physics and mathematics. In the radio division of the Signal Corps in 1918 he rose to a second lieutenancy, then returned to Chicago to receive the Ph.D. degree in 1919, and later that year entered the Systems Development Department of these Laboratories. He has been concerned with ringing and tone studies and other special technical problems in the local central office laboratory, and now supervises a group devoted to this work.

Joining the Western Electric Company in 1913 as Laboratory Assistant, L. Armitage spent five years in various development undertakings among which was that of iron dust cores. During this period he received the degree of B.S. from Cooper Union. After a year's absence in military service he returned to West Street and spent two years on the mechanical design of carrier equipment. For the next six years he was in business for himself, manufacturing radio sets. He returned to the Laboratories in 1927. Since then he has been employed in the development of impedance bridges, frequency equipment, and at present is engaged in designing testing apparatus.

J. J. Martin joined the Apparatus Development Department of the Western Electric Company after graduating from Clarkson College of Technology in 1923 with the degree of B.S. in Mechanical Engineering. After six years in Apparatus Analysis he was transferred to the Materials Department and recently was placed in charge of a group concerned with insulating materials problems.

C. C. Cash received the degree of B.S. in E.E. at Rose Polytechnic Institute in 1928 and M.S. at M.I.T. in 1930. Immediately afterwards he joined the De-

J. J. Martin

C. C. Cash

S. B. Ingram

velopment and Research Department of the American Telephone and Telegraph Company where he engaged in studies relating to the protection of communication circuits against atmospheric and power-line disturbances. In 1934 he was transferred to the Laboratories. Here his work has been largely concerned with the development of drainage methods for minimizing lightning interference to open-wire carrier telegraph circuits.

S. B. INGRAM received a B.A. degree from the University of British Columbia in 1925, and a Ph.D. in physics from the California Institute of Technology three years later. During the next two years, as National Research Fellow in Physics, he carried on research studies in experimental and theoretical spectroscopy at the University of Michigan. In 1930 he joined the Technical Staff of Bell Telephone Laboratories where he has since been engaged in the development of mercury-vapor rectifiers, three element gas-filled tubes, and other gas discharge devices.