Metallic Materials in the Telephone System*

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IN the development of electrical communication, metals and alloys have played a noteworthy part. To emphasize specifically the utilization of metallic materials the telephone handset serves as an admirable example. The assembly of intricate parts in this small piece of apparatus, shown sectionalized in Fig. 1, contains seventeen metallic elements, either alone or in combination as alloys.

The Bell System has therefore conducted extensive metallurgical researches, and the discoveries and developments have been numerous. Space permits a discussion of only a few of the developments relating to the more extensively used materials. These comprise the alloys of lead, copper, zinc and aluminum, and the precious metals, and magnetic materials.

Lead and Alloys of Lead

Lead alloys are used principally as sheathing for cable, and as solders for joining cable sheath and making electrical connections in apparatus.

Cables represent one of the largest single items of investment; approximately ninety-five per cent of the Bell System's total wire mileage is contained in lead or lead alloy sheath and this sheath requires an enormous amount of lead annually in its production. The largest size cable made by the System contains 4242 copper wires. The same number of open wires on telephone poles would take 70 rows of poles each carrying 60 wires. Under one street today in New York City there are 282 cables containing about 560,000 wires.

Since the wires in the cable are insulated from one another only by the paper or textile wrappings or sheaths and by the dry air contained in the cable, the presence of even a slight amount of moisture will interfere with transmission by drastically reducing the insulation resistance. A positive pressure of dry nitrogen is maintained in some cables as additional protection against moisture entrance and to disclose sheath breaks. Continued efforts are made, therefore, to improve cable sheath so as to keep sheath failures to a minimum.

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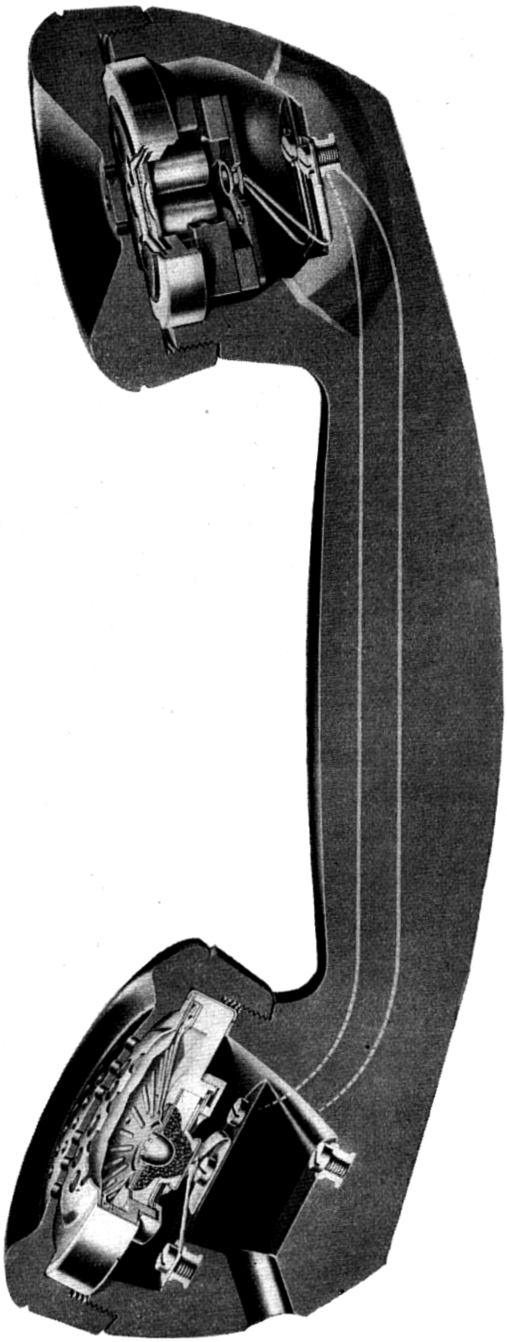

Fig. 1—Schematic cross-section of handset showing utilization of metallic materials.

The history of cable sheath development illustrates the value of metallurgical research to the telephone system. Unalloyed lead was first used because it was pliable, resistant to corrosion and could easily be manufactured into pipe. Nevertheless, it has serious shortcomings. Brittleness would not be expected in a material so soft and ductile, yet repeated stresses caused by wind sway, mechanical vibrations, and

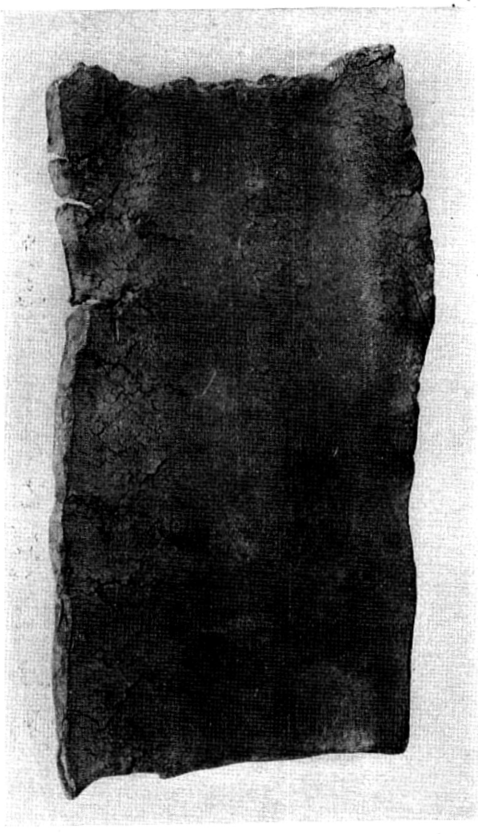

Fig. 2—View of piece of old cable sheath made of commercially pure lead, which failed in service from intercrystalline fracture.

movements due to temperature changes produce fine cracks in the cable sheath through which moisture may enter the cable. An advanced stage of such cracking is shown in Fig. 2. In fact this effect is so serious that, unless precautions are taken to minimize vibration, cables sheathed with unalloyed lead cannot be shipped for long distances by rail or boat without serious damage.

It was early found that the addition of three per cent of tin to lead greatly decreased the susceptibility to this type of failure. This alloy was also stronger than lead and more resistant to abrasion and the cutting action of the galvanized steel rings which usually fasten aerial cable to its supporting strand. As the quantity of alloy required for cable sheathing increased, however, it became evident that a large portion of the world's supply of tin would be needed, and this would cause a prohibitive rise in its price. A search was made, therefore, for an alloy of at least equal quality which would be less expensive.

As a result of investigation of the properties of twenty or more different alloys, an alloy of lead containing one per cent antimony was selected. After extensive manufacturing and field trials this alloy was adopted in 1912 as the standard for Bell System use. Had the lead-tin alloy been continued as a sheathing material to the present time the cost would have been twenty-five million dollars greater (figured on the amount of cable sheath used during the intervening years and on the price of tin which actually prevailed during this time).

Standardization of an alloy of lead with one per cent antimony for cable sheath was not accomplished without the appearance and solution of many technical problems. For example the extrusion of sheath around the cable core has been an intermittent process, since the cylinder of the extrusion press is not large enough to contain sufficient lead to cover a full length of cable. It was necessary, therefore, to stop extrusion to recharge the cylinder with the molten lead alloy which must weld to the previous charge, a slug of solid metal. If a layer of dross was present on the surface of this material remaining in the cylinder, a faulty weld was formed which would be subsequently extruded into the sheath. Also, during the recharging interval, the lead alloy remaining in the extrusion die receives a different thermal treatment from that of the previously extruded sheath. Since the properties of the lead-one per cent antimony alloy are markedly affected by thermal treatment, there were frequently abrupt differences in stiffness of the sheath extruded just before and just after the charging interval. When this change in stiffness was sufficiently great, serious buckles occurred during reeling and installation of the cable.

Through a knowledge of the constitution and characteristics of the alloy, and by continual improvement in the extrusion process, it has been possible to overcome obstacles such as these and to manufacture cable sheath of improved quality from the one per cent antimony alloy.

The telephone metallurgist is also concerned with the life of the alloy in service. Many samples from sheath which has failed are examined annually and compared with samples from sheath which is giving satisfactory service. Microscopic examination in some instances reveals a clue to the causes producing early failure and thus suggests methods by which the failures may be eliminated.

In developing new alloys such as have been described and in studying the causes of failure of these alloys in service, extensive laboratory facilities are required. For example, the Bell Telephone Laboratories possess an extrusion press, shown in Fig. 3, for experimental studies

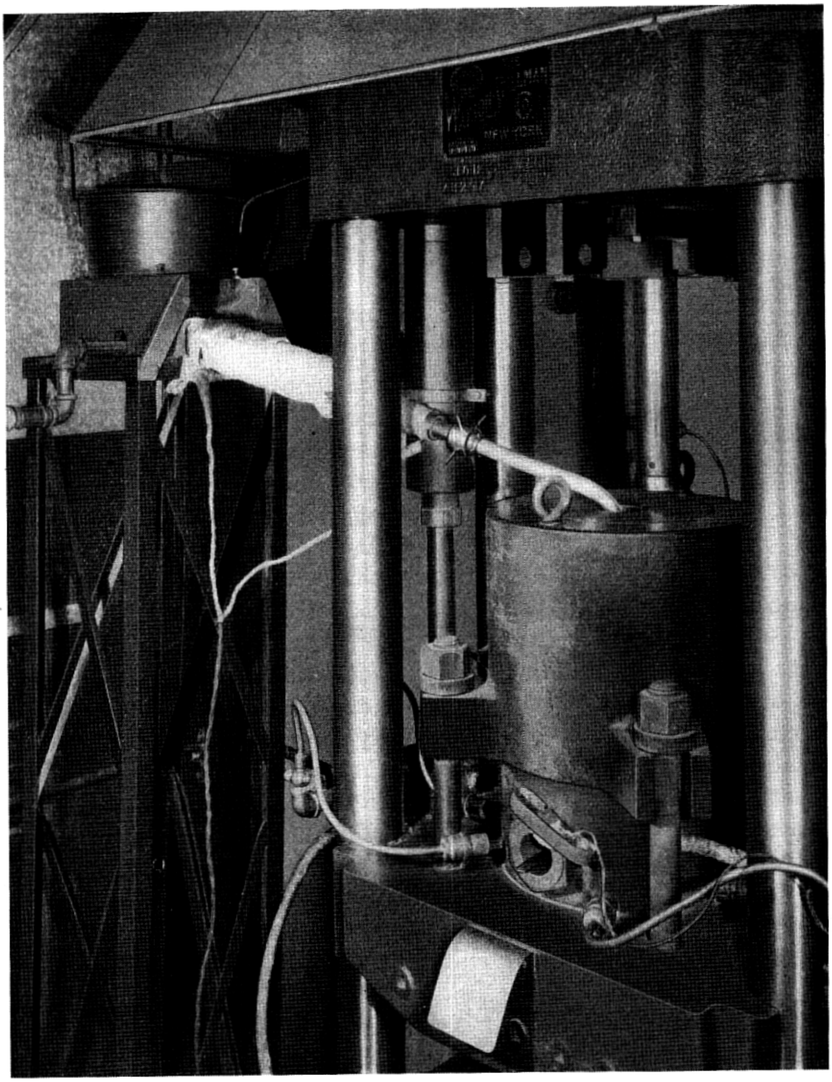

Fig. 3—Laboratory extrusion press for the study of the extrusion process and for the production of experimental cable sheathing alloys.

and for the preparation of new cable sheath alloys. With this equipment commercial extrusion conditions can be investigated or, when desired, extrusion conditions can be varied to determine the effect on the properties of the alloy.

The general layout of the metallurgical microscopic laboratory is shown in Fig. 4. In the foreground is a metallurgical microscope and camera equipped with facilities for examination with polarized light and dark field illumination. The preparation of specimens and photographic processing are done in conveniently arranged adjoining rooms. The microscopic equipment is complemented with X-ray diffraction apparatus shown in Fig. 5. This equipment consists of a demountable X-ray tube so arranged that targets can be readily interchanged. Cameras are provided for structure identification, precision determination of lattice constants, and texture and orientation studies.

Microscopic and X-ray diffraction equipment are both extremely valuable in a great diversity of metal problems. Some examples are given here of the utilization of microscopic equipment in cable sheath development studies. The possibilities of prolonging the life of cable sheath which has developed a weakened structure in service have been established through microscopic examination after a heat treatment consistent with the alloy structure. Again, the results of thermal treatment incident to the soldering and repair operations on cable in the field can be observed and used as a guide to the value of certain procedures. An interesting example is concerned with the opening of splices in installed cable sheathed with lead-antimony alloy, a procedure frequently necessary. During aging in service the antimony-rich particles coalesce into relatively large lumps. When material in this condition is heated by pouring hot solder over the joint, pools of liquid are formed around each lump of antimony, and if an attempt is made to pry the sleeve of the splice open at once, the sleeve crumbles. If heating is prolonged a few minutes, however, the tiny antimony-rich liquid pools diffuse into the surrounding solid material; at this time the sleeve can be opened without injury.

A few years ago, a new lead alloy containing from three to four hundredths per cent of calcium was produced and is being extensively studied now for cable sheathing and other applications. Laboratory tests indicate that under some conditions this material excels lead-antimony in resistance to fatigue failure. To illustrate the careful consideration given materials before making changes which might vitally affect telephone service, about one hundred miles of cables sheathed with a lead-calcium alloy have been installed for a commercial field test. In addition, thirty-six thousand feet of experimental

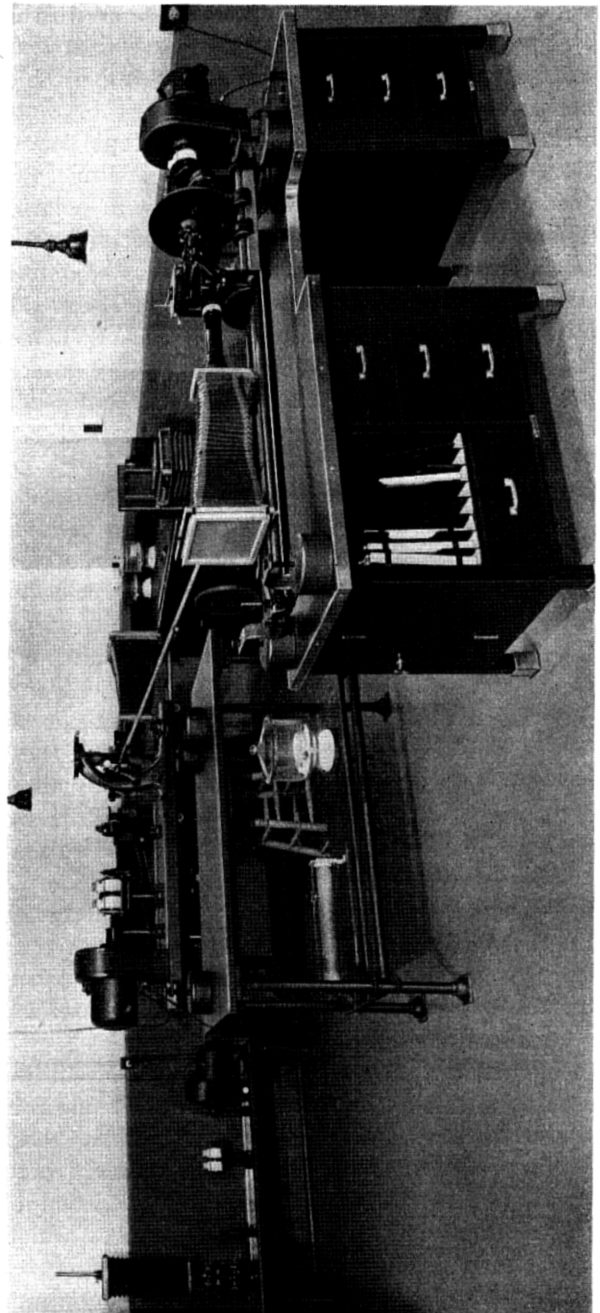

Fig. 4—Metallographic equipment used in the study of metal problems.

lead-calcium sheathed cable were installed on poles alongside of similar lengths of cable with standard lead-antimony sheath. Various sheath thicknesses ranging from .075 to the standard .125 inch were installed for comparison and to expedite early failure. In addition to the comparison between alloys this test will also give information regarding the minimum thickness of sheath which may be employed with both the standard and the experimental alloys.

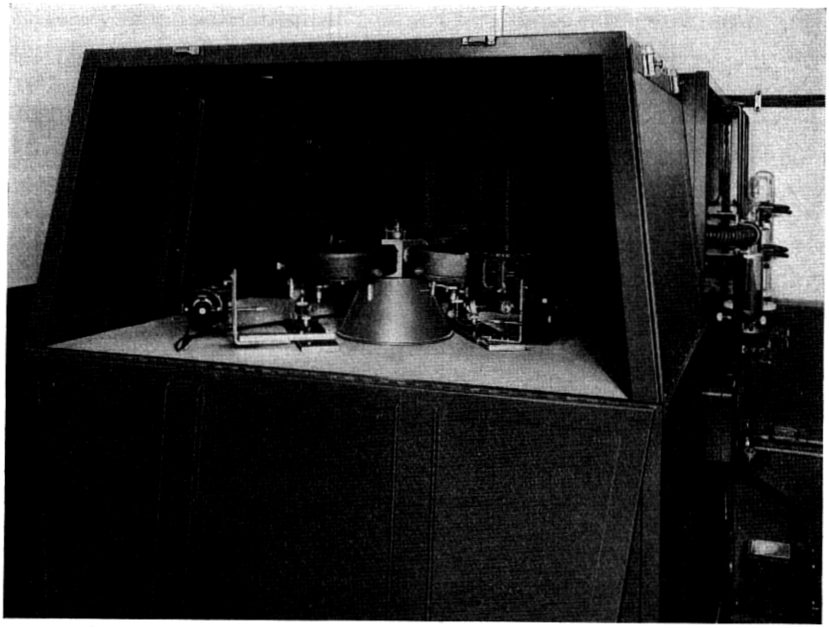

Fig. 5—X-ray diffraction apparatus showing cameras mounted for identification of structure and precision measurement of lattice constant.

Besides their application as cable sheathing materials, lead alloys are also extensively used by the Bell System as solders, storage battery plates, fuses and as corrosion protection coatings.

Copper and Copper Alloys

Unalloyed copper finds application as wire in the lead-sheathed cables already discussed, in open wire circuits and in central office equipment. In the telephone plant there are eighty million miles of it—enough to span the distance from the earth to the moon three hundred thirty-five times. To obtain the lowest transmission losses, cable conductors consist of high conductivity annealed copper wire.

For line wire in open wire circuits, hard drawn copper wire is used in order to take advantage of the conductivity of copper and the inherently greater strength resulting from strain-hardening. Line wire is subject to ice and wind loads, vibration fatigue, and in some localities, severe corrosion. Where loading conditions are severe the copper-cadmium and other high-conductivity, high-strength materials have attractive possibilities but require further evaluation before their introduction for general use.

For drop wire—the conductor running from the telephone poles to subscribers' buildings—a material with somewhat different properties is required. Here lower conductivities can be tolerated but higher strengths are necessary since the wire is smaller in size and long spans are sometimes necessary. Several materials have been utilized. The alloy most generally in service in the Bell System is composed of 98.25 per cent copper and 1.75 per cent tin. This is being replaced now as a result of research development with a higher strength copper alloy containing 3 per cent tin. This substitution makes possible a reduction in gauge size of conductor from 17 to 18 without sacrifice in the strength characteristics of the conductor.

For most purposes ordinary electrolytic copper containing a fraction of a per cent of oxygen is satisfactory. There are some limited applications, however, where the copper is subjected to high temperatures in the presence of reducing atmospheres at some stage in the manufacturing process. Under these conditions, the presence of oxygen in the ordinary copper produces a well-known embrittling effect. For these applications a copper free from oxygen is used.

A small but important application of copper in telephone circuits is in the production of copper-oxide rectifiers. For this purpose a copper imported from Chile is ordinarily used; for some obscure reason domestic brands of copper have not generally proved so satisfactory.

Copper in the alloyed form also is used extensively in the telephone plant. One application, that for drop wire, has already been mentioned. Other extensive applications are for springs and contacting members in electrical circuits and for structural parts where corrosion resistance or other desired physical properties justify their use. Nickel silver and to a lesser extent phosphor bronze find application for springs. Brass is used primarily for wiper contacts since it lacks the desirable spring properties of nickel silver and bronze. Included in satisfactory spring requirements is long service life which depends upon good fatigue characteristics and freedom, in many instances, from the tendency to season crack.

Die Casting Alloys

The demand in the Bell Telephone System for the economical production of large quantities of small complex parts has led to an extensive and growing use of die castings. If the past is a guide to the future, further expansion can be expected. Although the zinc base alloys represent the major proportion of all alloys consumed, other materials find application where specific properties are desired. High dimensional accuracy is obtained with tin base alloys; light weight is a notable property of aluminum base alloys. Lead base die castings are used principally in coin collectors where their sound and mechanical damping characteristics are important. To produce the desired properties consistently the metallurgical characteristics of these materials must be known and specific procedures followed.

Electrical Contact Alloys

Requirements of a suitable contact are many, and vary with the use to which the contact is subjected. Two requirements that are universal and paramount are that the contact material must provide an electrical path of a low resistance and must not wear away too rapidly. (Some contacts are expected to give satisfactory performance for more than 150 million operations.) In the communication systems both precious and base metal contacts are extensively used. Of the former class, platinum, palladium, silver, platinum-gold-silver, gold-silver, palladium-copper, or platinum-iridium, have given good service performances. Wiping contacts are widely employed in dial central offices. These consist generally of brass and bronze although silver is being used to an increasing extent.

Some idea of the extent to which our modern communication systems are dependent upon electrical contacts is illustrated by the number of pairs of precious metal contacts that must operate reliably to complete an ordinary dial system call between subscribers in a large city. Such a call brings into operation about three hundred relays involving over one thousand pairs of contacts. In a long distance call between New York and San Francisco about 1500 additional pairs of precious metal contacts must perform dependably for satisfactory transmission. In some years our communication systems have required more than 100 million pairs of contacts furnished on different kinds of telephone apparatus.

It may be readily appreciated, therefore, that knowledge of the factors governing contact performance is of vital importance.

Magnetic Materials

Telephone apparatus presents a great diversity of applications for magnetic materials. Both soft * and permanent magnet materials are extensively used. The soft magnetic materials are employed both as sheet and rod and in a finely divided form for compressing into cores for inductance coils. Previous to 1920 the primary soft magnetic material was iron; small quantities of silicon steel also were used. Since that date a large number of new soft magnetic materials have been developed with superior properties for particular applications. The discovery of permanent magnet characteristics in dispersion-hardening iron alloys containing no intentional carbon has resulted in a number of new permanent magnet materials of superior properties.

At this time, in the field of soft magnetic materials, iron and silicon steel find by far the most extensive application. The iron is a high grade commercial iron. The silicon steel used is the grade normally containing about 4 per cent silicon. For applications requiring higher permeabilities and lower losses, alloys of iron and nickel, known as the *permalloys*, are used. There are two principal *permalloys*, one containing about 80 per cent nickel and another 45 per cent. The higher nickel composition is also modified by molybdenum or chromium additions to increase electrical resistivity and improve magnetic properties. Sheet and rod stock are used in relays, transformers, miscellaneous coils, and ringers.

In investigating magnetic materials in the laboratory it is desirable frequently to fabricate the alloy into extremely thin sheet. The twenty roll cold-reduction mill shown in Fig. 6 is of value for this purpose. It is equipped with small diameter working rolls, each backed by a cluster of nine supporting rolls. With this arrangement high unit pressures are obtained and sheet a fraction of a mil thick can be produced readily.

In the form of 120-mesh powder and even in finer sizes certain of the *permalloys* find application in loading coils, filter coils and associated equipment. To secure low losses the powder particles are each insulated with a high resistivity, heat resistant material prior to pressing into cores. Manufacture of this fine alloy powder is a unique metallurgical process taking advantage of the effects of small amounts of added elements to achieve a desired result. The presence of a few thousandths per cent of sulphur in the iron-nickel alloys in the range of 80 per cent nickel results in a structure which can be rolled to small

* The term *soft* is used to designate materials of relatively high permeability and low magnetic loss. Likewise, permanent magnet materials are frequently referred to as "hard."

section when hot, but when cold it is exceedingly brittle and can be pulverized to fine powder. The manganese content of the alloy must also be controlled since it has an effect opposite to that of sulphur.

The iron-cobalt system yields a useful magnetic material, the one

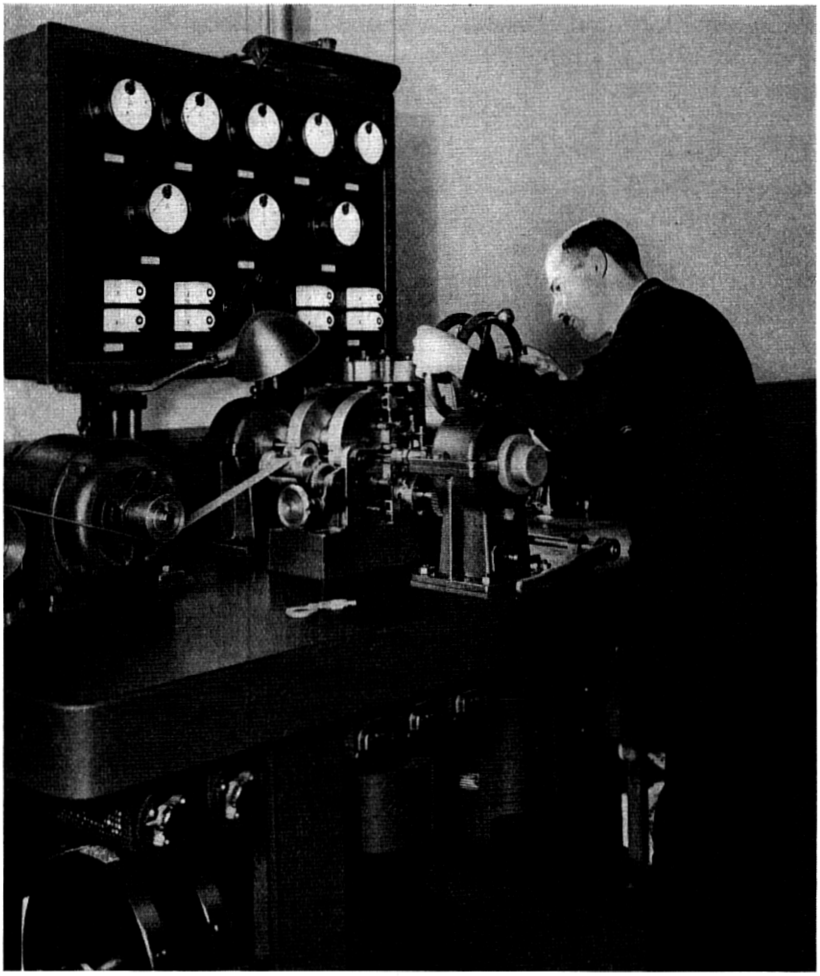

Fig. 6—Twenty roll cold-reduction mill for producing thin sheet materials for experimental studies.

containing approximately equal percentages of iron and cobalt. This alloy, called *permendur*, is characterized by high permeability at high flux densities and by a high reversible permeability when subjected to superposed direct current magnetizing forces. The binary alloy cannot be fabricated cold and this appeared at first to limit seriously the applications for the otherwise promising material. Brittleness in cold-rolling was overcome through the addition of approximately 2.5 per cent of vanadium, whereupon the alloy can be cold rolled after a quench from a high temperature. Fortunately the vanadium does not materially impair the useful magnetic characteristics. The alloy finds its chief application in the form of .010 inch sheet in the telephone receiver diaphragm.

Substantial tonnages of permanent magnet materials are also used in telephone apparatus per year. Of this most is 3.5 per cent chromium and other permanent magnet steels of low cost and low maximum energy product ($B \times H$ maximum for the demagnetization curve). Much of the remainder used is a material with high maximum energy product for receivers and other applications where space and weight limitations prevail. For this purpose 36 per cent cobalt steel has been used but it is now replaced in new apparatus by an iron-cobalt-molybdenum alloy, *remalloy*, which has superior magnetic properties and is of lower cost.

This iron-cobalt-molybdenum alloy, which contains approximately 12 per cent cobalt and 17 per cent molybdenum, has no intentional carbon addition and is of a dispersion hardening type. The hardening heat-treatment consists of quenching from 1180°–1300° C. in oil (after which the material is mechanically and magnetically soft) followed by aging at 670°–700° C. for one hour (which induces mechanical and magnetic hardness). The material can be hot-worked and machined except in the hardened condition, and welds readily, but is somewhat brittle.

Magnets of the iron-nickel-aluminum type are increasingly used in telephone apparatus. These alloys may be ternary compositions or may be modified by a number of additional elements; cobalt and copper additions have been found advantageous. The high coercive force, high maximum energy product, and light weight make them attractive. Disadvantages are non-workability and lack of machinability.

In addition to magnetic purposes, ferrous alloys are used extensively in other applications. Considerable quantities of carbon and alloy steels are used for structural purposes, and high alloy steels for installation and maintenance tools.

Prospective Developments

In concluding a discussion of metallic materials in telephone equipment interest naturally is directed toward the future developments.

The trends in the use of new metallic materials in the telephone service are difficult to predict. A large class of applications includes the incorporation of improved materials in existing apparatus with some modification in design resulting in a cost saving or in improved service. Such materials originate from developments by the metallurgical industry and from investigations by the System's engineers. Examples of this type have already been mentioned; for example, improved cable sheathing materials, electrical conductors, and magnetic alloys. This evolution in application of materials will undoubtedly continue and constitute a large part of the telephone metallurgists' activities.

There is another field of application for metallic materials, applications in newly designed apparatus or systems of communication. Here the properties of existing materials are frequently inadequate to perform the required duties and new materials must be developed with the necessary properties. One example already cited is the preparation of magnetic powder for inductance coil cores. A new system of transmission, a million-cycle system, requires newly developed materials in the coaxial cable and the associated equipment. Special properties are usually involved which are of interest only in connection with communications, and hence the development of such materials is dependent almost wholly on the activities of the System's research groups.