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Developments in the Manufacture of Copper Wire[1]

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SYNOPSIS: This paper describes a new copper rod and wire mill located at the Western Electric Company's Plant at Chicago. It includes a brief survey of the copper rolling and wire drawing art at the time the investigation was started; a summary of tests made in varying the practice in rod rolling and wire drawing; and an outline of the work done by the Western Electric Company engineers in developing and designing new types of wire drawing machinery.

The rod mill is converting 225 pound wire bars into ¼" rod in fourteen instead of the usual eighteen passes. This is accomplished by making heavier reductions in the first four passes while the copper is hot. The new wire mill incorporates many novel features, and the wire drawing machines are more compact in design and of considerably higher speed than those in general use.

The design of the wire mill was undertaken following a comprehensive survey of wire drawing processes and equipment used in this country and abroad. Part of this survey consisted of a study of the manufacture of diamond dies, it having been found that dies suitable for high speed drawing required a differently shaped "approach," a better polish, and a shorter "land," than those which were available for low speed work. The economies in floor space and plant investment due to the use of more compact and higher speed machinery are outlined. Some of the outstanding features in plant arrangement which contribute to more efficient operation are discussed in the concluding pages.

RAPID growth in the various branches of electrical communication accompanied by widespread research are constantly leading to the more efficient and economical meeting of the increasing demands for service. In this connection, one of the more recent and very interesting investigations indicated the possibility of effecting substantial improvement in the process of manufacturing copper wire. Accordingly, a comprehensive study of all the factors concerned was undertaken which resulted in the construction of a rod and wire mill at Chicago embodying many unique and improved features. A schematic layout is given in Fig. 1.

At the outset the sources of copper and its transportation were studied and it was found more economical to ship wire bars to Chicago for conversion into wire than to locate a wire mill near some of the large refineries and ship wire to the factory. It was also considered that this plan would reduce the investment in wire during the process of manufacturing cable and telephone apparatus.

[1] Read before the Midwinter Convention of the A. I. E. E., New York City, Feb. 8, 1927.

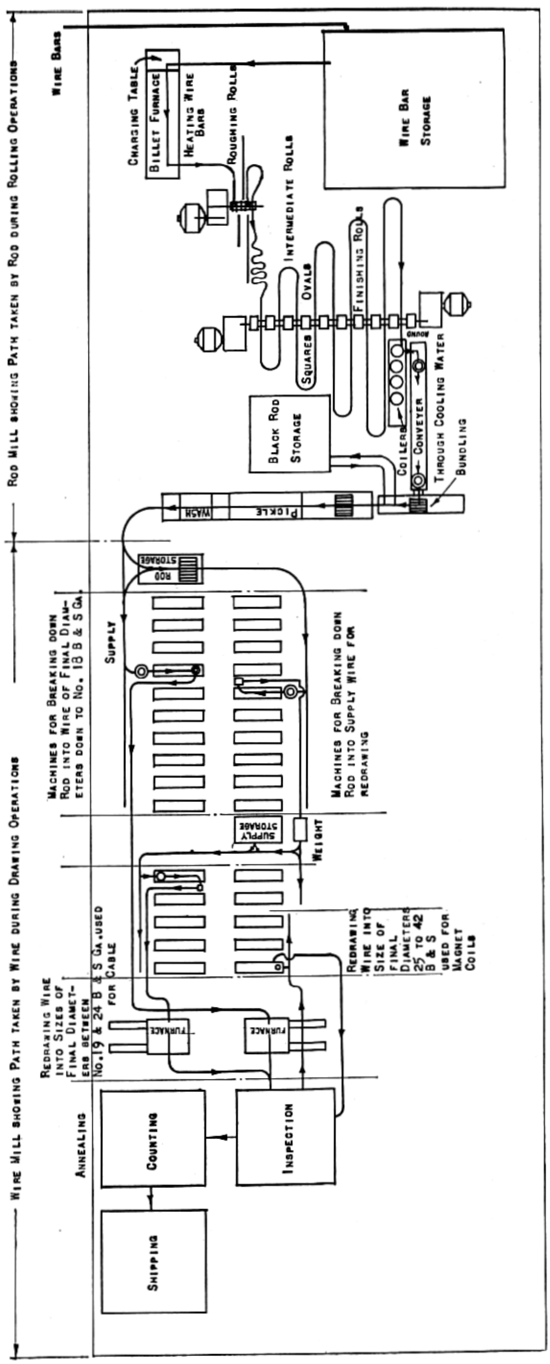


Fig. 1—Schematic layout of Western Electric Company's copper rod and wire mill at Chicago, Ill.

Rod Rolling Mill

The Rod Rolling Mill equipment consists of a billet heating furnace, a roughing mill, an intermediate mill, a finishing mill, coilers, conveyors, and pickling tubs. The mills are water-cooled and equipped with a down-draft exhaust which carries the fumes produced during the rolling operation to an air washer where the copper dust is recovered before the air is discharged.

The 225 pound wire bars as received in cars from the refineries are unloaded onto skids in the train shed and transported by an electric truck to the charging end of the billet heating furnace. Here they are transferred in groups of six by a hoist to the charging table, where a compressed air-pusher moves them along through the furnace which holds 120 bars. The bars are brought up to the required temperature for rolling as they move through the furnace, which is heated by fuel oil. When the bars reach the opposite end of the furnace they are withdrawn at about 1600° F. with a pair of tongs through the discharge door and pushed into the roughing mill one at a time. These tongs operate on a trolley suspended from a beam, which is in line with the first groove of the mill.

The roughing mill consists of three motor-driven rolls, one above the other. The bar, after passing through the first groove between the top and middle roll, drops upon feed rolls set in the floor and is returned through the second groove, between the middle and bottom roll; then raised into position and passed through the third groove, which is in the same rolls as the first pass. Five passes are made in this manner until its cross-section is reduced sufficiently for it to enter the intermediate mill. As the bar enters the roughing mill it is 54 inches long and about 4 inches square. When it leaves this mill it has been rolled into an oval cross-section and is about 124 feet in length. Formerly the last pass on this mill was handled manually, and recently a mechanical repeater has been added as illustrated by Fig. 2.

From the roughing mill the bar goes to the intermediate mill and is passed through the first pair of rolls. As it emerges an operator catches the end with a pair of tongs and passes it back through the next pair of rolls. The increased length between each pass at the intermediate and finishing mills is allowed to run out in a loop on a sloping iron covered floor on each side of the rolls. This catching and returning is repeated at each set of rolls until the original copper bar finally emerges a round, quarter-inch rod about 1200 feet long. This last pass goes through a guide pipe into a coiler, Fig. 3. The reductions in cross-section are illustrated in Fig. 4.

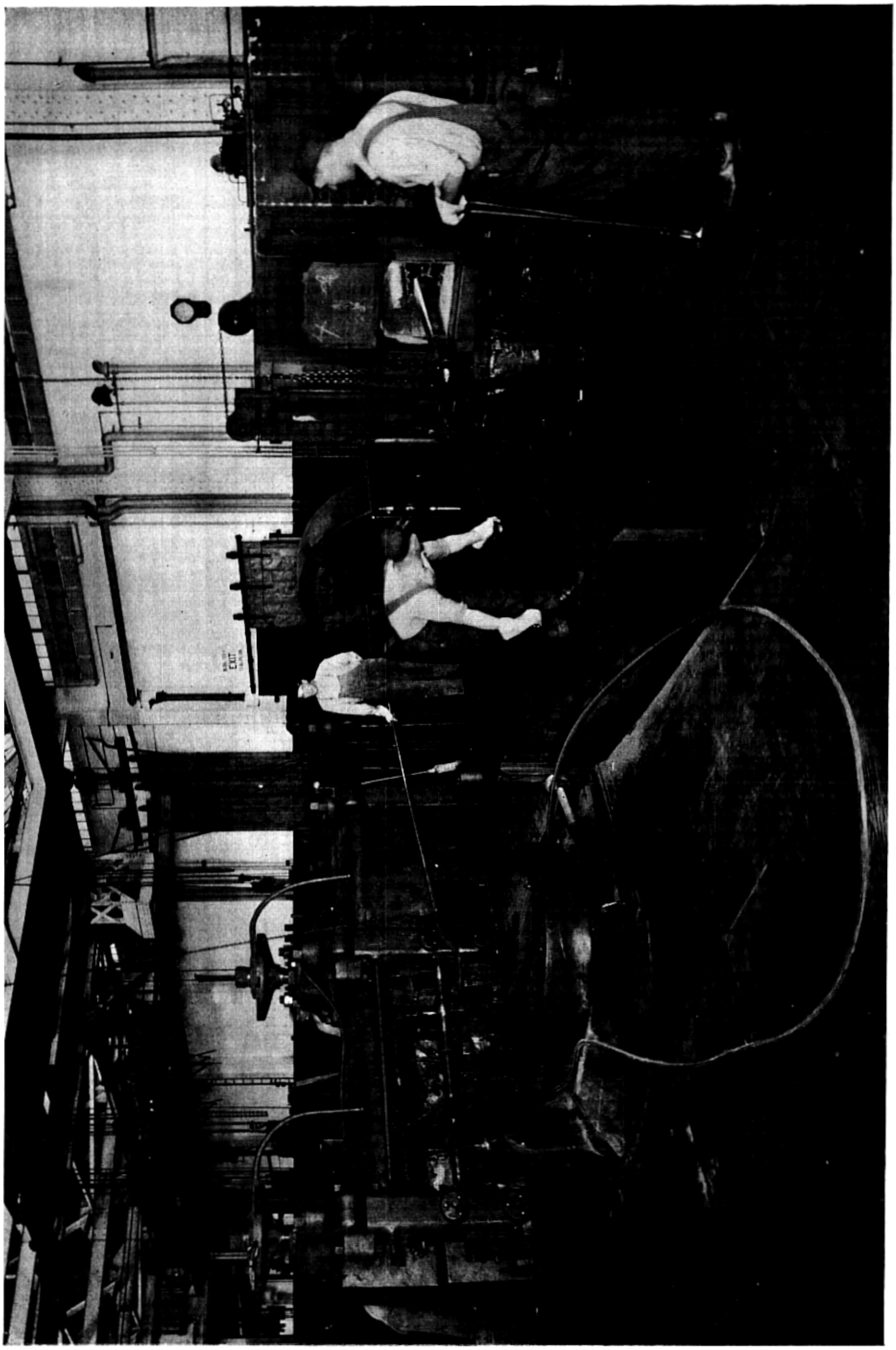


Fig. 2—View of roughing mill showing repeater on last pass

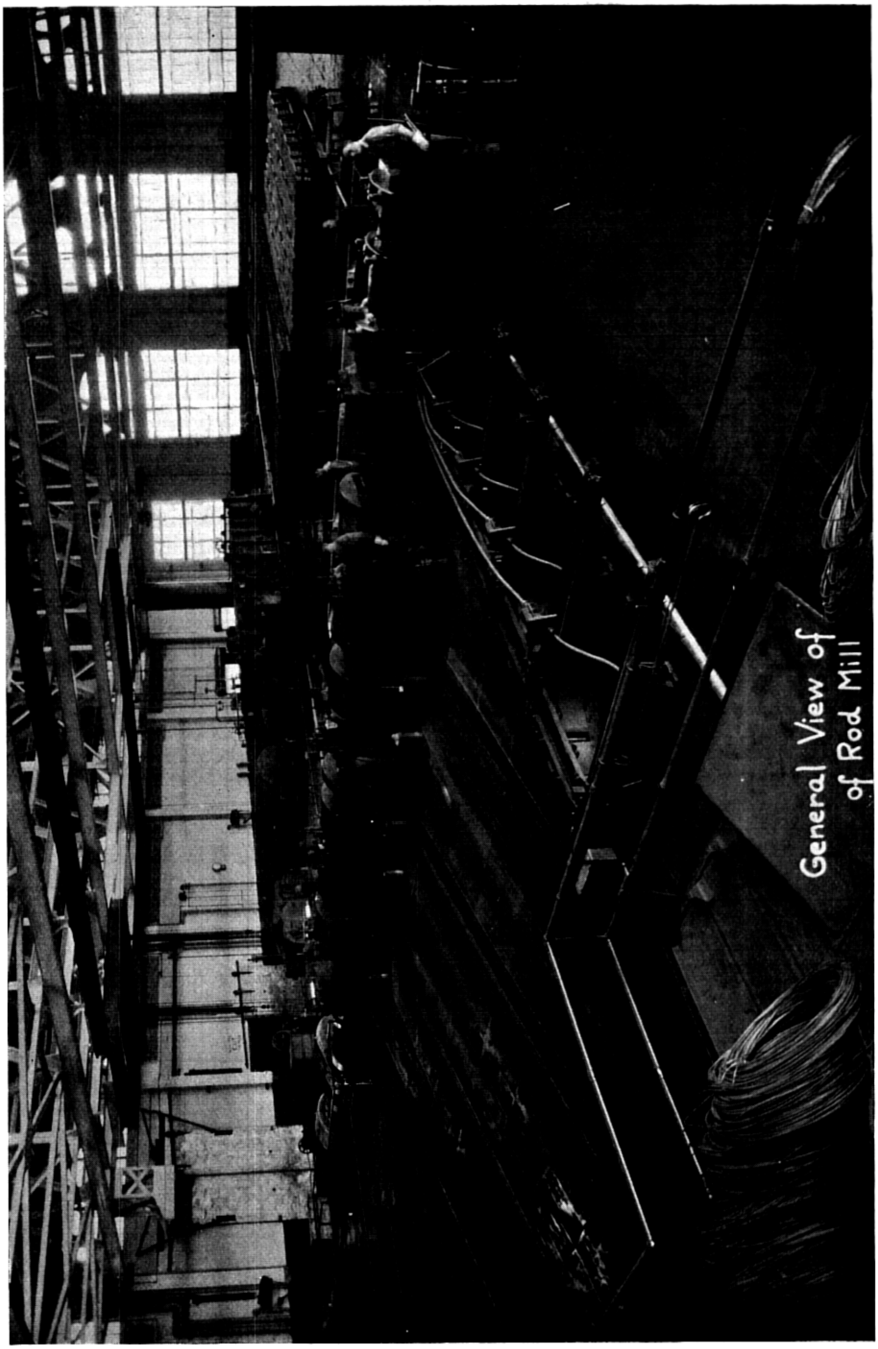


Fig. 3—View of intermediate and finishing mills and coilers

The coils are automatically unloaded from the coilers onto a conveyer, which carries them through cooling water in a tank underneath the floor. An appreciable amount of copper oxide scale is carried off

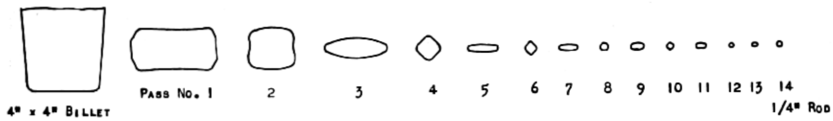


Fig. 4—Rod mill reductions—4 in. by 4 in. billet to ¼ in. rod

with the cooling water, and deposited in a reservoir from which it is later salvaged. Eighty-two seconds after entering the roughing mill the bar is a coil of ¼ in. rod ready to proceed on its way to the pickling tanks. The mill has a capacity of 70,000,000 pounds annually on a 48 hour per week basis.

While the diagram and photograph of the intermediate and finishing mills indicate for simplicity that the rod follows only a single path, in actual operation sufficient material is kept in the mill to practically

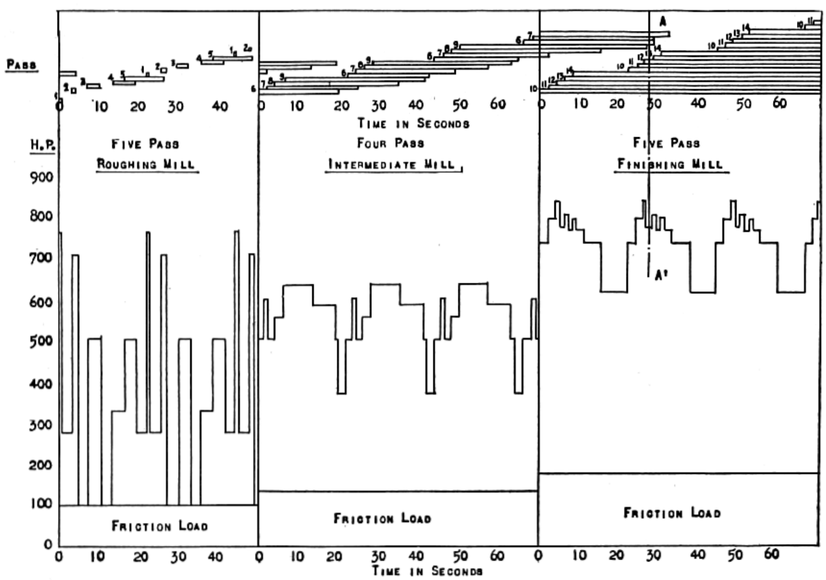


Fig. 5

maintain at least two rods in the finishing mill. This is illustrated graphically by that part of Fig. 5 which covers the finishing mill. Referring to line (A–A'), 11 reductions are being made in this mill at the same time, two for each of the first four pair of rolls and three on the final rolls. At this period in the cycle of operation 800 H.P. is required.

When the rod mill was started eighteen passes were in use by several of the most modern mills. A sixteen pass arrangement was adopted for the new mill, in which the metal was subjected to a greater amount of working in the earlier passes when it was hot. Later, as a result of further study, fourteen passes were adopted. Fig. 6 illustrates graphi-

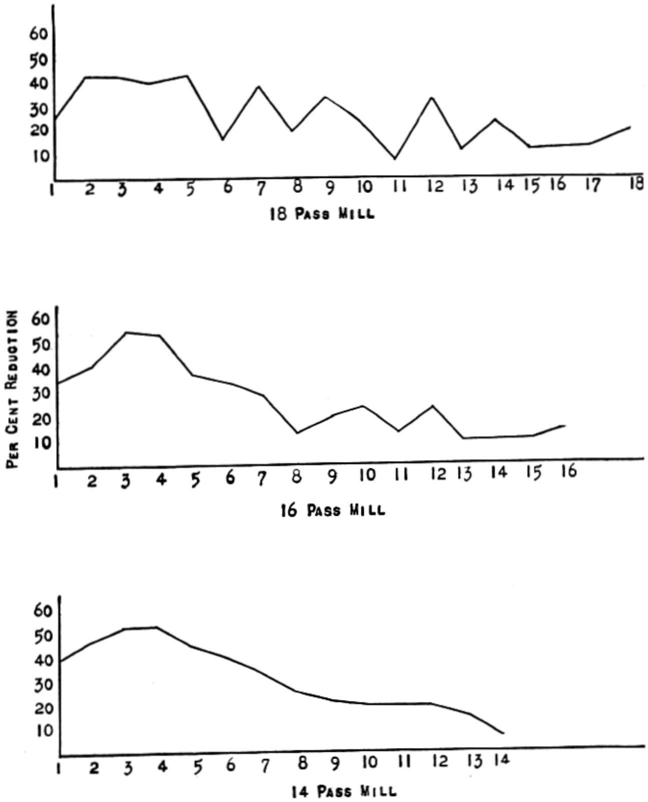


Fig. 6—Per cent reduction

cally the per cent reduction effected at each of the above passes. The reductions plotted as the abscissa are in terms of reduced area in cross-section at each pass and the passes reading from left to right are plotted as ordinates.

It is obvious that careful planning must be done in changing the number of passes in a mill in order not to exceed the safe working capacity of the mill rolls and stands. Such calculations have been made using rolling mill formulæ.[1] Based on the design of the mill using the eighteen pass arrangement the first four passes would operate at about 62, 100, 105, and 90 per cent of the safe working load of the mill. These same passes calculated on the basis of the sixteen and fourteen pass arrangement of the more sturdy mill at the Chicago plant operate at 86, 87, 90, 85 and 96, 96, 90, 90 respectively. This indicates that a further reduction may be made in the number of passes in the mill provided roll adjustment is improved.

Relation between Working and Physical Properties

It has been often stated that the more passes (i.e. the more gradual working) given the copper, the better the physical qualities of the rod. Actual tests (see Table I) made on representative lots of ¼ in. rod fail to confirm this impression.

TABLE I

Lot	Number of Passes	Elongation	Tensile Strength Lbs. per Square Inch
1	18	35.8%	33,752
2	18	40.0%	31,445
3	16	37.1%	32,468
4	16	41.0%	32,160
5	14	42.0%	32,391
	Average of 5 lots	39.5%	32,243

The averages indicate that fourteen pass rod is superior in elongation, and better than the total average in tensile strength.

Cleaning of Rod

When the coils emerge from the tank through which the rod coiler apron conveyor passes, they are cool enough to handle and after being tied with wire, several are lifted together by a monorail crane, and placed for thirty minutes in a pickling tank containing from 5 to 10 per cent free sulphuric acid, in order to remove the black oxide caused by oxidation of the hot copper in the air during rolling. The solution is maintained at approximately 120° F., and the copper content varies from 1 to 3 grams per 100 c.c. Experiments have shown a difference of less than 10 per cent in pickling time between the minimum and maximum acid used, the greater solubility being obtained from the weak solution. Actual results obtained were checked with Sidell's

[1] "Pass Limitation in Rolling Mill Practice," *Machinery*, July, 1918. "The Theory and Practice of Rolling Steel," Wilhelm Tafel.

Table of Solubilities (see Fig. 7). While a variation from the minimum to maximum acid concentration does not materially affect the pickling

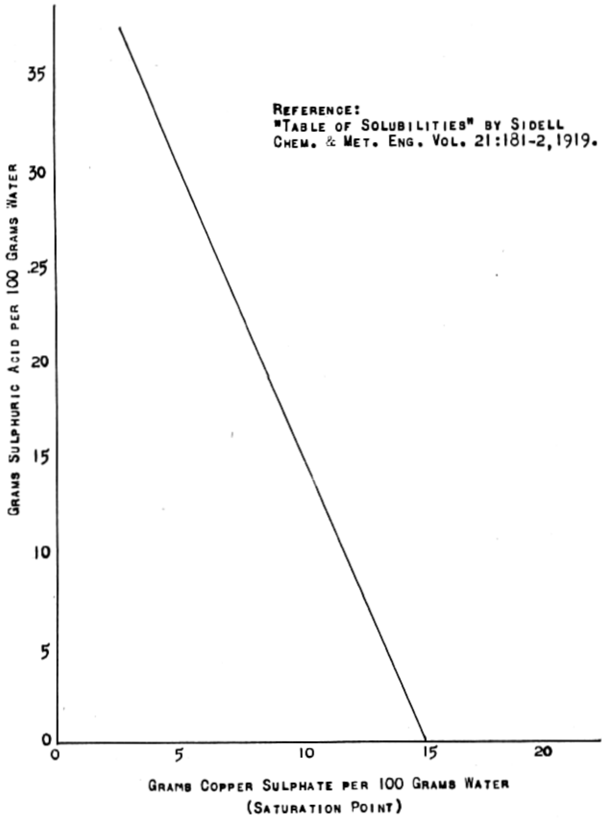


Fig. 7—Solubility curve of copper sulphate in a sulphuric acid solution (Temp. 25° C.)

time, a variation in temperature has a decided effect as may be seen from Fig. 8.

Electrolytic Plant

Figure 9 shows a plant in which the copper is reclaimed from the pickling bath at about the same rate as it is absorbed. This is accomplished by electrolytic deposition according to principles worked out and practiced in the large refineries which produce electrolytic copper.

The electrolytic system operates best with a minimum content of about 1 per cent copper and 5 per cent acid and a maximum of 3 per cent copper and 10 per cent acid. The copper and acid contents are kept as low as practicable to minimize "carrying out losses" [2] during the pickling operation. About 775 pounds of acid and 430 pounds of copper are recovered per day from the electrolyte. The anodes are operated at a current density of 5 amperes per square foot with a rate of deposition of about .00261 pound of copper per ampere hour.

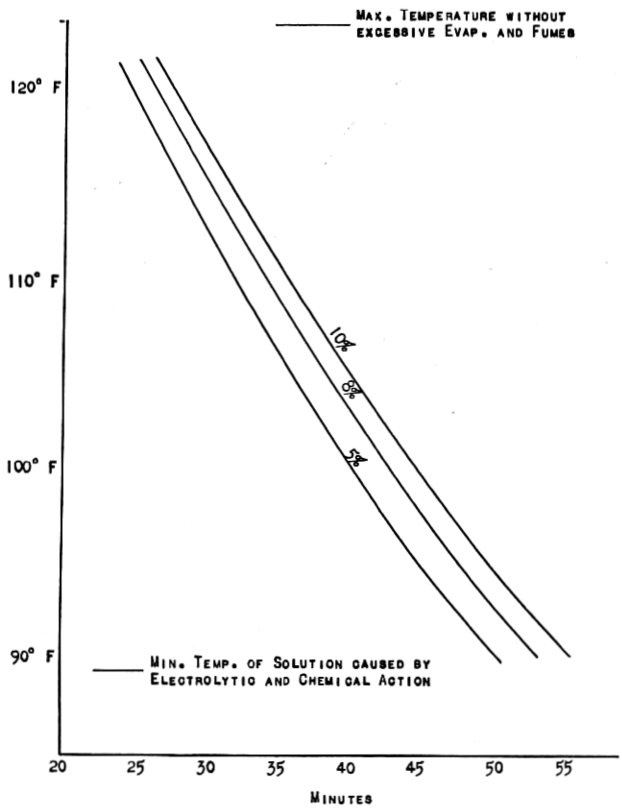


Fig. 8—Rate of pickling at practical acid concentrations

The heat generated in the plating tanks under normal operating conditions maintains a minimum temperature of about 90° F., throughout the acid system, and the maximum temperature is obtained through steam heating coils in the pickle tanks. Faster pickling would result from the use of higher temperatures but experience has shown that the additional steam and gas released above 120° F. results in unsatisfactory operating conditions.

[2] Pickling solution carried out when coils are removed from tank.

The coils of rod after pickling are thoroughly washed with lake water [3] at a pressure of about 70 pounds per square inch to remove loose

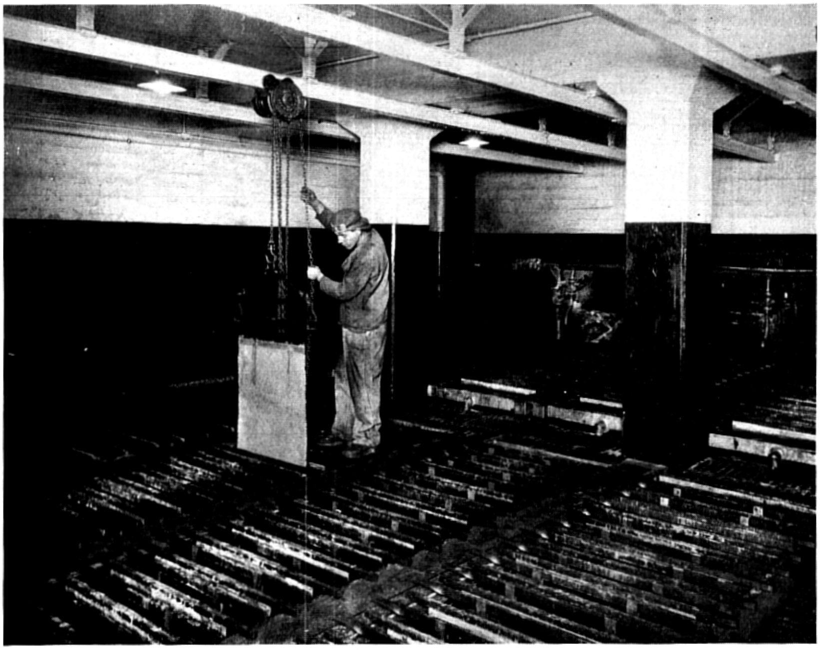


Fig. 9—Electrolytic recovery of copper from rod mill pickling solution

copper dust and acid, and then immersed in an alkaline fat solution to neutralize any trace of acid and to provide a protective coating against oxidation until converted into wire.

Wire Mill

The coils, after being pickled and washed, are carried by monorail cranes to the wire drawing machines where they are converted into wire of the desired size. The dies used in the heavy wire drawing machines are pulled into place at the starting end of the coil of rod on a die stringing machine (Fig. 10). The coil, with dies strung into position, is then placed in a heavy wire drawing machine.

The heavy gauges of wire, such as line wire, are drawn with one set-up on this machine; medium sizes, used in lead covered cable, are made by taking the wire as it comes from the heavy machine and re-

[3] Lake water is relatively free from mineral salts which would corrode the rod and affect the wire drawing compound.

drawing it on the intermediate machine; and finer sizes, commonly known as magnet wire, are produced by redrawing intermediate sizes.

The present capacity of the wire mill is approximately 42,000,000 pounds annually, and the sizes range from .165 in. line wire to 42 B. & S. (.00247 in.) gauge magnet wire. Provisions have been made in the construction of the building and its foundations so that the mill may be expanded in capacity when needed.

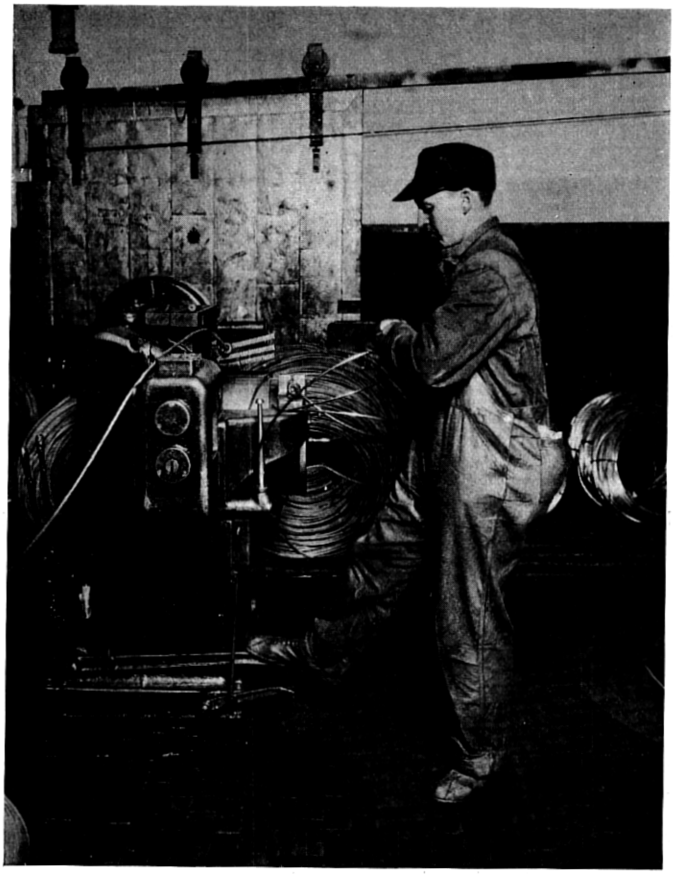


Fig. 10—Heavy wire die stringer

The No. 1 or heavy wire drawing machine shown by Figs. 11 and 12 draws line wire, heavy toll cable sizes, and supply wire for the loop cable wire machines. This ten die machine with its auxiliary equipment and operating area occupies a floor space of 270 square feet and

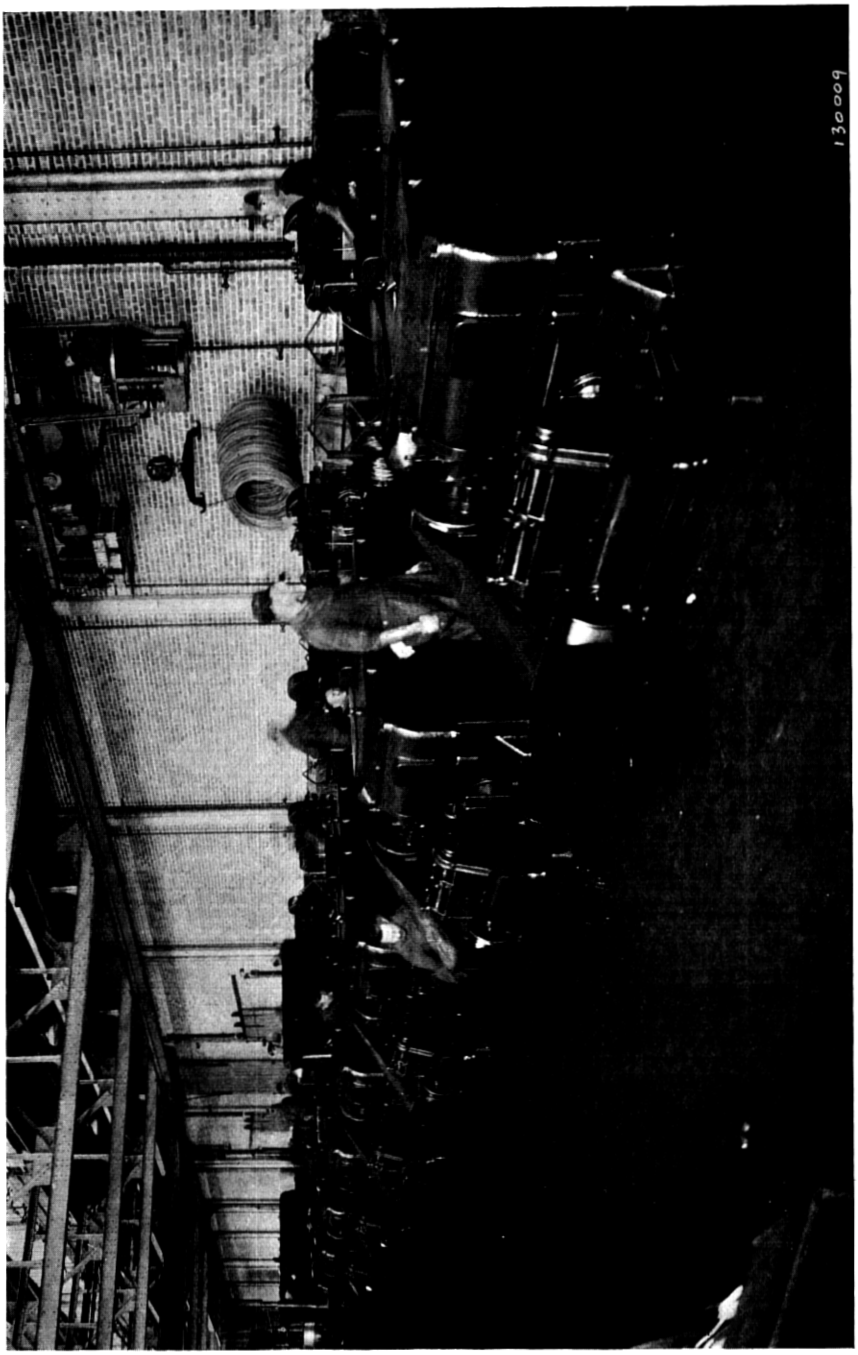


Fig. 11—Battery of No. 1 wire drawing machines

runs at 1500 to 2000 feet per minute as compared with 470 square feet for a commercial nine die machine running about 1000 feet per minute.

A battery of these machines costs much less than an installation of commercial machines of the same capacity, and in addition effects a considerable economy in floor space.

Fig. 12—Close-up of No. 1 machine

The commercial types of ten die intermediate machines for drawing cable wire require about 130 square feet of floor space as compared to 90 square feet for a twelve die multiple head machine. The former is a single unit machine and the latter a four unit machine operating at twice the speed and capable of producing about five times the output of the commercial equipment. This new multiple unit machine, Fig. 12A, costs more than regular equipment, but considering the four units, the cost is materially less per unit, and very much less on an output basis.

The magnet wire drawing machine is a high speed twelve die multiple head machine of eight wire drawing units occupying 90 square feet of floor space including the operating area. A close-up view of two heads of this machine is shown by Fig. 13. Fifty-one square feet of

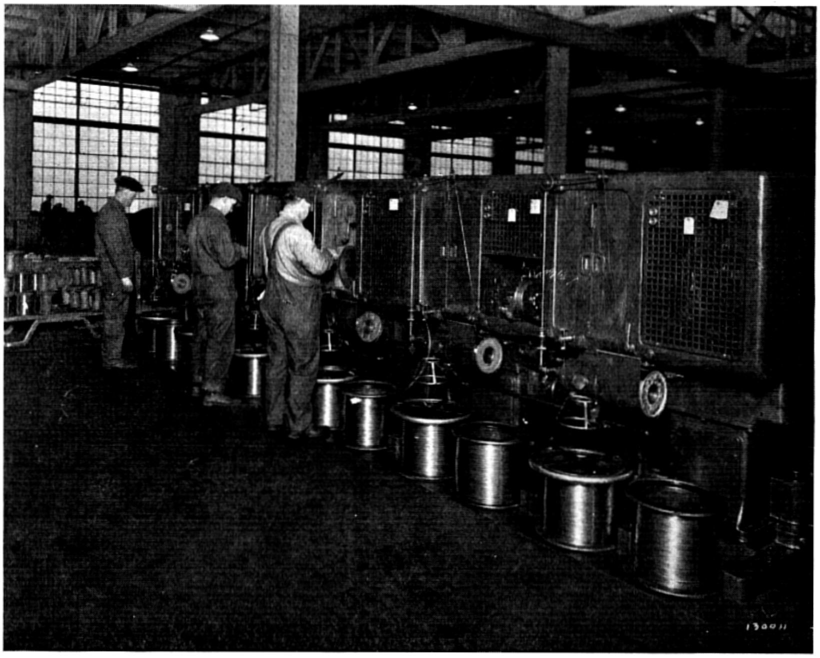


FIG. 12A.

floor space are required for a single unit (one head) commercial machine of the same die capacity. The saving in investment in this case is even greater than for the heavy and intermediate types of machines. The use of these compact machines and overhead monorail equipment for transporting material instead of using trucks with large aisles has permitted the installation of the wire drawing mill in less than one fourth of the building area which would have been required if commercial equipment had been purchased.

GENERAL PLANT FEATURES

The present connected load of the motors in the Rod and Wire Mill is about 6000 horse power for which it was necessary to enlarge the main power plant. A 700 foot tunnel connects the power plant with the Rod and Wire Mill in which are laid pipes for carrying hot and cold water, steam, gas, and air and lead covered power cables.

The basement under the Rod Mill houses the electrolytic equipment, control boards for the roughing and intermediate mills, pumps for cooling water, and exhaust fans connected with an air washer for removing the fumes from the Rod Mill. A tunnel which passes beneath the intermediate and finishing mills connects with a room which houses the drives for the four rod coilers, the coiler control boards, the finishing mill control board, and the main power panel. In the wire mill basement are six large tanks which hold the compound used to lubricate and cool the wire drawing dies. This compound is supplied under pressure to the wire drawing machines on the floor above and returns by gravity.

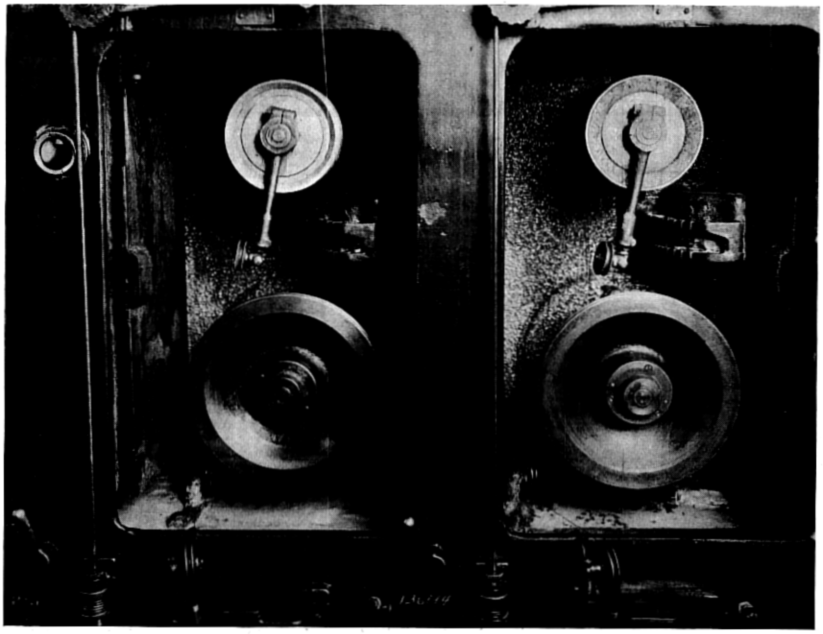


Fig. 13—Close-up view of units of No. 3 wire drawing machine

All the wire drawing machines are controlled by push buttons mounted on the machines, which connect with compensators in the basement. The 100 horse power motors driving the large wire drawing machines are mounted in a tunnel and are connected to the machines above by chain drive.

This arrangement permits accessibility for maintenance of the electrical equipment with a minimum of interference to production, prevents the wire drawing operators from having access to the electrical equipment, and reduces accident hazard to a minimum.

Developments in Wire Drawing Equipment and Methods

The Rod and Wire Mill just described was designed following a comprehensive survey of wire drawing processes and equipment used in this country and abroad. In connection with these studies, extensive laboratory investigations were undertaken relative to the characteristics of different types of commercial machines especially from

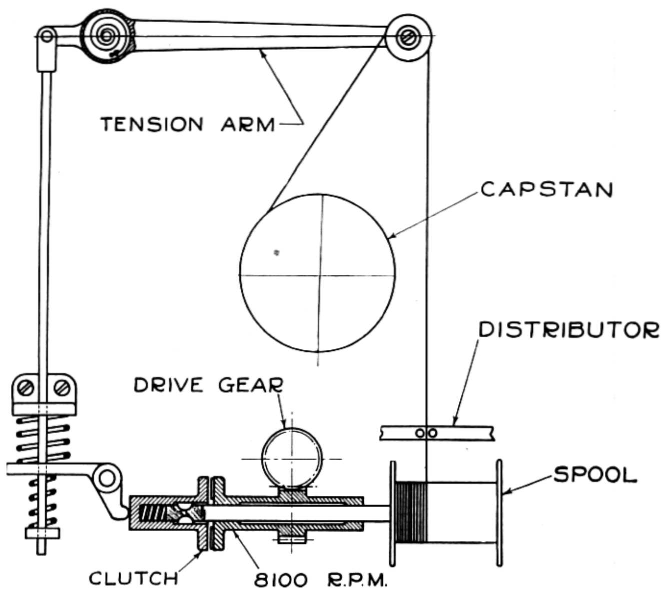


Fig. 14—Automatic tension mechanism—No. 3 wire drawing machine

the standpoint of operating efficiency, investment, and floor space requirements. As a result of these investigations, it developed that marked improvements could be effected if wire could be produced commercially at higher machine speeds and with more compact machine equipment.

While the design of the drawing mechanism in the new machine was very important, it was also deemed essential that the finished wire be taken up on spools instead of coils. After considerable experimental work, a sensitive take-up device was developed to permit spooling at a constant drawing speed.

This spooling mechanism is illustrated by Fig. 14 in which the spool spindle is driven by a slipping clutch member controlled through a tension arm, on which an idler pulley is located over which the wire passes on its way from the drawing capstan to the take-up spool. The take-up mechanism rotates the core of an empty spool at a speed synchronous with the speed of the wire as it leaves the drawing capstan. As the spool fills and the speed tends to increase, the wire on the tension arm tightens and compresses the tension arm against a spring adjusted for the proper gauge of wire. This in turn reduces the pressure of the clutch driving the take-up spindle, permitting the spool of wire to readjust its speed.

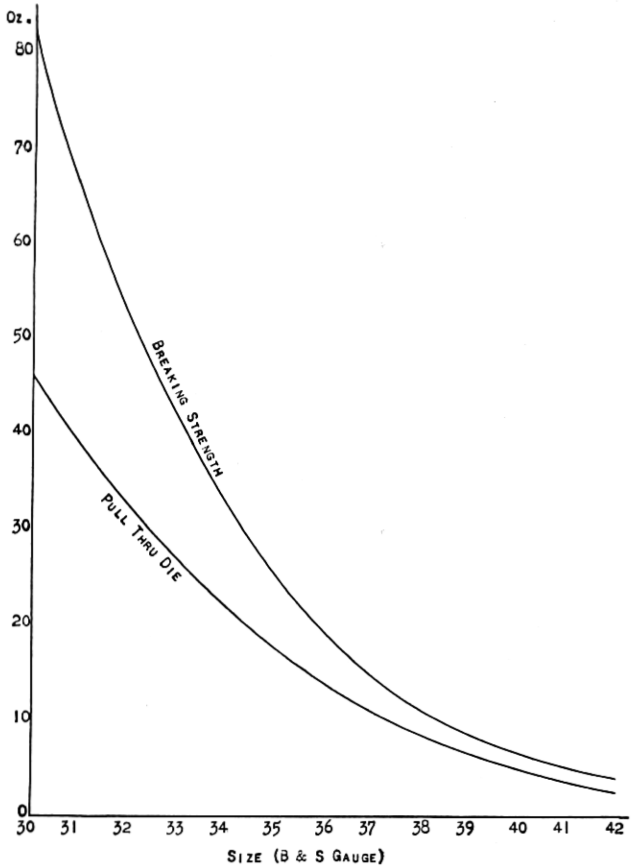


Fig. 15

This device is extremely sensitive as illustrated in the drawing of No. 42 B. & S. wire at 2000 feet per minute, in which case the control arm must be adjusted to operate between 90 and 150 grams, since the pull required is 87 grams and the breaking strength of the wire is 170 grams. This device is so flexible that it can be adjusted to a drawing tension of from 9 pounds for No. 25 wire to 3 ounces for No. 42 wire. Fig. 15 illustrates its operating range on wire sizes No. 30 to No. 42, showing the gradual narrowing of the limits as the sizes decrease. A larger machine used for drawing loop cable wire from No. 18 to No. 30 B. & S. gauges contains a similar mechanism.

The use of this sensitive device and a clutch which would slip without overheating as the spool filled, together with improvements in the wire drawing compound and the shape and quality of the diamond dies later described, permitted the drawing of wire at speeds ranging from 2000 to 3000 feet per minute.

Wire Drawing Compound

At low speeds it was discovered that the compound for lubricating wire drawing dies required little attention but as the speeds were increased the necessity for close analytical control was evident. The compound consists of an emulsion of soap, tallow, and water, the percentage of the soap and tallow being varied depending upon the size of wire and type of machine on which it is used.

It is important that the degree of emulsification [4] be carried far enough to break the tallow into particles about one micron in diameter, so that the material will stay in suspension in the water. If the tallow content is increased beyond a certain point, it holds in suspension in the solution a large amount of the copper dust which flakes off in a very fine state during the wire drawing operation and this clogs the dies and causes breakage during the wire drawing. Ordinarily this copper dust settles out of the solution while in the large cooling tanks and a considerable amount is salvaged in this manner.

Effect of Drawing on Copper

Tests were made to determine if the drawing of the smaller cable and all magnet wire sizes [5] in Brown and Sharpe (A.W.G.) steps was yielding the maximum reduction possible per die. These tests showed it was feasible to make much heavier than A.W.G. reductions at the first draft when annealed wire or soft copper rod was being drawn. It also showed that the elongation [6] of the rod or annealed wire was rapidly reduced to the drawing minimum after the first pass, and remained at that point throughout the process.

[4] "The Theory of Emulsions and Emulsifications," W. Clayton.

[5] A.W.G. ("American Wire" or "Brown and Sharpe" gauge) reductions are not used in converting the rod to line wire; these are generally specified in B.W.G. and N.B.S. gauges.

[6] See Figs. 16, 17, 18, and 19 showing the elongation of the rod or wire dropping to about 1½ per cent at the first die reduction and remaining practically constant.

Figure 16 illustrates the effect of a five die reduction on elongation and tensile strength. It may be seen that the elongation drops very rapidly at the first die when a reduction in area of about 42½ per cent is made, and the tensile strength increases rapidly because of the cold working of the metal.

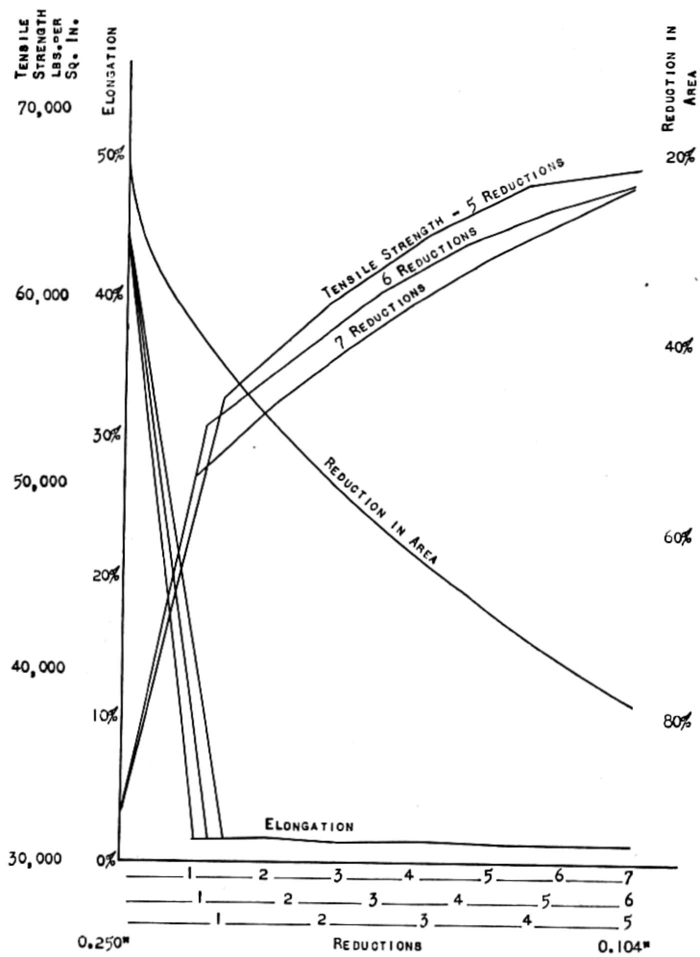


Fig. 16

This same figure shows the tensile strengths obtained when five, six, and seven die reductions are used to produce line wire of .104 diameter from the same supply. Here the elongation loss is about the same in each case, but the tensile strength is greater with the heavier reductions. The five die arrangement is satisfactory according to the results shown on the curve, but the heavy reduction at the first die often results in rough or slivered wire. The six die arrangement, therefore, gives the greatest factor of safety. The seven die arrangement is less satisfactory since the elongation and tensile strength in the finished wire are so close to the requirements.

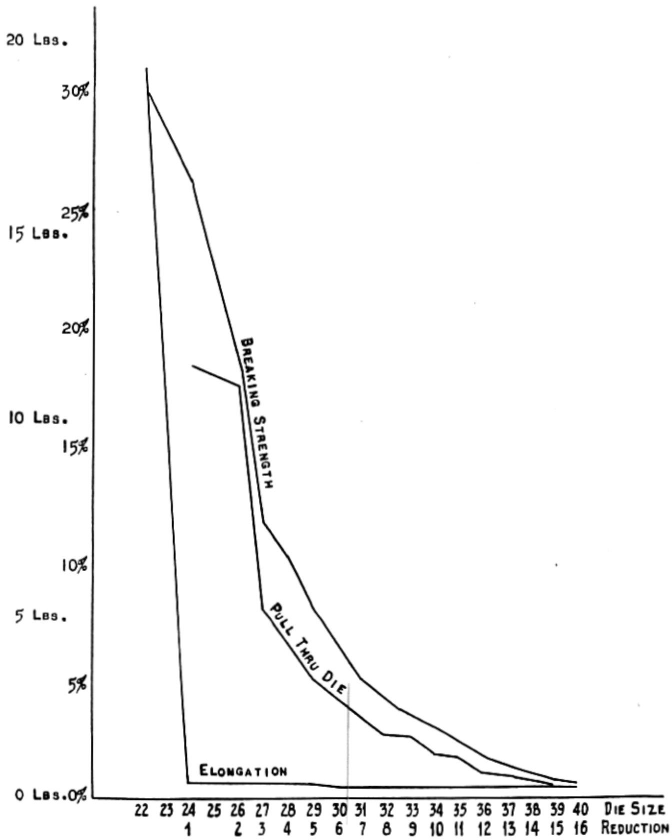


Fig. 17

The use of A.W.G. reductions for the finer sizes of cable and magnet wire provides flexibility since a change in the size of wire can be accomplished simply by increasing or reducing the number of dies used. Tests were conducted to determine the gain by using heavier reductions and annealing the wire before redrawing, and Fig. 17 shows the increased reduction possible at the first die when the metal is plastic. In this test, an annealed No. 22 gauge wire of 31 per cent elongation was reduced to No. 24, two gauges, in one draw. The soft copper permitted a double reduction at the first die, but the elongation dropped during the operation to less than 1 per cent; the second reduction on this test was from No. 24 to No. 26 gauge and the pull required for this pass practically coincides with the breaking strength of the wire. Wire drawing under such conditions is impractical because the annealing operation is much more expensive than drawing hard wire from No. 22 to No. 24 in two passes.

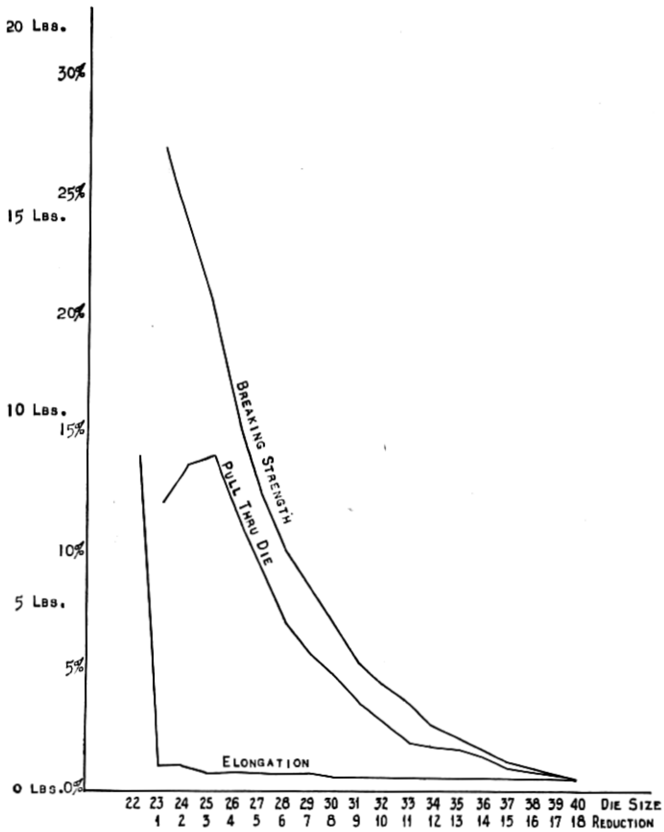


Fig. 18

Figure 18 illustrates the results obtained when drawing annealed wire with A.W.G. reductions. The large margin of safety between the pull required and the breaking strength of the material again disappears after two reductions. Fig. 19 [7] illustrates practical drawing

[7] Slight irregularities in the curves are due to variations from the mean in the diameters of the dies used during the test.

conditions adopted for drawing wire to finished sizes without annealing during the process.

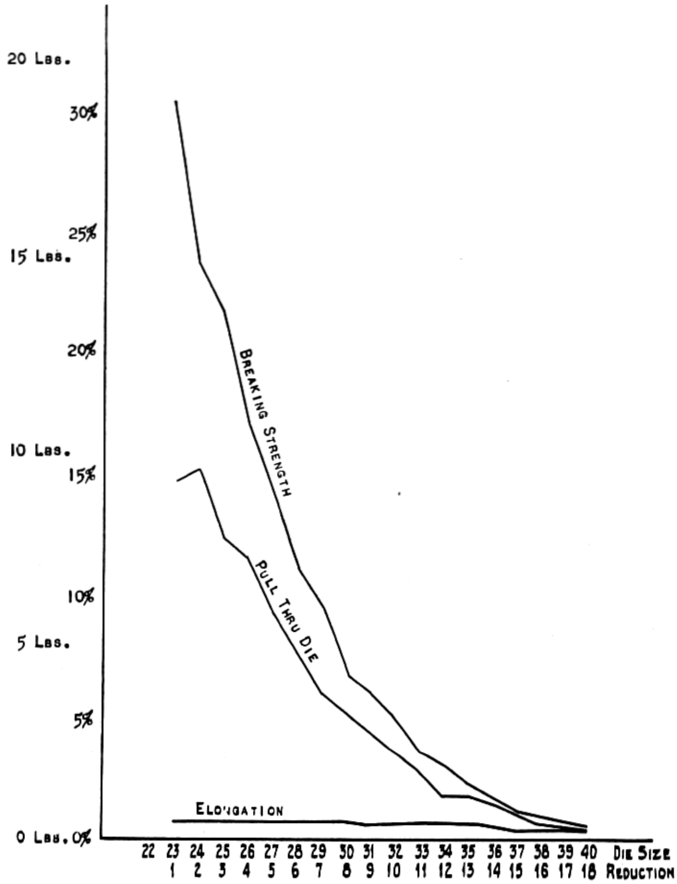


Fig. 19

Chilled Iron Dies

The dies used for drawing heavy wire are cast with a tapered hole from chilled cast iron and reamed to the desired size. When the die wears too large for a particular size of wire, it is reamed to a larger size and used in that manner until the die goes above the maximum size used. These dies, shown in Fig. 20, are used for drawing line and heavy gauge wire for which the cost of diamond dies would be excessive. Many alloy steel dies have been tested as substitutes for chilled iron dies for copper wire drawing, but so far have failed to replace them, due to excessive cost. For the wire sizes smaller than No. 16 down to as fine as No. 42 B. & S., diamond dies as described below are used.

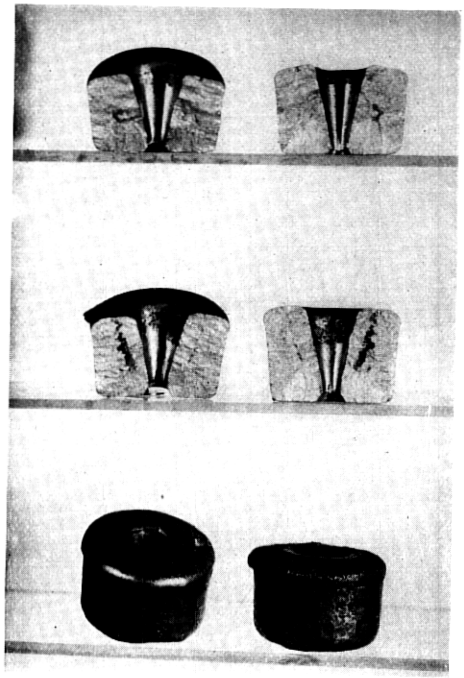


Fig. 20

Diamond Die Study

It was necessary to make an extensive study of the manufacture of diamond dies because dies through which wire could be satisfactorily drawn at low speeds failed to draw to gauge and without excessive breakage of the wire as the speeds were increased. At this time practically all commercial diamond drilling was done in Europe, Belgium being the hub of the diamond cutting industry, and the art was new to this country. The diamonds generally used for wire drawing dies are obtained from South Africa,[8] Australia, and Brazil, and made into diamond dies in Europe.

[8] The South African and Australian diamonds are the more suitable for wire drawing. There are two types of the former, the smooth brown premier which is not suitable for dies because of its tendency to crack and split, the other commonly known as the Jager, a product of the Jagerfontein mines. These stones, very irregular in contour and light gray to black in color, are most suitable for dies. The Australian diamonds are gray to brown to almost black in color and can be distinguished from the Jager. Many of the Brazilian diamonds are a dark gray similar to graphite in color and not being translucent are difficult to inspect for seams, cracks or inclusions.

In view of the difficulty of obtaining dies for drawing wire at high speeds and the large investment in dies required for the proposed wire mill, it was decided to undertake a laboratory investigation of the

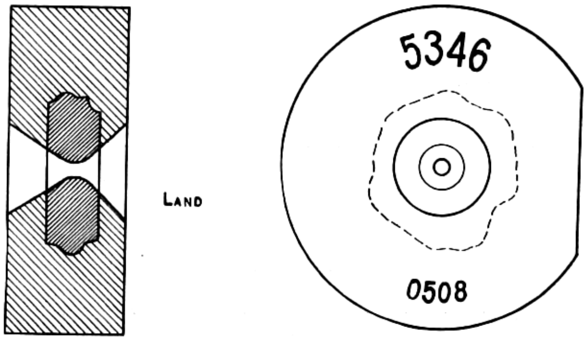


Fig. 21—Diamond wire drawing die (outline sketch)

manufacture of diamond dies suitable for drawing cable and magnet wire.

It was found that the dies suitable for high speed wire drawing required a differently shaped approach, a better polish, and a shorter land [9] than used for low speed drawing. In addition, the origin of the

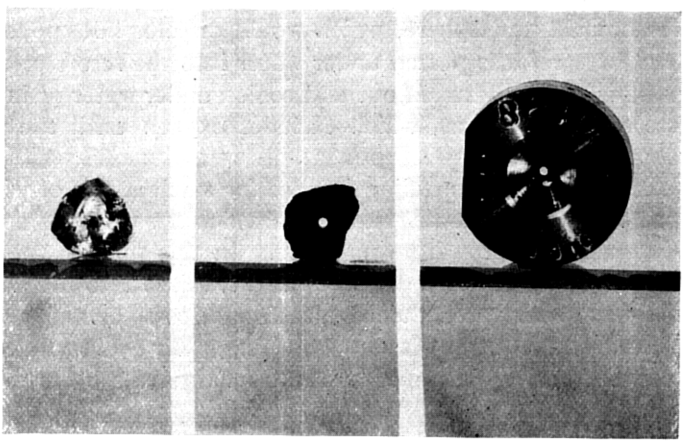


Fig. 22

stone, the shape of the diamond, and its setting are all very important because of the internal strain to which the die is subjected during the drawing operation.

[9] See Fig. 21.

It has not been possible to definitely establish any quantitative relationship as to the effect of high speed drawing on the wear of dies except that about the same number of million feet of wire may be expected from a properly lubricated die irrespective of the drawing speed. Under such conditions, the high speed die naturally runs a shorter time, but length of life is not the important factor; tonnage of a satisfactory quality with a minimum plant and labor investment is the prime consideration.

Figure 22 shows a diamond before drilling, a stone drilled and lapped, ready for mounting, and a die in the final mounting ready for use.

Figure 21 gives an outline of the shape of the working surfaces of a wire drawing die.

Annealing

Hard copper wire is obtained by using the wire as it comes from the wire drawing machine. This same wire may be softened by annealing, or medium-hard wire can be produced by annealing hard wire at such a point in the drawing operations that the final draws will give the desired degree of hardness.[10]

In a recent commercial type of annealing furnace, Fig. 23, wire may be bright annealed, but it requires a drying operation in order to remove the water through which it passes in leaving the furnace. The retorts of these furnaces are water-sealed and filled with steam to exclude the outside atmosphere, which would discolor hot copper. To obtain bright wire, it is passed under water into the retort to exclude the air and is generally taken out and cooled under water or in an atmosphere of steam or gas, which excludes oxygen until the wire is relatively cool.

A special steam seal annealing furnace for small spools of wire was developed on an experimental basis from which the wire was obtained bright annealed and free from moisture. In this furnace the spools were submerged in water to displace the air, raised into the charging end which was under water, thence to the muffle to be heated, and then along a cooling tube to the discharge opening. Air was excluded from the retort and cooling chamber at the discharge end by means of a steam jet.

The success of the small furnace led to the construction of a larger machine (Fig. 24) for annealing cable wire on spools. The spools are placed in perforated metal baskets which are charged into the furnace at a specified time interval, pushing each other through the retort and along the cooling tube to the discharge end.

[10] "Experiments in the Working and Annealing of Copper," F. Johnson, *Journal Institute of Metals*, Volume XXVI, No. 2, 1921.

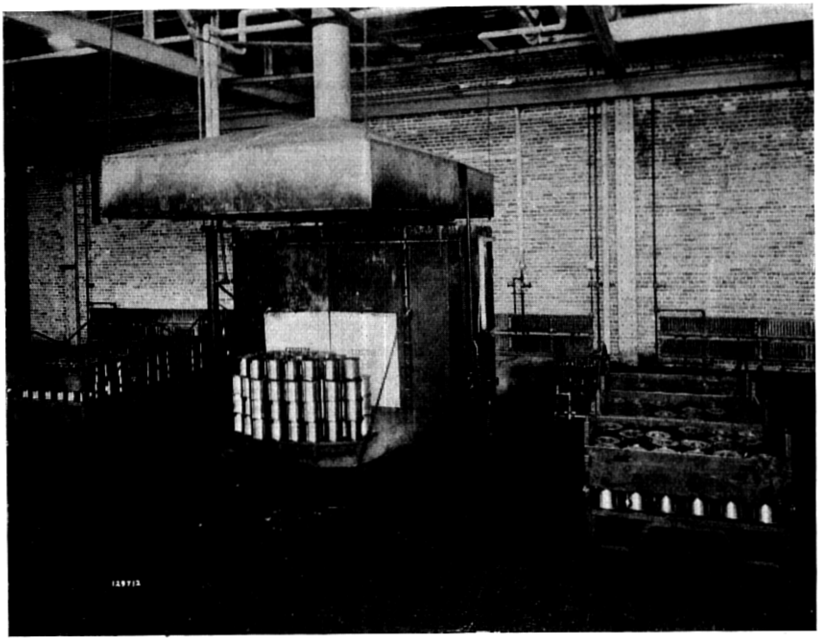


Fig. 23—Water seal annealing furnace

Inspection of Raw Material and Finished Product

Wire bar made from electrolytic refined copper is used as a material in the manufacture of wire. This material is practically free from silver and other elements which ordinarily exist in the ore, and which have a detrimental effect on the electrical or physical properties of the finished product. A small percentage of silver [11] seriously affects the annealing qualities of the wire. Traces of other impurities have a very detrimental effect on the wire drawing properties. During the refining process, the molten bath is oxidized in order to carry off the foreign material in the form of slag, and it is very important that the oxygen content be later reduced to a very small point if bars of proper set are desired. Fig. 25 shows three photomicrographs of wire bar containing varying amounts of cuprous oxide.[12] Ordinarily the surface condition on top of the bar is a good index of the oxygen content. If the bar is level set or slightly convex on top, it is usually a satisfactory material. If it is low set or concave, it usually contains a large amount of copper

[11] "Effects of Silver on the Recrystallization Temperature of Copper," Caesar and Gerner, *A. S. M. E.*, Volume 38, 1916.
[12] "Microscopic Structure of Copper," H. P. Pulsifer, *Mining and Metallurgy*, January, 1926.

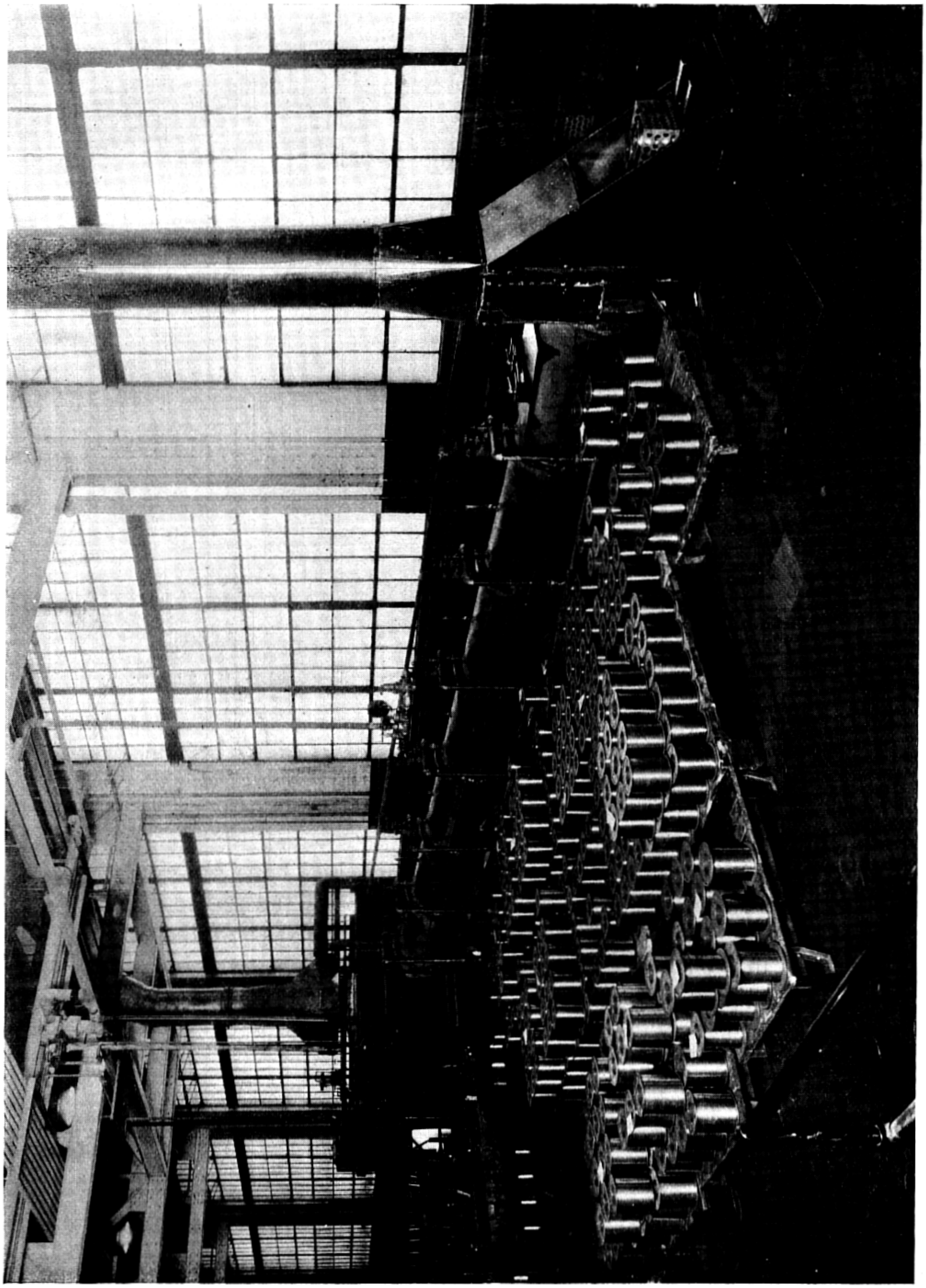
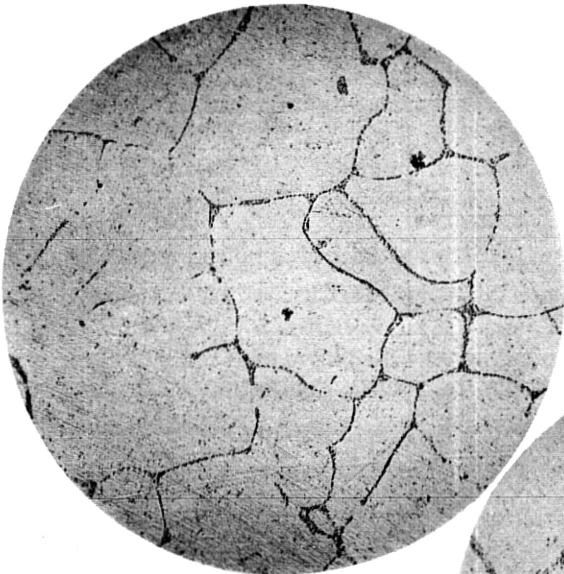
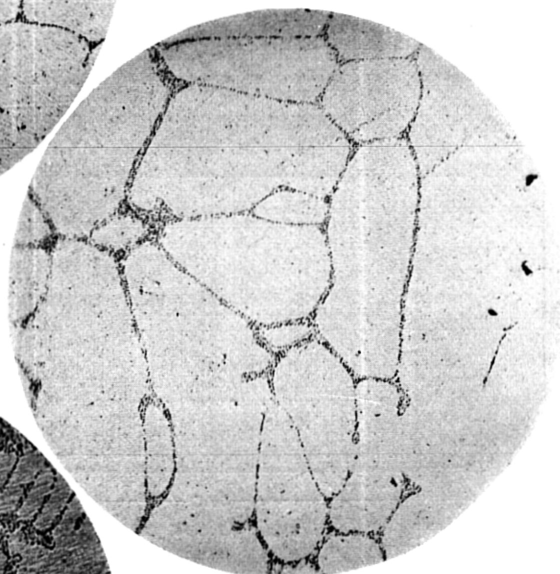


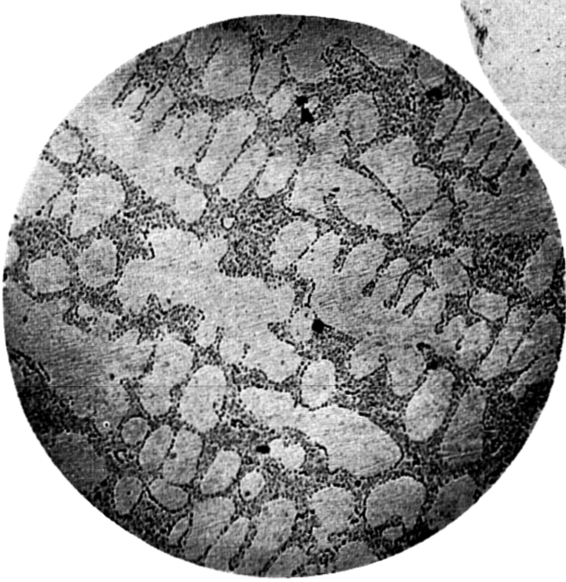
Fig. 24—Steam seal annealing furnace



A. High Set—Oxygen .035%



B. Level Set—Oxygen .050%



C. Low Set—Oxygen .12%

Fig. 25—Photomicrographs of wire bar (magnification × **100**)

oxide, which caused the metal to shrink in solidifying.[13] When excessive shrinkage occurs it has an adverse effect during the rolling operation.

The finished wire is inspected for dimensional limits, tensile strength, elongation, and surface condition. The limits for 42 B. & S. gauge wire (.002475 in.) are .00245 in. minimum and .0025 in. maximum.

Conclusion

The establishment of this industry as a part of the plant at Chicago represents the combined effort of a large number of inventors, engineers, designers, and mechanics. While the actual plant was built within a comparatively short period, the advances which have been made in the art represent several years' effort. Briefly, the development of com-

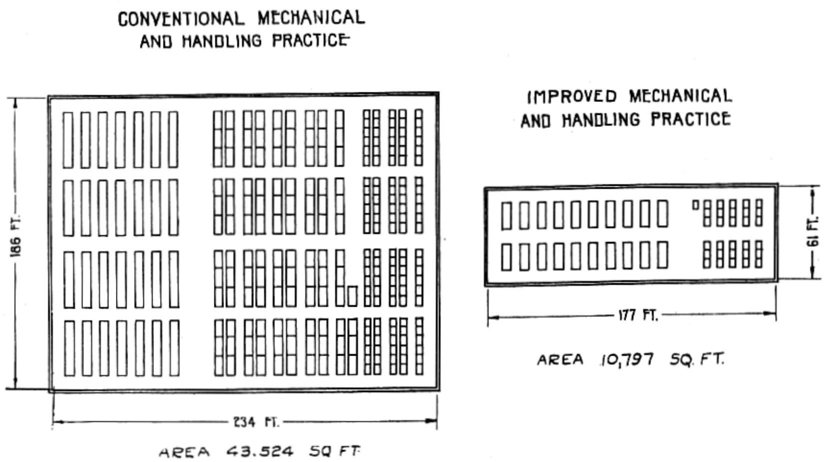


Fig. 26—Wire drawing plant

pact and high speed wire drawing machines has required a much smaller investment in buildings and equipment as compared with a plant of the same capacity using commercial equipment. A comparison of the relative floor area, based upon the conventional and the improved types of wire drawing equipment, is illustrated by Fig. 26. The supervisory force in charge of the operation of this new mill must be given a considerable share of the credit for its successful operation.

[13] "Copper Refining," Lawrence Addicks. "Metallurgy of Copper," H. O. Hofman.