Design and Operation of New Copper Wire Drawing Plant*

A new wire mill for the drawing of copper wire is described. The speeds attained are close to the theoretical limit set by the breaking strength of the wire under the centrifugal stress of winding. The No. 1 machine which draws from rod down to No. 16 A.W.G. and has 10 dies operates at 6000 ft. a minute. The No. 2 machine redraws to finished sizes of No. 19 A.W.G. down to No. 30, possesses 12 dies, and operates at 10,000 to 12,000 ft. a minute. With the single installation at the Western Electric Company at Kearny, N. J., over 2,500,000 pounds of annealed wire are now delivered monthly to the insulating machines for processing into lead covered cable. Part I deals with the design of the machines; Part II with the wire mill installation and operation.

PART I—DESIGN AND OPERATION OF HIGH SPEED COPPER WIRE DRAWING MACHINES

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Introduction

COPPER wire is used extensively in the making of facilities for communication purposes, the Bell Telephone System alone now using over 40 billion conductor feet per year. It is essential that this wire be of high quality with deviations in diameter kept to the minimum so that the apparatus with which it is to be used will function properly.

A study made some years ago showed it would be economical for Western Electric to manufacture its wire, with the possibility of greater production by increasing the speed of drawing. The equipment provided at that time operated at speeds much higher than were then in general use.

A few years later it became evident that the speeds selected were far from the ultimate at which wire could be drawn, and another development was started to determine a practical and economical speed, resulting in the design, construction, and placing into operation of two sizes of wire drawing machines. One, which will draw rod to sizes as small as No. 16 A.W.G., is called the No. 1 and is of 10 die capacity, designed to operate at 6000 ft. per minute. Figures 1, 2, and 3 show the front and rear views of this machine. A second machine for redrawing to finished sizes No. 19 A.W.G., and smaller, is called the No. 2, and is of 12 die capacity, designed to operate at 10,000 and 12,000 ft. per minute. Figure 4 shows the front

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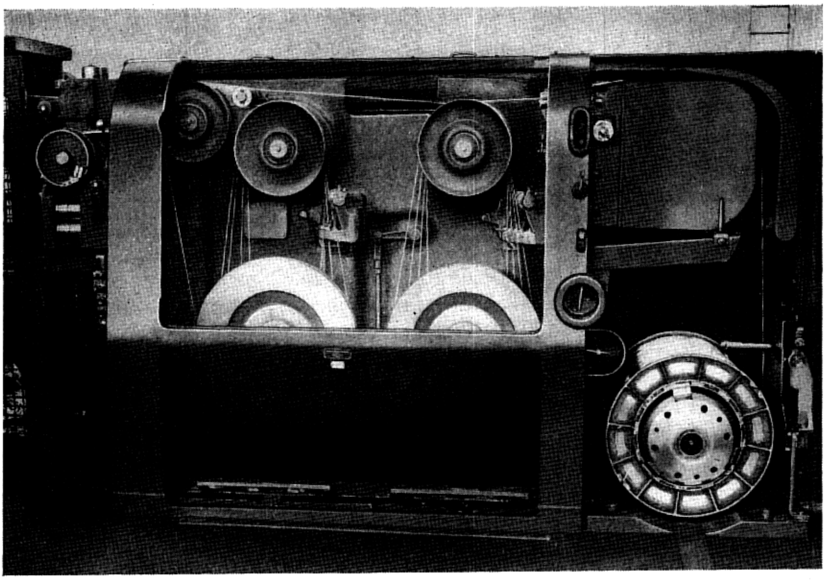

Fig. 1—No. 1 wire drawing machine—front view

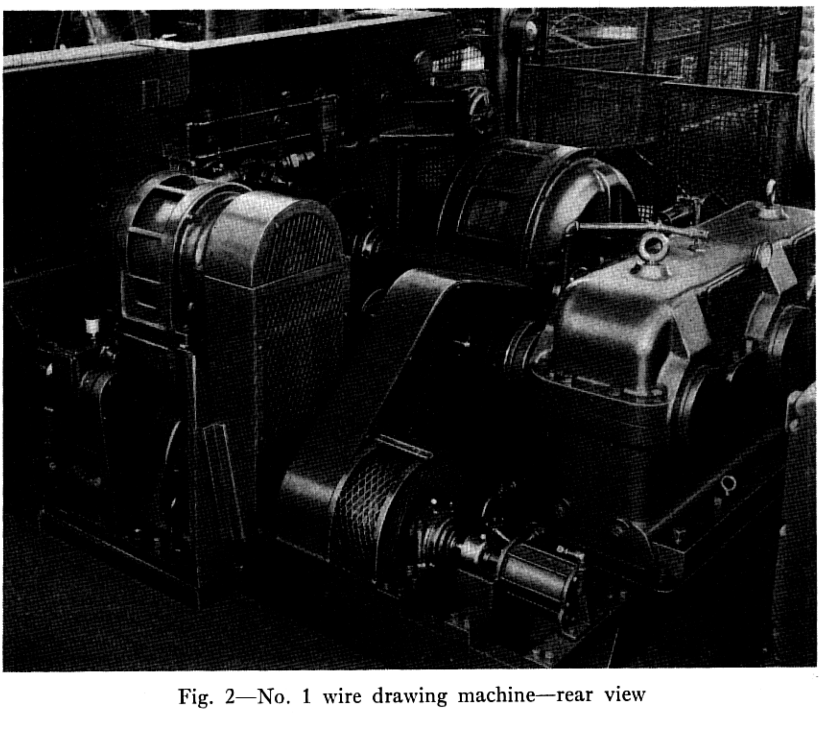

Fig. 2—No. 1 wire drawing machine—rear view

view of this machine. The design features outlined in the following text deal largely with the No. 2 Machine. Similar features are incorporated in the No. 1 Machines and reference is made to changes in design applicable only to that machine.

The Problem

Continuity of operation is essential to higher drawing speeds; therefore, wire should be delivered in as large a unit package as practicable to secure

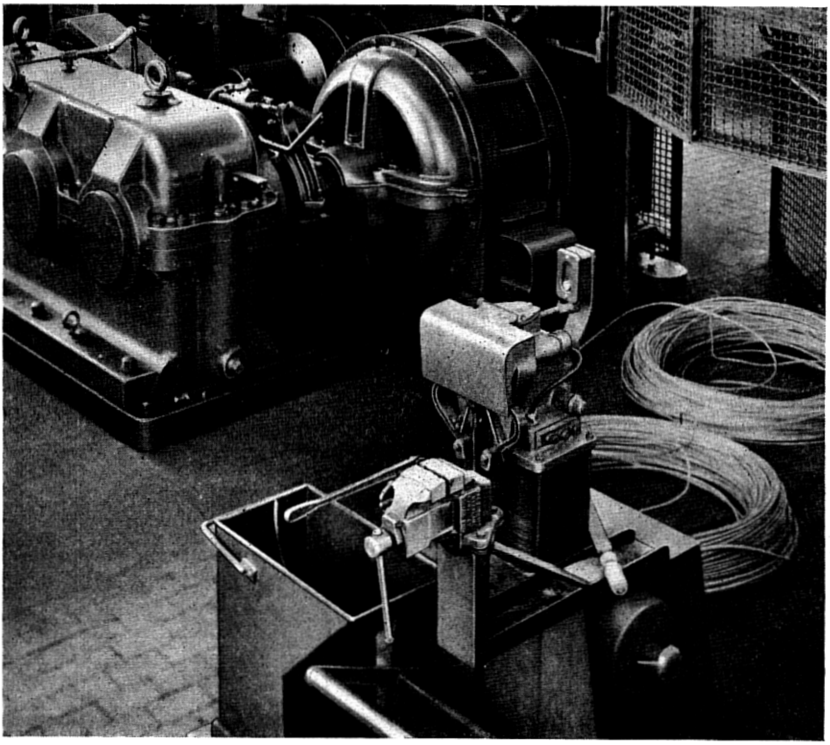

Fig. 3—No. 1 wire drawing machine—rear view

this continuity with a minimum of scrap at the subsequent operations. A survey of the wire using equipment showed that reels as large as 18″ diameter could be used with a capacity of 400 lbs. of wire. This requires that a suitable drive be introduced on the reel takeups of the wire drawing machines to allow for gradual deceleration of speed as the reels fill up with wire.

The drive for the takeup reel should be capable of producing a uniform tension in the wire as taken up for its entire length on the reel. This tension must be controllable for the different sizes of wire, in order that after being annealed it can be easily removed at the subsequent operation.

The application of torque motors on several installations at Western Electric to secure uniform tension in the product being taken upon a reel had demonstrated this to be a very satisfactory form of takeup drive, as the motor will slow down with build up of wire on the reel without changing

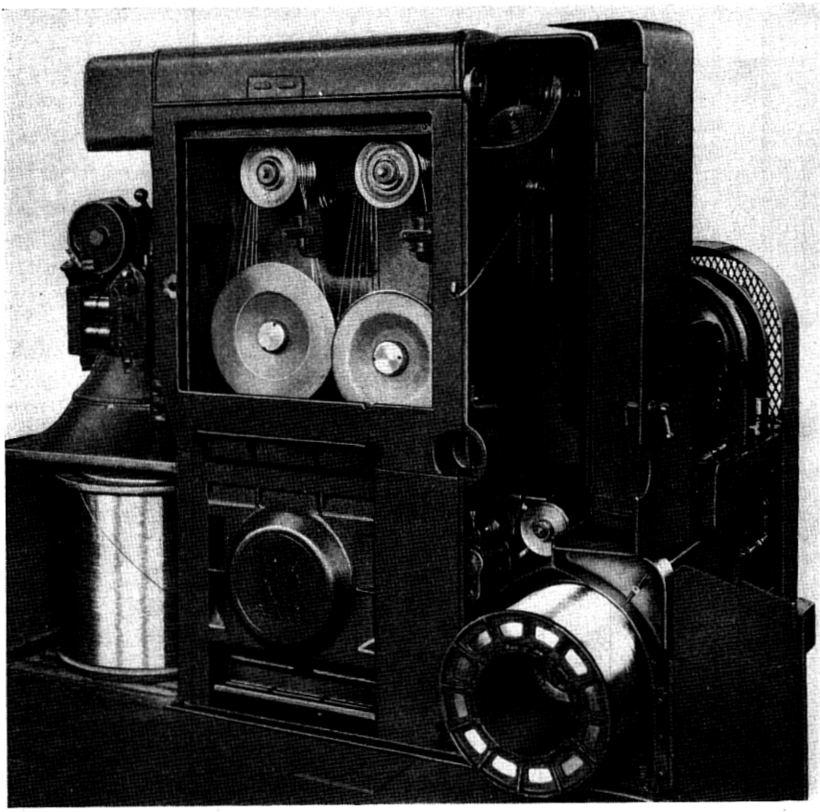

Fig. 4—No. 2 wire drawing machine—front view

the wire tension to any appreciable extent. By changing the stator voltage of this type of motor, the torque can be regulated to give tension suitable for drawing the various sizes of wire within the capacity of the machine. By a proper selection of motors, variations in speed, without undue heating, can be obtained with a ratio of 1–1.8, which is of sufficient range to permit the use of reels of 400 lb. capacity.

The next step was to determine the maximum speed at which wire might be drawn and the speed at which it could be wound onto a reel. The maximum drawing speed was considered to be that speed where the stress set up by centrifugal force would equal the safe stress for copper of 25,000 lbs. per sq. in. A maximum drawing speed of 27,400 ft. per minute was determined by the following calculations:

Let W = Weight of drawn copper wire per cu. in. in lbs. = .3212 (A.I.E.E.)

V = Speed of wire in feet per second.

G = Acceleration due to gravity.

1. Stress in Wire due to Centrifugal Forces = S

$$S = \frac{12 \times W \times V^2}{G} = \frac{12 \times .3212 \times V^2}{32.2} = .1197\ V^2$$

2. Maximum Wire Speed Considering Only Stress Due to Centrifugal Force. The speed at which S would produce a stress of 25,000 lbs. per sq. in.

$$V = \sqrt{\frac{25000}{.1197}} = 456 \text{ f.p.s. or } 27400 \text{ f.p.m.}$$

With the possibility of a range of speed of 1 to 1.8, the stress set up in the reel rim at a wire speed of 27,400 f.p.m. would equal 62,000 lbs. per square inch when the wire is being taken up on the core of the reel, and the rim running 80% faster. Since this speed and resulting stress are above the safe limit for low carbon steel, a speed of 12,000 f.p.m. was selected which provided a factor of safety of approximately five to one. The stresses set up in the wire and reel rims for the various speeds are shown on diagram, Fig. 5.

The horsepower requirement of the torque motor for the takeup is made up of three components:

1. Tension in Wire
2. Bearing Friction for Takeup
3. Reel Windage.

Wire should be taken up on the reel under sufficient tension to offset that created by centrifugal force. The tension in the wire resulting from centrifugal force is shown on diagram, Fig. 6, and is determined by taking the stress in copper wire at 12,000 ft. per minute, Fig. 5, and multiplying this by the area of each size of wire. The tension in the wire changes for each size of wire and remains practically constant throughout the entire reel; therefore, the horsepower required to take up wire on the reel remains constant from the core to the outside of the reels, the speed of the reel slowing down with the build-up of wire on the reel. The lower curves on diagram, Fig. 7, show the horsepower requirements for taking up wire of different sizes.

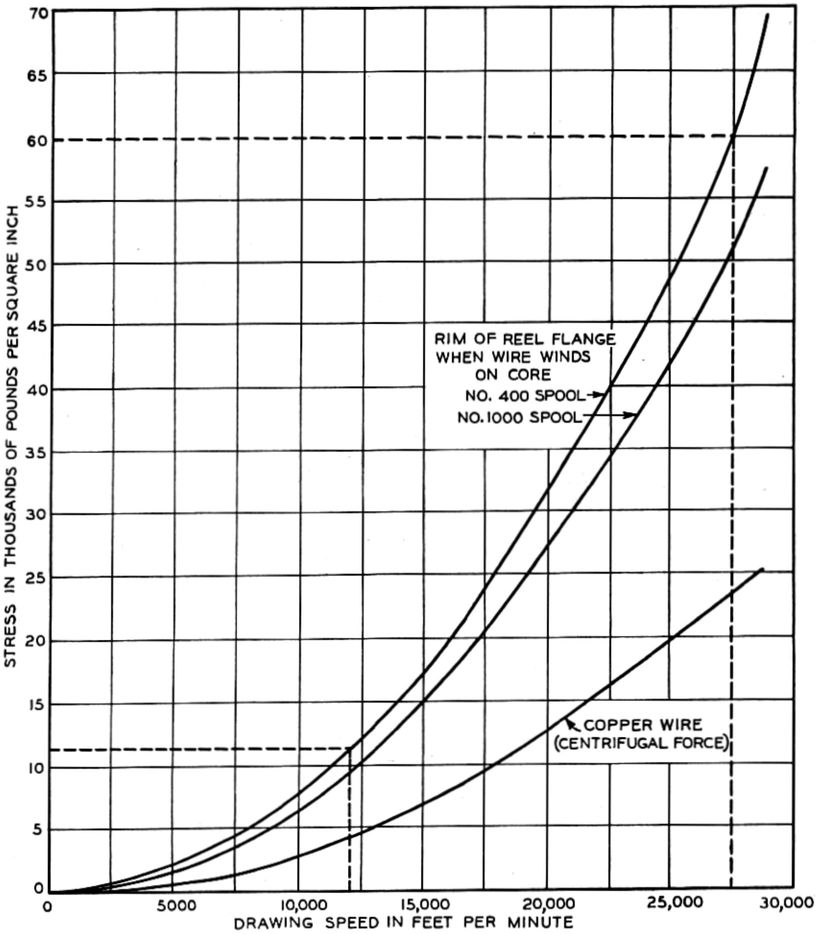

Fig. 5—Stresses produced in wire and takeup reel at various wire drawing speeds

Power Requirement

The horsepower required to overcome bearing friction was calculated and is constant for all sizes of wire. The windage is governed by the design of the reel and the horsepower was determined by test for the minimum and maximum reel speeds. The data for these components are shown by the upper curves of diagram, Fig. 7.

The constant horsepower requirement for uniform tension when converted into torque shows that the torque increases as the wire on the reel builds up due to the lengthening of the radius arm.

The decreasing horsepower requirement to overcome windage and friction when converted into torque shows that the torque decreases with this build-up of wire due to the slowing down of the reel when using a uniform

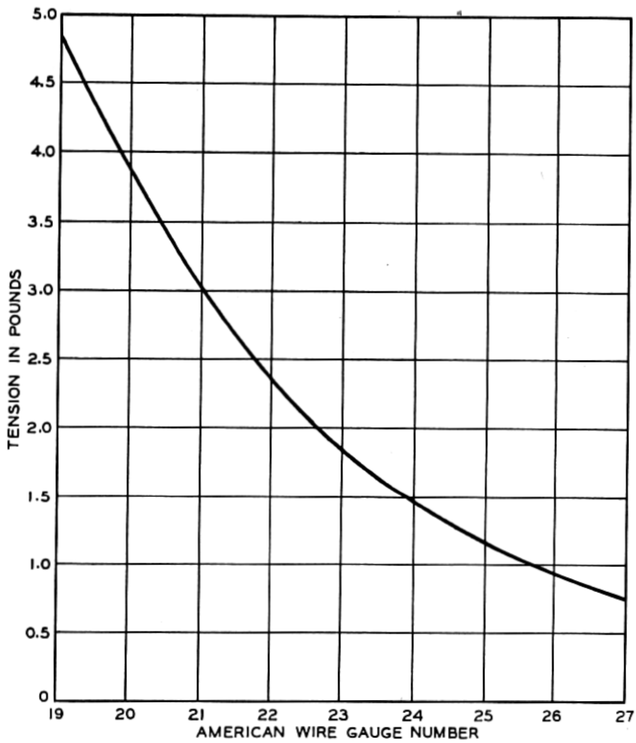

Fig. 6—Tension in wire due to stress set up at wire speed of 12,000 F.P.M.

speed of drawing. This decrease will be at a faster rate than the increase resulting from tension.

The calculated torques when plotted for the different sizes of wire within the scope of the machine show curves gradually diverging as the reel decreases in speed. To simplify the electrical control it was found these curves could be made parallel and still be within the allowable variation of wire tension and the required tolerances of the supplier of the electrical equipment. It was decided to select as the base curve that condition which would be most favorable to the making of the smallest size of wire and to use the average torque value from an empty to a full reel for the different tension requirements for the other curves. Therefore the composite curves as shown by diagram, Fig. 8, show the result of this compromise.

The curves showing the results of the test run of the takeup motors are shown by Fig. 9, which demonstrates how closely the motor manufacturer met the requirements of Fig. 8, which are superimposed for reference.

The minimum of slip between the wire and capstans has been incorporated

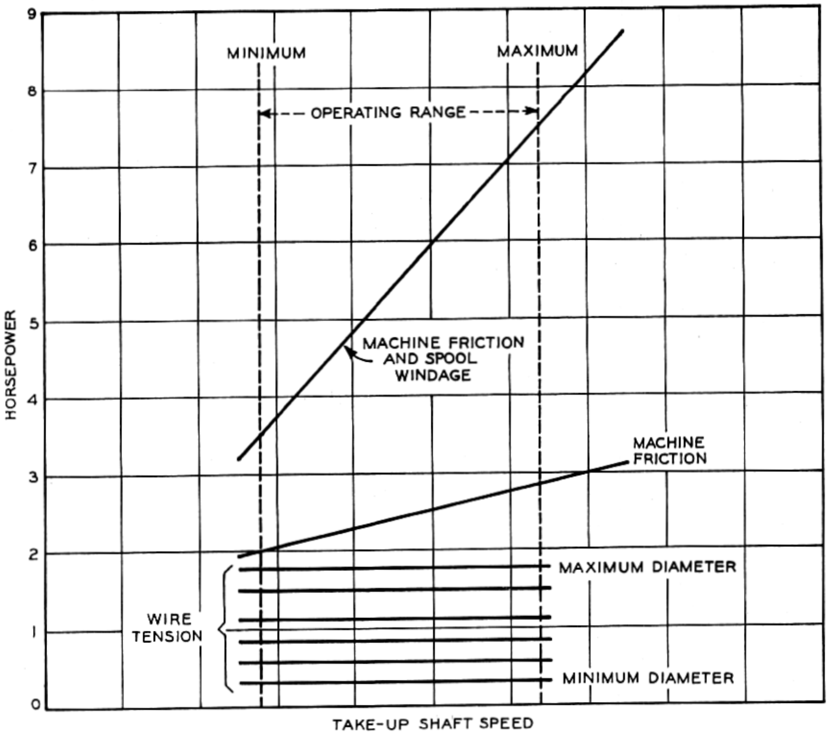

Fig. 7—Power requirements for torque motor for takeup of wire sizes No. 19 A.W.G. and smaller to secure uniform tension

into the design to secure the greatest economy of power. Each reduction of one size A.W.G. increases the length by 26%; and a ratio of 23% between each capstan step has been found most economical. To further reduce power required, ratios of 25% have been used, but because of the uneven wear of diamonds this ratio is disturbed and excessive breaks occur at the location where the die has worn the fastest. With the ratio of 25%, dies must be kept more evenly matched for reduction in area, and the expense of rematching dies, and the loss of production during the period of rematching, make this expense greater than the power charge with the 2% greater slip.

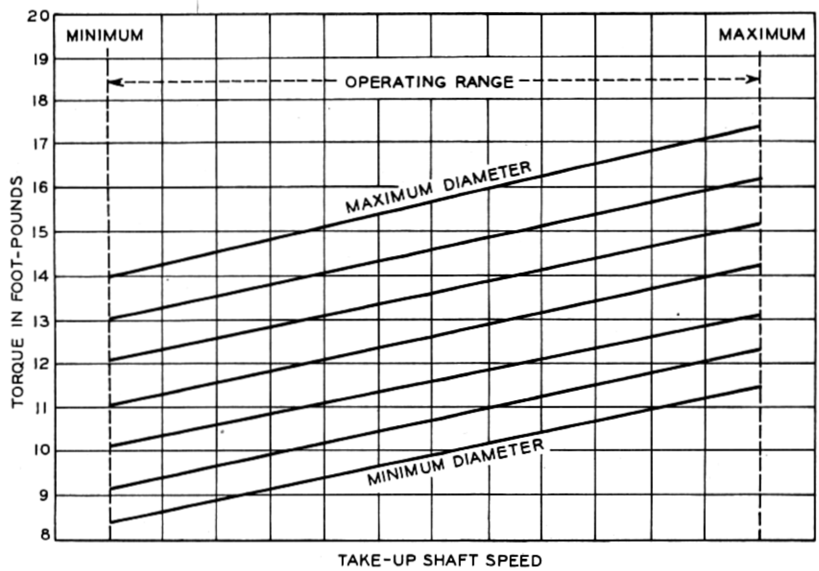

Fig. 8—Torque requirements of takeup motor with tension, friction and windage combined for wire sizes No. 19 A.W.G. and smaller

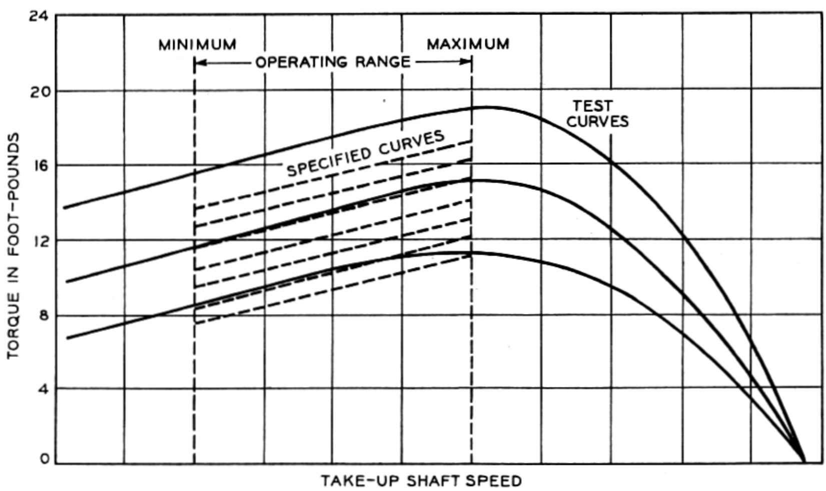

Fig. 9—Speed torque curves for takeup motor

Inasmuch as it is economical to maintain dies within definite ratios of reduction of area, by the same token it is also necessary to keep the diameter of the capstan steps within like proportion.

The die pulls and power required to draw copper wire of any size are determined by referring to the chart, Figs. 10 and 11, applicable for Tungsten Carbide and Diamond Dies respectively.

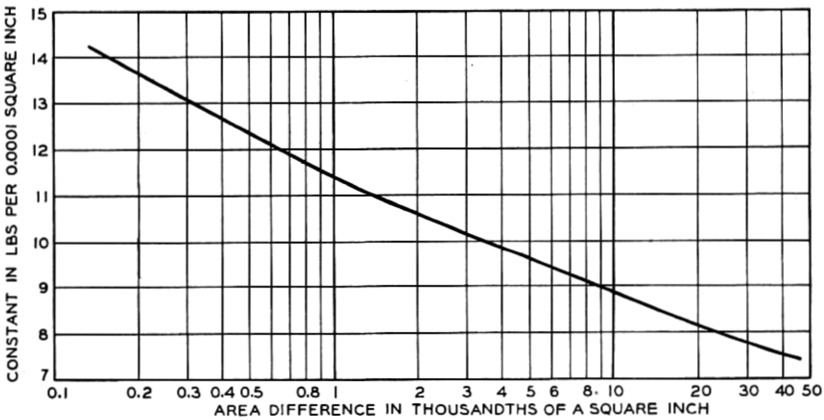

Fig. 10—Constants for determination of die pulls for tungsten carbide dies drawing copper

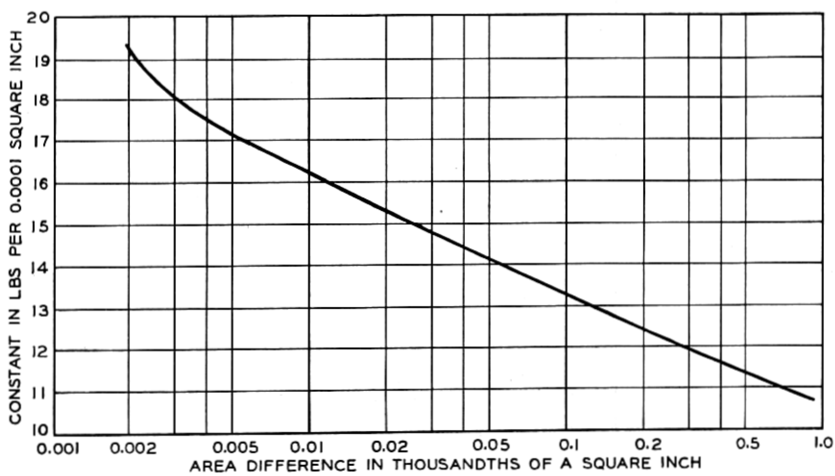

Fig. 11—Constants for determination of die pulls for diamond dies drawing copper

In using these charts the diameters of wire being drawn from and to are selected. The difference in areas represented by these diameters is determined, the curve is then chosen in the range of this difference, and by reading up from this difference to the proper range curve, the constant can be determined per .0001 sq. in. area reduction, which, when multiplied by the difference in area, will give the total pounds pull required to draw to the size selected.

Capstan diameters are determined to secure minimum slip, and from the die diameters selected the pull through the dies is calculated. The horsepower for the main motor is determined from these die pulls and capstan speeds, to which is added machine and motor losses.

As the drawing machine is required to start up and accelerate under full load, a high torque squirrel cage induction motor was selected. This type

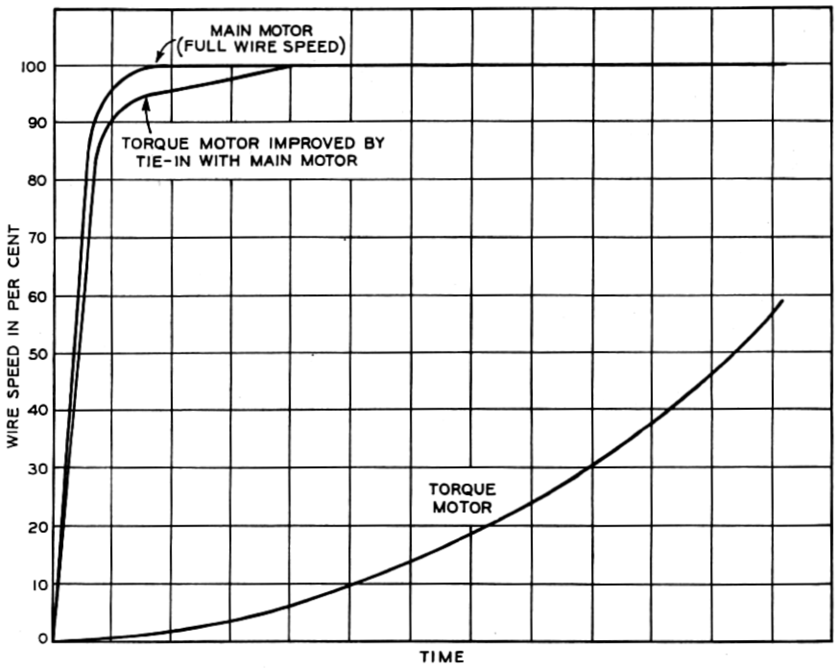

Fig. 12—Relative acceleration curves of main and takeup motors

of motor accelerates to full speed very rapidly, whereas the acceleration of the torque motor for the takeup is very much extended and would therefore result in very high slip between the wire and capstan. It was therefore necessary to introduce some auxiliary means to assist the torque motor to come up to speed. This has been effectively accomplished through the introduction of a magnetic clutch for coupling together the main and takeup motors during the starting period. This clutch is energized as soon as the starting button is operated and before the contactors for the main motor make contact. A time relay releases the magnetic clutch as soon as the main motor is up to speed. During this acceleration period on the No. 2 Machines a slip of 5% between wire and capstan occurs when the capstans are new, and no slip when the capstans are reduced to the minimum diameter. Curves showing the relative acceleration between main and takeup motors are shown on diagram, Fig. 12, which also represents the improvement of acceleration by the tie-in. An electric time clock is connected into the motor circuit for stopping the machine when the 400 lb. reel is full, a time setting being made for each size of wire. On the No. 1 Machine the takeup is accelerated by the magnetic clutch to full reel speed of the 1000 lb. reel and the contact made by the time clock re-energizes the clutch so that the takeup will slow down in synchronism with the main motor.

An under current relay is also interposed in the motor circuit to stop the machine should a break occur while drawing.

Lubrication

Introduction of oil lubrication introduced difficulties in securing effective sealing against oil leakage. It has been our experience that commercial seals are effective when used on shafts revolving at surface speeds below 1200 f.p.m., but above this speed they were inadequate. For the capstan bearings the seals have to be effective in both directions to prevent the leakage of mineral oil from the bearings into the wire drawing compound, and also to prevent the wire drawing compound from mixing with the lubricating oil. This has been accomplished very effectively by the use of multiple slingers, the design of which is shown by Fig. 13. The two front slingers throw off the compound which drains back into the compound system and the two rear slingers do the same with the oil. There is no friction and corresponding wear between surfaces and only occasionally can small drops of compound be seen in the drain reservoir, which shows the effectiveness of this type of seal. As an extra precaution against contamination of oil with wire drawing compound, only a small amount of oil is permitted to flow to the capstan bearings, sufficient for adequate lubrication. This is drained to a reservoir and clarified before re-use.

Another form of seal is shown by Fig. 14. This is used at the takeup arbor where oil was driven through any commercial gasket material by centrifugal force. The oil was thrown out into the inside of the reels and caused discoloration during the annealing. This has been effectively sealed by making a ring of dead soft copper wire carefully joined. The end cap is bevelled to force the ring to the inside of the arbor and against the edge of the bearing, making a tight three-point contact. These rings are never used more than once.

Reels:—The reels are provided with a magazine on the outside of the

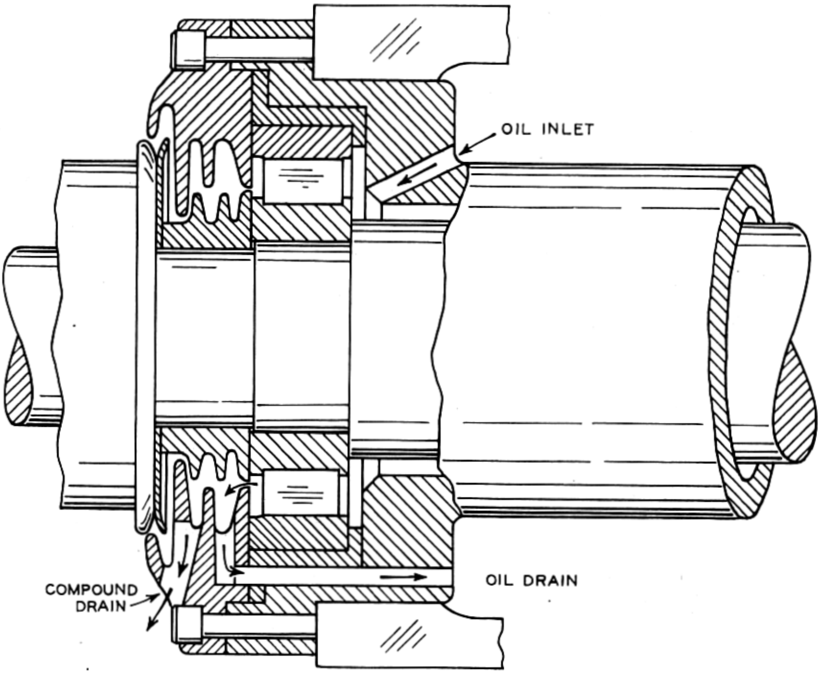

Fig. 13—Labyrinth oil seal

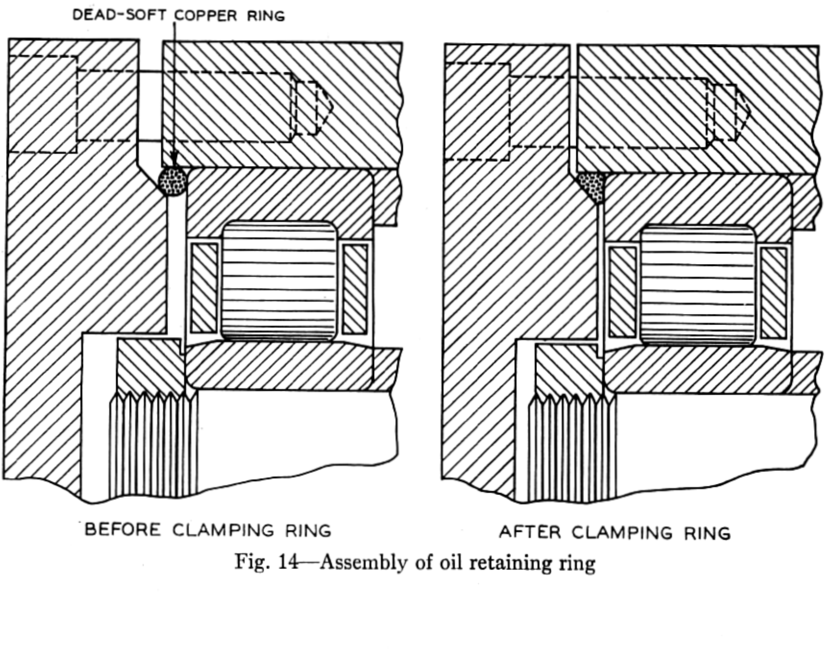

Fig. 14—Assembly of oil retaining ring

flange, in which magazine approximately 10 to 12 feet of the inside end of the wire is stored. At the subsequent operation this inside end is removed from the storage and joined to the outside end on the next reel, by which means continuous production with a minimum of scrap is secured.

Consideration was given to a reel machined all over to get it in correct balance. However, it was realized that distortion would occur as a result of annealing the wire on the reel, and from the handling. Therefore it was decided to provide a very substantial construction of the takeup unit, with bearings of ample capacity to provide for any eccentric loading which might result from spools which had become irregular by use.

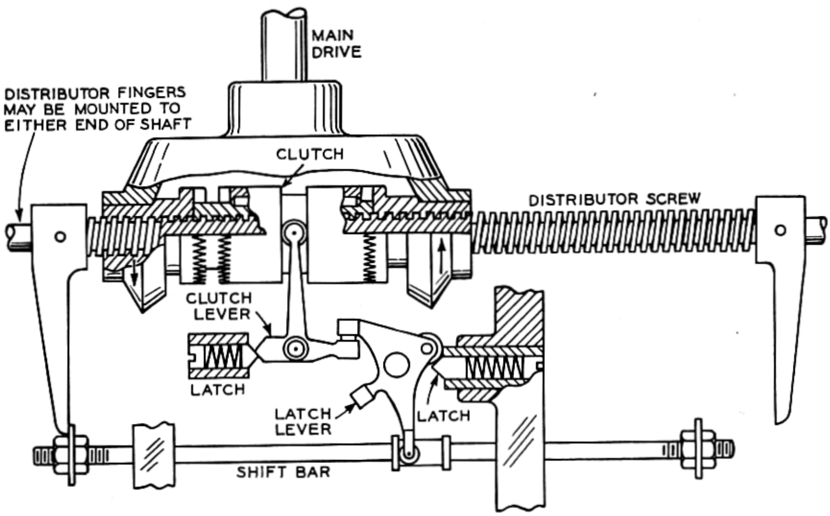

Fig. 15—Diagrammatic view of distributor

Welding facilities are provided to join the ends of wire on successive supply reels at the No. 2 Machines. A special hood permits the transfer of supply from the emptied reel to the succeeding reels. The contour of this hood had to be developed to reduce the noise from the wire which is whipping around. The noise is further minimized by suitable ribbing of the hood, irregularly spaced to break up the frequency of vibration.

A roller conveyor is installed beneath the hood with a capacity of three 1000-lb. reels. These reels are up-ended with magazine down before welding the ends of two reels. After emptying the front reel, the three reels are pushed forward, the empty one being discharged at the front, leaving space for another full reel at the rear.

A turntable is furnished at the supply end of the No. 1 Machine, which can be seen in Fig. 3, with capacity for four coils sufficient for one full takeup reel. In operation, the bottom of the coil of rod is welded to the top of the succeeding coil, thus securing continuity of drawing. With the emptying of one position, the table is revolved through one quarter of a revolution, leaving the empty space for reloading the next coil which is then welded to the one ahead, the welding and loading being performed during the period of drawing.

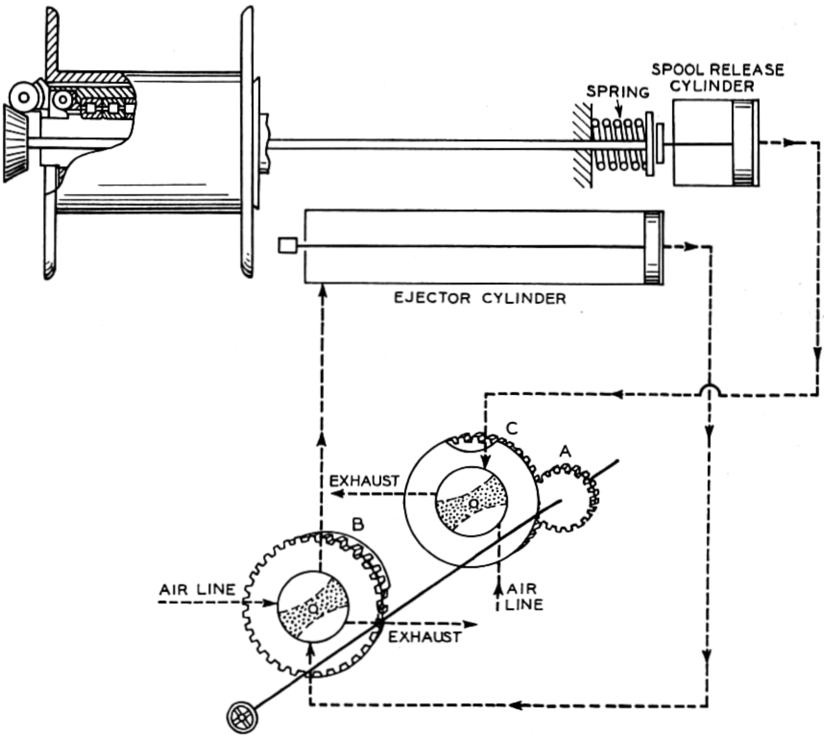

Fig. 16—Diagram of clamping and releasing mechanism

A slow speed stringing block and die support are provided for stringing the larger dies onto the wire and by depression of a foot switch the machine can be operated at slow speed for stringing the dies and wire into the machine.

Good distribution of wire on the reels is essential to permit of easy removal of wire from the reel. The distributor designed for this machine is of the reversing screw type with a reversing clutch as shown by diagram, Fig. 15. At the speed with which wire is being delivered to the reel, any pause at either end of the traverse would result in considerable build up of wire against the flanges. This type of distributor is practically instant-reversing.

Breaking of wire during drawing is not frequent, the average weight of wire on the takeup reel being well over 1000 lbs. for the No. 1 Machine and 300 lbs. for the No. 2 Machine.

Replacements and Safety Features

The design provides for readily replaceable unit assemblies so that the machines are out of production for the minimum of time when any repairs are necessary.

To reduce the effect of vibration to a minimum, the main frame of the machine was constructed to keep as much weight as possible close to the floor and thus secure a low center of gravity. All parts revolving at high speed are given a dynamic balance. Welded construction was not as readily adaptable as castings, and would have been noisier.

Safety features have been incorporated into the design for the protection of the operators. Doors are provided so that the wire is fully enclosed during the drawing process and all revolving parts are amply protected. The clamping of the reel on the arbor is effected through spring pressure, air being used for releasing and ejecting the reel. An interlock is provided between the reel release and ejector as shown by Fig. 16, Air Valve "C" effecting the reel release and air valve "B" controlling the ejector. Only one valve can be operated at a time, and they must be operated in proper sequence. The master control "A" is left in contact with the gear segment of Valve "C" until it is fully opened and the reel released. When "A" registers with the segmental opening, it can be withdrawn and moved over into mesh with segmental gear on Valve "B"; the master Control "A" cannot be disengaged from "B" until the ejector plunger is back in correct position. Additional safety was introduced into the reels by making the flanges of an alloy casting, changing the factor of safety from 4-1 to 8-1.

The use of high speed machinery with large capacities of the takeup unit and introducing the minimum of slip between the wire and capstan has resulted in meeting the performances anticipated from this development.