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Newberry et al.

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[45] May 14, 1974

[54] METHOD OF AND APPARATUS FOR DRAWING WIRE

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[52] **U.S. Cl.** **72/279,** 72/288, 72/289

[51] **Int. Cl.** **B21c 1/12**

[58] **Field of Search** 72/8, 9, 10, 11, 279, 280, 72/288, 289, 443, 425; 226/42, 111

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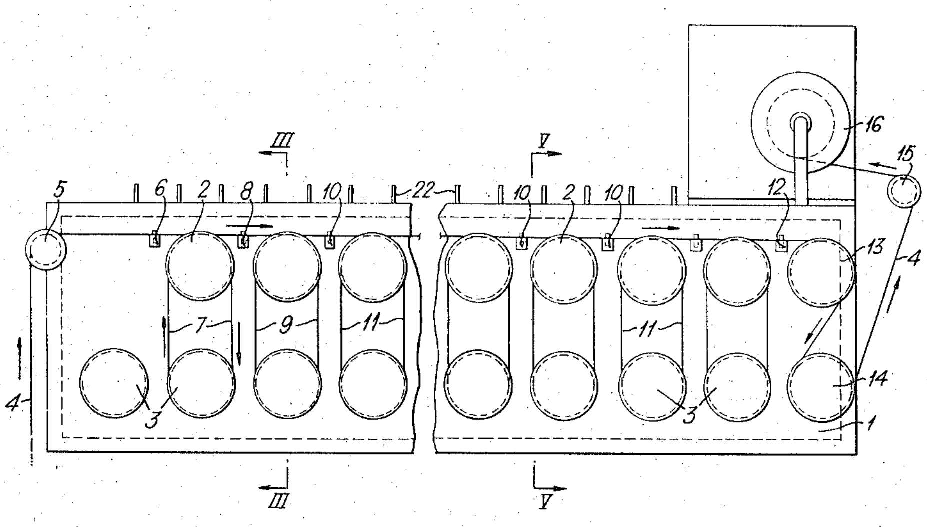
[57] **ABSTRACT**

In a wire-drawing machine with at least two dies, each drawing block has an effective surface that is tapered from one end of its rotation axis to the other and has independently adjustable driving means having a working range in which the angular velocity of the drawing block can change in response to variations in the speed of wire frictionally engaged therewith without any substantial change in the torque of the driving means and independently of the other drawing blocks. Preferred driving means are turbine motors or pneumatic displacement motors, preferably supplied from a common source of working fluid, and electric torque motors.

After threading up, the blocks are driven at a low speed and the take-up is adjusted to a starting condition in which at least some of the drawing blocks are overdriven, and any that are not overdriven engage the wire without slip; each slipping block is slowed until slip ceases, and then the drawing blocks and the take-up are accelerated in unison without slip recurring.

3 Claims, 16 Drawing Figures



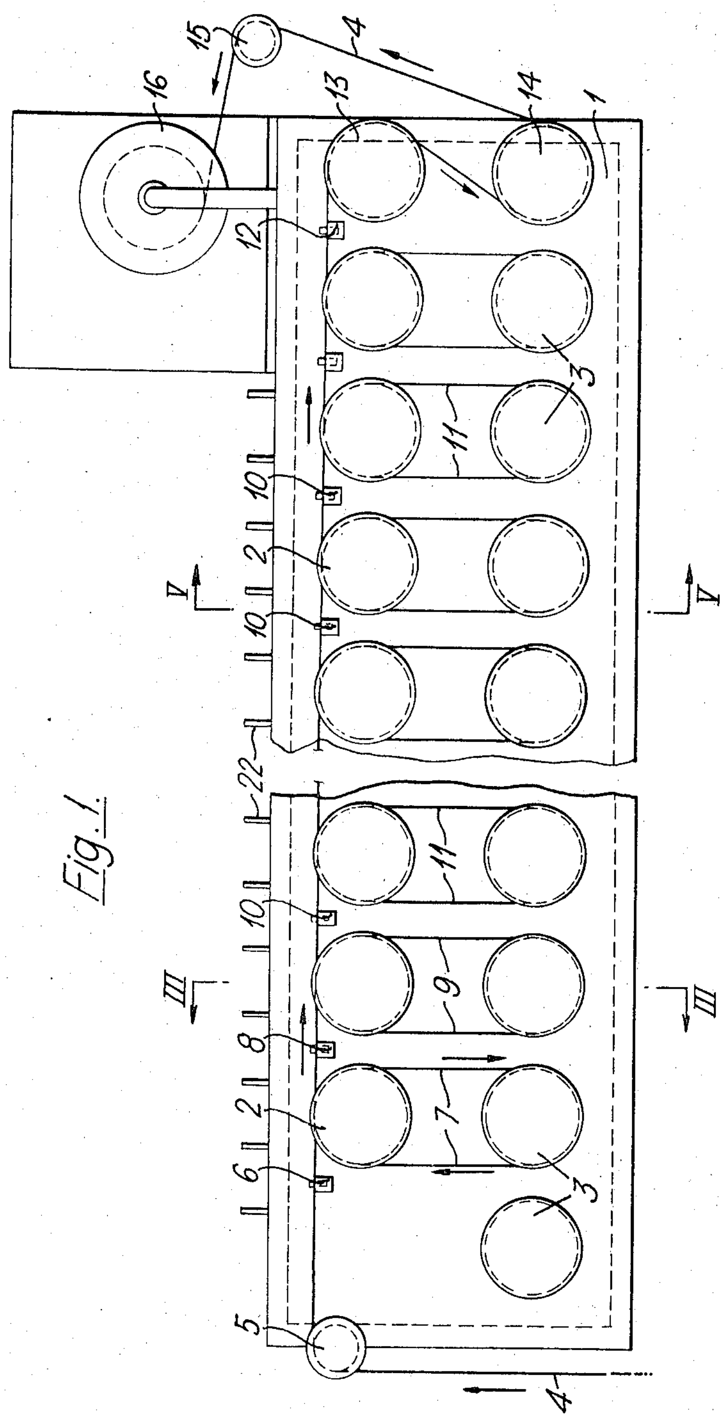
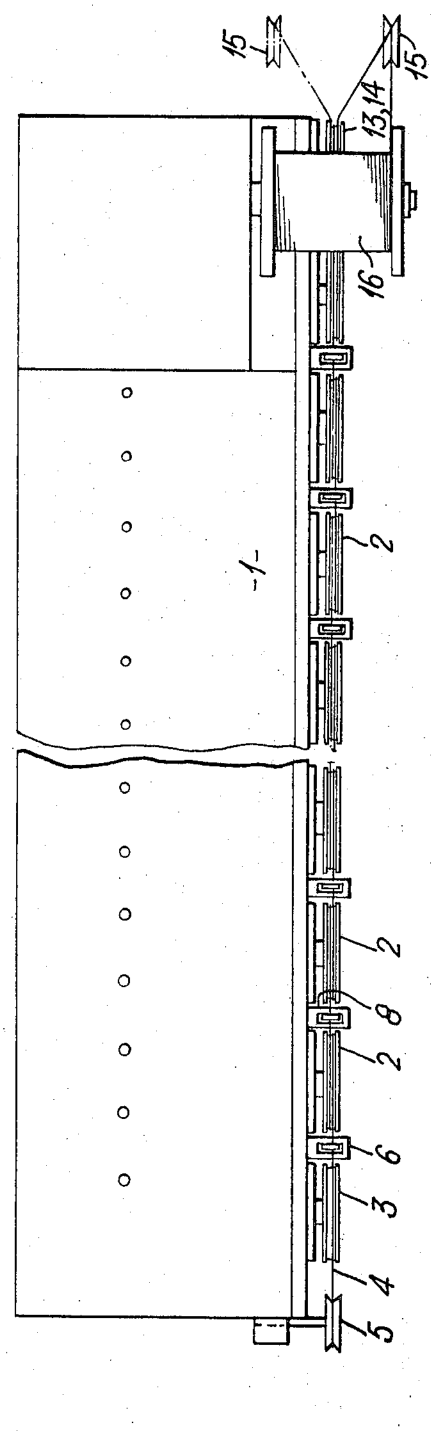


Fig. 1

Fig. 2



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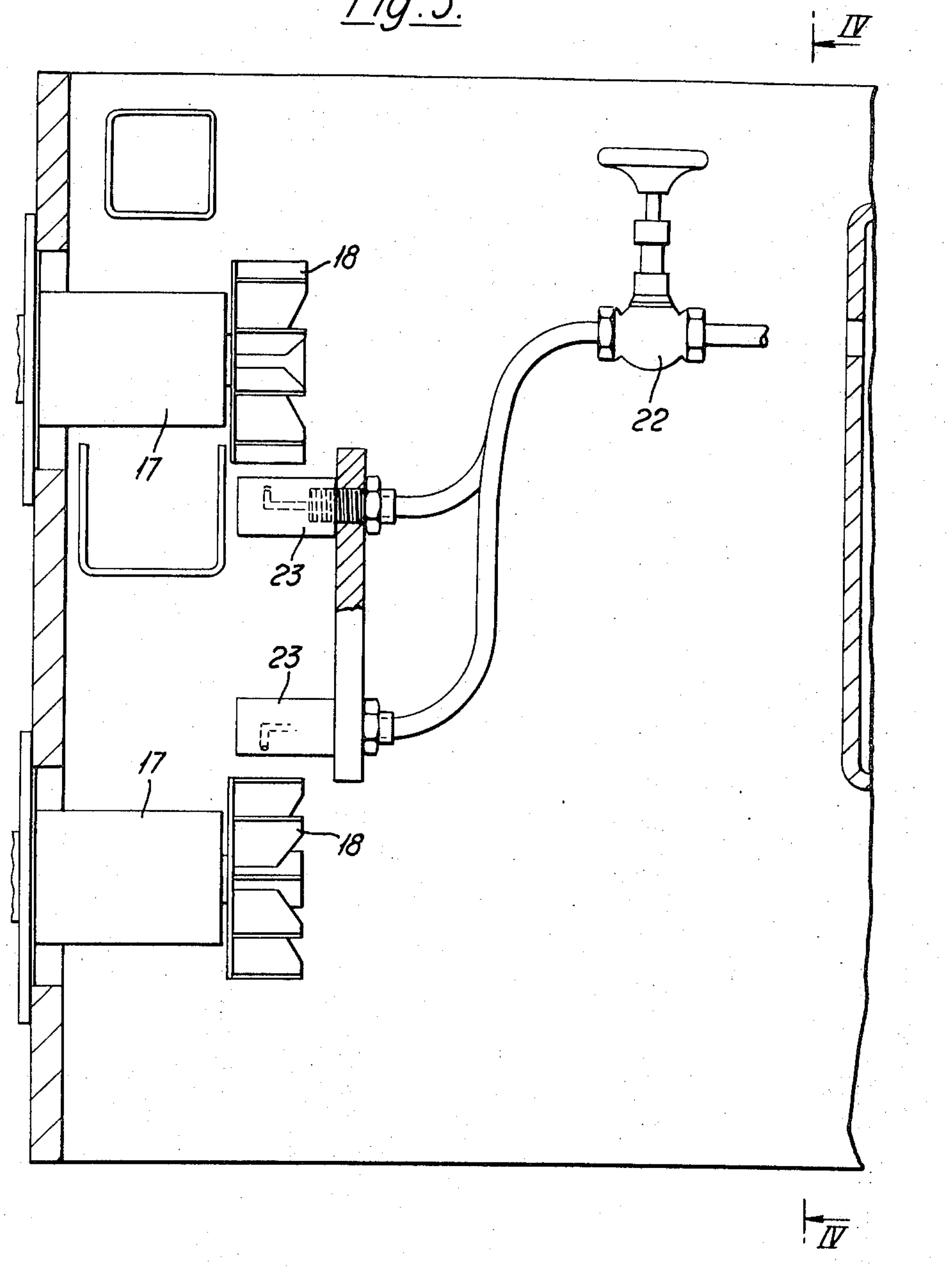

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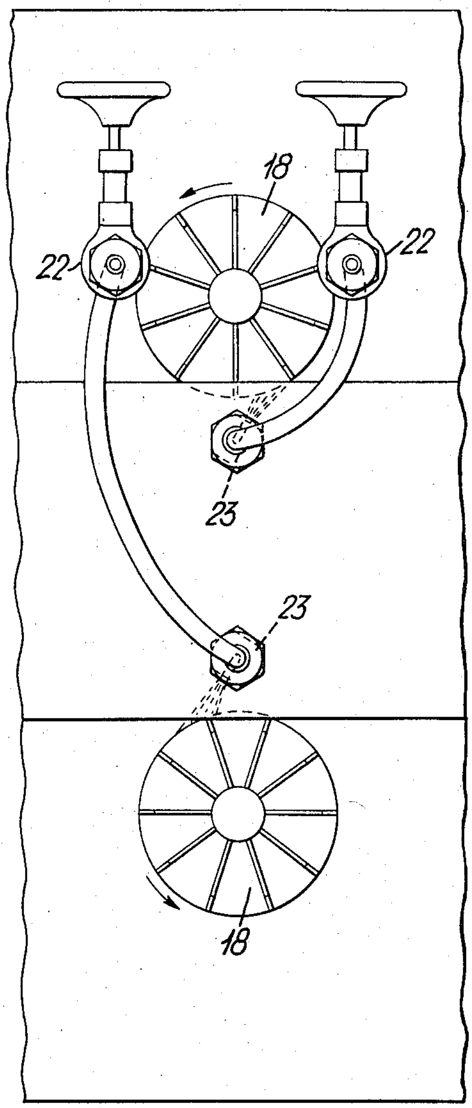
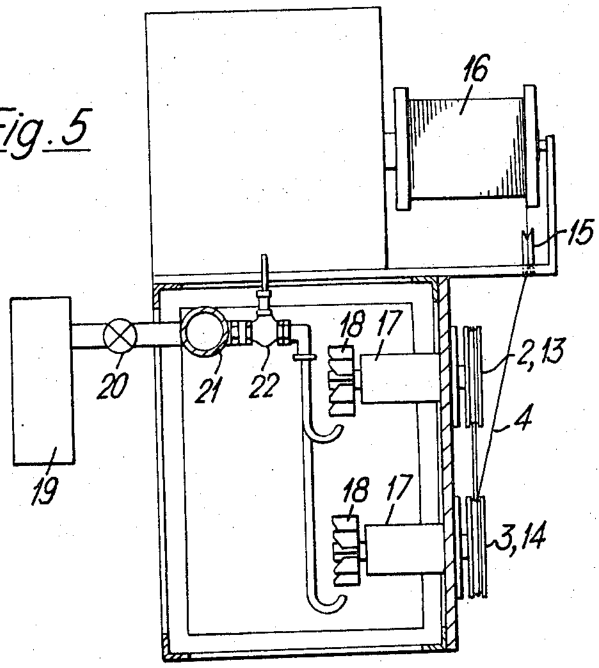


Fig. 5



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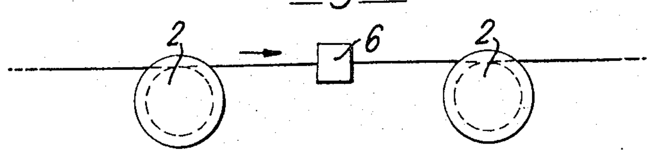

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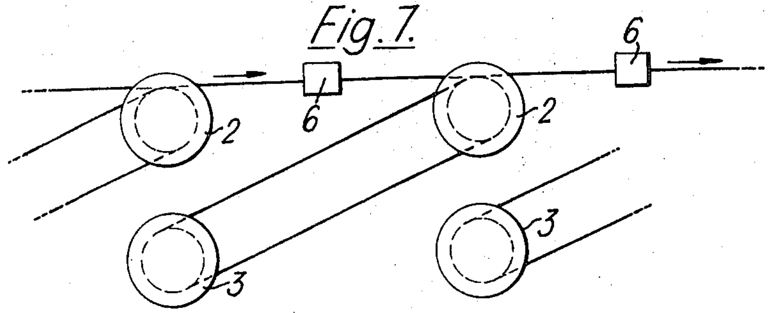

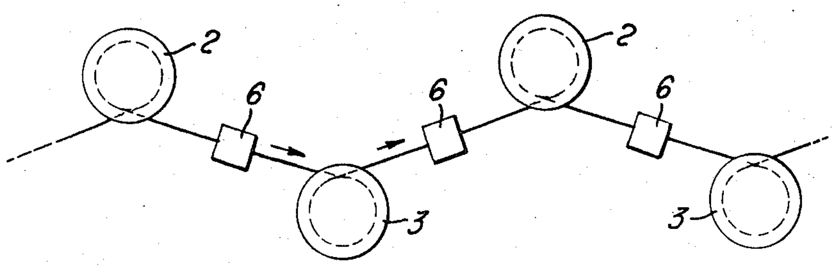

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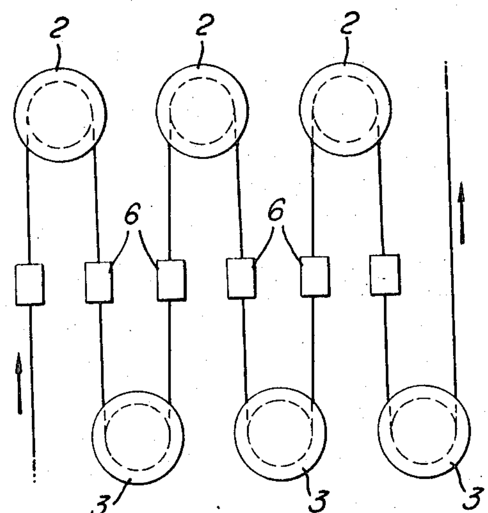
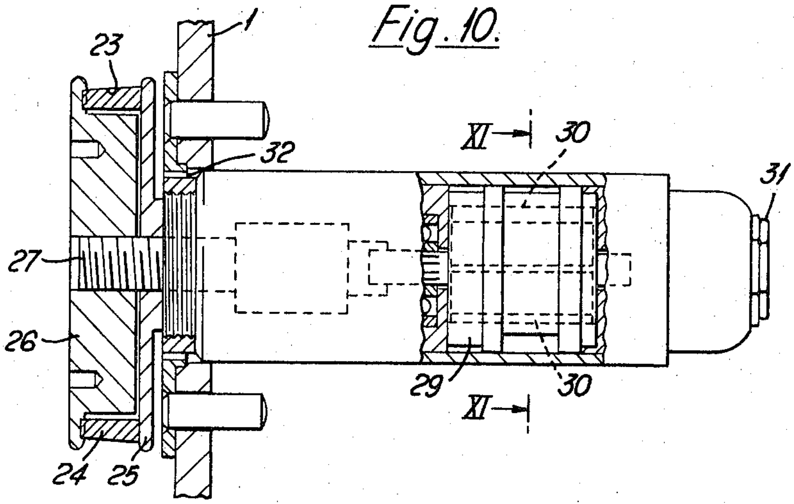


Fig. 9.

Fig. 10.



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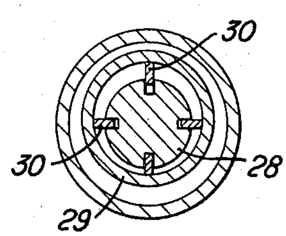

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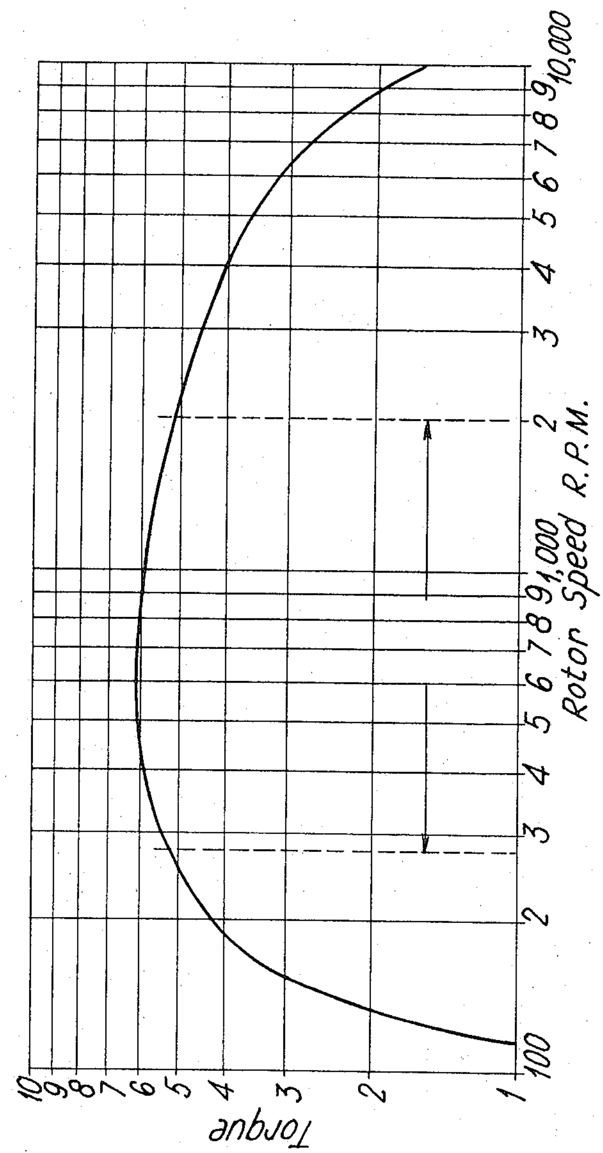

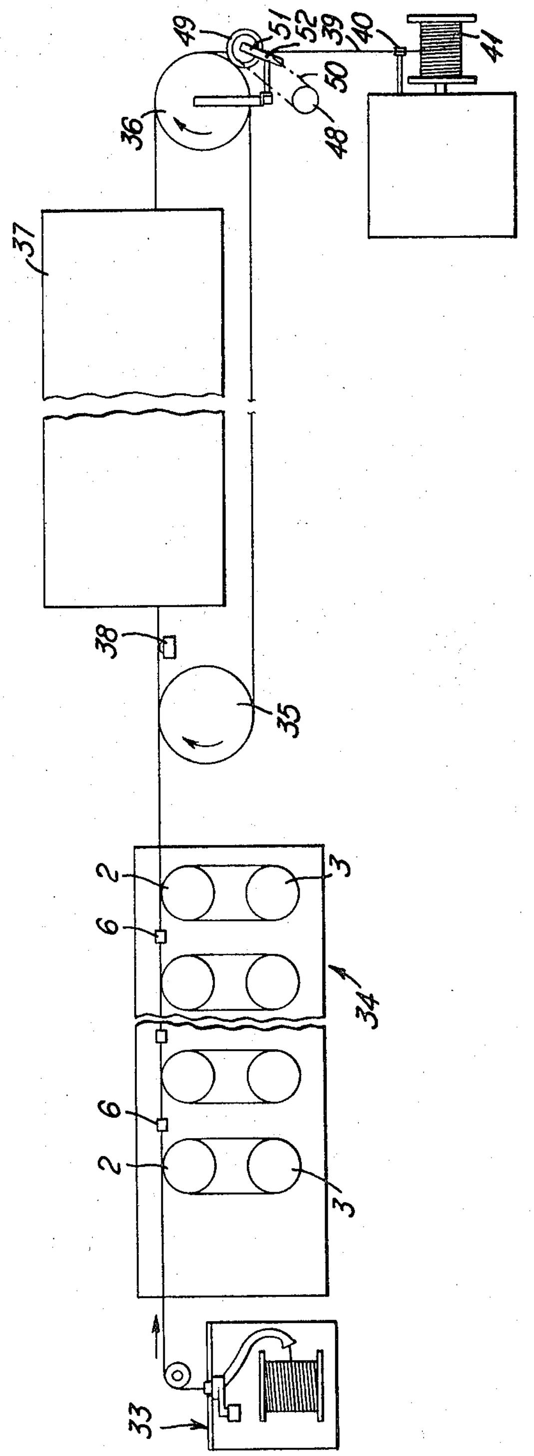

Fig. 13.

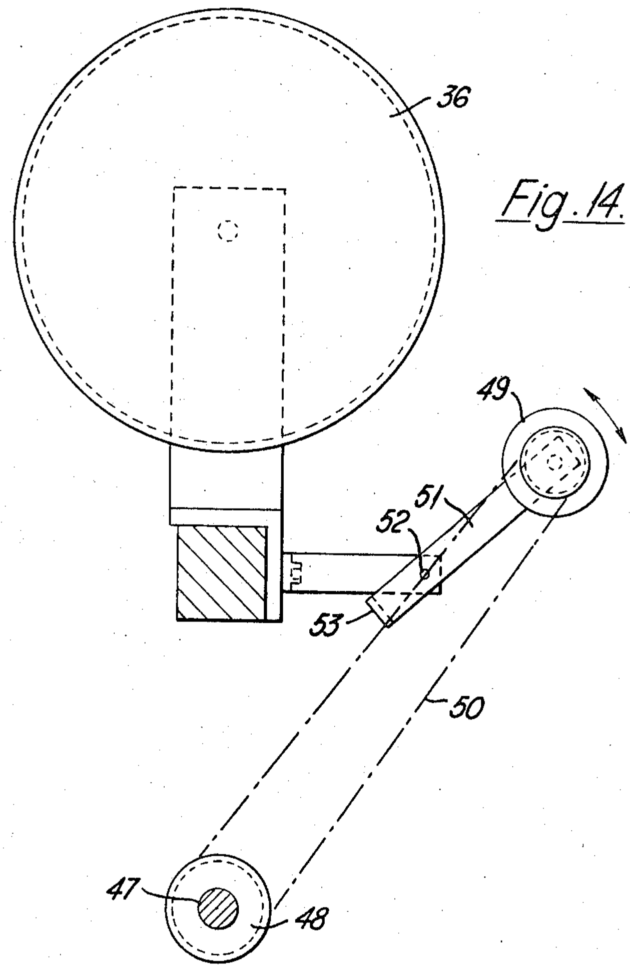

Fig. 14.

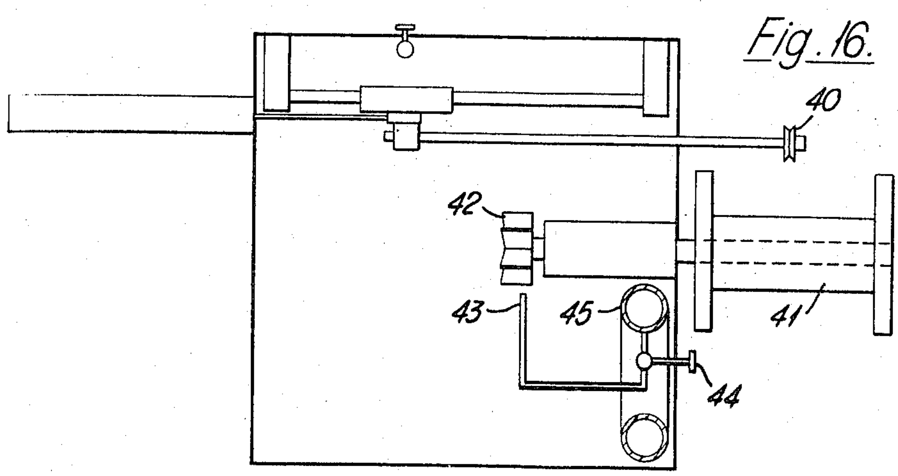

Fig. 16.

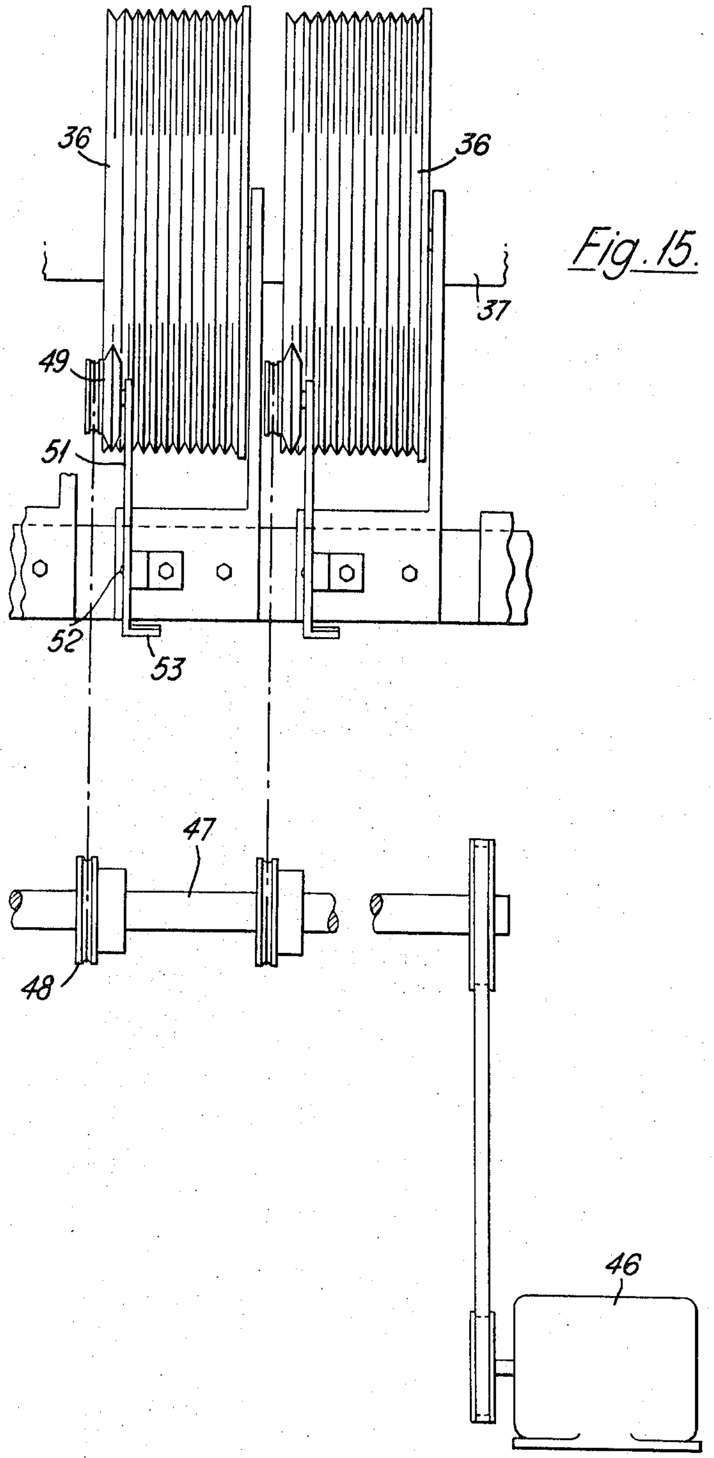

Fig. 15.

METHOD OF AND APPARATUS FOR DRAWING WIRE

This invention relates to apparatus for reducing the diameter of wire by drawing and a method of operating the apparatus. The invention is especially, but not exclusively, applicable to drawing wires that are of very small diameter and consequently of very low tensile strength.

Copper wire is currently being manufactured in diameters down to about 0.0075 mm (0.0003 inch), at which diameter it has a breaking load only of the order of a gram weight, and even finer wires would be desirable for some applications. With such fine wires it is difficult to maintain in the wires a tension that is always sufficient to avoid presence of slack wire and yet never sufficient to break the wire, especially when the wire speed must be kept substantially constant as for example to obtain satisfactory curing of an enamel coating on the wire. It is the main object of the invention as applied to processing of very fine wires to overcome or at least considerably alleviate these difficulties.

In drawing a wire through a series of dies, it is elongated at each die to an extent determined by the reduction at that die and the peripheral speeds of the drawing blocks (which term as used herein includes driven pulleys, capstans, cones and any other rotable traction means suitable for drawing wire through a die) must increase in proportion. In the case of relatively large wire sizes a reasonable tolerance is obtained by allowing slip to take place between the wire and the drawing block during running of the machine possibly with stretching of the wire on the block, but as the wire size decreases the amount of slip or stretch that can be tolerated decreases.

In most conventional wire drawing machines the drawing blocks are all rigidly coupled together and in many cases alternate blocks are mounted coaxially and formed integrally or rigidly connected together. Dies for use in such machines should therefore be accurately matched to ensure that each die produces an elongation appropriate to the blocks between which it is located, and such matching very greatly increases the cost of dies; further difficulties arise when the dies wear and therefore change in diameter. It would apparently be possible to use unmatched drawing dies, even for very fine wires, if the drawing blocks were all independently driven at speeds appropriate to the actual dimensions of the dies, but, except for drawing very strong steel wires, when elaborate tension-control arrangements have been used, this possibility has not been realised on a commercial scale; it is believed that this failure has been due to the lack of a suitable starting and running technique, which the present investion now supplies.

The invention provides a wire-drawing machine comprising at least two dies; at least one drawing block for drawing the wire through each die, each said drawing block having an effective surface that is tapered from one end of its rotation axis to the other; independently adjustable driving means for each said drawing block having a working range in which the angular velocity of the drawing block can change in response to variations in the speed of wire frictionally engaged therewith without any substantial change in the torque of the driving means and independently of the other drawing

blocks; and means for taking up drawn wire from the last drawing block.

The taper of each drawing block is preferably but not necessarily uniform unver the effective surface. Preferably the tapered effective surface extends throughout the effective axial length of the drawing block, but the use for example of a symmetrical block having a concave peripheral surface is not excluded. The angle of taper is not critical and the permissible range may vary to some extent depending upon the material and size of the wire but is generally in the range 0.3° – 10° semi angle. For copper or aluminum wires having a diameter of around 0.025 mm (0.001 inch) very good results have been obtained using tapers of either 1/2° or 6°.

The drive means for the drawing block is preferably a motor having an appropriate (flat) torque/speed characteristic but alternatively a drive arrangement that obtains such a characteristic by the use of a slipping clutch can be adopted. Turbines, pneumatic piston motors and electric torque motors with flat torque/-speed characteristics are avilable and good results have been obtained with each of them.

A form of turbine in which a jet of fluid impinges on an impeller in free air, or at least with a substantial clearance between the impeller and any shroud, has an extremely flat torque/speed characteristic and for the finest wires this may be the most suitable type of motor; it has however a low power efficiency, and for this reason it is now considered preferable in most cases to use an enclosed turbine or a pneuamtic displacement motor, for example of the rotary (or vane) type, or an electric torque motor, for example of the shaded-pole type.

When a turbine is used in a machine for drawing very fine wires, its working fluid is preferably air or another gas but for larger wires a liquid, for example water, may be preferable.

When turbines or pneumatic displacement motors are used they are preferably supplied with working fluid from a common source, preferably at an adjustable pressure so that the supply of fluid for all the turbines may be adjusted in unison. In such cases the same supply preferably feeds a turbine (or other) motor that drives the take-up for the drawn wire.

Similarly when electric torque motors are used they are preferably supplied, each through its own speed controller, from a common adjustable supply. For motors operating on alternating current, the preferred form of supply is a variable transformer (or a variable autotransformer), and the individual speed controllers may also be variable transformers (or autotransformers). Alternatively electronic controls can be used in either case of both cases.

The invention also provides a method of drawing wire using the machine described comprising the following steps:

1. threading up the machine by an inching technique
2. actuating the driving means to drive all the blocks at a speed low compared with the intended running speed
3. adjusting the take-up so that the speed of the wire engaging each of at least some of the drawing blocks is less than the peripheral speed of that block so that slip occurs between the wire and each of those drawing blocks and the speed of the wire

engaging any remaining drawing block or blocks is equal to the peripheral speed of that block

4. reducing the speed of each drawing block at which slip occurs until the said slip between the wire and that block is substantially eliminated, and
5. increasing the speed of all the drawing blocks and of the take-up in unison to a full running speed without causing substantial slip between the wire and any of the blocks.

Because the drawing blocks are tapered, slip can occur during step (3) without stretching of the wire, the tendency at this stage being for the wire to run "down" the block, i.e. towards its narrow end; when slip ceases, in step (4), the wire runs up the block, and this provides sufficient indication that the necessary adjustment is achieved and subsequently maintained, and the same test is effective to indicate the need for readjustment (as a result of wear) during subsequent running of the machine.

An important application of this invention is to the processing of wire by an in-line process in which the diameter of the wire is reduced by drawing and the drawn wire is passed, without being reeled and subsequently unreeled, into subsequent processing apparatus, such as an enamelling machine, that requires to operate at a substantially predetermined wire speed. This aspect of the invention is especially useful when applied to the manufacture of enamelled copper and aluminum wire (also known as magnet wire) of very small diameter.

In Large, Moss & Dutton U.S. Pat. application Ser. No. 92,795 filed Nov. 25, 1970, there is described and claimed a method of manufacturing drawn and further processed wire which comprises;

a. drawing a wire by at least one drawing capstan through at least two dies to produce a reduction in area of at least 30 percent;
b. driving the or each drawing capstan at a peripheral speed greater than the speed of the wire engaged thereby; and
c. passing the or each wire directly into subsequent processing apparatus including means determining the speed of the or each wire, during drawing as well as during subsequent processing, at such a value that the speed of the or each wire through each die through which it passes is so related to the reduction in cross-section effected at that die that the wire is not significantly heated.

Although very successful, this method has not overcome the problem of frequent wire breakage in processing very fine wires (say below 0.04 mm (1.5 mil)) and it has been found that the present invention proves a method that, although of general application, is especially suitable for manufacture of very fine enamelled or otherwise processed wires and enables them to be produced more economically and in longer continuous lengths than hitherto.

In a preferred method in accordance with the invention, after leaving the last drawing block the wire is subjected to at least one further processing step, after which the wire is received by the take-up, the take-up is driven by a fluid turbine, and in addition a constant speed drive is coupled to the wire downstream of the last of the drawing dies after the machine has been accelerated to substantially the required operating speed by the turbine drive.

Where the process carried out on the drawn wire is enamelling, the corresponding apparatus will consist essentially of an applicator for coating the wire with liquid enamel and means for converting the coating to a solid, cured condition. Conventionally the coated wire will be passed through an oven to evaporate solvent from the enamel and to cure the polymeric coating on the wire, but alternatively the wire may be preheated to obtain flash evaporation of the solvent immediately the wire emerges from the applicator, or a "solventless" enamel (in which the liquid constitutent of the enamel is copolymerisible with the polymeric sonstitutent of the enamel) can be used. A further possibility with appropriate enamels is to use ultra-violet or electron or other high-energy radiation instead of (or in addition to) heat to cure the enamel coating.

At the present time we prefer to use a conventional enamel of any of the usual classes applied to the wire by a metering applicator (which may be of the type using a metering roll or of the type that is closed, apart from passages for the entry and exit of the wire, and usually pressurised, and to which in each case the liquid enamel is supplied at substantially the same rate that the wire carries it away) and cured by means of an oven, which is preferably of a horizontal design.

The constant speed drive may be coupled to the wire at any point in its path between the final rawing die and the take-up or it could be coupled through the take-up itself provided that appropriate steps were taken to allow for variation in winding diameter, since if properly adjusted the turbine drive spontaneously adopts the speed set by the constant-speed drive. In the common case where the wire is passed back and forth between pulleys for the application drying and curing of several coats of enamel using a common oven or other heat source, it is especially convenient to connect the constant speed drive to one of those pulleys. For the finest wires the other one of these pulleys or in extreme cases each of these pulleys and any additional wire guides may also be equipped with a drive of the same kind as is used for the drawing blocks.

The constant speed drive may be of any kind that will maintain a speed that is constant within the tolerance of the system. It may be driven, for example, by a synchronous electric motor, a hydraulic or pneumatic displacement motor controlled by a centrifugal regulator, or any type of motor with electronic feedback speed control. For simplicity a synchronous electric motor is preferred. When several wires are to be processed simultaneously in parallel, a single prime mover may be used in the constant-speed drive for all the wires. Appropriate gearing may be used to obtain different constant speeds for individual wires if required, as for example when the wires are of different sizes.

With most types of constant speed drive it will be necessary to disengage the constant-speed drive during starting of the apparatus, by using a clutch or an equivalent arrangement; the clutch will then be engaged after adjusting the individual turbines to avoid slip and then setting the speed to approximately the desired value by adjusting the pressure of the common supply of working fluid to the turbines or otherwise accelerating them in synchronism. The constant speed drive will then maintain the speed despite small variations in tension due to variations in the supply, the take-up winding radius, and other incidental factors.

The invention will be further described, by way of example, with reference to the accompanying drawings in which,

FIG. 1 is a diagrammatic elevation of one form of wire-drawing machine in accordance with the invention;

FIG. 2 is a diagrammtic plan of the same machine;

FIG. 3 is a cross-sectional elevation on the line III—III in FIG. 2, partly in detail and partly diagrammatic;

FIG. 4 is a view in the direction IV—IV in FIG. 3;

FIG. 5 is a cross-sectional elevation on the line V—V in FIG. 2;

FIGS. 6–9 are diagrams showing alternative layouts and threading arrangements;

FIGS. 10–11 are details of a modified form of machine;

FIG. 12 is a graph showing the torque/speed characteristic of a motor used in the machine in accordance with FIGS. 10–11;

FIG. 14 is a detail showing a part of the apparatus of FIG. 13 in a different condition;

FIG. 15 is another view of part of the apparatus of FIGS. 13 and 14; and

FIG. 16 is a detail of a further part of the apparatus of FIG. 13.

Referring at first to FIGS. 1–5, the drawing machine comprises a suitable support 1 on which the mounted two rows of drawing blocks, the blocks of the upper row being referenced 2 and those of the lower row 3. Wire 4 to be drawn is taken from any suitable supply (which is not shown in detail because it forms no part of our invention) and passes over a pulley 5, through a first die-holder 6 and then in a single loop 7 around the first upper and the first lower drawing blocks; it then continues through a second die holder 8 and in a loop 9 round the second pair of drawing blocks, and so on through die holders 10 and loops 11 until it reaches the final die holder 12, from whence it passes in the manner shown round the last upper drawing block 13 and the last lower drawing block 14 which feeds the drawn wire to a traverse pulley 15 which is reciprocated on its own axis in a conventional manner to lay the drawn wire on the take-up reel 16.

As best seen in FIGS. 3 and 5, each of the drawing blocks 2, 3 is mounted in an individual low-friction bearing journal 17 and is rigidly coupled to an impeller 18 (see also FIG. 4). Compressed air from a compressor 19 is supplied through a main pressure regulating valve 20 to a manifold 21 and from the manifold by way of individual control valves 22 to jets 23 which cause streams of air to impinge tangentially on the impellors 18 so as to urge them to rotate; the direction of rotation is the same (clockwise as seen in FIG. 1) for all the blocks except the last lower block 14 which rotates in the opposite direction. The take-up reel 16 is driven by an identical impeller powered by an air jet supplied from the manifold 21 in exactly the same manner.

FIGS. 6–9 show alternative wire-wrap arrangements providing different extents of wrap of the wire on the drawing blocks. FIG. 6 shows a very simple arrangement in which the wire makes a single turn round one drawing block only between successive dies; this arrangement can be obtained without structural alteration to the machine of FIGS. 1–5 by using only the upper row of drawing blocks. FIG. 7 shows another arrangement that can be obtained without structural alteration to the machine: instead of being looped round drawing blocks that are vertically one above the other they are looped round diagonally relected blocks. The total wrap is the same, but the increased length of the first contact arc may be advantageous in some instances.

The arrangements shown in FIGS. 8 and 9 require minor structural alterations, in particular the positions of the die-holders 6 is changed and the direction of rotation of alternate drawing blocks (3 in FIG. 8, 2 in FIG. 9) is reversed. In FIG. 8 the spacing of the drawing blocks is also changed (or alternate blocks in each row could be used). It will be observed that these arrangements produce a total wrap of less than one turn per die-holder.

In accordance with the inventor, the effective surfaces of all the drawing blocks are tapered, preferably uniformly. The direction of taper is not critical but it is convenient for the direction of taper to be reversed from each block that the wire engages to the next block; if alternative threading patterns are required it may therefore be desirable that the blocks should be readily reversible. All the patterns illustrated, except that shown in for FIG. 6, should have opposite tapers on the blocks in the upper and lower rows. If reversal of taper is not used, there is a tendency for cumulative wire movements to occur and this may necessitate using drawing blocks of greater axial length and therefore of greater inertia.

FIG. 10 shows a suitable form of drawing block in which the tapered effective surface 23 is formed by a ring 24 of a ceramic material, for example aluminum oxide. Alternatively a metal ring flame-sprayed with tungsten carbide could be used. The taper has been exaggerated in the drawing in the interest of clarity; a taper of 0.5° is preferred, but as indicated above a much larger taper could be used. The ring 24 is mounted between flanges 25, 26 both threaded on the drive shaft 27 and it can be readily reversed by unscrewing the flange 26.

FIG. 10, together with FIG. 11, also shows an alternative form of pneumatic motor which is of the rotary displacement type. The motor 28, which is coupled to the drive shaft 27, rotates in an eccentric cylinder 29 and vanes 30 (urged outwardly by centrifuged force) divide the intermediate space into four components in which, expansion of the compressed air (entering through the gland 31) takes place to provide output power. Exhaust air escaping from ports 32 assists in keeping the drawing blocks free of dust particles. The motor illustrated in FIGS. 10 and 11 is obtainable from Desoutter Bros. Ltd. of The Hyde, London NW9, England as "Air motor MM/17000." By operating this motor at a lower air pressure than is normal for its usual use of powering portable tools, a useful range of substantially constant torque can be achieved; FIG. 12 shows a torque/speed curve for this motor at an inlet air pressure of 30 lbs/square inch (200 kN/m^2) gauge, and it will be observed that the torque is constant within ± 5 percent over a range from about 275 rpm to about 2,000 rpm.

It is desirable for the dies to be lubricated during operation, preferably by squirting a lubricant directly into the die apertures; the drawing blocks however should be kept free of lubricant.

Whether turbines or pneumatic displacement motors are used to drive the drawing blocks, the operation of the machine is substantially the same. Depending on the particular reduction required, an appropriate series of dies is inserted in the die-holders 6 or in some of them; where a particular die-holder is not used it may be possible to by-pass the corresponding drawing block or drawing blocks; if this is not possible or not desired the relevant blocks may be operated as driven guides.

In the following description values are given for operating parameters appropriate in drawing copper wire that is initially fully annealed from a starting diameter of 0.04 mm using a machine of the form shown in FIGS. 1–5 in which the drawing blocks have a radius of approximately 50 mm, with a series of **9** dies each effecting a nominal elongation of 11 percent, although the actual elongation at individual dies may differ substantially from this value (for example dies having actual elongations of 8 percent and 19 percent have been used together on an experimental prototype machine without difficulty).

With the individual valves **22** for all the drawing blocks partly open the air supply pressure at the compressor **19** is adjusted to 80 kN/m² (12 psi) and the valve **20** is closed. The wire is then threaded by hand from the supply (preferably a flyer take-off) over pulleys, through the first drawing die **6** and the in the loop **7** round the first pair of drawing blocks, after which the valve **20** is operated (preferably by a foot pedal) whilst tension is applied manually to the free end of the wire to obtain sufficient wire for threading through the next stage, and so on until all the drawing stages have been threaded, after which the wire is passed over the traverse guide **15** and secured to the stationary take-up reel **16.** The air supply pressure is next adjusted to a value in the region of 100 kN/m² (15 psi), which results in driving all the drawing blocks at speeds of about 250 rpm; at this speed slip between the wires and the drawing blocks is acceptable.

The valve controlling the supply of air from the manifold **21** to the turbine that drives the take-up is now adjusted to obtain a convenient take-up speed, which should preferably be as high as is consistent with ensuring that the peripheral speed of no drawing block falls below the speed of the part of the wire that engages it. Next the flow through each of the bleed valves supplying the turbines that drive the drawing blocks is reduced until slip ceases; this should be done in succession starting at the block **14** nearest the take-up and proceeding back along the wire, as succeeding adjustments then have no major effect upon preceding adjustments; minor readjustments may be required however during and after the major adjustments to ensure that slip does not recur and that the wire tension at the output remains within acceptable limits.

Finally the air supply pressure is gradually raised to say 350 kN/m² (50 psi) to accelerate the machine to full speed, after which only occasional attention is required until the whole length of the wire has been drawn.

During running the speeds of the drawing blocks will typically be in the range 1,000 – 10,000 rpm.

FIGS. **13 – 16** show a drawing machine in accordance with the invention arranged for operation in-line with enamelling apparatus. As seen in FIG. **13,** wire taken from the supply **33** is drawn in the drawing machine **34** which is identical with that just described except that the final drawing stage (comprising die **12** and drawing blocks **13** and **14**) and the take-up (**15,16**) are omitted. From the last regular pair of the drawing blocks **2, 3** the drawn wire passes directly to enamelling apparatus, which is preferably of the horizontal type. As shown for the purposes of illustration, the enamelling apparatus comprises "front" pulleys **35** and "back" pulleys **36** around which the wire is looped to make several passes through an oven **37.** Applicators **38,** sketched by way of example as wheel type metering applicators, apply one coat of enamel to the wire on each pass. The coated wire eventually passes from the back pulley **36** via a traverse guide **40** to a take-up reel **41.**

The take-up reel is powered by a turbine similar to those that drive the drawing blocks and comprising an impeller **42** and a jet **43** supplied by a control valve **44** from an extension **45** of the manifold **21** in the drawing machine.

As so far described, the machine is substantially identical with the drawing machine shown in FIGS. **1 – 5** except for the interposition of the enamelling apparatus between the last drawing stage and the take-up and it can be operated in exactly the same way. However, this would not permit consistent satisfactory production of enamelled wire because the wire speed could not be controlled sufficiently accurately to ensure satisfactory curing of the enamel.

To overcome this problem, an electric synchronous constant-speed motor **46** is provided; this drives a shaft **47** which is common to several "wire lines," that is sets of drawing and enamelling apparatus that are independent except that they share the oven **37.** For each wire line there is a drive pulley **48** on the shaft **47** and this drives a "jockey" pulley **49** through a garter spring or other form of resilient belt **50.** The jockey pulley **49** is mounted on a lever freely pivotted on a fixed support at a pivot **52** so placed that the tension in the spring belt **50** urges the jockey pulley either into the driving position shown in FIG. **13** or into the disengaged position shown in FIG. **14.** In the disengaged position a stop on the lever **53** engages a fixed frame member to limit movement, whereas in the driving position the jocket pulley is urged into frictional engagement with the back pulley **36** of the enamelling machine.

The lever **51** is placed in the disengaged position during threading up and starting of the machine and is moved into the engaged position after the machine has been accelerated to approximately the correct running speed by the turbine drive of the take-up and the motors of the drawing machines; thereafter the motor **46** determines the wire speeds and the speeds of the other motors are stabilized accordingly.

What we claim as our invention is:

1. A method of drawing wire comprising:

1. threading its leading end successively through the members of a series of drawing dies and after passage through each die around a tapered effective surface of a rotatable drawing block;

2. driving each of the drawing blocks in a direction to advance the wire and at a starting speed by means of individual independently adjustable driving means having for each adjustment a working range in which the angular velocity of the drawing block can change spontaneously in response to variations in the speed of the wire engaged therewith, whilst keeping substantially constant the torque applied to each drawing block;

3. taking up the wire from the last of the drawing blocks at a rate such that the speed of the wire engaging each said drawing block is not greater than the peripheral speed of the respective block and such that the speed of the wire engaging a plurality of said drawing blocks is less than the peripheral speed of the respective drawing block so that slip occurs between the wire and each of said plurality of drawing blocks;

4. reducing in turn the speed of the said plurality of drawing blocks until slip between the wire and each said drawing block is substantially eliminated; and then

5. increasing the speed of the wire by increasing the rate of take up and simultaneously increasing the speeds of all said drawing blocks in unison, without causing substantial slip between the wire and any one of said drawing blocks to recur, until the speed of each said drawing block is much higher than its starting speed.

2. A method of drawing wire comprising:

1. threading its leading end successively through the members of a series of drawing dies and after passage through each die around a tapered effective surface of a rotatable drawing block;

2. driving each of the drawing blocks in a direction to advance the wire and at a starting speed by means of individual independently adjustable driving means having for each adjustment a working range in which the angular velocity of the drawing block can change spontaneously in response to variations in the speed of the wire engaged therewith,

whilst keeping substantially constant the torque applied to each drawing block;

3. taking up the wire from the last of the drawing blocks at a rate such that the speed of the wire engaging each said drawing block is not greater than the peripheral speed of the respective block and such that the speed of the wire engaging at least one of said drawing blocks is less than the peripheral speed of said one drawing block so that slip occurs between the wire and said one drawing block;

4. reducing the speed of said one drawing block until slip between the wire and said drawing block is substantially eliminated; and then

5. increasing the speed of the wire by increasing the rate of take up and simultaneously increasing the speeds of all said drawing blocks in unison, without causing substantial slip between the wire and any one of said drawing blocks to recur, until the speed of each said drawing block is much higher than its starting speed.

3. A method as claimed in claim 1 wherein in step 4 the speeds of said plurality of blocks are reduced in a sequence determined by the path of said wire through the machine beginning at the drawing block nearest to said take-up and proceeding backwards along said path of the wire.

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