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ULTRASONIC WIRE DRAWING

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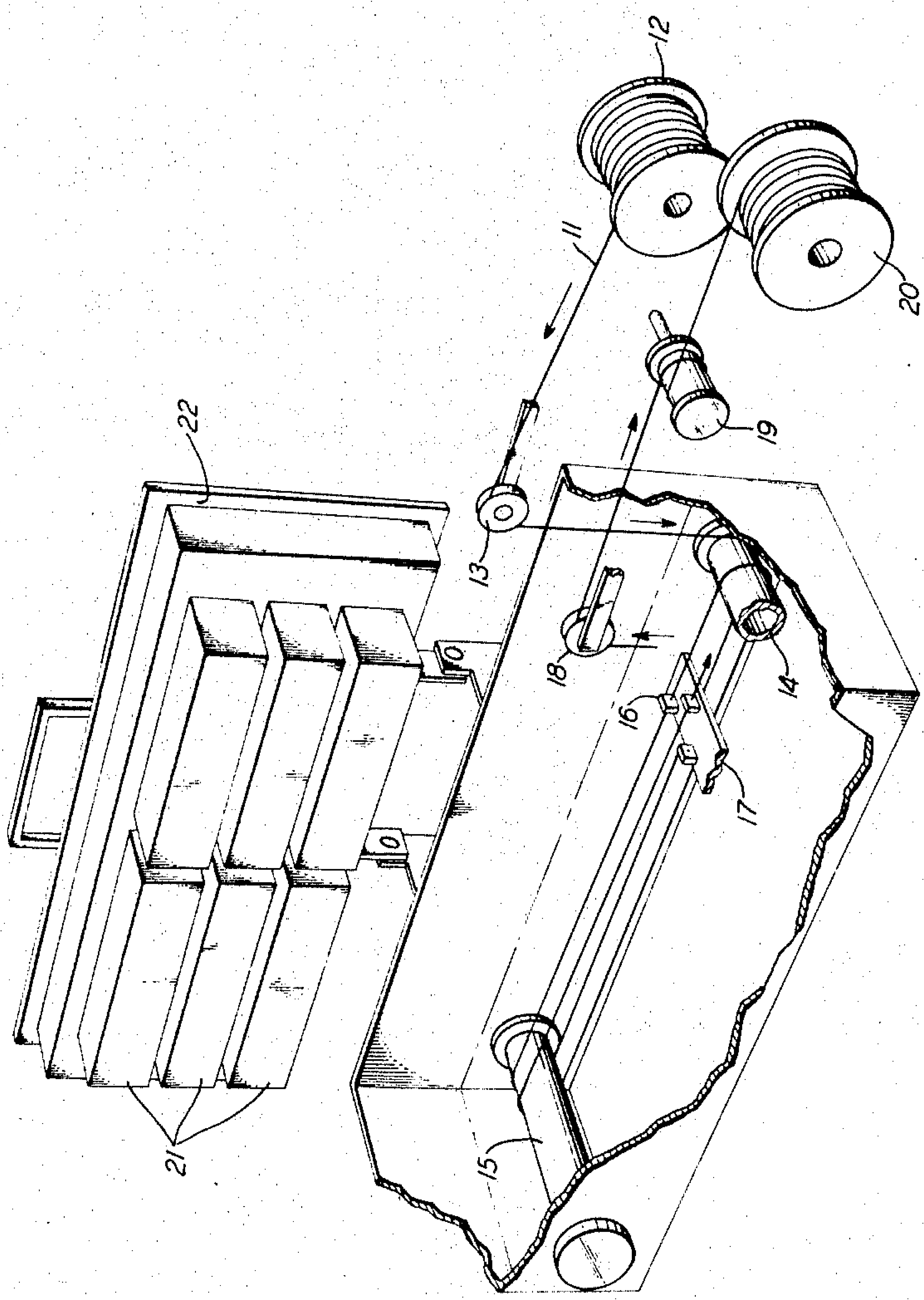

FIG. 1

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BY

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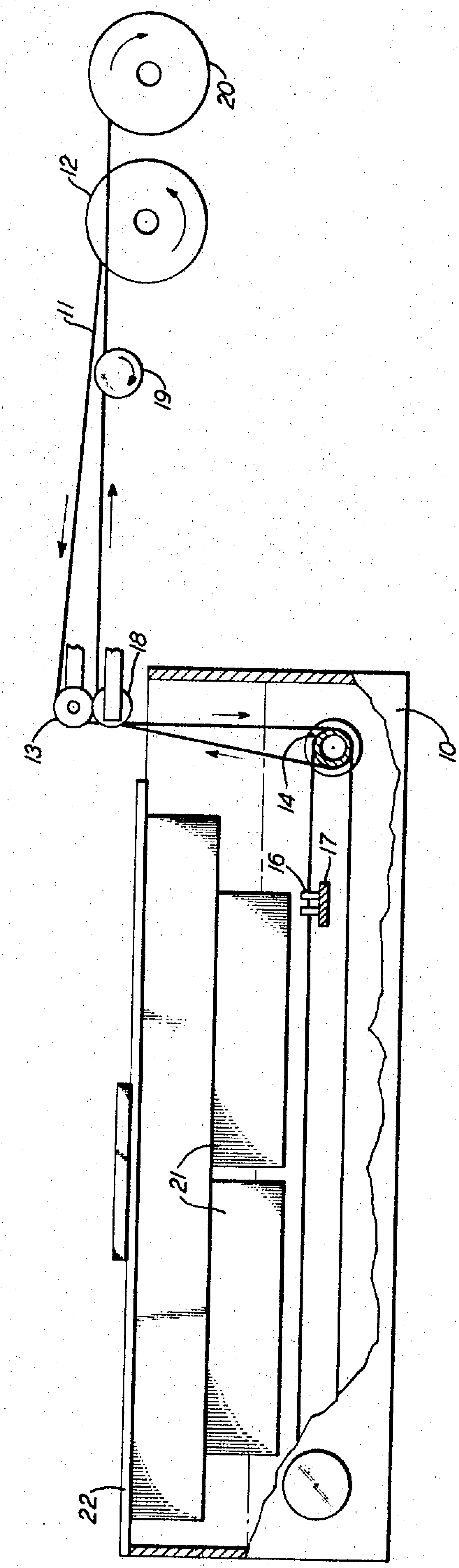


FIG. 2

FIG. 3

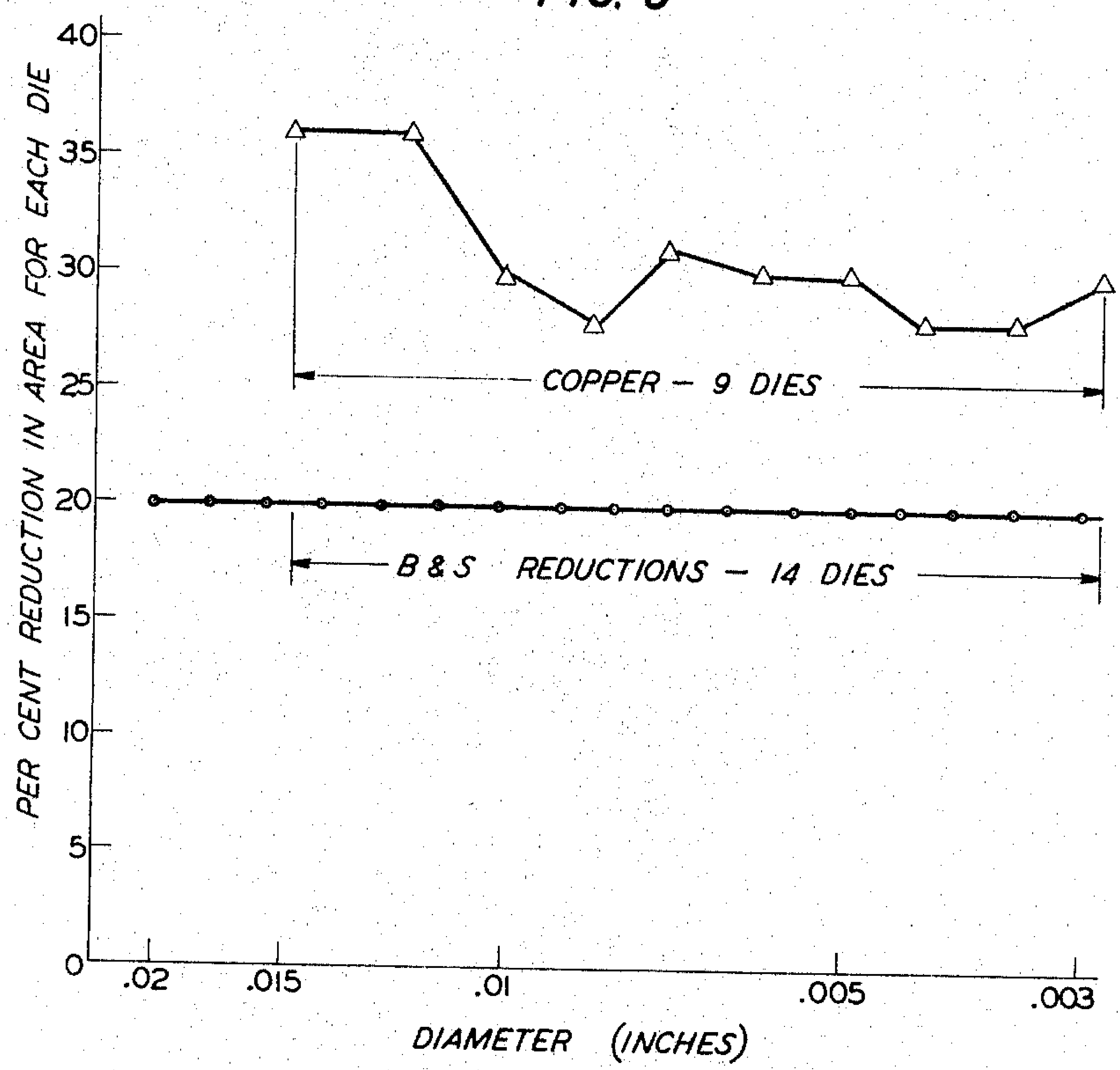
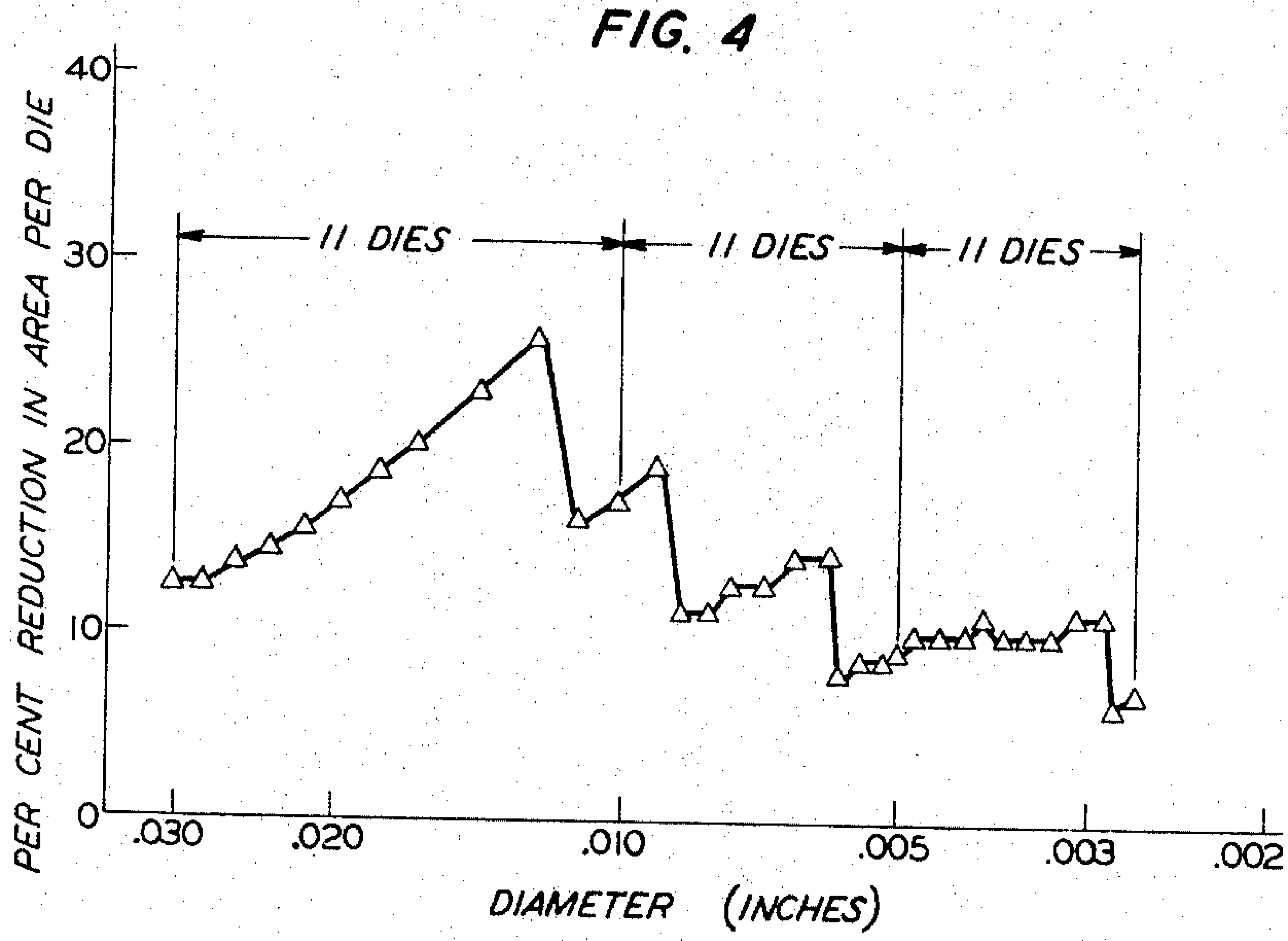

PER CENT REDUCTION IN AREA FOR EACH DIE
40
35
30
25
20
15
10
5
0
COPPER – 9 DIES
B & S REDUCTIONS – 14 DIES
.02
.015
.01
.005
.003
DIAMETER (INCHES)

FIG. 4


PER CENT REDUCTION IN AREA PER DIE
40
30
20
10
0
11 DIES
11 DIES
11 DIES
.030
.020
.010
.005
.003
.002
DIAMETER (INCHES)

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ULTRASONIC WIRE DRAWING

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This invention relates to drawing wire or similar continuous stock through a die member to reduce the diameter of the wire or stock.

The invention is based on the development of a wire drawing technique capable of producing long lengths of wire having a surface quality far superior to that obtained by normal drawing procedures.

The surface condition of wire is an important factor which must be considered in the development of many components designed for use in complex communications systems as well as many other applications. Improved surface quality is being sought in all wire sizes from heavy conductors to fine wire below 0.0015 inch diameter.

The source of surface imperfections in wire can be divided into two categories; those present in the starting rod stock, and those introduced by the wire drawing process.

During recent years advances in melting, casting and processing techniques have led to production of high quality rod stock which is relatively free of physical defects. Some of the advances are: vacuum casting, consumable arc and electron beam melting, reduction in formation of seam, overfills etc. during hot fabrication, and removal of the outer surface layer on rod by scalping, centerless grinding or chemical treatment. Preparation of rod stock directly from the molten state by continuous casting through rolls is now in the early stages of commercial production. Furthermore, the use of high-purity materials has minimized the presence of metallurgical inhomogeneities such as second phases and metalloid or oxide inclusions. For example, it is now possible to obtain commercial quantities of copper rod with a certified purity of 99.99%. In addition, it has been shown that a large variety of pure nickel and iron alloys can be made in which no single impurity is present in amounts exceeding 0.005% by weight (50 p.p.m.) Nickel materials having this degree of purity are now being made on a commercial scale.

Since high-quality rod stock for drawing can be procured, the remaining major source of defects are those introduced by the wire drawing process. Some of the common defects are:

(1) Longitudinal scoring caused by drawing through worn dies or through abrasive debris accumulated in the entry area of the die.

(2) Randomly distributed imperfactions produced by embedding of foreign particles into the wire as it passes over pulleys, capstans and through drawing dies.

(3) Voids created when some of the embedded particles become dislodged from the wire surface in drawing to finer sizes.

(4) Transverse chatter and roughness markings due to inadequate functioning of the die lubricant.

It is apparent that the cause of these surface imperfections is associated primarily with pickup of foreign matter from the surrounding environment, the drawing machine, and the liquid lubricant. Possible improvements

in surface finish might be realized by the use of super-clean white rooms, spotlessly-clean drawing apparatus, controlled-atmosphere enclosures, elaborate filtering of continuously-circulated lubricants or other similar methods. In many instances, these procedures would be costly, impractical and not easily adaptable to normal wire drawing processes.

According to the present invention ultrasonic energy is used to agitate the liquid lubricant in a tank through which the wire is being pulled over pulleys and drawn through the totally submerged die. With proper cavitation intensity the surface of the wire is well-cleaned before entering the die. In addition, particles in the liquid bath are kept in suspension and are not deposited on the wire prior to its passage through the die. Furthermore, the transmission of ultrasonic energy through the liquid to the die is intense enough to prevent accumulation of foreign matter in the die cavity.

Ultrasonic energy itself is not new to the wire drawing art. It has been proposed in several instances for improving wire drawing performance. Typical of such proposals is the teaching in United States Patent 2,638,207 issued to R. P. Gutterman on May 12, 1953. The principal idea is to reduce frictional forces by drawing wire through a die which is vibrated by direct metallic connection to a source of ultrasonic power. Experience using this suggestion has encountered the problem of overheating of the die, and consequent seizure of the wire in the die resulting in wire breakage. Even though reduction in friction may be realized in relatively slow-speed drawing of short lengths of wire, the rapid movement of the constricting die surface over the wire continually increases frictional heat until seizure occurs. The dissipation of the ultrasonic energy in the form of heat decreases its efficiency and also limits the power that can be transmitted to the die. Unfortunately the point at which sufficient ultrasonic energy is applied to obtain a significant benefit coincides with the energy level where overheating becomes a problem. For this reason, along with others, the use of ultrasonics in wire drawing apparatus has not achieved commercial acceptance.

According to the present invention ultrasonic energy is used in an entirely different manner in the drawing of wire and similar stock to achieve new and unexpected results. Specifically, large quantities of wire can be drawn with improved surface quality at percentage reductions and rates significantly above those obtainable using prior art drawing processes.

The invention requires the combined use of ultrasonic energy and a fluid in which the die and the wire being drawn are immersed. This combination is particularly useful since the fluid acts as a lubricant and coolant for the die as well as to introduce the novel ultrasonic effects. Using this arrangement the ultrasonic energy is effectively applied to the fluid in close proximity to the die and to the wire prior to its being drawn through the die. The consequence of ultrasonically agitating the fluid in this manner is to reduce die friction and die wear and to permit the drawing of long lengths of wire with an unusually high-quality, smooth, surface finish. All of the reasons for this improved drawing behavior are not fully understood. However, it is likely that some of the factors involved are the ultrasonic precleaning of the wire, the continuous cleaning of the entry area of the die by the agitated fluid and the cavitational activity of the fluid at the die providing enhanced lubrication.

These and other aspects of the invention may be more fully appreciated upon considering the following more detailed description of the invention. In the drawing:

FIG. 1 is a perspective view of an apparatus embodying the principles of the invention showing wire-drawing apparatus immersed in an ultrasonic tank with the top lid open to permit an overall view;

FIG. 2 is a schematic front-sectional view of the apparatus of FIG. 1 showing the transducers in place adjacent to both the wire being drawn and the die;

FIG. 3 is a reduction schedule for copper wire drawn on the apparatus of FIGS. 1 and 2 showing the reduction in wire diameter per pass for a nine stage (9 dies) reducing operation; and

FIG. 4 is a similar reduction schedule for high-purity aluminum wire.

An apparatus used to demonstrate the principles of the invention is shown in FIGS. 1 and 2. In FIG. 1 a perspective view is shown of the tank, the submerged rolls and die assembly, and the tank lid which carries the ultrasonic transducers. The lid is shown in the open position for a clearer picture of the apparatus.

The tank **10** is a stainless steel container having dimensions of 36 inches x 15 inches and an approximate depth of 8 inches. The wire **11** is taken from a spool **12** and threaded over a pay-out pulley **13**. After it enters the tank it is fed around driven roll **14** along the length of the tank, around driven roll **15**, returning through the first die **16**. The pulleys are free wheels. In this particular apparatus provisions are made for twelve reduction stages as shown mounted on the die holder plate **17**. The wire passes around each end roll and through each die in succession. After the last pass the wire loops around the end roll **15**, emerges from the tank over free pulley **18** as it is being pulled by the motor-driven capstan **19** and is spooled on a take-up reel **20**. The give-up and take-up spooling devices are, in practice, somewhat more elaborate and use servo motors which permit precise control of wire tension.

The stainless steel transducers **21** containing resonant piezoelectric crystal units are rated at 150 watts and are mounted on the lid **22** of the equipment. The ultrasonic generator for this particular unit delivers approximately 1000 watts so that the six transducers, each rated at 90% efficient, deliver approximately 900 watts to the fluid in the tank. To avoid excessive dissipation of this energy in the fluid prior to reaching the wire it is important to arrange the transducers in close proximity to the path of the wire and the dies. This can be seen in FIG. 2 which is a schematic front-sectional view of the apparatus of FIG. 1 showing the top lid **22** in place. The separation should not exceed 12 inches and is preferably less than 6 inches. For the apparatus described herein the fluid space between the wire **10** and the surface of the transducer **21** was less than one inch and the return or lower pass was approximately 3½ inches from the transducer surface. Obviously it makes little difference whether the transducers are top, bottom or side mounted with respect to the wire and die or dies.

A survey was made of the capability of this new machine for producing fine wires of a variety of metals and alloys. All of the starting wire was chemically cleaned. Except as noted, all the wire was drawn through an eleven-die setup in the multi-die holder **17** at a speed of 150 to 200 feet per minute under an ultrasonically agitated lubricant solution consisting of 0.1 percent by volume of vegetable oil compound in distilled water. The average reduction in area through each die was approximately 15 percent. The results of the survey are as follows:

(1) *Copper*

No difficulties and no wire breakage were encountered in drawing OFHC or 99.99% pure copper from 0.020 inch to 0.0015 inch diameter (#46 B & S). Some of this wire was drawn at 50 feet per minute to produce a 1000 foot length of 0.0007 inch diameter wire (#53 B & S).

OFHC copper wire was drawn from 0.015 inch to 0.0028 inch diameter at 1000 feet per minute using average reductions of 30% per die. The reduction schedule for this drawing operation is given in FIG. 3. The ordinate is plotted as percent reduction vs. wire diameter on the abscissa. Each pass (reduction stage) is designated by a triangular plot point. As can be seen, only nine dies were used for drawing this wire as compared with the fourteen dies required by conventional (B & S) gauge reductions schedule. (Approximately 20% reduction per die.) Examination of the dies after this heavy-reduction, high-speed drawing showed no accumulation of particles in the entry area of the dies.

(2) *High-purity aluminum (99.99+%)*

Perhaps the most startling demonstration of the effectiveness of employing ultrasonically agitated liquid lubricants in wire drawing was the success achieved in drawing very soft, pure, aluminum. No difficulty was encountered in producing a 5000 foot continuous length of 0.005 inch diameter wire by drawing 0.030 inch diameter wire through two sets of eleven dies. A portion of this wire was drawn through another set of eleven dies to produce 1000 feet of 0.0028 inch diameter wire. During the drawing operation it was observed that the ultrasonic cleaning action was causing evolution of a cloud of fine particles from the surface of the wire located in the sections between the dies. The same evolution was observed during subsequent drawing through the following sets of dies. When the drawing operation was completed and the ultrasonic agitation was stopped, the particles (which are probably aluminum oxide) remained in suspension and could not be removed by the available filtering equipment. However, no evidence of the presence of these particles was found in the entry areas of the dies after drawing. The ability of the ultrasonic action to clean the surface and keep the particles out of the die was undoubtedly a major factor in overcoming the usual difficulty of drawing pure aluminum to fine wire.

The reduction schedule for drawing the pure aluminum wire is shown in FIG. 4. The coordinates are the same as in FIG. 3. Available conventional diamond dies were used whose bore sizes decreased uniformly in increments of 0.002 inch, 0.001 inch, etc. This accounts for the step-like character of the reduction schedule curve. The average reduction per die was approximately 12 percent and the processing of the 0.0028 inch diameter wire required thirty-three reduction stages (achieved by three passes of the wire through the 11 die setup). It is very possible that fewer dies would be needed if appropriate matched sets of short bearing dies were used.

(3) *High nickel content alloys*

(a) High-purity nickel+20% chromium
(b) Commercial nickel+20% chromium+2.5% aluminum+2.5% copper
(c) Commercial nickel+17% iron+4% molybdenum

All of these alloys were drawn from 0.020 inch to 0.001 inch diameter with no difficulty. About 1000 feet of the hard Ni-Cr-Al-Cu alloy was drawn from .001 inch to 0.0007 inch diameter using a set of nine dies and an average of 10% reduction per die.

Fine particle evolution similar to that obtained in drawing aluminum was observed in drawing the Ni-Cr-Al-Cu alloy. In drawing the high-purity nickel-chromium alloy, particles settled out quickly to form a black smudge on the bottom of the tank when the ultrasonic energy was shut off at the end of the processing. This smudge was found to be mainly nickel oxide. No significant accumulation of these particles was found in the entry area of the dies after drawing any of the high nickel content alloys.

To date a variety of materials ranging from very soft aluminum to hard nickel alloys have been drawn into fine wire using the new multi-die machine. Dimensional uniformity along the length of the copper, aluminum, and Ni-Cr-Al-Cu wire was determined by calculations derived from electrical resistance measurements. The measurements were made on several samples taken from locations corresponding to the start, midpoint, and end of the wire drawing. The maximum variation in area along the length was found to be ±0.2%. Such a slight variation for 1000 feet of 0.0028 inch diameter pure aluminum wire shows that this soft material is not being stretched after pulling through the last die.

The foregoing examples show that in addition to providing a means for improving the surface condition of wire, the use of ultrasonically agitated liquid lubricants in wet wire drawing processing enhances the feasibility of drawing wire to fine sizes. The high frequency agitation of the liquid undoubtedly lowers the frictional resistance associated with the drawing operation. A large part of the decrease in friction is due to the ability of the ultrasonic action to clean the wire surface, to keep foreign particles suspended in the liquid, and to prevent accumulation of debris in the die cavity.

It is felt that other beneficial actions must also be operative to account for the success achieved in the drawing operations described above. For instance, it is difficult to believe that control of cleanliness alone would enable long lengths of soft aluminum wire to be laced around driven rolls 2½ feet apart and drawn through eleven dies at a speed of 100 feet per minute, especially when it is realized that the breaking load of the aluminum wire decreases from 350 to 100 grams as a result of the reduction from 0.005 inch to 0.0028 inch diameter. There is some evidence that the cavitational energy transmitted by the liquid exerts enough penetrating action to force the liquid through the die along with the wire thereby providing a hydrodynamic lubricating effect. The strong penetration effect may also maintain a liquid film under the area of contact between the wire and the driven rolls which provides a cushioning effect and prevents erratic slippage of the wire passing over the rolls during the drawing operation.

It should be appreciated that an appropriate amount of ultrasonic energy must be applied to the fluid in the vicinity of the wire and the die or dies to obtain the results discussed above. Accordingly, for the purposes of this invention ultrasonic energy at a power density of at least 1 watt/in.^{2} of transducer area must be delivered to the fluid adjacent the die area and the wire prior to entry into the die. Especially good results are obtained with a power density of at least 2.5 watts/in.^{2}. It is preferred that this power density be applied to the liquid over a length of twelve inches encompassing the die region and the wire path entering the die. This prescribed power density is regarded as a minimum for high-speed wire drawing, e.g., one thousand to several thousand feet per minute. Consequently these limitations on the ultrasonic energy are valid for any conventional wire drawing rate. If the rate is extended beyond normally used rates the power density may be increased proportionately or longer exposure lengths used. Slower speeds present no difficulty as the only possible critical parameter is the minimum useful exposure time for a given increment of wire length.

The ultrasonic frequency may vary from 20 kc. to 400 kc. The transducers used in the equipment described in this specification operated at 25 kc.

Various modifications in the arrangement described here may be made within the scope of the invention. For instance, the fluid composition may be varied. Trichloroethylene is useful for its solvent capabilities and its physical properties may permit useful cavitation at slightly lower power levels. Kerosene, benzene, alcohol, acetone, etc., are other alternative fluids. Obviously, since the hydrodynamic characteristics of the fluid are as important as its chemical behavior, a wide latitude in the selection of the fluid is possible. In many instances the type of fluid used will be dependent upon the nature of the wire being drawn. Water is economic, relatively inert, and has been found to be particularly effective for this application. Lubricant additives other than the vegetable oil used here may be employed with the water.

While it is convenient to operate the equipment at room temperature the fluid may be heated if desired to increase the efficiency of the ultrasonic agitation. Temperatures around 60° C. are especially good for water.

The apparatus can be constructed in various designs. For instance, a given tank or portion of a tank may contain several dies of the same size and a plurality of continuous filaments may be treated simultaneously, side by side, passing through several die stations to achieve the desired reduction. Several similar alternative arrangements may also be foreseen.

While the invention is particularly applicable to drawing wire for size reduction, it should be understood that it is also useful in connection with the size reducing of other continuous stock where the continuous filament is drawn through a die. Such materials as rods, tubes and thin sheets or tapes are in this category. The considerations and results discussed herein apply to wire or other continuous stock of any ordinary dimensions.

Various other modifications and deviations which basically rely on the teachings through which this invention has advanced the art are properly considered within the spirit and scope of this invention.

What is claimed is:

1. An apparatus for drawing continuous stock through a die comprising a fluid-tight, a die mounted below the rim of the tank adapted to be completely immersed with fluid in the tank, means for drawing the continuous stock through the die, ultrasonic means adapted for applying ultrasonic energy to a fluid contained in the tank said ultrasonic means disposed in a position to deliver ultrasonic energy at a power density of at least 1 watt/in.^{2} to the region of the fluid containing the die and a twelve inch length defined by the path of the continuous stock just prior to entering the die, the said ultrasonic means in said region spaced at less than twelve inches from the said die and continuous stock path.

2. A method for drawing continuous stock through a size reducing die which comprises drawing the continuous stock through a die suostantially completely immersed in a fluid while applying ultrasonic energy to the fluid at a power density of at least 1 watt/in.^{2} in the region of the die and over at least a twelve inch length of the path of the continuous stock just prior to entering the die, the effective power density of said ultrasonic energy occurring within less than twelve inches of the die and the continuous stock.

3. The method of claim 2 wherein the fluid comprises a member selected from the group consisting of water, trichloroethylene, kerosene, alcohol, acetone and benzene.

4. The method of claim 3 wherein the fluid comprises water.

5. The method of claim 2 wherein the continuous stock is wire.

6. The method of claim 5 wherein the wire is copper.

7. The method of claim 5 wherein the wire is aluminum.

8. The method of claim 5 wherein the wire is a nickel alloy.

9. The method of claim 2 wherein the power density is at least 2.5 watts/in.^{2}.

10. An apparatus for drawing wire to reduce its diameter comprising a fluid-tight tank, a plurality of dies mounted within said tank below the fluid surface-defining level of the tank, wire handling means associated with said tank including roller means disposed within said tank below said surface-defining level for passing a continuous wire through an ultrasonic treatment portion within said tank and directly thereafter through said dies,

said ultrasonic treatment portion having a length of at least twelve inches as measured along the wire path defined by the wire handling means and consisting of at least one ultrasonic transducer mounted on said tank and capable of delivering ultrasonic energy at a power level of at least 1 watt/in.^{2}, the said transducer having its effective surface extending over the entire ultrasonic treatment portion of the tank and spaced within six inches of the said wire path.

11. The apparatus of claim **10** wherein the said wire handling means is arranged to pass at least one wire sequentially through at least some of said dies certain of which have varying size.

References Cited

UNITED STATES PATENTS

2,638,207	5/1953	Gutterman	72—284

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