Oct. 21, 1969 CHIH-CHUNG WANG 3,474,009

PROCESS AND APPARATUS FOR THE PRODUCTION
OF ELONGATED METAL ARTICLES

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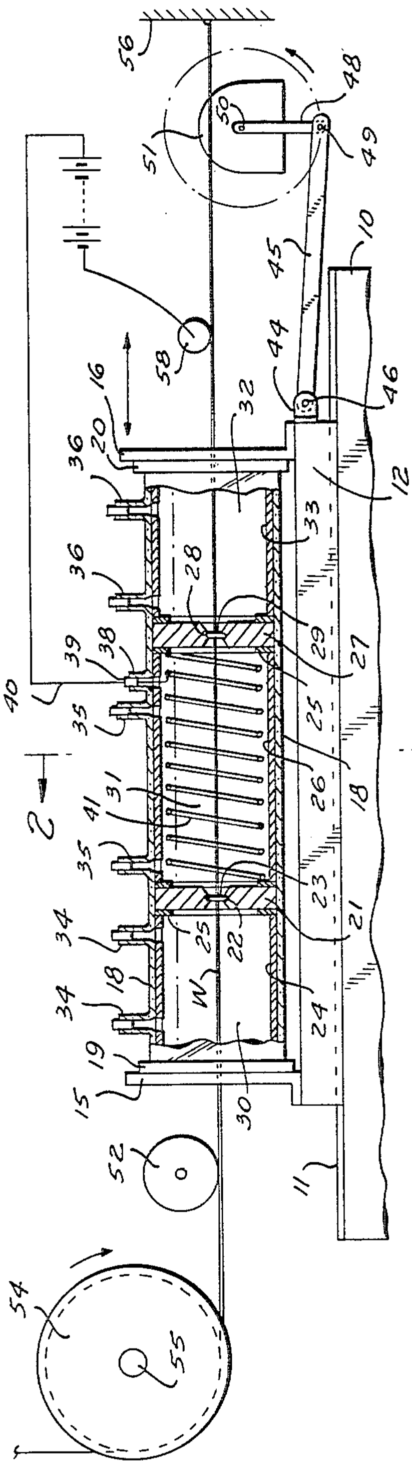

FIG. 1

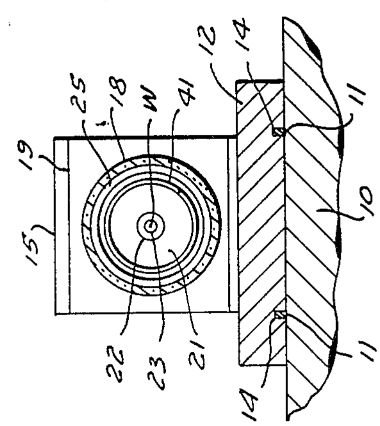

FIG. 2

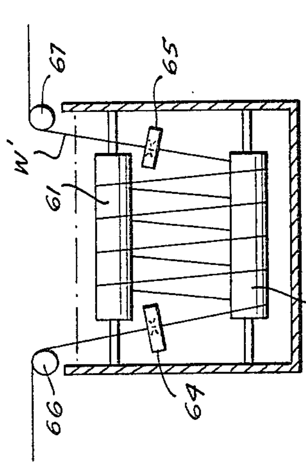

FIG. 3

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PROCESS AND APPARATUS FOR THE PRODUCTION OF ELONGATED METAL ARTICLES

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ABSTRACT OF THE DISCLOSURE

This disclosure relates to a method and apparatus for producing elongated metallic articles by simultaneous electrolytic deposition, reduction, and collection of the metallic article so produced. The electrolytic deposition is accomplished in an apparatus that provides lengthwise reciprocatory relative movement between a length of the elongated metallic article and a bath of an electrolyte. A pair of dies disposed at the ends of the electrolyte bath continuously reduce the elongated metallic article while a takeup reel collects the increments of additional elongated metal articles produced.

This invention relates to processes and apparatus for the production of elongate metal articles, such as wire, and to the products produced by the processes and apparatus. More particularly, the invention is concerned with processes and apparatus for the production of fine copper wire, and with the wire itself.

At the present time, commercial production of metal wire, including copper wire, is accomplished mechanically. In the production of copper wire, for example, an ingot or wirebar of copper, of the desired grade, is worked mechanically through successive reductions, until eventually a wire of the desired diameter is obtained.

The repeated drawings that are required constitute an appreciable item of cost in the production of the wire. For very fine wire, this cost factor assumes increasing importance, especially because breaks in the fine wire, that occur during the manufacturing process, not only make the manufacturing process difficult, but also add substantially to the cost involved.

There have been proposals in the past to avoid these mechanical costs by the production of wire electrolytically. In general, such proposals have involved the use of a starter wire that was passed lengthwise through an electrolyte bath, in one, consistent direction. An electrolytic deposit of metal on the wire, during its passage through the bath, increased the diameter of the wire. The enlarged diameter wire was passed through a die or the like to reduce its diameter and simultaneously to increase its length. A portion of the wire thus produced was returned through the process as the starter wire.

A number of drawbacks are inherent in any such process, and perhaps have accounted for the failure of such processes to have current commercial stature. These include, for example, the need for cleaning the starter wire. Due to this requirement the practice of the process would require, for economy, as thick a layer of deposited copper as possible. This causes dendritic growth and the deposit is usually poor. Deposition of a thin layer would require more frequent cleaning and would increase the cost to the extent of being economically unattractive.

One object of the present invention is to provide new, practical processes and apparatus for the production of elongate metal articles such as, for example, metal wires, and particularly, fine metal wire.

A more specific object of the invention is to provide a new and practical process for the production of fine copper wires, particularly magnet wire.

A related object of the invention is to provide a new and practical process for the production of fine diameter copper wires that are characterized by physical and chemical properties that are equivalent to or superior to those of copper wire produced by conventional techniques.

Still another object of the invention is to provide an electrolytic wire production technique whose characteristics are such as to permit the use of high current densities, whereby attractive rates of wire production may be attained.

Other objects of the invention will be apparent hereinafter from the specification and from the recital of the appended claims.

In the drawings:

FIG. 1 is a fragmentary, schematic, vertical section of apparatus for carrying out the process of the present invention in accordance with one preferred embodiment thereof;

FIG. 2 is a fragmentary section taken on the line 2—2 of FIG. 1 looking in the direction of the arrows; and

FIG. 3 is a fragmentary, schematic vertical section of other apparatus for carrying out the process of the present invention, in accordance with another preferred embodiment thereof.

In practicing the process of the present invention in accordance with the one preferred embodiment thereof can be practiced with the apparatus that is shown in FIG. 1, wire is produced on a continuous basis. A lengthwise reciprocatory relative movement is established between a length of wire and a bath of an electrolyte, and metal is deposited upon the wire electrolytically from the bath. As metal is deposited on the length of wire in the bath, the diameter of the wire is enlarged. A pair of dies, that are disposed at the opposite ends of the bath respectively, continuously reduce the diameter of the wire, thereby simultaneously increasing its length. The wire is maintained under continuous tension, as by a takeup reel that is mounted at one side of the electrolyte bath, and that is driven by a constant torque motor. The takeup reel withdraws from the bath the increments of additional wire length that are produced.

Referring now in detail to the drawings by numerals of reference, the numeral **10** denotes a base upon which a pair of guide rails **11** are disposed in parallelism. A carriage **12** is mounted for sliding movement over the surface of the base **10**. The carriage **12** is formed with a pair of lengthwise-extending grooves **14** in its lower surface. The rails **11** engage in these grooves **14**.

A pair of brackets **15** and **16** are mounted on the upper surface of the carriage **12**, at its opposite ends respectively. A cylinder **18**, preferably made of glass or other inert material, is disposed to extend between the two end brackets, and a pair of resilient discs **19** and **20** are interposed between the opposite ends of the cylinder **18** and the end brackets **15** and **16** respectively, to seal the ends of the cylinder. The left end bracket **15**, and its associated sealing ring or disc **19**, are formed with registering small openings through which a wire W can pass in operation of the device. The right end bracket **16** and its associated sealing disc **20** are similarly formed with registering openings through which the wire can pass. The openings in the sealing discs **19** and **20** are preferably sufficiently small so as to engage the wire W resiliently, to form seals about the wire.

A ring-shaped die **21** is mounted within the cylinder **18** intermediate the midpoint of the cylinder and its left end. A diamond or other hard insert **22** is disposed within the die **21**, and is formed with a center aperture **23** through which the wire is passed. A sleeve **24** is disposed within the cylinder **18**, to serve as a spacer for the die **21**. A pair of washers are disposed at each side of the die ring **21**, to serve as cushions. A second spacer sleeve **26** is disposed centrally within the cylinder **18**, to secure the die ring **21** firmly in place.

The die aperture **23** is disposed in registry with the other apertures in the equipment through which the wire must pass, such as, for example, those in the end brackets **15** and **16**. It is sufficiently small so that the wire is snugly engaged, to provide a seal about the wire.

The die ring **21** effectively divides the interior of the cylinder **18** into separate compartments on each of its sides.

In a similar arrangement, a second die ring **27** is disposed intermediate the right end of the cylinder **18** and its midpoint, further separating the interior of the cylinder into compartments, on each of its sides. The second or right die ring **27** is formed in a manner similar to the left die ring **21**, i.e., with a diamond or other hard insert **28** that has a center aperture **29** through which the wire is passed. A spacer sleeve **33** is disposed within the cylinder, to retain the die ring **27** in position, and a pair of washers **25** are interposed between the die ring and the spacer sleeves **26** and **33** respectively.

The interior of the cylinder **18** is thus divided into three compartments, which are identified hereafter as compartment **30**, **31**, and **32**.

The cylinder **18** is also formed with a pair of ports **34** that provide an inlet and an outlet for the left compartment **30**; and with a pair of ports **35**, that provide an inlet and outlet for the middle compartment **31**; and with a pair of ports **36** that provide an inlet and outlet for the right compartment **32**. The cylinder is also formed with an additional port **38** in which a stopper is disposed as a seal. An electrical contact wire **40** is passed through the stopper **39** into the middle compartment **31**, where it makes electrical contact with a helical wire **41** that serves as the anode. The spacer sleeves **24**, **26**, and **33** are formed with openings that register with the ports in the cylinder **18**, respectively.

A bracket **44** is secured to the right end of the base **12**. One end of a drive rod **45** is pivotally secured to this bracket **44** by a pivot pin **46**. The other end of the drive rod **45** is pivotally secured to a crank arm **48** by a pivot pin **49**. The crank arm **48** is secured to the drive shaft **50** of an electric motor **51**.

At the left side of the base **10**, a tension wheel **52** is disposed. This wheel is maintained motionless and thus friction between the wheel and the wire creates a tension in the wire when the carriage is moving toward the right. Close by this tension wheel, a take-up reel **54** is mounted. This reel is detachably secured to a shaft **55** that is driven by a constant torque electrical motor (not shown). The take-up reel is driven in a clockwise direction relative to FIG. 1, as indicated in the drawing by the arrow.

The wire W is anchored at its right end to a fixed support **56**, and is passed through the end openings in the right end bracket **16** and right sealing disc **20**, through the right compartment **32**, the aperture **29** in the die ring **27**, the middle compartment **31**, the opening **23** in the die ring **21**, the left compartment **30**, the registered openings in the left sealing disc **19** and the left end bracket **15**, under and against the tension wheel **52**, and about the take-up reel **54**.

To practice the process of the present invention, to make a fine copper wire, an initial section of clean, fine copper wire W is anchored at its right end, threaded through the apparatus, is engaged against the tension wheel **52**, and is secured at its left end to the take-up reel **54**. The middle compartment **31** is filled with an acidic solution of copper sulfate. The end compartments **30** and **32** may be left empty or may be filled with de-oxygenated water or other solution, as a wash, which may be circulated, if desired. A D.C. voltage is applied by making an electrical contact with the wire W, for example, through a trolly **58** and/or the tension wheel **52**, using the wire W as the cathode. The other electrical contact is made with the wire **40**, to use the helical wire **41** as the anode. For present purposes, the helical wire **41** may be made of some inert metallic material such as, for example, platinum or the like.

The electric motor **51** is then operated to drive the crankarm **48** in a counter-clockwise direction. Rotary movement of the crankarm **48** is transmitted to the carriage **12** through the drive rod **45**, and causes the carriage **12** to move back and forth over the surface of the base **10**. Copper is continuously deposited electrolytically on the length of wire within the middle compartment **31**. The length of stroke of the carriage **12** is approximately equal to or slightly greater than the length of the length of wire within the middle compartment **31**, plus the increment of additional length that is produced by the simultaneous reduction and elongation that occurs. As the carriage **12** moves to the left, the enlarged diameter wire, that has been formed within the electrolytic cell, is reduced in diameter as it passes through the opening in the die ring **27**. Thereafter, when the carriage **12** reverses its direction of movement, and begins to travel to the right relative to FIG. 1, the enlarged diameter wire is reduced in diameter as it passes through the opening in the die ring **21**.

As the wire is reduced in diameter, its length is simultaneously increased. Since the wire is held under tension by the tension wheel **52** and by the action of the take-up reel **54**, as the length of the wire is increased, the incremental increases in wire length are taken up on the take-up reel **54**, as a product.

Preferably, fresh electrolyte is continuously circulated through the inlet and outlet ports **35** of the middle compartment **31**, during operation. The die rings **21** and **27**, in addition to reducing the diameter of the wire, have the additional advantage of forcibly removing spent electrolyte from the surface of the wire, and preventing polarization at the cathode surface, thus permitting the use of high current density.

Another advantage of the repetitive reductions of the wire is that the surface of the wire is kept smooth so that undesirable dendritic formation is prevented.

EXAMPLE I

In one specific demonstration of the invention, for the production of copper wire, employing substantially the same techniques just described, the diamond drawing dies were designed to reduce the wire drawn to a diameter of 5.1 mils. Plating conditions and the speed of the apparatus were contrtolled so that one drawing pass was made whenever the deposit achieved a maximum thickness of 0.19 mil. This was approximately a 15% reduction for each pass. The electrolyte was continuously replenished, and wire was continuously produced and wound up on the take-up reel.

The electrolyte solution employed was a rather concentrated solution containing, in one liter of water, 272 grams of $CuSO_4 \cdot 5H_2O$ and 32.6 grams of H_2SO_4. No other agent was used in the electrolyte. A current density of approximately 165 amperes per square foot was employed.

The characteristics of the product compared favorably with those of electrolytic tough pitch copper wire, particularly with respect to flex strength, electrical conductivity, tensile strength, and elongation. In fact, the product obtained was superior in all of these respects to electrolytic tough pitch copper wire. The microstructure of the product revealed that the product was free from oxide inclusions.

The following wire characteristics were observed in the product, and are representative of the characteristics of other wire specimens produced in accordance with this invention:

Wire characteristics.—(After annealing for one hour at 500° C.)

Tensile strength	p.s.i.	34,000
Elongation	percent	36
Electrical resistivity	percent I.A.C.S.	102

EXAMPLE II

In another demonstration of the invention, the electrolyte was prepared with 400 grams of $CuSO_4 \cdot 5H_2O$ and with 96 grams of H_2SO_4 per liter of water. The electrolyte was maintained at a temperature of approximately 50° C., and the distance between the helical wire anode 41 and the wire W cathode was approximately 1 cm.

The reciprocatory speed of the carriage was adjusted to provide two drawings every six seconds. The current density was varied to different levels, as high as 1,000 amperes per square foot. The product obtained was uniformly either the equivalent of or superior to electrolytic tough pitch copper wire.

GENERAL

Various modifications can be made in the apparatus and in the process.

For example, instead of using a closed cylindrical container for the electrolyte, a simple channel, that is open at the top, may be used, in a minor departure or modification of the apparatus that has been described.

While the use of rinsing baths is desirable, they are not absolutely essential for the production of copper wire, and the two end compartments for the rinsing baths could be omitted, therefore, in some cases. If diamond dies are employed, the dies can be relied upon the function as the end seals. The end compartments **30** and **32** are useful, however, where it is desirable or essential that the exposed metallic surfaces, that are to be returned into the electrolyte bath, be maintained in an inert atmosphere until such time as they are no longer to be exposed to further plating action. This is usually the case when the wire is being produced from some metal other than copper. In such a case, the end compartments may be filled with either an inert gas or an inert liquid such as, for example, distilled water.

In another mechanical modification of the apparatus for the performance of the process of the present invention, take-up reels and tension wheels are mounted at each end of the equipment. Each was provided with a constant torque motor drive, to maintain the wire under constant tension, by forces applied equally at both ends of the wire. In this case, the product wire was collected on both take-up reels.

Where the electrolyte bath is reasonably short in extent, the wire will not sag between the dies. However, for commercial installations, where a long length bath may be desired, one or more additional dies, operative in one or in both directions, may be inserted within the electrolyte compartment, both to support the wire and to provide additional drawing and wiping action.

It is also contemplated, as shown in FIG. 3, that a long length of wire W can be wound serially about a pair of driven rollers **60** and **61**, so that a long length of the wire is submerged in the bath of electrolyte. In such an installation, two or more dies **64**, **65**, are disposed to achieve the desired reduction in each direction. Electrical contact with the wire is made through one or both of a pair of guide wheels **66**, **67**, or in any other convenient manner. The anode (not shown) may be an inert or a soluble anode.

The wiping action that is produced by the dies is an important factor in permitting high current density and good efficiency. Further efficiency can be achieved, and higher current densities can thus be permitted, where some form of mixing or turbulence is provided within the bath, so as constantly to bring fresh electrolyte into contact with the surface that is being plated.

Ordinarily, the preferred mode of operation is to use rinsing baths, and to provide that the length of wire in each bath (at the opposite respective ends of the electrolyte bath) is greater than the length of wire drawn into the rinsing bath on each pass. This insures that the wire that emerges from a rinsing bath will not again enter the electrolyte bath, thus preventing any possible detrimental action by the atmosphere on the surface of wire that is to be plated.

Among the advantages of the present process are that very high current densities can be employed, since there is no dendritic formation, and that indefinite deformation without annealing is possible. Another very important advantage is that addition agents such as glue need not be employed in the electrolyte bath, probably because of the absence of dendritic formation. The absence of such addition agents improves the purity of the product and, because the cell voltage can be reduced, permits greater operating efficiencies.

Important advantages accrue from the fact that the drawing dies are in contact with the plating solution. One such advantage is that the dies can serve as very effective seals about the wire at the places where it enters and leaves the plating solution. Another important advantage is that this arrangement permits utilization of the plating solution as a lubricant for drawing, although at the same time the dies remove depleted plating solution efficiently and thus make the metal deposition phase of the process efficient. A further advantage accrues from the use of the dies as dividers or separators, between the plating solution and the distilled water or other inert or rinsing material, is that no cleaning is necessary before additional metal can be deposited on the metal, since drawing takes place in a protected environment rather than at a separate drawing station that is exposed to the atmosphere.

While practice of the process using an insoluble anode has been described, a soluble anode of copper or other metal can be used. For high volume production of wire in accordance with this invention, it is anticipated that a copper anode would ordinarily be used.

The invention has been described in detail in connection with the production of fine copper wire. However, it is equally applicable to the production of wires of other metals, such as, for example, iron and nickel.

Thick deposits or high current density can cause dendritic growth (or uneven surface), which is detrimental to the wire quality. It is desirable, therefore, to increase the cross-sectional area of the wire by only 5% to 10% before it is reduced by drawing through a die. By keeping this deposit layer thin, one can use a much higher current density and make the process more economically attractive. In fact, this is an important advantage of this process over others and was made possible due to the fact that no cleaning step between cycles is needed in this process. In other processes where cleaning is needed before each plating cycle a thicker deposit on the wire (eq. 30% increase in cross-sectional area) is desirable for economic reasons. It is an important advantage of the present invention that the deposited layer, of copper, for example, may have a thickness of as little as or less than 0.0003″, that is formed between drawing steps. This insures against dendritic growth even when high current densities are used.

While I have described one particular form of apparatus for carrying out the process of the present invention, in which the electrolyte and dies are mounted for movement as a unit relative to the wire, this arrangement represents only one embodiment of an important principle of the present invention, that there be reciprocatory relative movement between the wire and the electrolytic deposition zone. Accordingly, it is equally possible to practice the invention with apparatus in which the electrolytic cell is stationary, and the two take-up reels, at opposite sides of the cell, are caused to reciprocate as a unit. It is also contemplated that both the take-up reels and the electrolytic cell can be mounted for movement, to provide the desired relative reciprocal movement of the wire relative to the cell and its associated dies.

Once a clean starter wire has been threaded through the apparatus and the process has been started, no additional starter wire need ever be employed, for the practice of the same process. It is simply necessary to take off full reels of product wire from time to time, while continuing the practice of the process. The process itself continuously renews the wire upon which further deposits are made, and the problem of cleaning the starter wire surface is thus avoided and eliminated.

While the invention has been disclosed herein by reference to the details of preferred embodiments thereof, it is to be understood that such disclosure is intended in an illustrative, rather than a limiting sense, and it is contemplated various modifications in the construction and arrangement of the parts of the apparatus, and in the practice of the process, will readily occur to those skilled in the art, within the spirit of the invention and the scope of the appended claims.

I claim:

1. A process comprising the steps of:
maintaining a length of an elongate metallic base member submerged in an electrolyte in an electrolytic bath, with a portion of said member projecting from the bath;
providing anode means in electrical contact with said bath;
establising electrical contact with said projecting portion of the base member, to permit the submerged length thereof to serve as the cathode;
energizing said anode and cathode and electrolytically depositing metal on the submerged portion of said member;
subjecting said member to the action of die means that are in contact with said bath, to effect reduction in the cross-section thereof with simultaneous increase in length, to produce incremental additional lengths of said member as a product, and
causing reciprocatory relative movement between said base member and said bath, and wherein said reduction and elongation step involves passing said base member first in one direction, then in the opposite direction, through said die means.

2. A process in accordance with claim 1 wherein the electrolytic deposit upon the wire is sufficient to increase the cross-sectional area of the wire up to about 5% before reduction.

3. A wire-forming process comprising the steps of:
maintaining a length of a metallic wire in an electrolytic bath from which metal can be deposited on the wire electrolytically;
establishing and maintaining a reciprocatory lengthwise relative movement between the length of wire and the bath of electrolyte;
electrolytically depositing metal on the wire in said bath, to enlarge its diameter;
subjecting said wire over said length thereof to reduction first in one direction along its length, while continuing the electrolytic deposit of metal on the wire, then in the opposite direction along its length, thereby reducing its diameter and simultaneously increasing its length, to produce incremental additional lengths of wire, and
withdrawing the incremental lengths of wire from the bath for collection as a product.

4. A proces in accordance with claim 3, including the additional step of maintaining at least one inert zone adjacent the electrolytic bath, into which the wire passes directly from the electrolytic bath.

5. A process in accordance with claim 3, wherein the electrolytic deposit upon the wire is sufficient to increase the cross-sectional area of the wire up to about 10% before reduction.

6. A process in accordance with claim 3, including the additional step of taking up the incremental wire lengths produced, by movement of the wire along its own length.

7. A process in accordance with claim 6, wherein the take-up is in one direction only.

8. A process in accordance wtih claim 6, wherein the take-up is in two opposite directions, both lengthwise of the wire.

9. A process in accordance with claim 5 wherein the wire produced is a copper wire, and wherein the electrolyte consists essentially of an acidic solution of copper sulfate.

10. A wire-forming process comprising the steps of:
maintaining a substantially constant length of a metallic wire in an electrolytic bath from which metal can be deposited on the wire electrolytically;
electrolytically depositing metal on the wire in said bath, to enlarge its diameter;
passing said wire, at least over a substantial portion of its said length, through at least one die that is in contact with the electrolyte, to reduce the diameter of the wire first in one direction along its length, while continuing the electrolyte deposit of metal on the wire, then in the opposite direction along its length, to reduce its cross-sectional area while simultaneously increasing its length to produce incremental additional lengths of said wire as a product, and
collecting the incremental wire lengths.

11. A process in accordance with claim 10, wherein said reduction step comprises passing said wire through at least one pair of one-way, opposite-acting dies, each of which is in contact with the electrolyte.

12. A process in accordance with claim 10, including the additional step of causing reciprocatory relative movement between said wire and said bath.

13. Apparatus for producing a metallic article by electrolytic deposition, comprising:
an electrolytic cell adapted to contain an electrolyte from which a metal can be deposited electrolytically;
means for maintaining a length of an elongate metallic base member submerged in the electrolyte in said cell with a portion of the member projecting from said cell;
anode means disposed in said cell in electrical contact with the electrolyte;
means for establishing electrical contact with the projecting portion of said member to permit the submerged length of said member to function as the cathode;
die means disposed in said cell in contact with the electrolyte;
means for passing said base through said die means, following enlargement of the cross-sectional area thereof, for simultaneous reduction and elongation, to produce additional lengths of said member as a product, and
means for causing reciprocatory relative movement between said base member and said die means, to cause reduction and elongation to occur first in one direction, then in the opposite direction.

14. Apparatus for producing a metallic article by electrolytic deposition comprising:
an electrolytic cell adapted to contain an electrolyte from which a metal can be deposited electrolytically;
means for supporting a length of a metallic base member in the electrolyte in said cell;
means for making electrical contact with said base member whereby it can serve as a cathode in the electrolyte in said cell;
anode means disposed within the electrolyte in said cell;
means for subjecting said base member over said length thereof to reduction first in one direction along its

length, then in the opposite direction along its length, thereby to reduce its cross-section and simultaneously to increase its length, to produce incremental additional lengths of said member as a product; and

means for removing the incremental lengths thus produced from said cell.

15. Apparatus in accordance with claim 14 including means for causing reciprocatory relative movement between said base member and said cell.

16. Apparatus in accordance with claim 15 in which said means for subjecting the base member to reduction comprises at least one die that is disposed in said cell in contact with the electrolyte.

17. Apparatus in accordance with claim 16 wherein said base member is a wire, and wherein said means for subjecting the wire to reduction comprises at least one pair of dies that are fixedly supported in said cell in contact with the electrolyte and that are disposed to reduce the diameter of the wire upon relative movement between the wire and the dies in opposite directions respectively.

18. A wire product produced according to the process of claim 1.

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