March 5, 1957 A. KORBELAK ET AL 2,784,154

ELECTROLYTIC WIRE REDUCING APPARATUS AND METHOD

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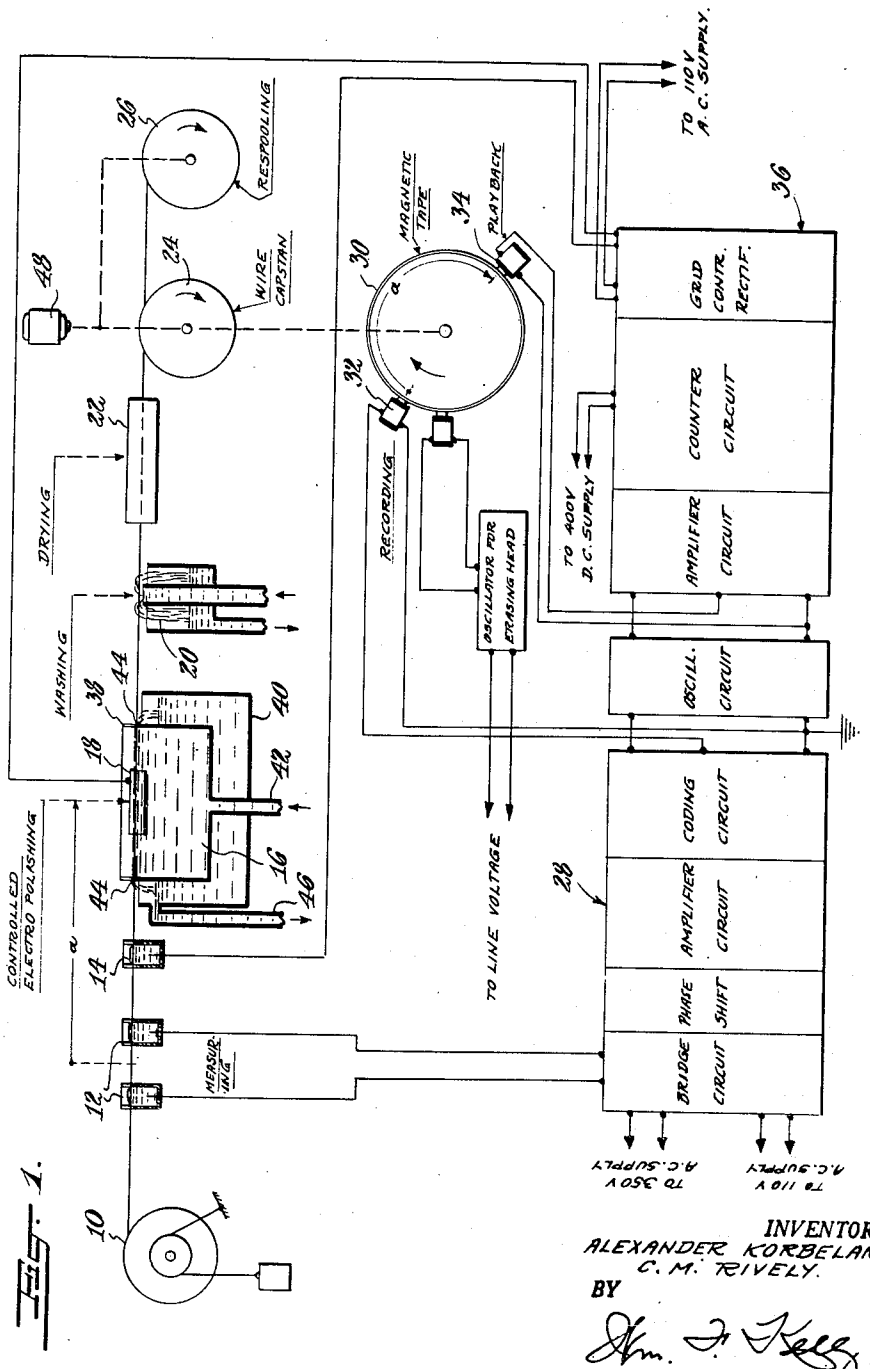


Fig. 1.

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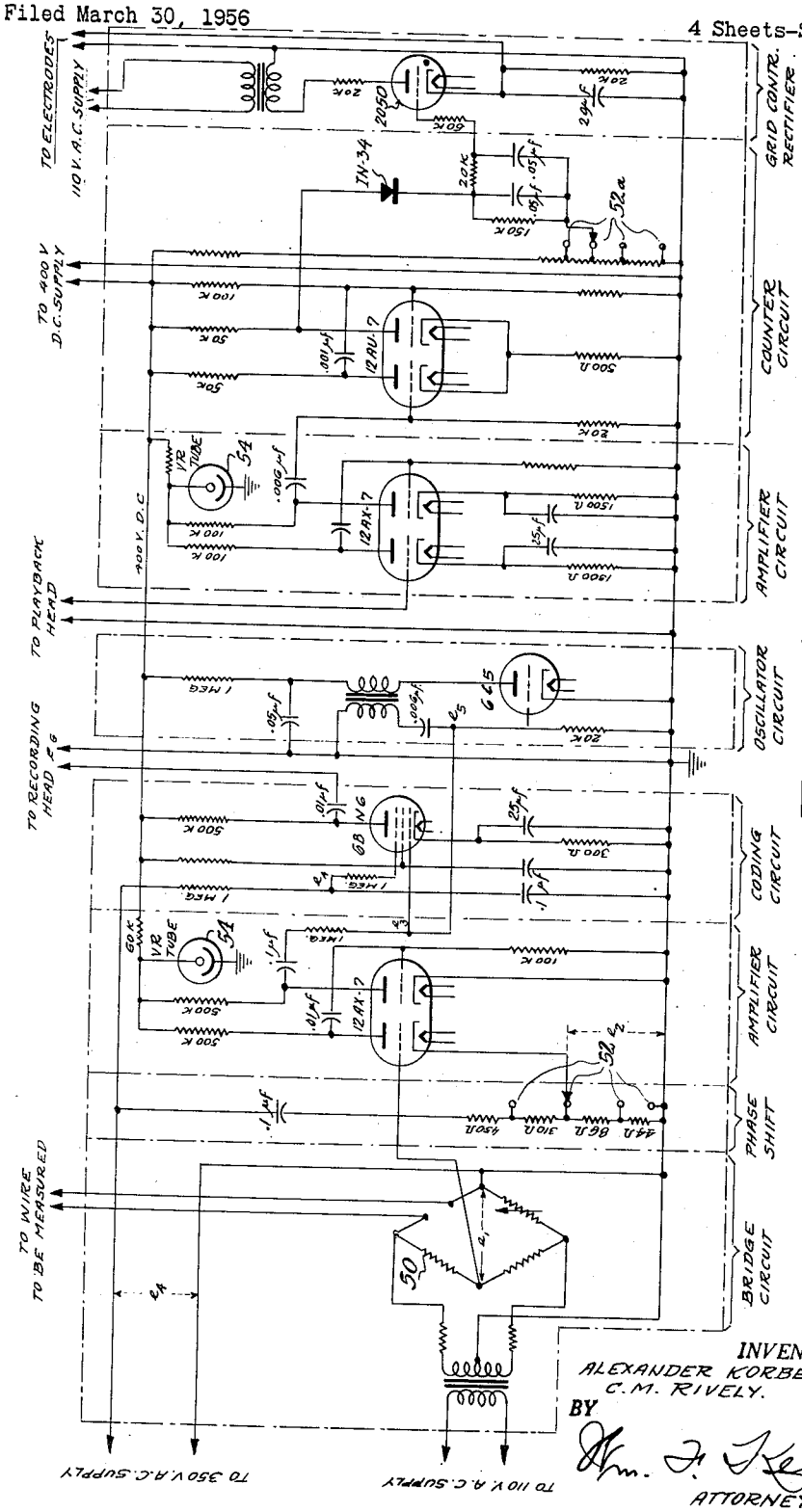


FIG. 2.

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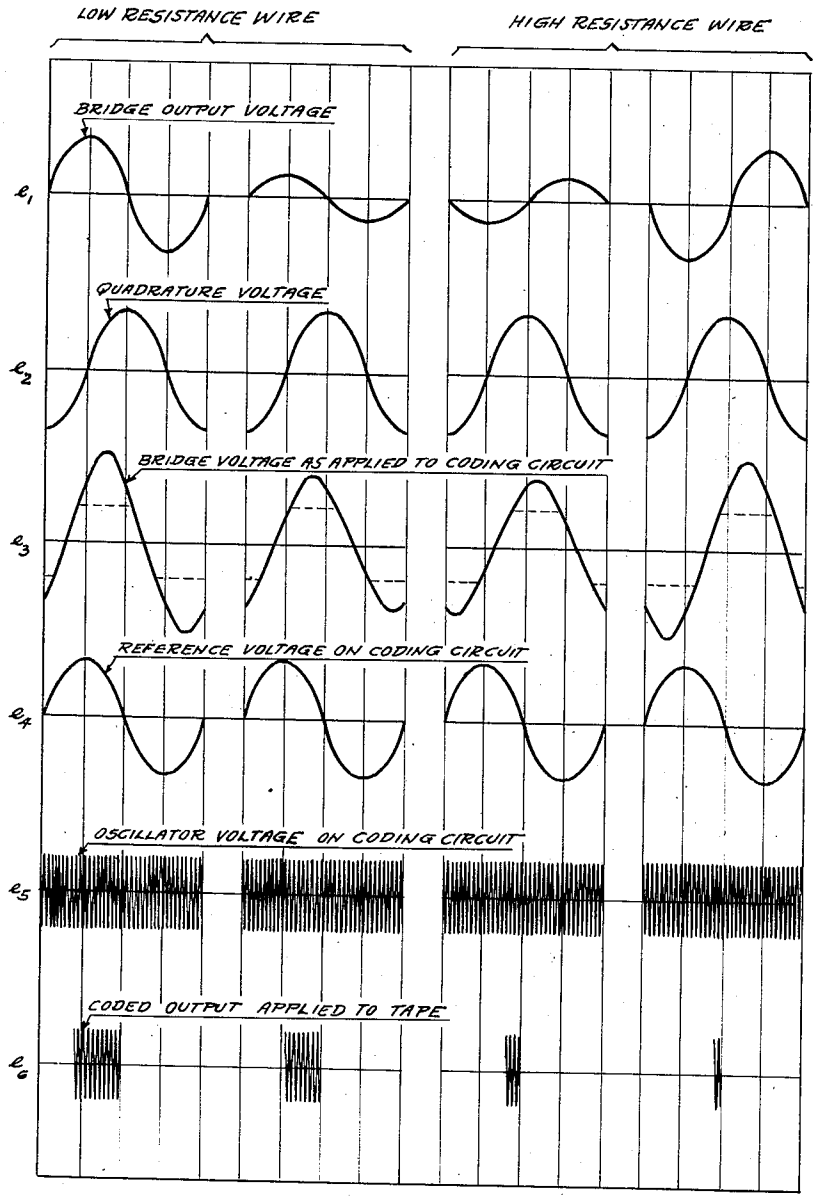
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Fig. 3.



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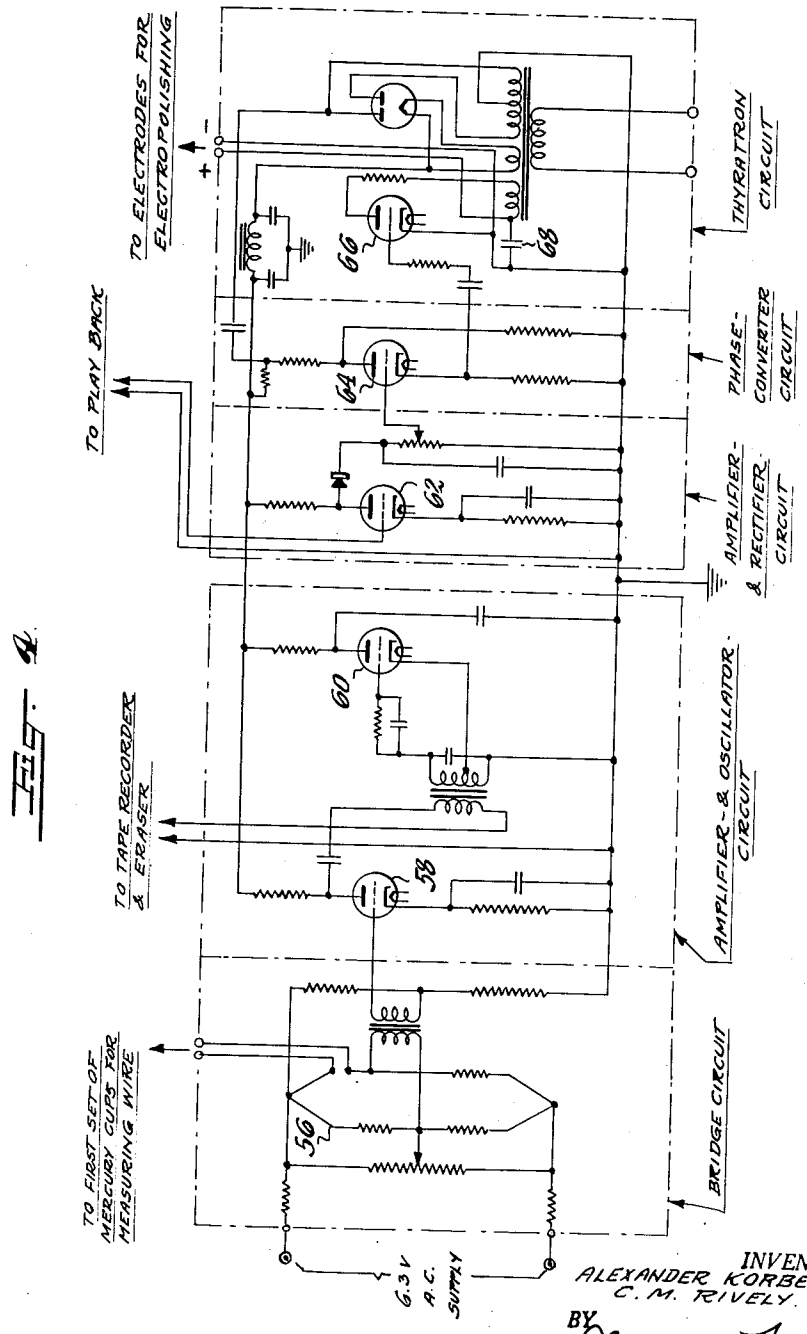


Fig. 4.

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2,784,154

ELECTROLYTIC WIRE REDUCING APPARATUS AND METHOD

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Application March 30, 1956, Serial No. 575,060

6 Claims. (Cl. 204—141)

This invention relates to the manufacture of fine wire and, more particularly, to a method and apparatus for electrolytically manufacturing ultra-fine wire and is a continuation-in-part of application Serial No. 267,151, filed January 18, 1952, now abandoned, titled "Reducing Apparatus and Method" by Korbelak & Rively, the co-inventors herein, and owned by the present assignee.

The production of fine wire and strip with a substantially uniform cross-section or thickness has for many years been the goal of the wire industry. It is particularly the concern of the producers of electric lamps since any so-called necked-down or non-uniform portions of the tungsten wire filament causes the filament to operate hotter and thus vaporize faster than adjacent heavier sections of the wire, thus shortening the lamp life. The electronic industry is also concerned with uniform, fine wire, particularly in new miniaturization developments, which have resulted in tighter standards. There are three common methods of producing fine wire, namely (1) drawing the wire through a series of diamond dies, (2) chemical dissolution and (3) electropolishing. In drawn wire, the resulting cross-sectional area is affected by varying die temperatures during the drawing operations, non-uniform hardness of the wire being drawn, die wear and die imperfections which result in irregularities in the finished wire. Also, when drawing ultra-fine wire the problem of strand breakage becomes acute. In chemical dissolution, the metal is etched to dissolve a portion of the wire. An etch may consist of a mixture of molten sodium nitrate and sodium nitrite for example, but the method of chemical dissolution has been found to be slow, hazardous and expensive. Electropolishing is a destructive method in which a portion of the wire is dissolved and this has been known in the practices of prior art. In both the electropolishing and chemical dissolution methods, however, an even amount of surface material is removed from the wire so that any imperfections, which may have been drawn into the wire during the wire drawing process preceding the electropolishing, are continued thus resulting in wire of non-uniform cross-sectional area. It should be understood that electropolishing and chemical dissolution can only be used economically for very fine wire or strip since it is a destructive method and where larger sizes of wire, such as those having a diameter of 0.005" or larger are concerned, standard wire drawing methods are normally quite adequate.

In order to avoid and overcome the foregoing and other difficulties of prior art practices, it is the general object of this invention to provide a method and apparatus for reducing wire size to a uniform diameter by electrolytic action, which method and apparatus will also produce such wire without the problem of strand breakage during reduction.

Another object of the invention is to provide a method and apparatus for reducing to a substantially uniform thickness, a strip of very fine metal.

The foregoing objects of the invention and and other

objects which will become apparent as the description proceeds are achieved by measuring on a continuous basis the average electrical resistance of individual portions of the wire to be reduced. These measured portions are then passed through an electrolytic bath, in which bath the measured wire constitutes the anode. Reducing current through the bath and varied in accordance with the measured average electrical resistance of that segment of the wire which is undergoing reduction. Thus, the smaller the average measured electrical resistance for the portion of wire which is in the bath, the greater the wire diameter and the greater the reducing current.

For a better understanding of the invention, reference should be added to the accompanying drawings wherein:

Fig. 1 is a cross-sectional elevation of an electrolytic wire reducing apparatus showing associated therewith, in block diagram, the wire diameter measuring means and electrolytic bath current-controlling means used to control the cross-sectional area of the reduced wire;

Fig. 2 is a circuit diagram for the wire electrical-resistance measuring means and current-controlling means, as shown in black diagram in Fig. 1;

Fig. 3 is a chart showing the phase relationships of certain critical voltages generated in the measuring and control circuit of Fig. 2;

Fig. 4 is a circuit diagram for an alternative embodiment of the wire electrical-resistance measuring means and current-controlling means.

Although the principles of the invention are broadly applicable to reducing the cross-sectional area or thickness of ultra-fine wire or strip, the invention is usually employed in conjunction with the reduction of ultra-fine wire to uniform cross-sectional area, and hence it has been so illustrated as will be so described.

With specific reference to the form of the invention illustrated in the drawings, the electrolytic reducing apparatus is illustrated in Fig. 1, and generally comprises a supply spool 10, electrical-resistance-measuring mercury cup electrical contact 14, electrolytic reducing bath 16, which includes bath reducing electrode 18, water wash bath 20, infrared wire drying means 22, driving capstan 24 and wire rewinding spool 26. It will be noted that from the supply spool 10 to the wire rewinding spool 26, the wire is passed through the reducing apparatus in a straight-line pass, which minimizes stresses which might cause strand breakage.

The wire electrical-resistance-measuring cups 12 are connected to the input of an electrical resistance measuring and electrical signal means 28 which is shown in block diagram in Fig. 1 and which consists of the electrical-resistance-measuring bridge circuit and the phase shift circuit, amplifier circuit, coding circuit and oscillator circuit, which generate an electrical signal corresponding to the bridge output. The output of this measuring and signal means is placed upon a magnetic tape 30 which preferably takes the form of a drum type recorder. This drum-type magnetic tape recorder 30 revolves at a rate which is the same as the rate at which the wire is passed through the bath and the peripheral distance between the recording head 32, which receives the output of signal means 28, to the play-back head 34 is the same as the average distance (a) between the mercury contact measuring cups 12, and the electropolishing electrode 18, which is positioned within the bath 16. Thus the signal which is placed upon the magnetic tape 30 by the recording head 32 is delayed in response until that portion of the wire which has been measured in centered over the electropolishing electrode 18 and the impressed signal is under the play-back head 34. The signal which is received by the play-back head 34 is fed into a bath current-controlling means 36 which is indicated in block diagram in Fig. 1, and which consists of the amplifier circuit, counter circuit

and grid-controlled rectifier. The output of this bath current-controlling means is electrically connected to the electrolytic bath, through the mercury cup contact **14** and electrode **18**.

The mercury contacts **12** which effect electrical contact between the wire being measured and the bridge circuit are preferably spaced apart a distance which is substantially equal to the dimension of electropolishing electrode **18**, in order that an equivalent length of wire be measured as will be reduced. The mercury contact for the electropolishing bath **14** serves to effect electrical connection between the wire which is to be reduced and the bath current-controlling means **36** and is electrically connected to the positive side of the grid-control rectifier shown in block diagram in Fig. 1. These mercury cups may be fabricated of methyl methacrylate and are designed so as to permit the wire passing therethrough to remain as deeply as possible in the mercury, thereby minimizing the affect of surface turbulence.

The electrolytic reducing bath **16** may take various forms, but preferably constitutes a dual tank design wherein the reducing or inner tank **38** is encased by an outer or storage tank **40**. Electrolyte is continuously supplied to this inner tank **38** by supply connection **42** and the electrolyte overflows inner tank **38** through apertures **44**, provided just above the level of the wire in the reducing bath. The overflowing electrolyte then spills into the outer tank **44** and thence to the overflow pipe **46** from where the electrolyte may be reused. Various types of electrolyte solution may be used but, as a specific example, a solution which has proved to be very good is trisodium phosphate maintained at a concentration of 160 grams per liter plus or minus 10%. The best operating temperature for this electrolyte at the specified concentration was found to be 110° F. plus or minus 5° F. It should be realized that this electrolyte and these operating temperatures are only given by way of a specific example and not by way of limitation. As noted, the electrolytic bath, wire contacting mercury cup **14** and electrode **18**, are connected to the output of the grid-controlled rectifier in order to effect a wire reduction, as will hereinafter be explained more fully.

The water wash tank **20** is of conventional bubbler-overflow design and is intended to remove any electrolyte which remains on the reduced wire. The drying means **22** may be of an electric-infrared type, or any other type of suitable dryer, in order to remove the water from the wire.

The wire capstan **24** and wire rewinding spool **26** are both driven by a motor **48** and, for the specific embodiment as given, a wire speed of 200 meters per hour has been found to be very satisfactory. The motor and associated capstan and spool thus constitute a wire advancing means to advance the wire through the entire reducing operation. The magnetic tape is also geared directly to the motor drive so that the tape speed and wire speed will be substantially the same. It is preferred that the motor **48** be a constant speed type so that the wire speed and recorder speed is constant. However, it is possible that a variable speed motor may have some utility for some applications. In such an embodiment, the operation would remain unchanged for speed variations in the wire would be compensated for by corresponding speed variations in the recorder drum **30**.

In Figs. 2 and 3 are illustrated the measuring-signal circuit means and the bath current-controlling means and the voltages which are shown in Fig. 3 are critical voltages appearing at portions of the circuit of Fig. 2, as will be explained more fully. It should be understood that all A. C. supplies to the circuit in Fig. 2 are from a common source so that all individual A. C. power supplies will be in phase.

In the operation of the electropolishing unit, the average electrical resistance of the wire which is between the measuring cups **12** forms one leg of the Wheatstone bridge **50**. The bridge has two fixed resistive legs, a third leg comprising the wire increment being measured and a fourth leg comprising a potentiometer which is set to the center or desired value of resistance of the wire to be measured. The output of the bridge will thus vary both in phase and amplitude and if the wire which is to be reduced is greater in diameter than desired, a low average resistance value will be measured and the bridge output voltages will be as indicated at "e_1" left-hand side, of the phase chart of Fig. 3. If the wire resistance is greater than that value which has been decided upon as desired, the phase relationship will be reversed and as indicated on the right-hand column of the phase chart in Fig. 3 and designated "e_1." The output of the bridge is applied across the first section of the 12AX7 amplifier tube. A quadrature voltage is applied to the cathode of the first section of this amplifier tube, which quadrature voltage is indicated as "e_2" in Fig. 3. This phase shift is effected by the R. C. circuit formed by the 450 ohm, 310 ohm, 86 ohm and 44 ohm resistances and the 0.1 microfarad condenser. The voltage taps designated **52** are provided to vary the percent or ratio of possible reduction in the wire by varying the amplitude of the quadrature voltage which is added to the output of the bridge. It should be noted that while the quadrature voltage is applied to the cathode of the amplifier tube, the effect is the same as if it were applied to the grid along with the bridge output voltage "e_1." The voltage regulator tubes designated **54** serve as decoupling circuits as is usual on multistage amplifiers with a common power supply.

The bridge output voltage "e_1" and quadrature voltage "e_2" are added and then amplified by the two stages of the first 12AX7 amplifier tube. Only the phase variable of these added signals designated as "e_3" is used since the amplitude variable is clipped off by driving the second 12AX7 to saturation at the amplitude peaks. This clipping is indicated by the dotted lines in the voltages designated "e_3" in Fig. 3.

A blocking oscillator designated 6C5 has an output frequency of 5 kilocycles. This output frequency is given by way of example and is not critical. The 5 kilocycles signals are indicated as "e_5" in Fig. 3. This "e_5" and the bridge output-quadrature voltage designated as "e_3" are applied to the grid of the 6BN6 gated beam type tube. The tube will have as its output the full amplitude of the 5 kilocycle signals of the blocking oscillator when both the reference voltage designated as "e_4" in Fig. 3 which is applied to the coding circuit, and the bridge output-quadrature voltage "e_3" are positive. The output of the gated beam type tube will be zero if either of the foregoing applied voltages are negative. This results in an output which is modulated at 5 kilocycles and is indicated as "e_6" in Fig. 3. The number of 5 kilocycle pulses per group thus varies as the average resistance of that portion of the wire which has been measured, the number of pulses being greater for a smaller resistance which indicates a larger wire diameter.

This output is then coupled to a recording and delay means, shown as magnetic tape **30** in Fig. 2. While any suitable type, commercially-available recording drum may be used, as a specific example, a Brush model BK603 recording rubber has been found suitable. This unit has a 5 inch diameter disc which has been found to be satisfactory. The standard erasing head and erasing oscillator available with this unit are shown only in block diagram since their design is well-known and their operation in this circuit is standard.

The recording drum **30** rotates to a clockwise fashion as viewed in Fig. 1 and the control signal from the coding circuit is applied to the recording head **32** as a series of pulses. When the recording drum rotates a distance equivalent to the average distance between the electrical contact measuring cups **12** and the electropolishing electrode **18**, the recorded signal will pass under the play-

back head 34 which picks up the pulses as recorded and applies same to the amplifier circuit consisting of the second 12AX7 tube in the bath current-controlling means 36. The amplified signal is applied to the grid of a counter unit which consists of the 12AU7 tube and the associated circuit elements. This 12AU7 tube and associated circuitry is essentially an Eccles-Jordan one-shot multivibrator. The 5 kilocycle signal is passed by the first section of the 12AU7 tube and the first 5 kc. pulse actuates the second section of the 12AU7 tube, which tube has an output of constant amplitude and duration. The output of this multivibrator is applied through an isolating rectifier designated IN34 to an R. C. circuit constituting the 150,000 ohm resistance and the .05 microfarad condensers paralleled thereacross. When the second section of the 12AU7 multivibrator conducts, the output serves to charge the 0.05 microfarad condensers and the amount of charge on these condensers determines the bias on the grid of the 2050 thyratron tube. Thus the bias on the thyratron tube grid is controlled by the number of times which the second section of the multivibrator fires to charge the 0.05 microfarad condensers and the number of 5 kc. pulses which trigger the 12AU7 tube varies according to the average measured resistance of the wire being reduced. It is noted that the even output of the 12AU7 tube is independent of any so-called "wow" in the recorder or memory system.

The 0.05 microfarad condensors charge to a voltage which is proportional to the number of pulses passed by the 12AU7 tube, which pulses are averaged or integrated when charging these condensors. While this charge is proportional to the desired reducing current, the power is very small and to increase the power a current amplifier system is used which incorporates the 2050 thyratron. The 20 microfarad condensor in the cathode circuit of the thyratron tube is sufficiently large that the electrolytic bath discharges it relatively slowly. Thus as the system operates, the 20 microfarad condensor assumes a charge which is proportional to the charge on the 0.05 microfarad condensors, the proportion depending on which of the taps 52ª is connected. Thus the grid-connected 0.05 microfarad condensors and the cathode-connected 20 microfarad condensor control the firing of the thyratron, and thus the reducing current.

The electrode 18 in the electrolytic bath is made the cathode, that is, it is connected to the ground in the circuit as shown and the mercury cup electrode designated 14 is made the anode. Thus the current will flow through the electrolyte in the etching bath between the wire adjacent to the electrode 18 and the electrode 18 itself. In the circuit as shown there will be one series of coding pulses for every A. C. cycle, that is, there will be one series of coding pulses every one-sixtieth of a second which will cause the thyratron to fire for varying periods of time sixty times per second.

The time constant of the 0.05 microfarad condensors and the 150 K. resistor are such that the condensors will substantially discharge between each series of coding pulses. The taps designated 52*a* correspond to the taps designated 52 and are correspondingly adjusted according to that percent or ratio of wire reduction which is to be effected, that is, whether imperfections in the wire are 5% or 50% of its diameter, for example.

In the described reducing apparatus, the measured length of wire, that is the distance between the cups 12, may be varied between wide limits, for example between 4 and 200 mm. and as shown the distance between the cups 12 and the dimension of electrode 18 are set for measuring and reducing a length of 50 millimeters. It is desirable that the measured and reduced lengths be as short as possible in order to compensate for a short length of oversize wire, for if the reduced length is overly long some of the normal-size wire may be reduced. However, it has been found that variations in the wire size are relatively slow in occurrence and for wire of original wire diameter of 0.0005 inch with a measured wire length of 50 millimeters, the finished wire diameter will be constant to an accuracy of 0.3% where the original variation in wire diameter was plus or minus 5%.

In operation of the unit, the wire is first preferably cleaned free from oxides and drawing lubricants by a run through a boiling solution of 25% tetrasodium ethylenediamine tetraacetate, although other suitable cleaning means may be used. For an electrode spacing of 50 millimeters, and with the circuit as illustrated, a total current of 250 milliamperes has been found effective for the electrolytic reduction.

It will be recognized that the objects of the invention have been achieved by providing an electrolytic reducing apparatus and method whereby wire may be reduced to a uniform diameter of ultra-fine sizes in which the problem of strand breakage has been eliminated. This is, of course, also applicable to very fine metal strip with the same identical apparatus and method.

Possible alternatives for the circuit as outlined are possible. For example, instead of using the coding circuit, the output of the amplifier could be applied directly to the recorder and the amplified signal as delayed by the recorder could be used to trigger a thyratron. This will introduce some effects of recorder speed variations or so-called "wow" as it is known to Hi-Fi experts, which are eliminated in the previously described circuit. Such an alternative circuit as is suggested is shown in Fig. 4 wherein the resistance of the wire to be measured is introduced into one leg of a Wheatstone bridge 56. The bridge output voltage and a constant amplitude voltage in quadrature therewith are added and applied to the grid of an amplifier tube 58. The output of the amplifier tube 58, which varies according to the resistance of the wire being measured, is modulated with the output of an oscillator 60 and the varying, modulated signal is applied to the revolving drum-type tape recorder 30. The output of the oscillator 60 may also be used to erase the signal impressed on the recorder after the impressed signal has passed the recorder pick-up head 34.

The signal from the pick-up head of the recorder unit (which unit may be as shown in the preferred embodiment) is impressed upon the grid of an amplifier tube 62 and the output signal from this tube is rectified and impressed upon the grid of a phase converter tube 64. The signal which is applied to the grid will be phase shifted in accordance with the phase shift encountered in adding the bridge output and the quadrature voltage, as applied to the grid of the amplifier tube 58. Applied to the plate of the phase converter tube 64 is a fixed A. C. and plate D. C. supply, which tube will conduct in an amount proportional to the phase shift of the signal supply to the grid. Thus the phase converter acts to convert a phase variation to an amplitude variation. The resulting signal is taken from the cathode of tube 64 and applied to the grid of the thyratron 66, which in turn charges a condenser 68 to supply current to the reducing bath.

Other alternative embodiments are also possible. For example, if a wire reduction from .0005" to .0002" is to be effected, it is desirable to precede the controlled wire reduction of this invention with two stages of straight (uncontrolled) electrolytic reduction and to follow the controlled reduction stage with an addition stage of uncontrolled electrolytic reduction in order to give the substantially uniform wire a final polishing. The reducing current for these stages may each be 125 milliamperes, for example, although these reducing currents may be varied as indicated by the desired wire size.

While in accordance with the patent statutes, one best-known embodiment has been illustrated and described in detail, it is to be particularly understood that the invention is not limited thereto or thereby.

We claim:

1. An apparatus for reducing the cross-sectional area

of electrically-conducting material to a substantially uniform cross-sectional area, comprising electrical measuring means to measure the average electrical resistance of increments of the material to be reduced, electrical signal means to convert each of said increment resistance measurements into a corresponding current-controlling signal, a controlled electrolytic bath reducing means to reduce the cross-sectional area of said material in which bath said material constitutes the anode, advancing means to advance said material to and through said measuring means and to advance said measured material into and through said bath, bath current-controlling means responsive to signals of said electrical signal means to control the bath current flowing from said measured material in said bath so that said current is inversely proportional to the average electrical resistance of said measured material increments, and delay means cooperating with said electrical signal means and said bath current-controlling means to delay the application of said current-controlling signal to said current-controlling means until that increment of said measured material which corresponds to the applied current-controlling signal constitutes the bath anode.

2. The apparatus as specified in claim 1 wherein said advancing means advances said material at a substantially uniform rate.

3. An apparatus for reducing the cross-sectional area of electrically-conducting wire to a substantially uniform cross-sectional area, comprising electrical measuring means to measure the average electrical resistance of increments of the wire to be reduced, electrical signal means to convert each of said increment resistance measurements into a corresponding current-controlling signal, a controlled electrolytic bath reducing means to reduce the cross-sectional area of said wire in which bath said wire constitutes the anode, advancing means to advance said wire to and through said measuring means and to advance said measured wire into and through said bath, bath current-controlling means responsive to signals of said electrical signal means to control the bath current flowing from said measured wire in said bath so that said current is inversely proportional to the average electrical resistance of said measured wire increments, and delay means cooperating with said electrical signal means and said bath current-controlling means to delay the application of said current-controlling signal to said current-controlling means until that increment of said measured wire which corresponds to the applied current-controlling signal constitutes the bath anode.

4. The apparatus as specified in claim 3 wherein said advancing means advances said wire at a substantially uniform rate.

5. The method of reducing the cross-sectional area of electrically-conducting material to a substantially uniform cross-sectional area, comprising measuring the average electrical resistance of increments of the material to be reduced, continuously passing the measured material increments through an electrolytic bath having a cathode so that the individual measured increments are immersed in said bath and pass said cathode, applying a difference of potential between said cathode and the immersed material in accordance with the average measured electrical resistance of the material increment passing the cathode so that the current flowing in said bath is inversely proportional to the measured average electrical resistance of the material increment passing the cathode, whereby the material is reduced to a substantially uniform cross-sectional area.

6. The method of reducing the cross-sectional area of electrically-conducting wire to a substantially uniform cross-sectional area, comprising measuring the average electrical resistance of increments of the wire to be reduced, continuously passing the measured wire increments through an electrolytic bath having a cathode so that the individual measured increments are immersed in said bath and pass said cathode, applying a difference of potential between said cathode and the immersed wire in accordance with the average measured electrical resistance of the wire increment passing the cathode so that the current flowing in said bath is inversely proportional to the measured average electrical resistance of the wire increment passing the cathode, whereby the wire is reduced to a substantially uniform cross-sectional area.

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