METAL WORKING PROCESS AND APPARATUS

Filed Feb. 13, 1961 3 Sheets-Sheet 1

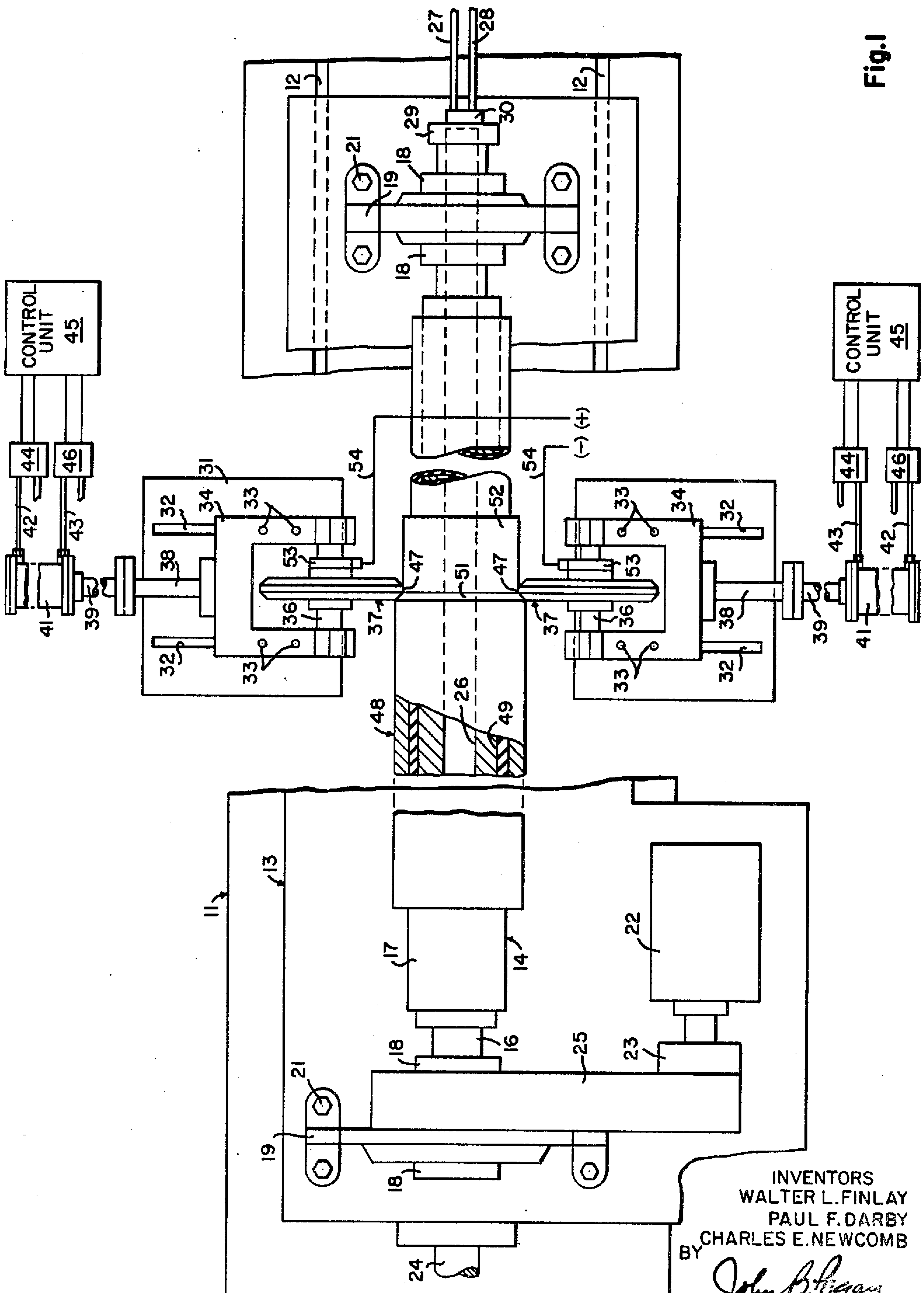


Fig. 1

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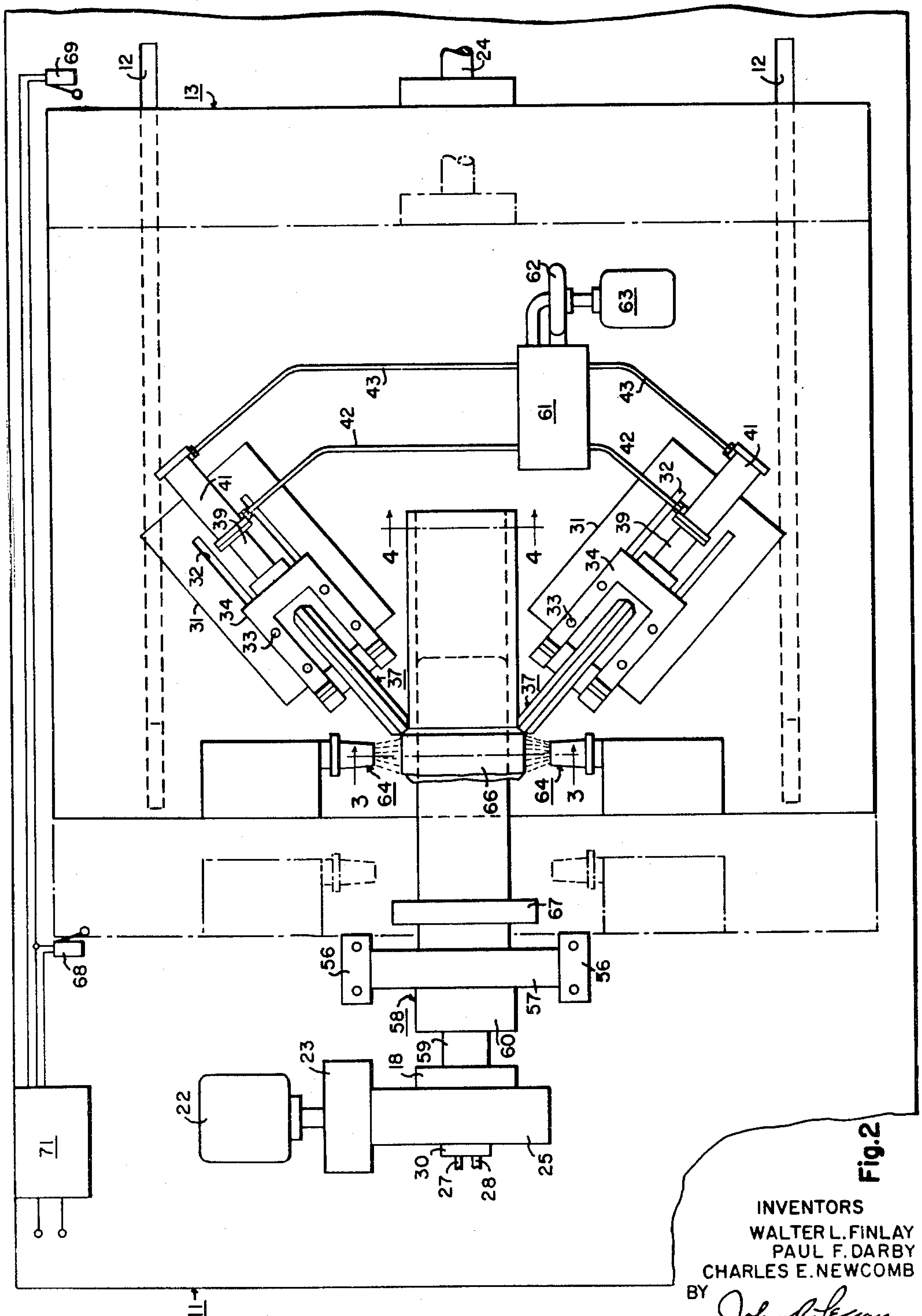


Fig.2

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April 27, 1965 W. L. FINLAY ETAL 3,180,024

METAL WORKING PROCESS AND APPARATUS

Filed Feb. 13, 1961 3 Sheets-Sheet 3

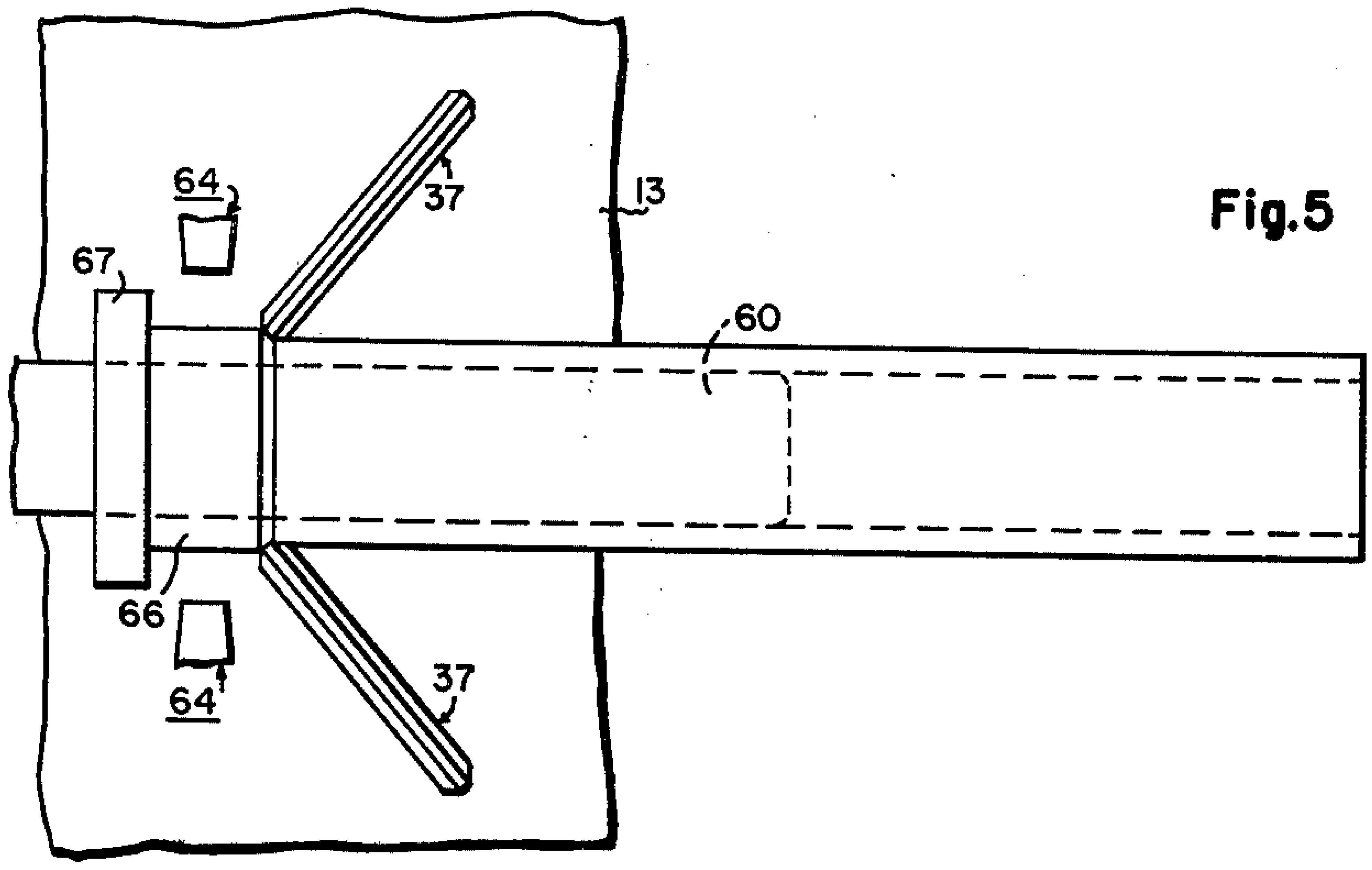


Fig.5

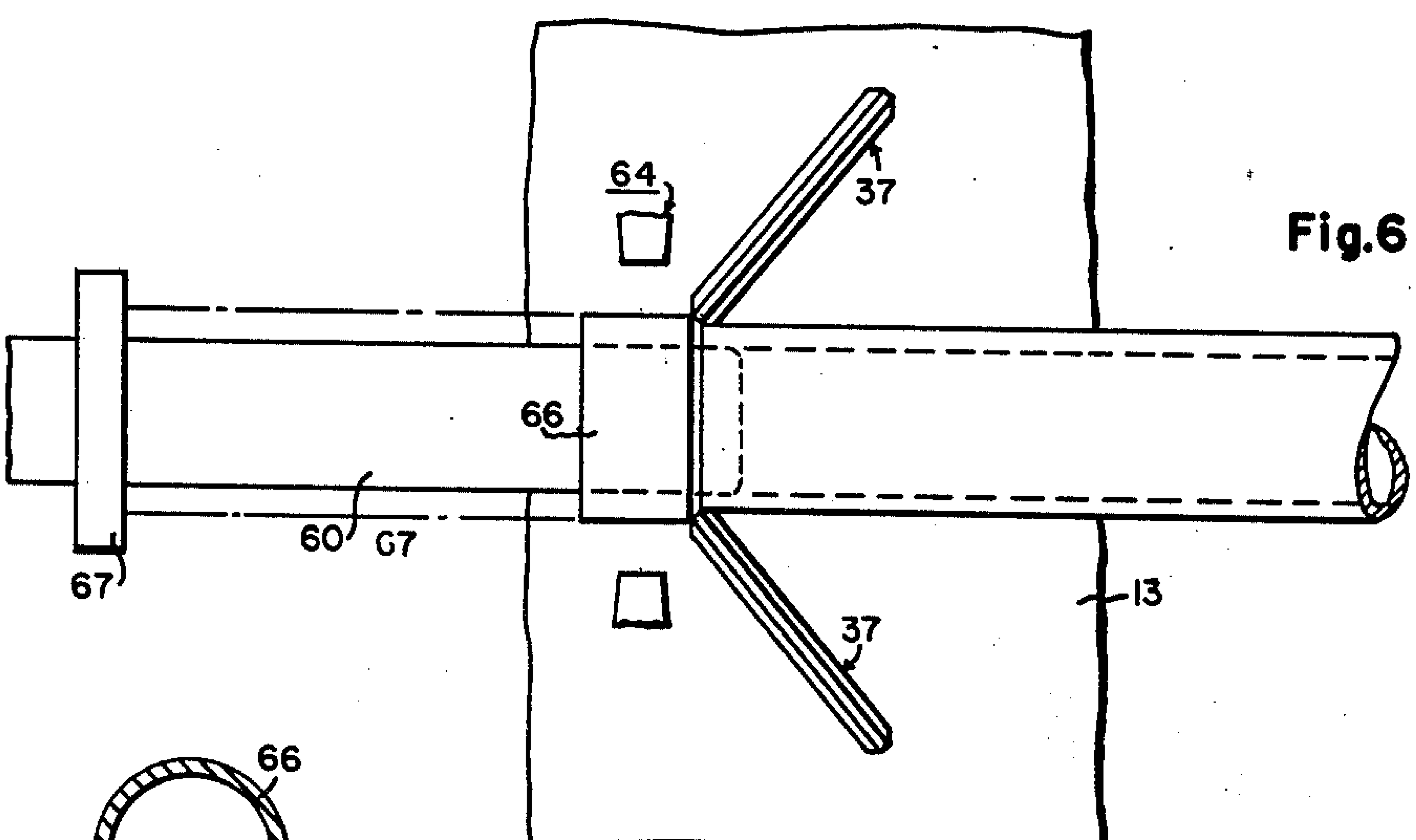


Fig.6

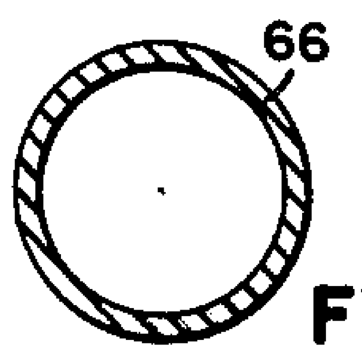


Fig.4

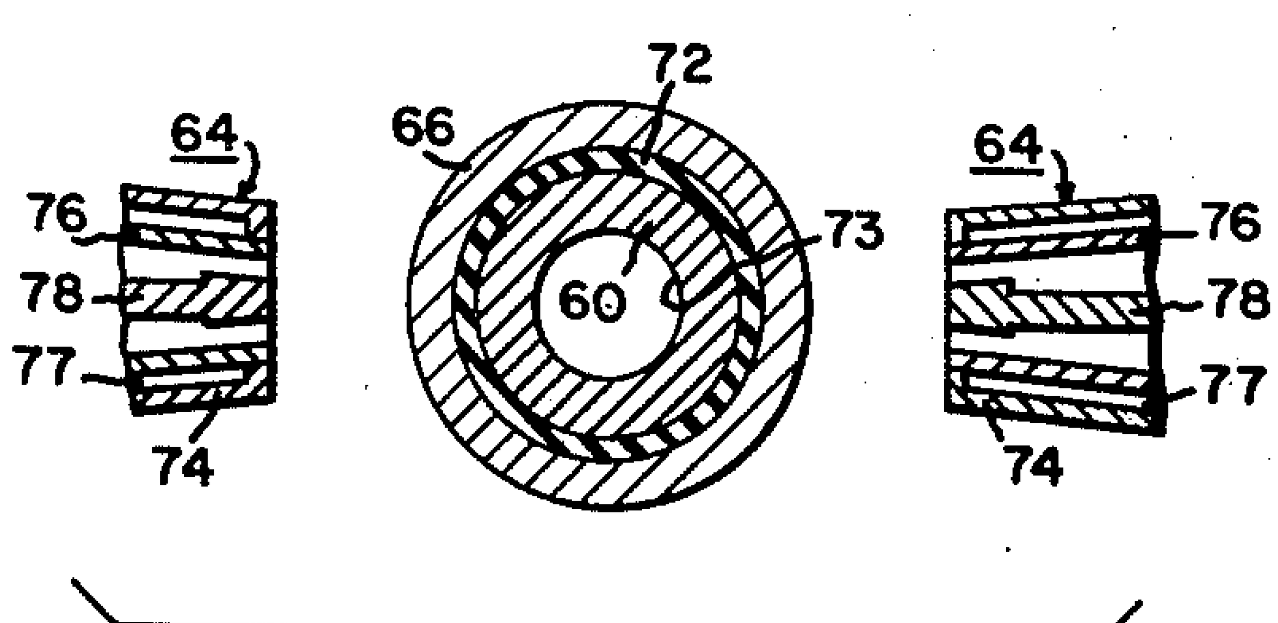


Fig.3

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# United States Patent Office

3,180,024
Patented Apr. 27, 1965




3,180,024

## METAL WORKING PROCESS AND APPARATUS

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Filed Feb. 13, 1961, Ser. No. 88,876
2 Claims. (Cl. 29—528)

This invention pertains to improved methods and apparatus for working metals and alloys, and, more particularly, to methods and apparatus for the mechanical reduction of difficultly workable materials, such as high strength steels, superalloys and refractory metals and their alloys to thin gauge article forms.

There is a present and ever increasing need in the metal working industries for metals and alloys exhibiting high strengths at elevated temperatures, for example, 1000° F. and over. Many of the materials suitable for such applications, however, are not readily susceptible of mechanical fabrication into the variety of product forms and shapes desired, for example, thin sheets, due to the inherent low ductility of these materials. Representative of the difficultly workable, high temperature, high strength materials are the stainless steels, especially the nickel and cobalt base superalloys, many alloys of the refractory metals such as columbium, tungsten, zirconium, vanadium, molybdenum and chromium, as well as alloys of titanium and beryllium. Many of the foregoing materials are relatively nonductile and have high melting points which, consequently, do not readily lend themselves to the usual mechanical processing methods. Thus, due to such properties of these materials, it is extremely difficult to form the same into wrought forms, such as thin gauge sheet and strip, by ordinary "line rolling" techniques. In order to produce these materials in thin gauge sheet and strip form, as well as many other wrought forms, it is necessary to subject them to extremely high pressures necessitating commensurately heavy equipment. However, with the use of equipment of a size and pressure capacity sufficient to reduce such materials, difficulty is encountered in the form of cracking, splitting and/or shattering of the materials unless they are worked at relatively high temperatures. Even then, extensive mechanical reduction of many of these materials is impossible by prior art practices. Consequently, prior art efforts to fabricate such materials by means of the usual type of rolling mill equipment generally include the heating of the material to quite high temperatures. Many of the above-mentioned materials, such as vanadium, columbium, molybdenum and titanium, however, are subject to extensive contamination or even progressively rapid destruction by catastrophic oxidation when heated to elevated temperatures in air. Therefore, usual processes for working such materials at elevated temperatures require protection against contamination or destruction, as by the application to the metal of various protective coatings, such as glassy materials or as by enclosure of the metal in a disposable sheath or can of another formable and less reactive metal or, alternatively, by conducting the mechanical working of the material in an inert atmosphere.

In an effort to overcome the aforesaid and other limitations of prior art processes of mechanically working such difficultly workable materials consideration has been devoted in the recent prior art to the mechanical operation variously known as "power spinning," "extrusion scanning," "flow forming," etc. The gist of such mechanical operation is the application to a forged and/or ground or machined preform or workpiece of a pressure or force of exceptionally high magnitude as achieved by directing the pressure or force against the workpiece in an essen-



tially point contact fashion. Concentration of the applied force to a very small area or, substantially, a point upon the surface of the workpiece causes the latter to plastically deform in cold flow. This operation is hereinafter termed "point contact rolling," as opposed to conventional "line rolling" procedures utilizing the usual elongated, cylindrical rolls.

Point contact rolling is itself a generic term applied to a variety of individual mechanical operations among which are those commonly referred to as "shear spinning," "tube spinning" and "contour spinning." The shear spinning operation, utilized primarily to produce conical shapes, makes use of a workpiece, generally in the form of a flat blank or disc which, by the application of pressure to the workpiece by rotating disc-like tools, is caused to flow over a rotating mandrel of generally conical form to produce a final product in conical form wherein the wall thickness varies in accordance with the so-called "sine law." A further species of point contact rolling is the so-called "tube spinning" wherein a workpiece, preformed as by forging and/or rolling and machining, generally consists of a relatively short and thick-walled tube which, by application of pressure by a rotating disc-like tool, is caused to flow over a cylindrical mandrel. In this type of operation, there is no inherently limiting relationship between the wall thickness of the preformed workpiece and the finished product, any desired final wall thickness being attainable, depending upon the original wall thickness of the workpiece, the magnitude and direction of the force applied, and the flow characteristics of the metal. The third mentioned species of point contact rolling, contour spinning, is frequently utilized where the final product form deviates from straight line conical or tubular shape and involves either shear spinning or tube spinning or combinations thereof.

Such prior art embodiments of point contact rolling, although highly advantageous in certain applications, possess numerous inherent disadvantages. Thus, it is necessary to fabricate a preformed workpiece in some manner, generally, as aforementioned, by forging, rolling, grinding and/or machining. This step, in addition to requiring added time and effort, also results in considerable product waste. Moreover, the mechanical properties of the preformed workpieces are highly variable, depending upon the method by which they are made. Further, it is necessary, in the usual point contact rolling operations, to start with a preform having a relatively heavy wall thickness in order to produce a final, thin-walled product of the desired size.

The aforementioned variations of the usual point contact rolling operation necessitate heavy mechanical reductions per pass of the preform wall in order to obtain deformation or extrusion of the full wall thickness of the workpiece. Thus, a pass of inadequate reduction will result in flow only of the surface and immediate sub-surface portions of the preform wall, the innermost portions of the wall adjacent the supporting mandrel remaining underdeformed. This requirement necessitates extraordinarily high pressures and commensurately heavy equipment. Even with the provision of the necessary heavy mechanical reductions per pass, usual point rolling procedures still generally require a number of passes to obtain the desired final thin gauge product wall thickness.

The usual yield in prior art point contact rolling of materials such as tungsten alloys and the like is on the order of 20–25 percent of the starting materials (electrode rods), about 75–80 percent of the starting material constituting waste produced during the various operations incident to the production of the final product.

It is a further characteristic of the so-called "space age" metals and alloys that they are most often required in relatively small quantities and, consequently, even in those cases where ductility is sufficiently great to permit production by procedures approximating normal mill practice, e.g., continuous strip rolling with the additional application of a large tensile force to the strip being rolled, the small quantities involved do not economically warrant use of existing, high speed strip rolling facilities. Therefore, there is a great need for processes and equipment capable of the ready, relatively economic, production of small quantities of articles of large widths and lengths, small thicknesses, close dimensional tolerances and high surface quality specifications.

Therefore, it is an object of the present invention to provide methods and apparatus for readily working the refractory materials and other difficultly workable metals and alloys thereof.

It is another object of the invention to provide methods and apparatus for point contact rolling wherein the disadvantages of a separate, preformed workpiece are eliminated.

It is a further object of the invention to provide methods and apparatus for the production of thin gauge articles of metals and alloys in a single or very few passes in an improved point contact rolling operation.

It is a still further object of the invention to provide thin gauge articles of difficultly workable materials by utilization of an improved point contact rolling procedure wherein the deforming force is substantially less than heretofore required.

It is yet another object of the invention to provide methods and apparatus for point contact rolling at elevated temperatures without appreciable impairment of the workpiece by air contamination or oxidation.

It is still another object of the invention to provide methods and apparatus capable of readily and economically producing articles, as strip and sheets, of large length and width, small thickness and close dimensional tolerance, together with a highly finished surface.

In accordance with the aforesaid objects, a preferred embodiment of the novel method of the invention comprises depositing, upon a suitable support, a coating of the metal or alloy to be worked, as by use of a plasma jet gun, solidifying the deposited coating and reducing the same to a desired final gauge thickness by application thereto of a point contact rolling force. A preferred embodiment of the apparatus of the invention suitable for carrying out the novel method thereof comprises a rotatable mandrel for receiving and supporting the coating of metal to be worked, means adjacent the mandrel to raise the coating metal above the melting point thereof and to spray the molten metal upon the mandrel, and roller means adjacent the mandrel advanceable toward the mandrel and engageable with the deposited coating to reduce the same to a desired final gauge thickness.

Other novel features and advantages of the invention will become apparent by reference to the following detailed description, when considered in conjunction with the accompanying drawings, wherein:

FIG. 1 is a top plan view of one embodiment of an apparatus in accordance with the invention comprising a plurality of rollers for the point contact rolling of a metal coating deposited upon a rotatable mandrel adapted for linear movement past the rollers;

FIG. 2 is a top plan view of an apparatus for depositing and point contact rolling a metal coating upon a rotatable mandrel, the apparatus being adapted for the production of continuous tubing or sheet forms of the deposited metal;

FIG. 3 is a cross sectional view taken along line 3—3 of FIG. 2;

FIG. 4 is a cross sectional view taken along line 4—4 of FIG. 2;

FIG. 5 is a schematic representation, in plan view, of a mandrel and associated rolling and metal-depositing means of the type of FIG. 2, wherein the rolling and depositing means are adjacent a terminal position relative to the mandrel, and

FIG. 6 is a schematic representation, in plan view, of the apparatus illustrated in FIG. 5, wherein the rolling and depositing means are in an initial position relative to the mandrel.

Referring now to the drawings, wherein the same reference numerals are used to designate similar parts, FIG. 1 illustrates one embodiment of an apparatus in accordance with the invention wherein the numeral **11** designates generally a fixed base, the upper surface of which is provided with grooves **12** for the reception of keys (not shown) depending from an under surface of a slide member designated generally by the numeral **13**. A cylindrical mandrel, designated generally by the numeral **14**, and comprising a shaft portion **16** and an enlarged body portion **17**, is mounted upon the slide **13** and is rotatable about its longitudinal axis by reason of the mounting of the end portions of the shaft **16** in suitable journals **18** which are in turn mounted on standards **19** which are affixed to the slide member **13** by suitable means, such as bolts **21**. The mandrel is driven by any suitable prime mover such as a motor **22**, through a gear reducer **23** and connecting means **25**. The mandrel driving means are mounted upon the slide **13** and are movable therewith. The slide **13** and associated mandrel and mandrel driving means are reciprocably movable with respect to the base **11** by application of a reciprocating force applied to the slide, through ram **24**, by any suitable driving means (not shown).

As illustrated in FIG. 1, the mandrel **14** may possess a central cavity **26** for reception of a suitable cooling fluid if desired. The latter may be introduced into the hollow mandrel and removed from the same through cooling entry and exit lines **27** and **28** respectively, secured to the mandrel by means of a sealing bushing **30**. The latter may be connected to the mandrel through a packed, rotatable ring bearing **29** mounted at one extremity of the shaft **16**.

Mounted upon the base are a number of roller support members **31** having slots **32** formed in the respective upper surfaces thereof for slideable reception therein of guide lugs **33** depending from an under surface of yoke members **34**. Journaled near the extremities of the legs of each of the U-shaped yokes **34** are the ends of freely rotatable shafts **36** upon each of which is mounted a forming roller designated generally by the numeral **37**. Each of the yokes **34**, together with the associated roller **37**, is movable toward and away from the mandrel **14** by reciprocation of the yoke in the slots **32**. Reciprocation of the yokes and associated rollers is accomplished through rams **38** each of which is secured, at one extremity thereof, to yoke **34** and at the other to a rod **39** acting in association with a fluid pressure cylinder **41** to which a pressurized fluid is supplied, as through fluid pressure lines **42** and **43**. The direction of travel of the rollers **37**, i.e., either toward or away from the mandrel **14**, is controlled by the flow direction of the pressurized fluid in lines **42** and **43**. Fluid flow is regulated by reversible check valves **44** and **46** in lines **42** and **43**, the open-close direction of the valves being determined by means of a controller **45**. The latter may be energized by a preset timer (not shown) having a timing cycle set in accordance with predetermined process variables or, alternatively, controller **45** may be energized by a microswitch (not shown) actuated by movement of mandrel **14** into a terminal position with respect to the rollers **37**.

The apparatus illustrated in FIG. 1 is, of course, merely illustrative of the broad principles of the invention and the apparatus actually used in carrying out the method of the invention may take a variety of forms. Thus, the mandrel may be cylindrical, as illustrated in FIG. 1, or it may, alternatively, comprise a flat bed reciprocally movable with respect to the forming tools. The latter, as illustrated in FIG. 1, may take the form of the generally circular discs or rollers 37, illustrated in FIG. 1, each of such rollers having a working edge or nose 47 adaptable to contact and to deform a deposited layer or coating, designated generally by numeral 48, of a metal to be worked. The exact size and geometry of the forming roller and the nose thereof depends, of course, upon the nature of the material to be worked and the size and geometry of the desired final product.

The mandrel 14 may be constructed of any suitable material such as mild steel, tool steel, nickel-iron alloys, cast iron, etc., and the coating 48 may be deposited directly thereon. Alternatively, the enlarged body portion 17 of the mandrel may be provided with an overlying jacket 49 which may, in accordance with certain aspects of the invention comprise an electrically insulative matedial, as, for example, porcelain or other ceramic, etc.

The operation of the apparatus of FIG. 1 starts with the placement of a coated mandrel 14 in position upon the slide member 13, the latter member being located in an initial or starting position to the extreme left of FIG. 1, i.e., the right hand extremity of the coated portion of the mandrel is located between the forming rollers 37. Initiation of the control cycle of controller 45 actuates the drive means for ram 24 to start the slide 13 and mandrel 14 moving past the rollers 37. Simultaneously, controller 45 actuates the fluid pressurizing means and valves 44 and 46 to drive the rods 39, and associated yokes 34 and forming rollers 37 radially inwardly toward the mandrel and into contact with the deposited coating 48 which overlies the mandrel. Continued application of the applied force against the rollers 37 and continued movement of the mandrel 14 past the rollers results in deformation of the deposited coating 48 adjacent the roller noses 47, as shown by the numeral 51, whereby the coating 48 is reduced in thickness as illustrated by the numeral 52. Movement of the slide 13 and associated mandrel past the rollers is continued until the full extent of the deposited coating 48 is reduced in thickness by the rollers 37. The mandrel is, of course, formed of a sufficient length to accommodate the increased length of the reduced coating 48 due to the reduction in wall thickness thereof. If the full reduction in wall thickness of the coating 48 is not achieved in a single pass the slide and associated mandrel is redirected to the starting position and additional passes are taken until full reduction in wall thickness is achieved.

The choice of the method of deposition of the material to be worked, within the broad aspect contemplated by the invention, lies largely with the nature of that material and, consequently, with the ease or difficulty with which it may be produced in a form suitable for deposition by one or another of the aforementioned processes contemplated herein. For example, certain materials, such as iron and nickel, may conveniently be deposited upon the mandrel by the decomposition of gaseous compounds thereof such as the respective carbonyls. These and other materials such as, for example, cobalt, copper, nickel, iridium and alloys thereof may conveniently be deposited directly upon the supporting mandrel by suitable electrochemical means. In the case of deposition of the metal coating 48 by such electrochemical means, it is desirable to provide the mandrel with a conductive parting coat, such as, for example, graphite.

A preferred method for depositing the metal coating 48 is by use of a plasma jet gun whereby the metal or alloy to be worked is spray deposited in a molten state upon the mandrel. The use of the plasma jet gun is especially useful in the deposition of the more difficultly workable metals and alloys which generally possess extremely high melting points. In the case of the plasma jet gun, the metal is generally fed to the gun in the form of finely divided powders which, as in the case of the extremely high melting point materials, such as tungsten and its alloys, is reduced to its molten state and accelerated electrostatically and otherwise by the gases in the jet and deposited, in the molten state, upon the supporting mandrel. The metal to be worked can thus be deposited, in the form of relatively thin films or coatings of quite uniform thickness, upon a rotating mandrel of the type illustrated in FIGS. 1 and 2 or, alternatively, upon a reciprocating mandrel. The feed to the plasma jet gun, or the flame spray gun, if that method is utilized, may, of course, comprise single metals, or a mixture of powdered or pre-alloyed powders. Such powders may be produced by a variety of means, such as atomization, milling, hydride production and subsequently electrolytic reduction, etc. depending upon the nature of the metal feed.

Deposition of the coating by others of the contemplated methods, e.g., dipping, although not preferred since control of the coating wall thickness is more difficult, are nevertheless highly useful. For example, dipped coatings equally well eliminate the need for machining the inside surface of the mechanically reduced article produced by the inventive processes. Moreover, all of the various contemplated deposition methods provide good adherence of the deposited coating to the mandrel without the necessity of providing special apparatus for that purpose as must be done in the case of the separately prepared preformed workpieces utilized by prior art point contact rolling procedures. Additionally, the deposited structures are, in the case of many materials, admirably suited for subsequent mechanical working.

An additional important feature of the invention lies in the discovery that the workability of the more difficultly workable materials, such as the highly refractory metals, tungsten, zirconium, molybdenum, vanadium and their alloys, as well as some of the less refractory metals, such as chromium, titanium and alloys thereof, by the point contact rolling procedure herein contemplated is greatly enhanced, without substantial deleterious oxidation or contamination by utilization of a substantially point heating step simultaneously with the point contact rolling step. Thus, it has been found that, particularly with the use of a mandrel-cooling step, relatively thin coatings of the metals to be worked can be substantially uniformly heated to an elevated temperature throughout the full thickness of the coating and only adjacent to the point of application of the rolling pressure without raising the temperature of the surrounding metal of the coating to an extent as would deleteriously affect the properties of the adjacent material due to contamination by or reaction with atmospheric constituents. Thus, the substantially instantaneous heating of the differential segment of the metal undergoing deformation by the forming tools and the mandrel facilitates deformation and flow of the workpiece metal with a consequent reduction in magnitude of the required deforming force. Prior art processes involving the heating of a workpiece to be point contact rolled have caused excessive heating of relatively extensive portions of the workpiece and have invariably resulted in drastic alteration of the properties of the workpiece due to contamination of the unprotected workpiece by or its reaction with atmospheric constituents. Attempts have been made to overcome such contamination and deterioration by protecting the workpiece from contact with air as by covering the workpiece with an inert film or layer of a less reactive material or a glassy material, or by containing the entire operation in an inert atmosphere. Such unwieldy alternatives are avoided by the present invention. Thus, according to our invention, the heating of the workpiece is confined substantially to a circumferential line about the deposited coating only in the area undergoing deformation. This may be accomplished, for example, by the input of electrical energy into such restricted portion of the workpiece as illustrated in FIG. 1 wherein an electrical circuit comprises an electrical energy source (not shown), two of the forming rollers 37 and the conductive coating 48 itself. Thus, the roller supporting shafts 36 are constructed of an electrically conductive material, the extremity thereof journaled in the yoke members 34 being electrically insulated against conduction of current to the yoke members. Each of the shafts 36, in electrically conductive relationship to the rollers 37, is provided with a slip ring 53 for attachment of electrical lead wires 54 whereby the electrical current enters one of the rollers, from which it is conducted to the metal layer 48 and thence out through the other of the rollers 37. Restriction of the heating effect of the electrical energy input upon the coating 48 is facilitated by the introduction of a cooling fluid, through line 27, into the hollow interior 26 of the mandrel and thence out the fluid exit line 28. Supplemental cooling means may be utilized if necessary, for example in the form of sprays and coolant fluid directed to the exterior of the coating 48 or by the use of immersion tanks adjacent to the forming rollers. Where the coating 48 comprises an extremely reactive material, the portion undergoing deformation may be contained within an enclosure filled with a suitable inert gas. However, such measures are not generally required in the performance of the invention. The magnitude of the heating energy input depends upon the conductivity and thickness of the metal workpiece and upon the desired extent of temperature increase in the workpiece.

Alternatively, the point heating steps may be accomplished by the direction of small flame jets to the workpiece at the point of deformation, although control of the degree or extent of heating is not as fine as that obtainable by use of the aforesaid electrical heating method. Heating of the deposited coating may also be accomplished by the use of an electrical arc discharge means.

The contemplated spraying techniques, especially, impart large quantities of heat energy to the underlying mandrel. Accordingly, by utilizing the coating deposition step and the point heating step in a close time sequence, and with reduced or no mandrel heating, use may be made of the residual heat of the deposited coating to effect a savings in the amount of heat energy input required to raise the coating to a desired point heating temperature.

Operation of the apparatus illustrated in FIG. 1 leads to the production of thin-walled tubes of discrete length. After removal of the tubes from the mandrel, the same may be split and flattened by any suitable means to produce elongated flat articles, such as strip, sheet and the like.

A great variety of final product forms may be produced by use of the methods and apparatus of the invention. Thus, the rollers 37, if used in conjunction with a cylindrical mandrel as illustrated in FIGS. 1, or with a flat, reciprocable mandrel, may possess nonuniform working edge portions or, alternatively, regular disc type rollers may be programmed in their movement relative to the mandrel and associated deposited coating to produce final products of non-uniform geometrical configuration. Thus, by use of either of the aforesaid alternatives, final products may be produced having uniform or variable wall thicknesses, embossed or recessed surface configurations, etc.

The concepts of the invention are also useful for the substantially continuous production of elongated articles, such as continuous tubing, continuous sheet, strip and the like. Thus, an apparatus suitable for such continuous processes is illustrated in FIG. 2 wherein there is mounted upon the base 11 a pair of upright stanchions 56 to which are secured a suitable mandrel-bearing member 57. The latter, in turn, rotatably supports a relatively shortened mandrel designated generally by the numeral 58. The latter comprises a shaft portion 59 which is suitably geared and driven through gear reduction means 23 and connecting means 25 by a prime mover such as motor 22. The mandrel driving means are secured to the base 11. The mandrel also comprises an enlarged body portion



60, a portion of which is cantilevered outwardly from the mandrel supporting means and over a portion of the slide member 13. The forming rollers 37 and associated roller supporting, advancing and retracting means are mounted upon the slide 13. Pressurized fluid is admitted to and withdrawn from the fluid pressure cylinders 41 through lines 42 and 43. Flow direction of the pressurized fluid into the cylinders 41 is controlled by means of a fluid pressure controller 61. Pressurization of the pressurized fluid is accomplished, for example, by means of a pump 62 driven by a motor 63. Also mounted upon the slide member 13 is one or more metal spray means such as plasma jet guns, designated generally by the numeral 64. The latter are spaced a predetermined distance from the cantilevered body portion 60 of the mandrel 58 and are adapted to apply a uniform thickness coatign 66 to a limited portion of the mandrel surface as it rotates about its longitudianl axis. The mandrel 58 is provided with a circumferential flange 67 to define the maximum extent to which the coating 66 is applied to the mandrel surface. Limiting microswitches 68 and 69 are provided for contact and actuation by the slide 13 at the respective extremities of the reciprocating travel thereof. Control of the movement of the slide 13 and associated mechanism, together with the control of the movement of the rollers 37 toward and away from the mandrel is achieved by means of a sequence timer 71.

FIG. 3 illustrates, in cross sectional view, the makeup of the coated mandrel and the associated plasma jet guns. Thus, as illustrated in FIG. 3, the body portion 60 of the mandrel may bear an electrically insulative jacket 72, as in those instances wherein it is desired to effect an electrical point heating of the workpiece as aforementioned. As also in the case of apparatus of FIG. 1, the mandrel 58 may have a central cavity 73 for reception of a cooling fluid, the latter being carried to and from the cavity 73 through coolant lines 27 and 28 through sealing bushing 30. As also shown in FIG. 3, the plasma jet gun may comprise an external nozzle wall 74 and interior nozzle wall 76, defining therebetween an annular space 77 for circulation of a coolant fluid. The gun 64 also comprises a coaxially extending electrode 78 from which an arc is struck to create the high temperature necessary to melt the refractory powders which are generally deposited by means of such equipment.

FIG. 4 shows, in cross section, the tubular character of the coating 66 after wall thickness reduction by the forming rollers 37.

In operation of the apparatus of FIG. 2, the slide 13, together with the associated rollers 37 and spray means 64, has an initial starting position at the extreme right hand side of its travel, as illustrated schematically in FIG. 6. Upon actuation of the mandrel drive means by the timer 71, the mandrel is set to rotating and the plasma jet guns 64 are set in operation to commence the deposition of the coating 66 upon the rotating mandrel. After a predetermined thickness of the coating 66 has been obtained, the timer 71 actuates the slide moving means and, substantially simultaneously, the means to advance the rollers 37 into contact with the coating 66. Upon continued advancement of the slide 13 (to the left as viewed in FIGS. 2, 5 and 6), the rollers 37 commence to reduce the 66 and the extent of the coating applied to the mandrel is advanced to the left by reason of the commensurate movement of the plasma jet guns 64. When the slide has advanced to the point where the coating build-up is adjacent to the flange 67, the microswitch 68 is actuated, e.g., by contact with the slide 13, and, a predetermined time interval thereafter, the timer 71 effectuates discontinuance of the spray of metal emanating from the plasma jet guns. This position of the apparatus is illustrated in FIG. 5. Movement of the slide, however, continues until the remaining last portion of the coating 66 has been reduced in thickness by the rollers 37, at which point the rollers are in abutment with the flange

67, the reduced coating now being much elongated as compared to its original length and projecting over the free end of the mandrel in the manner illustrated in FIG. 5. At this point, as by operation of the timer 71, the slide is retracted to its original starting position, as illustrated in FIG. 6, whereupon microswitch 69 is actuated and the cycle is repeated. In this manner, individual, separate lengths of tubing may be produced, subsequently slit and flattened to provide articles of the desired type. Alternatively, the thus-reduced tubing may be supported by suitable means (not shown) with a small portion of the extremity adjacent to the mandrel left in contact therewith and the next portion of the coating material deposited on the mandrel and over that extremity of the tubing. In this manner, tubing of any desired length may be produced by simply repeating the aforementioned cycle any number of times. In the case of production of continuous articles, as aforesaid, the coating-depositing means is controlled in such a manner as to produce a coating having one extremity of relatively less thickness, so that, upon overlapping with the next successive coating, the desired full thickness is obtained.

Obviously, the above described apparatus is subject to various modifications; for example, the operation is substantially the same whether the mandrel or the forming rollers are moved relatively to the other. Moreover, the number and exact disposition of the rollers and the plasma jet guns, if these are used to form the deposited coating, may be varied in accordance with known design principles.

In the preferred method of the invention, i.e., deposition of the metal coating by means of a plasma jet gun, it is unnecessary to provide the supporting mandrel with a parting coat since the deposited coating adheres sufficiently tightly to the mandrel to permit rolling so long as the mandrel surface is provided with a suitable finish. However, the deposited coating is not so tightly bonded to the mandrel as to prevent movement of the extruded metal over the mandrel during rolling. In some instances, however, a lubricant, such as a suitable salt (or molten glassy material in the case of elevated-temperature operations as described hereinabove) may be utilized to facilitate movement of the deformed metal over the mandrel surface.

As aforesaid, the process of this invention is especially suitable for the production of thin gauge sheets of difficultly workable materials, such as the refractory and similar metals. However, the invention is also applicable to other metals, such as nickel, iron, aluminum, cobalt, beryllium, copper, iridium, magnesium, tin, hafnium, uranium, antimony, etc. For example, ⅛ inch diameter commercially pure aluminum wire was fed, at a rate of 4 feet per minute, into a wire type flame spray gun provided with an oxy-acetylene fuel. A coating of aluminum $\frac{1}{16}$ inch thick was thus applied, in air, to the outside of a mild steel mandrel having a grit-blasted surface and rotating in a lathe. The deposited coating was then machined to a uniform wall thickness of 0.032 inch. Such machining operation is unnecessary and may be eliminated in commercial practice by precise control of deposition factors. The aluminum coating was thereafter point contact rolled, at 25 surface feet per minute, to a final thickness of 0.013 inch, using a rotating disc-type forming tool having a 3¾ inch diameter and a $\frac{1}{16}$ inch forming edge or nose radius. Two passes were utilized, a first, to a wall thickness of 0.025 inch simply to loosen the coating on the mandrel, and a second, to final gauge. No parting coat nor mandrel lubricant was required. After rolling had been completed the thus-formed aluminum tube was easily slipped from the supporting mandrel and was then slit longitudinally and flattened. The resulting sheet product was quite ductile, had an extremely smooth, defect-free surface and a maximum thickness deviation of plus or minus 5 percent, i.e., only one half of A.I.S.I. tolerance.

In another example, one end of a workpiece comprising A.I.S.I. 304 stainless steel, having an original wall thickness of 0.038 to 0.040 inch, was cold rolled in accordance with the invention. The wall thickness was reduced, in one pass, to 0.035 to 0.036 inch. In contrast, the other end of the same workpiece was heated to a temperature between 900 and 1000° F., in accordance with the invention, by introducing a 500 amp direct current across a single forming roll, through the workpiece and thence out from an electrically conductive mandrel. At the 60 cycle, 115 volt primary transformer the output voltage was 2.5 volts and, across the mandrel was 0.8 volt. Accordingly, the power input to the workpiece was about 400 watts. The abrasion-resistant steel mandrel had a 5 inch working length and outside diameter of 1⅜ inches. The metal workpiece directly under the roller was red hot (900–1000° F.) but cooled to about 400° F. at a point three quarters of one revolution past the roller contact point. Utilizing such a point heating apparatus, and with other factors identical to the cold rolling operation, the workpiece was reduced to a wall thickness of 0.030 to 0.032 inch in a single pass, i.e., about twice the reduction that was obtained on the same workpiece as cold rolled.

The invention is also particularly suited to the production of thin article forms, as sheet and strip, of materials usually produced from an initial powder form, such as beryllium. For example, present practice for the production of beryllium sheet and strip is extremely involved and tedious, resulting in high cost of such articles. Such prior art practice requires production of beryllium ingots from sintered powder, followed by extensive machining and then encasement of the ingot in steel sheaths, followed by repeated line rolling steps, generally of 10% reduction or less per pass. The steel sheath is then removed by acid treatment of the rolled composite. Critical temperature control is necessary to raise the metal to a feasible working temperature while avoiding excessive temperatures which cause grain growth and accompanying impairment of physical properties. In accordance with the present invention, however, the production of such articles is highly simplified. A coating of beryllium is deposited, as by spraying of molten powder, upon the mandrel. A small grain size inherently results. Subsequent point rolling further reduces grain size, and there is no excessive heating step required which would increase grain size. Consequently, physical properties are enhanced, simultaneously with the production of close tolerance, thin gauge articles.

The methods of the invention are also admirably suited to the production of multi-layered articles, especially those wherein one or more of the layers are quite thin gauge. For example, products can be made wherein the various layers are deposited by the same or by different deposition procedures, depending upon the procedure best suited to the particular metal or alloy, followed by point contact rolling. The exceptionally high pressure per unit area exerted by the point contact rolling operation results in excellent bonding between the layers of the juxtaposed dissimilar metals or alloys. As an example, a useful article is readily made, in accordance with the invention by plasma jet deposition of a titanium base coating, followed by the deposition thereover, of a nickel coating by decomposition of gaseous nickel carbonyl. Point contact rolling of such a duplex structure produces a titanium sheet clad with an extremely thin, adherent nickel layer or film.

Similarly, thin films of brazing alloys may be applied to a base material, predeposited upon a suitable mandrel and the product point contact rolled to form an article ready for fabrication and/or joining simply by juxtaposition to another part or parts and heating to the requisite brazing temperature.

By a proper combination of the steps of the invention together with proper selection of the form of the mandrel and forming rollers and the relative movement therebetween, it is possible to produce not only uniform, thin gauge sheets heretofore unavailable, but also a wide variety of products of greatly differing geometrical configurations.

The provision of a starting material for point contact rolling in initially relatively thin wall form affords the means to readily produce articles heretofore extremely difficult or impossible to make. The inherent requirement of the point rolling contact operation that a relatively large reduction be taken in order to obtain metal flow across the full wall thickness dictates, in the case of non-ductile metals, as thin a wall as possible for the workpiece. The inability of the prior art to provide thin wall preforms of these non-ductile materials as by conventional casting, forging, machining or line rolling procedures, has rendered the point rolling contact technique heretofore unapplicable in many instances. This defect has been overcome by the present invention whereby, by starting with a deposited coating of the non-ductile metal relatively small total thickness reduction can be taken while at the same time maintaining metal flow across the full wall thickness. In the case of extremely brittle materials which are to be worked, wall thickness reduction can be accomplished by simultaneously effecting a point heating step which does not result in damage to the workpiece or to the resultant product.

The various deposition methods herein contemplated have, in common, the ability to produce a starting blank or coating have a relatively small thickness, as compared to prior art practice utilizing separate preforms, and which blank, despite its inherent fragility due to reduced thickness, is firmly anchored to the supporting mandrel so that the point contact rolling operation can be preformed without the necessity of providing additional anchoring means. The use of commensurately thin-walled preforms in accordance with prior art practices is practically impossible due to the difficulty in producing such preforms and in preventing such preforms from separating from the underlying mandrel upon application of a deforming force of the magnitude needed to point contact roll. In contradistinction, this invention provides a method whereby one or a number of starting materials may be utilized, in relative thinness, and which are inherently affixed to the mandrel with sufficient tenacity to permit point contact rolling but sufficiently loosely to permit extrusion of the metal or alloy over the mandrel surface.

The high degree of coating thickness uniformity enhances uniformity of thickness in the final product, a highly desirable attribute in the production of thin sheets to close tolerances. Moreover, coatings of many materials, applied as herein contemplated, for example, by plasma jet spray, have microstructures of a form optimum for subsequent mechanical working. Thus, it has been found that columbium alloys, for example, alloys of columbium with tungsten, molybdenum and zirconium, for example, 15 percent tungsten, 5 percent molybdenum, 1 percent zirconium, balance columbium, when deposited



in the form of a plasma jet spray on a metal mandrel, in an inert atmosphere, e.g., nitrogen, argon, etc., result in a homogeneous coating having a fine-grained microstructure which, as compared to the relatively coarse-grained microstructure generally obtainable by usual casting or forging techniques, is easily workable.

It is to be understood that the foregoing description and drawings are merely illustrative of the principles of the invention and modifications thereof may be made by those skilled in the art without departing from the spirit and scope of the invention.

We claim:

1. Metal working apparatus comprising a base, a cylindrical mandrel rotatably mounted on the base, means to rotate the mandrel, a slide member mounted on the base and reciprocably movable longitudinally of the mandrel, slide moving means, metal spray means mounted on the slide and adapted to deposit upon the rotating mandrel a coating of a metal to be worked, rotatable forming roller means movably mounted on the slide, means to advance and retract the roller means toward and away from the mandrel, and control means actuable by the relative positions of said mandrel and said slide to control the deposition of said coating upon the mandrel, advancement and retraction of the roller means and reciprocation of the slide member.

2. A method of producing in flat-sheet form a difficultly workable metal having an extremely high melting point, comprising

plasma-jet-gun depositing said metal on a mandrel to form a coating,

simultaneously reducing the thickness and increasing the length of said coating by applying substantially point-contact pressure thereto to produce a worked coating,

removing said worked coating from said mandrel,

slitting said worked coating, and

flattening the slit-worked coating to form a sheet.


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UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 3,180,024 April 27, 1965

Walter L. Finlay et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 8, line 18, for "longitudianl" read -- longitudinal --; line 62, for "the 66" read -- the coating 66 --; column 10, line 62, after "invention" insert a comma; column 11, lines 34 and 35, for "preformed" read -- performed --.

Signed and sealed this 21st day of September 1965.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents