Dec. 14, 1965 A. W. ERNESTUS 3,222,905

METHOD OF FORMING TUBULAR METAL PRODUCTS BY EXTRUSIVE ROLLING

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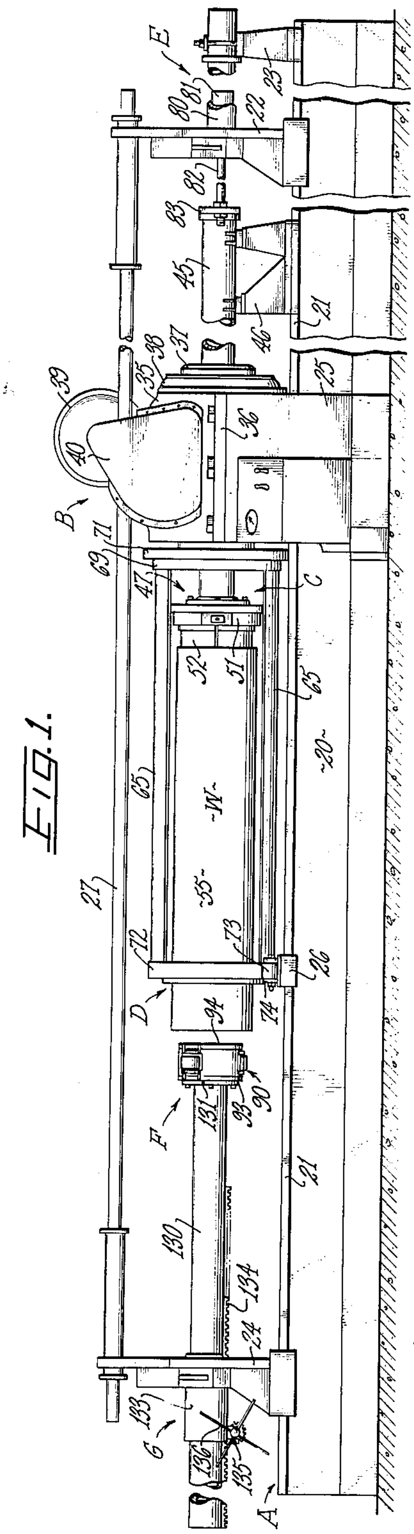

FIG. 1.

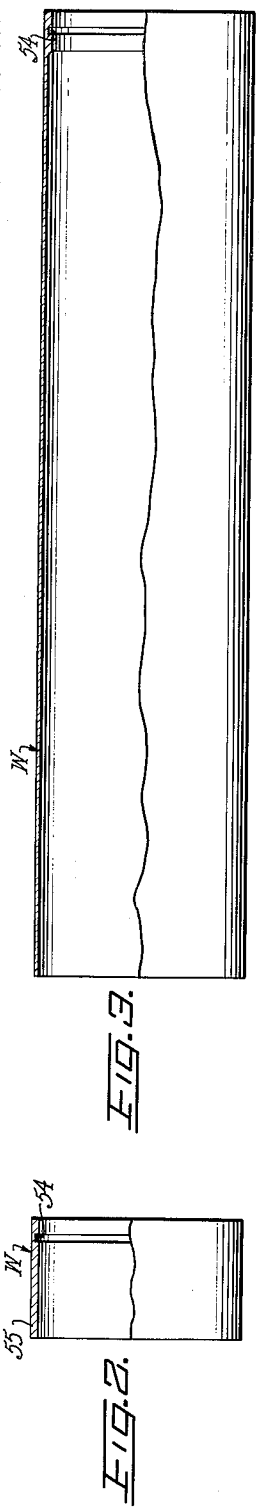

FIG. 3.

FIG. 2.

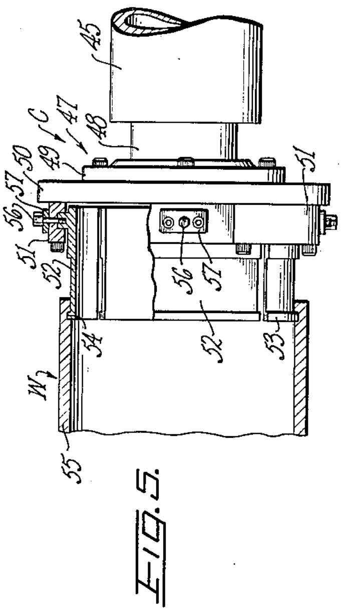

FIG. 5.

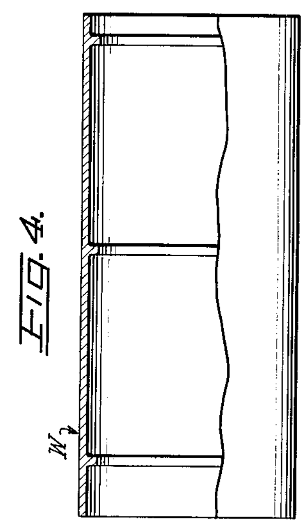

FIG. 4.

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Fig. 6.

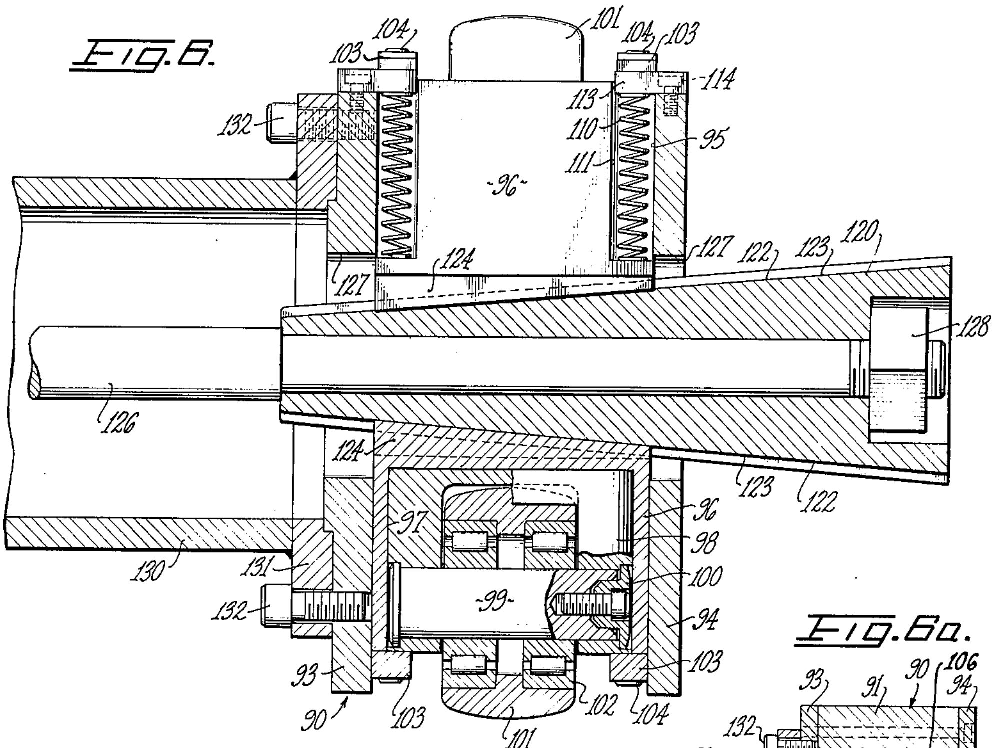

Fig. 6a.

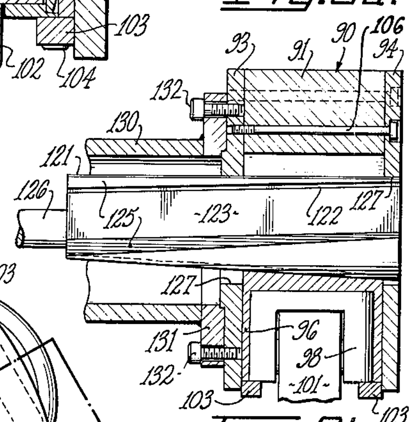

Fig. 7.

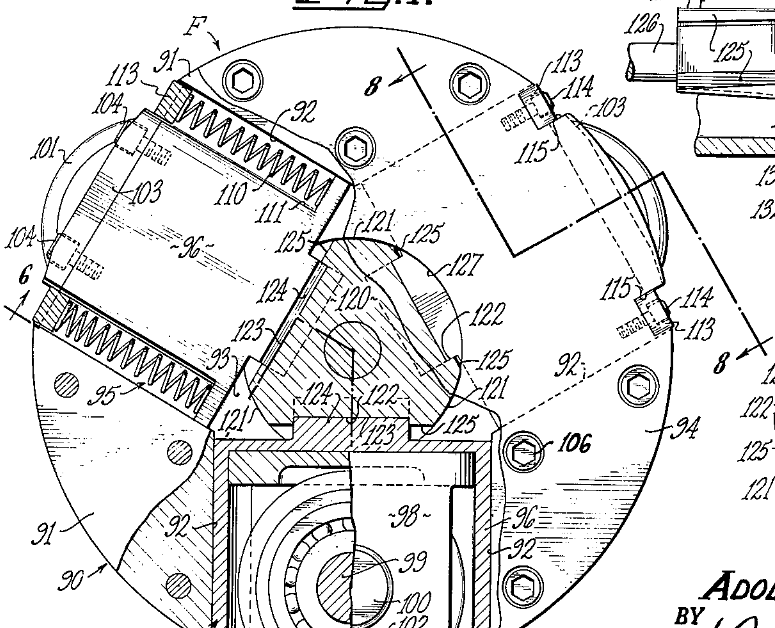

Fig. 6b.

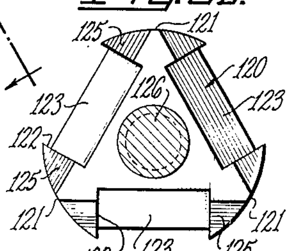

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FIG. 9.

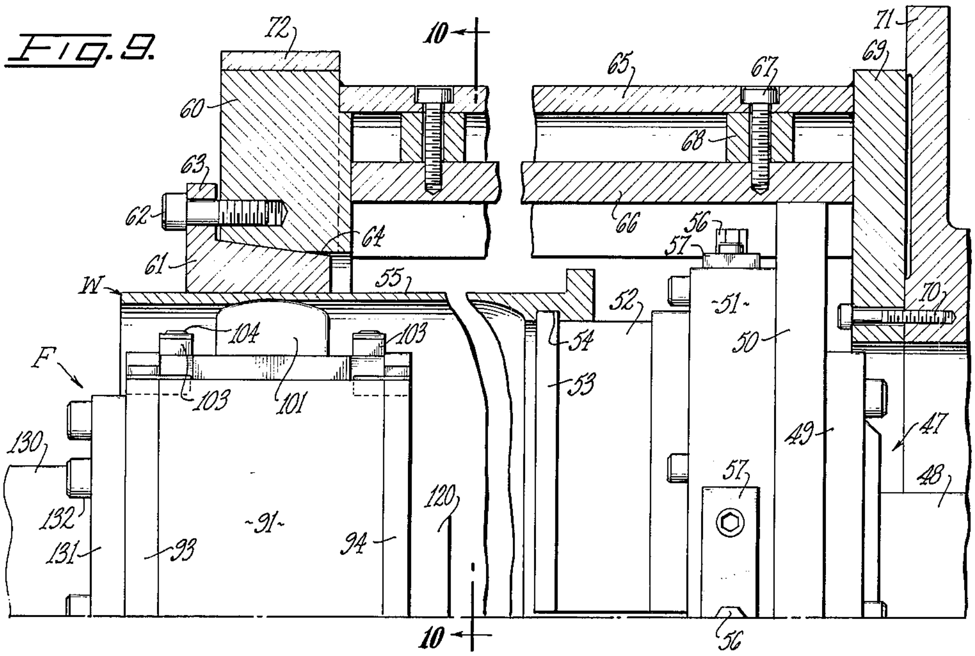

FIG. 10.

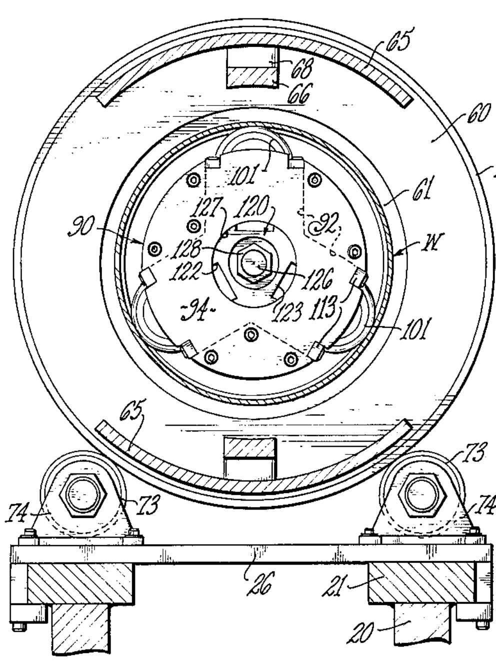

FIG. 8.

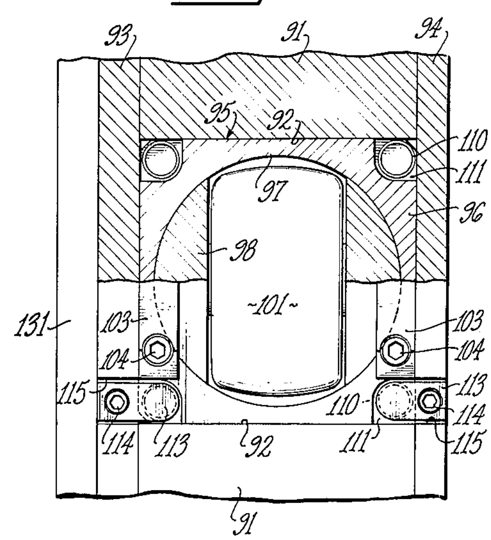

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Fig. 11.

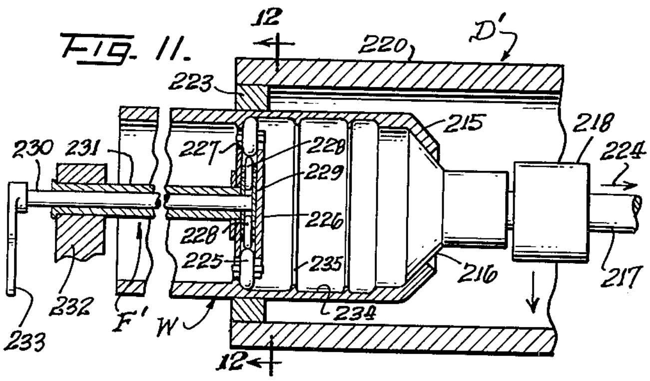


Fig. 12.

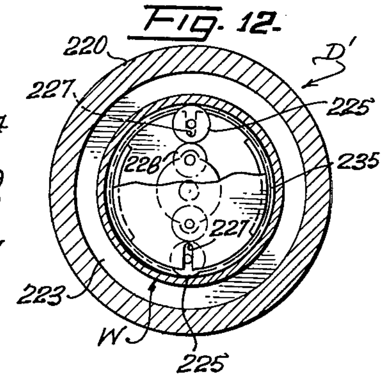


Fig. 13.

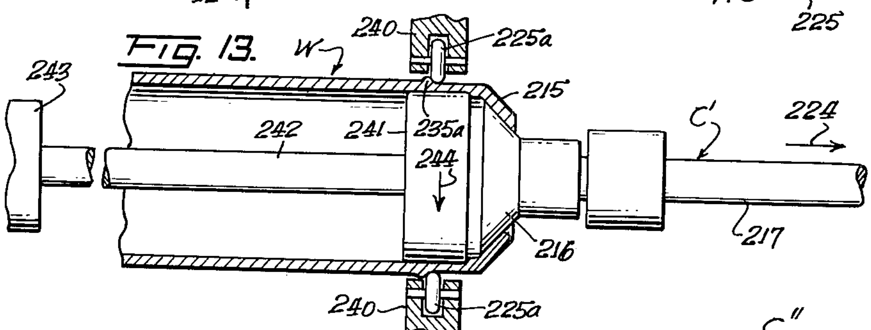


Fig. 15.

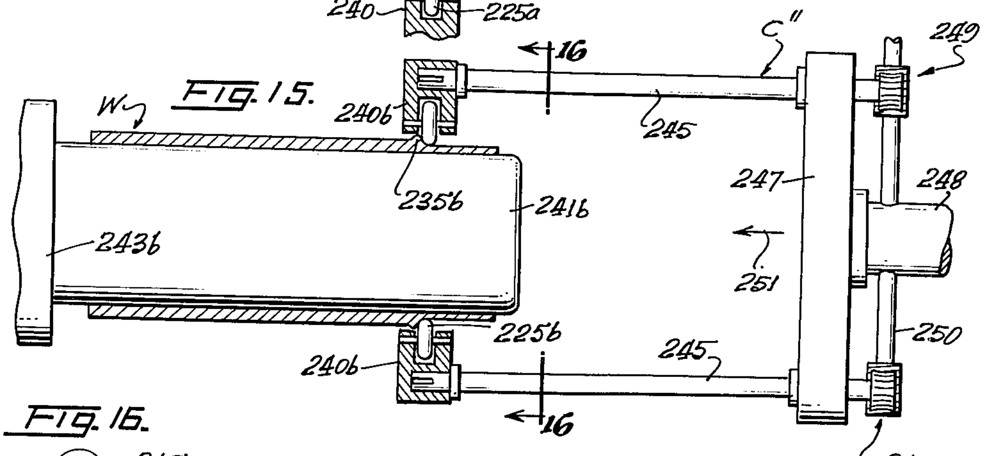


Fig. 16.

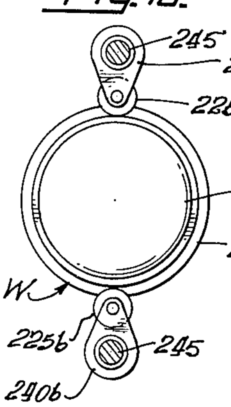
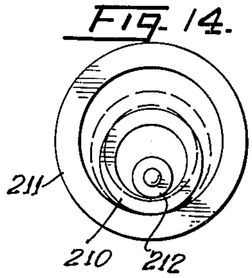


Fig. 14.



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United States Patent Office

3,222,905

Patented Dec. 14, 1965

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3,222,905

METHOD OF FORMING TUBULAR METAL PRODUCTS BY EXTRUSIVE ROLLING

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Filed Dec. 13, 1963, Ser. No. 330,454

16 Claims. (Cl. 72—91)

This application is a continuation-in-part of my pending application S.N. 52,915 (now abandoned) filed August 30, 1960, for Method and Apparatus for Roll Forming Metal Products, and a continuation-in-part of my pending application S.N. 186,612 (now abandoned) filed April 9, 1962 for Extrusive Rolling Method and Apparatus.

This invention relates to the forming of cylindrical metal tubular articles. In general, the object of the invention is to provide an improved method of forming an elongated, relatively thin-walled cylindrical tubular article from an annular work blank of considerably greater thickness, involving, in general, the simultaneous reduction of wall thickness and elongation of the tubular wall structure.

The invention contemplates the expansion and reduction of an annular blank into relatively thin-walled tubular form, utilizing an extrusive rolling technique. The invention also contemplates the formation of integral ribs of annular or other form in one surface of said annular work blank during such reducing operations.

A particular object of the invention is to provide an improved method of fabricating metal tubes having greatly improved toughness, resistance to failures caused by development of surface scratches into failure cracks, greatly increased tensile strength per unit cross sectional area, increased ratio of strength to flexibility, increased abrasion resistance, improved surface smoothness, and correspondingly decreased coefficient of friction as related to the drag of air currents against aircraft skin surfaces in high speed flight.

The present invention, in general, provides a process whereby relatively thin structural tubes with or without integral reinforcing ribs are ultimately formed through a series of forming steps all of which utilize non-abrasive surface working techniques (such as rolling and die extrusion) wherein the work surfaces are constantly worked and toughened while an initially relatively thick work blank is gradually reduced in thickness and expanded in area and, in some instances, formed with reinforcing ribs.

The invention is directed particularly to the formation of tubular articles of metals or alloys of metal, such as titanium, which have characteristics of resistance to extremely high temperatures that are considerably improved over the older, more common metals and alloys including alloy steels. Titanium, for example, is now being used and required in the manufacture of casings and nose cones for space-exploration vehicles which are boosted to extremely high speeds for escape from the earth's gravitational field and, upon reentry into atmosphere, are subjected to air friction-generated temperatures considerably higher than can be successfully withstood by the older, more common alloys. There is a corresponding need for methods of satisfactorily working the newer metals such as titanium. Along with their improved characteristic of high heat resistance, however, such metals, in general, are much more brittle and less malleable than the commoner alloys. Furthermore, they are very expensive, and there is a pressing need for methods of working which do not require the machining away of metal.

Attempts to work these newer metals to accurate predetermined contours, diameters and wall thicknesses by

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rolling them externally upon a mandrel have largely met with failure. Instead of conforming smoothly to the contour of the mandrel within, the tubular skin will usually wrinkle, buckle, and increasingly depart from the shape of the mandrel to which the operation is intended to conform the article. I have discovered that all of the difficulties inherent in that type of attempted operation have been eliminated by drawing a tubular blank internally through a sizing die while simultaneously subjecting the internal wall of the blank to a rolling operation or a series of rolling steps wherein the wall thickness is decreased, in stages, by increasing the internal diameter of the work while the work is simultaneously elongated axially until finally the wall thickness is reduced to the finished dimension and the full finished length of the article is achieved. The elongation of the work is accompanied and assisted by drawing out the work axially in response to a high tension load applied to one end thereof while the other end is free to follow through the die at a rate of axial travel that is somewhat slower than the rate of axial movement of the end that is being pulled, the differential representing elongation of the article. The die through which the work is pulled maintains the outer diameter of the work exactly uniform, corresponding to the inner diameter of the die which in turn corresponds to the required outer diameter of the finished article. As the successive passes of rolling operation successively move the inner wall of the work outwardly, the extruded metal has but one direction in which to move, namely, parallel to the axis of the tubular shape, and the resulting elongation occurs without any distortion from the true cylindrical shape which is imposed on the article by the encircling die. Furthermore, since the forces imposed upon the wall of the tubular work piece are confined to (a) the radial squeezing effect, (b) the axial pull drawing the work through the die, and (c) the longitudinal extrusion of excess metal which is absorbed by the elongating area of the work immediately beneath the rolls and does not pile up ahead of the rolls, there is no resultant tearing or fissuring of the wall structure but on the contrary, the tensile and compressive strength of the wall structure is increased by the compacting action of the rolls.

With the foregoing in mind, the general object of the present invention is to provide an improved method of working an annular metal blank into an elongated tubular article while maintaining high accuracy of circular cross section and maintaining a wall structure of uniform strength throughout, free of fissures or weakened areas and of improved tensile and compressive strength as compared to the work blank from which the article is produced.

A further object is to provide an improved method of developing an annular metal work blank into an elongated tubular article of exacting conformity to dimensional requirements and true circular cross section, without the removal of metal.

A further object is to provide an improved apparatus for performing an internal rolling operation within a die through which an annular work blank is drawn.

Another object is to provide such an apparatus including a rolling head adapted for an internal rolling operation within a confining die, in which the internal wall diameter of the work blank is increased while the blank is drawn axially and thereby elongated.

A still further object is to provide such an apparatus embodying an internal rolling head having improved means for successively varying the rolling diameter at which it operates against the internal wall of an annular work blank.

Another object is to provide an improved method and apparatus for extrusive roll-forming of relatively thick, short annular blanks of metals of varying degrees of ductility, into very thin-walled, axially elongated articles of circular cross section, with an extremely high degree of conformity to external wall configuration and finish requirements. For example, I find that the invention can be utilized to fulfill a demand which is currently developing for a hollow article (e.g. fuel container) liner or skin of a suitably corrosion-resistant metal such as aluminum having a wall of paper thinness, e.g., as thin as .030″.

Other objects and advantages will become apparent in the ensuing specification and appended drawing in which:

FIG. 1 is a side elevation of an apparatus embodying my invention;

FIG. 2 is a side elevation, partially in axial section, showing a work blank upon which my apparatus is adapted to operate;

FIG. 3 is a side view partially in axial section showing the work blank elongated to substantally finished dimensions, using my improved method;

FIG. 4 is a side view, partially in axial section, showing a tubular article processed by a modified form of the method;

FIG. 5 is a detailed side view, partially in section, showing a work blank attached to the drawing head of the apparatus;

FIG. 6 is an axial sectional view of the rolling head of my improved apparatus, showing the roll-adjusting mechanism, as seen on line **6—6** of FIG. 7;

FIG. 6*a* is an axial sectional view in a diametral plane, showing the actuator mandrel in elevation;

FIG. 6*b* is a front end view of the adjustment actuator mandrel of the rolling head, with its draw stem shown in section;

FIG. 7 is a cross sectional view of the same;

FIG. 8 is a detailed sectional view of one of the roll mounts taken as indicated by line **8—8** of FIG. 7;

FIG. 9 is a fragmentary axial sectional view of the apparatus, showing the internal structure of the sizing die and its mounting, showing the work blank in an intermediate position of draw in the leftward section of the figure and in a substantially terminal position of draw in the rightward section of the figure;

FIG. 10 is a cross sectional view of the apparatus taken as indicated by line **10—10** of FIG. 9;

FIG. 11 is an axial sectional view schematically illustrating the roll-forming stage of my improved process in one of its various forms;

FIG. 12 is a transverse sectional view thereof taken on the line **12—12** of FIG. 11;

FIG. 13 is an axial sectional view schematically illustrating a modified form of my method;

FIG. 14 is a schematic view illustrating the initial phase of processing;

FIG. 15 is an axial sectional view illustrating another modified form of my method; and

FIG. 16 is a transverse sectional view taken on the line **16—16** of FIG. 15.

General description of process

In general, the process of my invention operates upon a tubular work blank which initially is relatively short and thick-walled, e.g. as shown at **55** in FIG. 2 and at W in FIGS. 11, 13 and 15. For applying an axial pull to the blank, a coupling groove **54** is machined in its inner wall near one end, as in FIG. 2, or an annular inwardly-projecting lip **215** is formed at one end of the blank, as in FIG. 11. The blank is then inserted into a sizing die (e.g. die D of FIG. 9 or D′ of FIG. 11) and a draft coupling (e.g. chuck **47** of FIG. 1 or coupling head **216** of FIG. 11) is inserted into the blank and coupled to the end of the blank (e.g. by engagement against lip **215** of FIG. 11 or in groove **54** of FIG. 5). A rolling tool (e.g. tool F of FIG. 1 or tool F′ of FIG. 11) is then applied to the blank (e.g. to the inner surface thereof as in FIG. 11) and is held in fixed, radially opposed relation to the die ring **223** while the die ring is rotated and a strong axial pull is applied to the end of the blank by a suitable draft unit (e.g. unit C of FIG. 1 or C′ of FIG. 11). Thus the work blank is drawn through the die ring while its interior is rolled, thereby enlarging its internal diameter, reducing its wall thickness, extruding it axially with the assistance of the axial pull applied by the draft unit, and drawing it through the die with a sizing operation on its outer surface. Such sizing operation is accentuated by the tendency of the rolling operation to expand the wall of the blank into tight compressive contact with the inner surface of the die ring.

The tubular work blank may be formed in an initial phase of the process wherein a work piece of compact proportions in the form of a ring such as that indicated at **210** in FIG. 14 is subjected to a rolling operation wherein it is gradually developed into a cylinder of gradually increasing diameter and axial length. The rolling is preferably effected within a cylindrical mandrel **211** in which the work piece **210** is confined and supported while it is rolled internally by a roll **212**. The mandrel **211** may be mounted for idling rotational movement imparted to it through the work piece **210** by rolling action of roll **212**, which may be the power transmitting member. The mandrel **211** finally functions as a shaping form when the diameter of the work piece **210** has finally been expanded to completely fill the mandrel. This initial phase of thinning and area-expansion may be performed in a series of stages beginning with a relatively small diameter mandrel and successively utilizing mandrels of larger diameter as the work piece **210** is expanded. Thus the maximum difference between the diameters of work piece and mandrel may be kept at a satisfactory minimum and greater support for restraining the work piece from departing too far from a cylindrical shape, is thereby provided. Also, the successively larger mandrels may be of greater length as well as greater diameter to accommodate the expanding length of the work piece as its wall thickness is successively decreased.

As an alternative to the internal roll forming shown in FIG. 14, for the first phase of thinning and area expansion, the invention may utilize an operation comparable to those shown in FIG. 13 and in FIG. 15, wherein the work blank is placed over a male mandrel and is rolled externally thereon, with a similar extension in diameter and length as the rolling progresses, and with a transfer of the work piece periodically onto mandrels of larger diameter as the diameter of the work is increased, and a continuation of the rolling on such larger diameter.

In this initial phase of the process, the wall thickness is reduced to a dimension somewhat greater than the web thickness of the final product in the web portions thereof bridging between the reinforcing ribs, the thickness being such that when the ribs have been extruded to their final height, the wall structure will have been reduced to its final web thickness.

The apparatus of FIGS. 1–10

Referring now to FIG. 1, I have shown therein, as an example of another form of apparatus embodying my invention, a horizontal-axis rolling machine comprising, in general, a frame structure A; a rotary drive unit B for transmitting rotation to a work-rotating and drawing plunger C having a chuck for grasping the work W so as to rotate the same while drawing it axially through a die D; a pulling actuator E for applying axial pull to the unit C while permitting it to rotate; a rolling head F for internal rolling operation on the work W and embodying means for adjusting its radius of rolling operation; and a boom and boom-handling apparatus G by which the rolling head F is supported and actuated for application to the work, withdrawal from the work, and adjustment of its rolling radius.

Frame structure A comprises, in detail, a horizontal bed **20** having, along its upper side margins, ways **21** on which other units of the apparatus are mounted. Such other units include standards **22** and **23** which are fixed to the bed **20** and which support respective ends of the actuator E; a standard **24** likewise fixed to the bed **20** and supporting the rolling head boom G; a saddle **25** in which the rotary power unit B is mounted; a yoke **26** for supporting rolling bearing mounts for the die D; and a truss rod **27** extending between the upper ends of standards **22** and **24** and bracing them in spaced relation.

Rotary power unit B comprises the saddle **25**, anchored to the bed **20** in a fixed position; a pillow bearing cap **35** secured to saddle **25** at **36**; a rotary drive spool **37** rotatably mounted in a bearing unit **38** which in turn is mounted between saddle **25** and cap **35**; a drive motor **39** (e.g. electric motor) mounted upon cap **35**; and a reduction drive gear unit **40**, which can be of the Boston gear type, for transmitting rotary drive to the spool **37** from the motor **39** at a greatly reduced speed. The basic apparatus thus far described may utilize conventional engine lathe structure wherein the bed **20** is the lathe bed and the drive unit D is the drive head of the lathe. Accordingly, the structure of drive unit B, being well known, is not disclosed herein in detail.

Rotary drive unit C embodies a tubular shaft **45** extending through and having a rotary drive-receiving connection (not shown) with drive spool **37**; a pillow bearing unit **46** in which the shaft **45** is slidably and rotatably cradled, the unit **46** being secured to the ways **21**; and a chuck **47** which is shown in detail in FIG. 5. Mounted on the end of shaft **45** is a shank **48** carrying a flange **49** to which is secured a face plate **50**. Face plate **50** has a collar **51** in which are mounted an annular array of chuck jaws **52** each having at its end an arcuate lip **53** which is engageable in an annular internal groove **54** in a work blank **55**. Actuator screws **56**, mounted in fittings **57** on the periphery of collar **51**, are operative to adjust the jaws **52** radially so as to enter and to clear the grooves **54** respectively when the work is being chucked.

FIG. 2 discloses a typical work blank **55** when first chucked in the machine. The blank is relatively short axially and has a wall that is relatively thick radially. The groove **54** is machined internally in one end of the blank preparatory to its installation in the machine.

Sizing die D (FIGS. 9, 10) comprises a circular mounting ring **60** of ample radial cross section to resist the very high radial expanding forces imposed by the rolling head F; and a die ring or collar **61** secured thereto by cap screws **62** extending through apertures in an integral flange **63** of the collar **61** and threaded into the mounting ring **60**. The collar **61** has a frusto-conical outer wall **64** snugly fitted within a frusto-conical inner wall of mounting ring **60** having a corresponding taper, and tightly wedged therein by the action of cap screws **62** drawing the collar **61** into the mounting ring **60**. Collar **61**, which is of an extremely hard material resisting the wearing effect of the work sliding therein, has a highly polished cylindrical inner wall for supporting and sizing the outer wall of the work W.

Die unit D is power-rotated in unison with chuck **47**, by means of a pair of bridging arms **65** of arcuate cross section (FIG. 10) to which a pair of longitudinal bars **66** are secured by screws **67** and are spaced therefrom by spaced collars **68**, the arms **65** being welded at one end to the die mounting ring **60** and at their other end to a flat ring **69** that is anchored by screws **70** to a flange **71** on the forward end of driving sleeve **37**. In order that chuck **47** may rotate the work W as hereinbefore stated, a conventional sliding drive connection between chuck **47** and drive unit B (e.g. between face plate **50** and longitudinal bars **66**) is provided. Mounting ring **60** has a hardened, wear-resistant tire **72** secured on its periphery, and is rotatably supported by engagement of the tire **72** against bearing rollers **73** (FIG. 10) which are rotatably mounted in brackets **74** carried by yoke **26**. The axial loads imposed upon die D by the drag of the work W as it is pulled through the die, are taken by the arms **65** in compression, functioning as struts.

Pulling actuator E (FIG. 1) is of a hydraulic cylinder type, comprising a cylinder **80** anchored at its respective ends in the standards **22** and **23** and having therein a piston **81** selectively subjected to hydraulic pressure moving it in one direction or the other under the control of a suitable two-way valve. Such hydraulic actuators are well known in the art and accordingly the details of the hydraulic connections and valving are not disclosed herein.

A piston rod **82** is attached to piston **81**, extends through a conventional sealing gland in one end of the cylinder **80**, and is attached by a fitting **83** to the end of shaft **45**. The heavy working loads of the successive rolling passes are taken by the stem **82** in tension, pulling the work W toward the drive head B while the rolling head F, held in a fixed position within the work, in the plane of the die D, exerts a thinning and extruding action against the wall of the work W. On the return stroke, the rolling head F is idle and does not present any substantial resistance to the return movement of the work W to a starting position, and the piston rod **82**, transmitting such movement by a pushing action, is rigid enough to exert the relatively light push required for the return stroke, without buckling.

Rolling head F (FIGS. 6–10) comprises a generally cylindrical spider **90** composed of three triangular segments **91** having flat inward faces **92** subtending an obtuse dihedral angle, and joined together by flat end rings **93** and **94** bolted thereto by bolts **132**. Defined between the flat dihedral faces **92** of segments **91** and the flat inward faces of end rings **94** are sockets **95** of square cross section (FIGS. 6, 6*a*) in which are mounted, for radial sliding movement, respective roller mounting cups **96** having cylindrical swivel socket bores **97**. In the bores **97** are mounted respective roller mount harps **98** with cylindrical outer faces fitted in the bores **97** for swiveling adjustments. Each harp **98** embodies fork arms, in which is mounted a roller shaft **99** secured by end caps **100**. A roller **101** is mounted on the respective shaft **99** between the arms of harp **98**, with anti-friction roller bearings **102** interposed to provide free rolling movement under the heavy radial loads applied by the rollers **101**. The harps **98** are held in their swivel socket bores **97** by retainer bars **103** (FIGS. 7, 8), secured by cap screws **104** to respective sides of the outer end face of the mounting cup **96** and overhanging the respective swivel socket **97** and the respective fork arms of the harp **98** therein, clamping the latter tightly in its socket. By loosening the retainer bars **103**, the harps **98** may be adjusted by swiveling them to selected positions of angular displacement of the roller axes from parallel relation to the major axis of rotation of head F, pitching the rollers for helical travel with respect to the internal wall of the work W. Such helical travel may be adjusted to correspond to the relationship between the rate of rotation and the rate of axial movement of the work W, so that the rollers may execute a true rolling movement against the inner wall of the work, without slippage. The several parts **91**, **93**, **94**, head **90** are secured together by tie bolts **106**.

The mounting cups **96** are biased for radially inward movement toward the bottoms of their respective sockets, by coil springs **110** accommodated in corner recess **111** in the respective mounting cup **96** and engaged under compression between feet **112** at the bottoms of the respective recesses **111** and abutment fingers **113** which are secured by cap screws **114** in peripheral notches **115** in the respective end rings **93** and **94** and project axially inwardly to overhang the spring recesses **110**.

Against the compressive resistance of springs **110**, the three mounting cups may be simultaneously adjusted radially outwardly (maintaining equal radial spacing from the major axis of head F) by means of an actuator mandrel **120** having a cylindrical periphery **121** which is interrupted by three axially extending grooves **122** of progressively increasing depth from end to end of the mandrel, the bottoms of said grooves constituting ramps **123** which are in sliding engagement with wedge shaped shoes **124** on the bottoms of the respective mounting cups **96**. Shoes **124** are of rectangular cross section, narrower than their respective cups **96**, and fitted into the grooves **122** as best illustrated at the bottom of FIG. 7. Between the segmental cylindrical peripheral faces **121** and the grooves **122**, the mandrel is faced off with chordal faces **125** to clear the bottoms of the mounting cups **98**. Faces **125** are parallel to ramps **123**, in frusto-pyramidal converging relation as best seen in FIG. 6*b*.

Mandrel **120** has an axial bore in which is received a reduced shank on the end of a draw stem **126**, the mandrel being secured thereon by a nut **128** threaded onto the end of the shank.

The cylindrical peripheral surfaces **121** are fitted in central apertures **127** in the annular end plates **93**, **94**, the cylindrical inner walls of apertures **127** providing bearing surfaces for supporting the mandrel in coaxial relationship to the major axis of the head so that the three rollers may be adjusted to uniform radial spacing from said major axis at all positions of the mandrel. It will now be apparent that as the mandrel is drawn into the head, its wedging action against the shoes **124** will force the respective mounting cups **96** radially outwardly, increasing the radius of rolling operation of the three rollers **101**. Vice versa, by retracting the mandrel from the head, the three mounting cups **96** will be permitted to ride inwardly under the loading of their springs **110**.

Mounting assembly G comprises a tubular boom **130** having an end flange **131** to which head F is mounted by the cap screws **132**.

Referring now to FIG. 1, the boom **130** is mounted for axial sliding movement in a suitable bearing **133** carried by standard **24**, and is provided with suitable means for feeding it axially. Such means is shown schematically in FIG. 1 as a series of rack teeth **134**, a drive element **135** (such as a worm, for non-reversible drive) meshing with the teeth **134**, and a suitable actuator unit **136** for actuating such driving gear shown schematically at **135**. Although a manual actuator is indicated, a power driven actuator can be employed, and is preferred in view of the size of the apparatus. By operating the mechanism G, the head F can be inserted into a new work blank **55** chucked in the machine and properly positioned in the plane of die D as shown in FIG. 9; can be withdrawn at any time during the processing, for inspection of the work W internally, and then reinserted; and can finally be withdrawn after the work has attained its final dimensions.

Operation (*the method*)

Using the apparatus disclosed in FIGS. 1, 5–10, the improved metal working method of my invention may be executed. A work blank in its initial form shown at **55** in FIG. 2, with relatively short axial dimension and relatively thick radial wall dimension is prepared and the mounting groove **54** is machined in its inner wall near one end. This blank is chucked upon the drive transmitting unit C in the manner previously explained, and the unit E is then operated to project the work into the embrace of die D. The rollers **101** of roll-forming head F are retracted in the manner previously described, to positions of minimum radius so as to clear the inner wall of work blank **55**, and by operating the mechanism G, the head F is projected into the work blank. In the initial positioning of the blank **55**, it is located so that when the head F is inserted to a depth such as to bring the common plane of its rollers **101** into registration with the plane of die D, the rollers will initially engage the inner wall of blank **55** adjacent the ends of chuck jaws **52**. The drive unit B is then operated to rotate drive transmitting spool

37, such rotation being transmitted simultaneously to the chuck **47** and to the flange **71** which in turn transmits rotation to the die D through the bridging arms **65**. The boom **130** is held in its mounting bearing **133** against rotation, thus fixing the head F against rotation. The work blank **55**, secured on the chuck **52** and encircled by the rotating die D, will be rotated around the head F. While continuing such rotation, the mandrel **120** is actuated to adjust the rollers **101** radially outwardly until they bear compressively against the inner wall of the work blank, impressing an annular channel in said inner wall with an arcuate cross section corresponding to the crowned peripheral contour of the rollers **101**. Adjustment is continued until the rollers are projected into the wall of the work blank a selected depth. They are then fixed in their existing radial positions by fixing the mandrel **120** against axial movement. This may be accomplished by anchoring the end of the actuator stem **126** with respect to the boom **130**, near the rear end of the latter, by any suitable means (not shown). With the rotation of the work continuing, the head F held in a fixed position in the plane of die ring D, and the rollers **101** embedded in the inner wall of the work at a selected depth, the draw actuator E is then subjected to power to slowly pull the work blank axially toward the right as viewed in FIG. 1 while rolling head F is held against axial movement, thus causing the rollers **101** to traverse a helical path with respect to the inner wall of the work blank until they reach a selected position of proximity to the trailing end of the blank. In this first pass, the wall thickness will be reduced by the radial depth to which the rollers are embedded in the inner wall of the work, and a corresponding elongation of the work blank will take place. Without changing the adjustment of the rollers **101**, and while continuing the rotation of the work, the actuating unit E will be reversed to return the work leftwardly as viewed in FIG. 1, to the starting position where the rollers are adjacent the ends of jaws **52**. While continuing the rotation of the work, the rollers **101** will again be adjusted radially outwardly under pressure from leftward movement of mandrel **120**, rolling an annular channel within the work adjacent its rightward end to a depth selected for the second pass. When this depth has been achieved, the rollers are fixed in the positions of radial projection which they then occupy, and, while continuing the rotation of the work, the draw unit E is again actuated to draw the work over the roll forming head F while the latter remains fixed axially. A second reduction in wall thickness will thus take place, with a corresponding elongation of the work.

A series of consecutive axial passes of the work over the head F is thus executed until the work has been reduced to the selected wall thinness and axial length as shown by way of example in FIG. 3. During all of these successive passes, the head F is anchored in a fixed position axially except when it is desired to withdraw it from the work for inspection purposes. Throughout the series of operations, the outer wall of the work is maintained at an accurately uniform diameter and true cylindrical contour by the sizing operation of the inner wall of die collar **61** as the work is drawn through it while subjected to the outward pressure of rollers **101**. Wrinkling cannot possibly occur for the reason that the work is completely restrained by the tightly encircling embrace of die collar **61** in the area where it is being subjected to the extrusive action of the rollers **101** gradually moving the excess metal axially so as to elongate the work. Fissures cannot occur because the action of the rollers is a compressive one, compacting the metal and exerting no circumferential drag thereon, since the rollers are mounted for substantially frictionless rotation in their respective sockets. I find that relatively brittle metals such as titanium can thus be worked with a high and uniform degree of success, without developing flaws or weaknesses in the wall structure and actually with an increase in tensile and compressive strength.

Arms 65 function to transmit rotation to die ring 72. They may also function as embracing guides for centering the chuck 47 on the axis of draw shaft 45.

Modified form—FIG. 4

Instead of a continuous path the full length of the work blank, a series of partial-length passes may be executed, with the rollers being retracted at the end of each of such sectional passes and again moved outwardly into extruding engagement with the work after the latter has been shifted a slight distance to leave a thin annular web 140 between the successive areas of extrusive engagement, so that, in the finished work, a series of internal annular reinforcing ribs, integral with the relatively thin intervening cylindrical wall structure, will be provided. Except for such intermittent withdrawal of the rollers, intervening shifting of the work slightly, and reengagement of the rollers after such slight axial shift, the method of producing the work shown in FIG. 4 is the same as that described above, and the same apparatus may be used to execute it.

Detailed description—FIGS. 11, 12

Apparatus.—The draft unit C′ includes a head 216 which is receivable through the tubular work blank W and has a frusto-conical shoulder adapted to engage the interior of lip 215 with a self-centering action such that a pull can be applied along the longitudinal axis of the work blank. Head 216 is secured to the end of a draw bar 217 through the medium of a rotatable coupling 218 embodying suitable anti-friction bearing means such as to permit free rotation of the work blank W and the head 216 without imposing such rotation upon the draw bar 217.

The die unit D′ includes a supporting member 220 which may be in the form of a relatively rigid tube as shown, and a sizing die 223 consisting of an annular ring welded or otherwise secured to the end of supporting tube 220 and having a smooth, circular inward surface for exerting a smoothing and sizing action on the outer surface of the work blank W, as the blank is drawn therethrough as indicated by the arrow 224.

The die ring 223 also functions, through tight constricting engagement with the outer surface of work blank W, to impart thereto rotation transmitted from the die D′ which is provided with means (not shown) for rotating the same. Forming tool F′ comprises a plurality of rolls 225 mounted for rotation in a cage 226. More specifically, the cage 226 may comprise a pair of axially spaced parallel discs, as shown, in embracing relation to the rolls 225 and having peripherally open radial slots 227 in which the axles of rollers 225 are mounted for rotation and for free radial sliding movement. The forming tool F further includes a pair of control rollers 228 carried by a spider 229 on the end of a control shaft 230 which is rotatably mounted within a tubular shaft 231 secured to the center of cage 226. The tubular shaft 231 is secured at its end remote from the cage 226, to a suitable anchorage bracket 232 which secures it against rotation. The shaft 230 on the other hand, is rotatable within tubular shaft 231 and is provided at its remote end with a suitable means such as crank lever 233, for imparting rotation to the spider 229, thus to shift the control rollers 228 circumferentially. It will now be apparent that such circumferential shifting may be utilized for displacing the control rollers 228 between working positions radially aligned with forming rolls 225 as shown in FIGS. 11 and 12, and retracted positions withdrawn circumferentially from such working postions, wherein the rolls 225 are permitted to yield radially inwardly with their trunnions sliding in the guide slots 227. In the working positions of the forming rolls 225, they will exert outward forming pressure against the inner wall of work blank W, for forming therein, internal annular grooves 234, with inwardly extruded ribs 235 being defined between the grooves 234.

The die ring 223 serves further as a backing member for resisting radial pressure applied to the internal wall of the blank W by one or more pairs of forming rolls 225 of the forming tool F.

Forming tool F includes the rollers 225, the cage 226 in which the rolls 225 are mounted for rotation on their individual axes and for radial movements with respect to the major axis of the forming tool F′, and for restraining the rollers against rotating with the work blank W.

Method.—In my improved method, explained by reference to the apparatus of FIGS. 11–16, as a preliminary step a relatively thick-walled annular work blank W may be formed by any of the methods shown in FIGS. 13–15, or by extruding through a circular extrusion die (or by any acceptable technique of rolling a flat plate into cylindrical form and seam welding the meeting edges thereof). Alternatively, the annular work blank, of relatively thick initial wall thickness and relatively short initial length, may be procured from a suitable source, and my process may be performed on such procured material. Subsequently, a retainer lip such as lip 215 is formed on one end as by rolling or swaging, or by cutting an annular groove such as groove 54 of FIG. 9. The head 216 of draft unit C may, if desired, be utilized as the mandrel around which the lip 215 is formed.

The head 216 having been inserted into the blank W, engaging the lip 215, the assembly of draft unit C′ and work blank W is inserted into the combined drive and sizing die D′, with the conical nose of the work, defined by lip 215, entering the die ring 223, and with the draw bar 217 extending through the opposite end of the support tube 220. In the initial fabrication of the work blank W, its outer wall is formed to a diameter equal to or slightly larger than the internal diameter of die 223 so that an interference fit will be established between the outer wall of the work and the inner wall of die 223. This requires the application of substantial pull to the forward end of the work blank W to draw it forcibly through the die 223.

In the next major step of operation, a strong pull is applied to the forward end of the work blank W through the draw bar 216 and rotatable coupling 218, while simultaneously, rotational force is applied ot the work holder tube 220 of die D′. As the work blank W is forced into and through the die ring 223, a tight frictional grip of the die 223 against the outer wall of the work blank W will be developed by reason of the interference fit, and the rotation of die D′ will thereby be transmitted to the work blank W as a frictional drive. Thus the work blank W is rotated while pull is continuously applied to the work blank, the rotation being accommodated in the rotatable coupling 218.

While the work blank is thus being rotated and advanced axially into the die D′, the forming unit F′ (previously inserted into the work blank while forming rolls 225 are retracted and moved to a starting position adjacent tractor head 216) is held against rotation by the holding member 232 while torque is gradually applied to the control shaft 230 to shift the control rollers 238 circumferentially in bearing engagement with forming rolls 227, gradually forcing the latter outwardly into the metal of the interior of work blank W and forming an annular internal groove therein. A strong pull is then applied to the work W by draft unit C′ while die unit D′ is rotated, thus effecting extrusive rolling action in which the rolled annular groove is extended axially and the wall thickness of the work blank is reduced while it is elongated under the combined effect of the extrusive rolling and the drawing action of draft unit C′.

Simultaneously with the internal extrusive rolling, the outer wall of the work blank W will be sized and burnished by the longitudinal drawing of the work blank through the die ring 223.

The invention provides greatly improved results in that both faces of the work will be work hardened and strengthened by the rolling and sizing operations to which they have been subjected. The smooth outer cylindrical surface of work blank W will be improved by the burnishing operation performed by the die 223 as the work blank is drawn therethrough. Such work hardening operations will greatly increase the tensile strength of the work, harden and toughen the surface and make it more resistant to failure originating in surface striations.

Where reinforcing ribs are to be formed within the work tube, an initial annular groove can be formed adjacent draft head 216 as previously described and then widened into annular channel 234 of FIG. 11 by applying draft to the work W through draft unit C′ and pulling the work a short distance through the die.

The shaft 230 is then actuated to shift the control rollers 228 out of registry with forming rolls 225, permitting the latter to yield inwardly past the shoulder formed in the internal wall of work blank W at the end of the rolling operation just described. The rolls 225 are shifted past the shoulder to an extent corresponding to the thickness of the rib 235 to be formed. The control shaft 230 is then again actuated to shift the control rollers 228 against the forming rolls 225 and force the latter outwardly to begin a new annular recess in the interior of work blank W, which recess is widened by the gradual forward feeding movement of work blank W by draft unit C′ until another full width internal channel 234 has been formed. The rolls 225 are then again retracted to clear the shoulder at the end of this last groove and to reach a position where another internal annular channel may be commenced. These rolling operations are repeated as the work blank W is fed axially in the direction 224 through the sizing die ring 223.

These operations are continued until a series of circular internal integral ribs 235 are formed in uniformly axially spaced relation in the inner wall of the work blank W substantially from end to end thereof. The forming tool F′ is then removed from the end of the work blank W where the last operation was performed, the work blank is removed from the die unit D′ (e.g. through the end thereof opposite the end which carries the die ring 23) and the work blank is separated from the draft unit C′.

Modified form—FIG. 13

FIG. 13 discloses a modified apparatus which can be used for performing a modified form of an initial stage of preparation of work blank W. The apparatus in this instance includes a draft unit C′ which may be substantially the same as of FIG. 11 and the work blank W is formed with a retainer lip 215 for engagement by draft head 216 for drawing the work blank between a pair of opposed forming rolls 225*a* rotatably mounted in suitable radially adjustable supports 240. While passing between the rolls 225*a*, the work blank W is drawn over a mandrel 241 of circular cross section which has been inserted into the beginning end of work blank W previous to the forming of lip 215 around tractor head 216 by a suitable spinning operation. Mandrel 241 is carried by a drive shaft 242 through which rotation is transmitted to the mandrel 241 from a suitable power unit 243 as indicated by the arrow 244. Mandrel 241 has an interference fit within the work blank W so as to establish a tight frictional driving connection therewith, whereby the rotation is transmitted to the work blank W.

As the work blank is thus rotated, a strong pull will be applied to the work blank through the draft unit C′, gradually drawing the work blank over the mandrel 241 and thereby sizing and burnishing the inner wall of the work blank. At the same time, the forming rolls 225*a*, rotating against the outer wall of the work blank W, pressed radially inwardly by forcing the mounting members 240 inwardly (using any suitable mechanism—not

shown—for that purpose) will effect extrusive rolling at 235*a*.

Modified form—FIGS. 15 and 16

In the initial stage of preparation of work blank W, shown in FIGS. 15 and 16, the work blank W is supported upon and rotatably driven by a mandrel 241*b* which in turn may be driven by any suitable drive unit 243*b*. While it is driven, the exterior of the work blank is worked by one or more pairs of forming rolls 225*b* rotatably mounted in suitable clevises 240*b* which are keyed or otherwise firmly secured to the ends of actuator shafts 245, in a manner such that torque may be transmitted through the shafts 245 to swing the clevises 240*b* arcuately from positions clearing the surface of work blank W to positions in which the rolls 225*b* will form the external surface of the blank W to smaller diameter. The shafts 245 are carried by an axially movable carrier C″ comprising a cross head 247 on the end of a ram 248 through which high pressure can be aplpied to the shafts 245 from a suitable hydraulic actuator or the like. Rotation may be simultaneously transmitted to shafts 245 by any suitable means such as the worm gearing 249 linked by a common drive shaft 250 rotatably extended through ram 248.

In an alternative use of the apparatus of FIGS. 15, 16, by manipulating the roller carrier unit C″ just described, the forming rollers 225*b* may be fed forwardly forcibly against the work W, intermittently swung arcuately to retracted positions clearing the annular external ribs 235*b* which are extruded outwardly by the rolling operation, and then returned inwardly for a further period of axial advancement of the rolls as indicated by arrow 251, whereby a series of annular external grooves, with intervening ribs 235*b*, will be formed in work W.

I claim:

1. An improved method of fabricating integrally ribbed tubes of malleable metal, including the following steps: preparing an annular work piece of greater wall thickness than the required thickness of the completed tube; supporting said work piece by a work holder of circular cross-section against which one annular face of the work piece is seated; applying a forming tool to the other annular surface of the work piece under radial pressure; and applying an axial pull to the work piece while effecting relative rotation between the work holder and the forming tool to cause the forming tool to rotate under pressure against said other annular surface of the work piece in a manner to reduce the radial wall thickness of the work piece and to elongate the work piece axially in the direction of said axial pull while extruding integral reinforcing ribs radially away from the said other annular surface until a series of spaced reinforcing ribs, integrally attached to and projecting transversely from thinned intervening wall sections, are formed.

2. The method defined in claim 1, wherein said work holder comprises a die ring and the work is supported internally thereof; and wherein a series of axially spaced internal annular depressions of channel form are formed in the inner wall of the work piece, with extruded inwardly projecting annular ribs being defined between said annular depressions, said depressions being formed by forcing a plurality of forming rolls radially outwardly against the inner wall of the work piece while rotating said rolls on axes parallel to the axis of the work piece and simultaneously pulling the work piece through the die ring and extruding the wall of the work piece axially between said ribs, by action of said rolls, by intermittently withdrawing said rolls radially inwardly, and by again forcing them radially outwardly at a position axially removed from the previous position of operation.

3. An improved method of fabricating metal tubes, including the following steps: providing a tubular work piece of greater wall thickness than that required in the finished tube; applying an axial pull to said work piece

and thereby forcibly drawing it through a sizing die to effect a sizing and burnishing operation against its outer surface; and simultaneously applying against its inner surface a plurality of forming rolls applying balanced radially outward pressure against said inner surface to reduce the wall thickness of the work piece while simultaneously elongating the work piece axially.

4. An improved method of metal tube fabrication, comprising the following steps: preparing a work piece in the form of a relatively short, thick-walled tube; forming a radially inwardly projecting abutment lip at one end of the work piece; supporting the work piece within a die ring that is fitted to its outer circumference; applying an axial pull to said lip to draw the work piece axially through said die ring; and simultaneously rotating said die ring to cause the work piece to rotate while circumferentially rolling the interior of the work piece under pressure, thus enlarging its internal diameter, reducing its wall thickness, extruding it axially with the assistance of said axial pull, and drawing it through said die ring with a sizing operation on its outer surface.

5. An improved method of metal tube fabrication, comprising the following steps: preparing a work piece in the form of a relatively short, thick-walled tube; supporting the work piece within a die ring in encircling engagement with its outer surface; applying an axial pull to one end of said work piece to draw it axially through said die ring; and simultaneously rotating said die ring to cause the work piece to rotate while circumferentially rolling the interior of the work piece under pressure, thus enlarging its internal diameter, reducing its wall thickness, extruding it axially with the assistance of said axial pull, and drawing it through said die ring with a sizing operation on its outer surface.

6. The method defined in claim 5, wherein said work piece is axially elongated by the combination of tension under which it is drawn through the die ring and the wall thinning operation of said forming rolls.

7. An improved method of fabricating integrally ribbed tubes of malleable metal, including the following steps: providing a tubular work piece of greater wall thickness than that required in the finished tube; and forcibly drawing said work piece through a sizing die to effect a sizing and burnishing operation against its outer surface while simultaneously applying against its inner surface a plurality of forming rolls applying radially outward pressure against said inner surface to reduce the wall thickness of the work piece while extruding radially inwardly a series of spaced reinforcing integral ribs and simultaneously elongating the work piece axially.

8. An improved method of metal tube fabrication, comprising the following steps: supporting a work piece in the form of a relatively short, thick-walled tube in alignment with a die ring adapted to have encircling interference engagement with its outer surface; applying an axial pull to one end of said work piece to draw it axially into said die ring; and then rotating said work piece while circumferentially rolling the interior thereof under pressure in a rolling path progressing axially from one end of the tube to the other in accordance with the axial movement of the tube through the die ring, thus enlarging its internal diameter, reducing its wall thickness, extruding it axially with the assistance of said axial pull, and simultaneously drawing it through said die ring with a sizing and burnishing operation on its outer surface such as to toughen and strengthen the resulting tube structure.

9. A method of forming cylindrical tubular metal articles of circular cross-section, including the following steps: applying an axial pull to an annular blank to draw it axially through a circular sizing die and simultaneously rolling the inner wall of the blank to enlarge its internal diameter while correspondingly reducing its thickness along a rolling path radially opposed to said die, and moving displaced metal axially ahead of said rolling path so as to elongate the blank axially.

10. A method of forming thin-walled cylindrical tubular articles of a metal of low ductility, including the following steps: applying an axial pull to a relatively short, thick-walled cylindrical tubular blank to draw it axially through a circular sizing die and simultaneously applying rotation in unison to the die and to the leading end of the blank while applying rolling pressure to the inner wall thereof at a point indented in said inner wall and radially opposite the inner wall of said die and while holding said die and point of rolling pressure axially fixed, whereby said inner wall is enlarged in diameter while the outer wall of the blank retains unchanged in diameter, thus thinning the blank; and continuing to draw the blank through the die to extend said thinning along the length of the blank, and utilizing said rolling pressure to move metal that is displaced as the result of said thinning, axially ahead of said point of rolling pressure so as to elongate the blank axially.

11. A method of forming thin-walled cylindrical articles of a brittle metal such as titanium, including the following steps: applying an axial pull through a chuck to one end of a cylindrical tubular blank so as to draw it axially through a sizing die while rotating the die and chuck in unison so that both will transmit rotation to the blank and holding the die fixed against axial movement, applying rolling pressure to the inner wall of the blank at an axially-fixed point radially opposite the inner wall of said die, so as to indent said inner wall along a rolling path extending along the length of the blank, while restraining the outer wall within the die to prevent enlargement thereof, thereby thinning the blank and moving displaced metal axially so as to elongate the blank, while effecting a sizing and burnishing operation against the outer surface of the blank by the drawing of the blank through the die, thereby toughening and strengthening the resultant article.

12. A method of forming thin-walled cylindrical tubular articles of a metal of low ductility, including the following steps: applying an axial pull to a relatively thick cylindrical annular blank so as to draw it axially through a circular sizing die and simultaneously applying rolling pressure to the inner wall of the blank at a point indented in said inner wall and radially opposite the inner wall of said die, with said die and point of rolling pressure remaining axially fixed, whereby said inner wall is enlarged in diameter while the outer wall of the blank retains unchanged in diameter, thus thinning the blank; utilizing said rolling pressure and said axial pull to move metal that is displaced as the result of said thinning, axially ahead of said point of rolling pressure so as to elongate the blank axially with the displaced metal being absorbed smoothly into the elongating blank adjacent the point of rolling pressure as a result of said axial pull, avoiding piling up of displaced metal ahead of said point; continuing said drawing and rolling movements to complete one pass of the rolling action substantially the full length of the blank while holding the point of rolling pressure radially fixed; releasing said rolling pressure while returning the blank axially to the starting position; and repeating said steps of axial drawing through the die and application of rolling pressure and axial displacement metal, completing another pass with the point of application of rolling pressure held at a fixed radius greater than the radius of rolling pressure in the previous pass.

13. A method of forming cylindrical tubular metal articles, including the following steps: providing a work piece in the form of a relatively short, thick-walled tube; coupling an end of said tube to a pulling device and operating the same to forcibly insert said tube into a die ring having encircling interference engagement with its outer surface; applying a plurality of forming rolls in

contact with the inner surface of said tube at points spaced circumferentially; then rotating said tube by transmitting drive thereto both at said pulling device and at said die ring while adjusting said rolls radially outwardly and applying radially outward pressure of said rolls against said inner surface such as to indent the same and to develop therein an internal annular groove of selected depth; and subsequently applying an axial pull from said pulling device to one end of said tube and thereby forcibly drawing it through said die ring to effect a sizing and burnishing operation against its outer surface while holding said rolls in fixed positions radially opposed to said die ring and simultaneously rotating said tube so as to produce extrusive rolling of said inner surface gradually along the length of the tube such as to move displaced metal axially ahead of said rollers and to absorb said displaced metal into the tube wall structure adjacent said rolls with the assistance of said axial pull, thereby to elongate the blank axially.

14. The method defined in claim **13**, wherein rotation is transmitted to said tube simultaneously, and in unison, through said die ring and through said pulling device.

15. A method of forming cylindrical tubular metal articles, including the following steps: providing a work piece in the form of a short, thick-walled cylindrical tube; forcibly inserting said tube into an axially narrow circular die ring in tight encircling engagement with its outer surface; applying a plurality of forming rolls in contact with the inner surface of the tube near one end thereof at circumferentially spaced points of contact radially opposed to the interior of said die ring; rotating said tube and simultaneously adjusting said rolls outwardly under radial pressure so as to indent said inner surface to a selected depth and to form an annular internal channel therein; then applying an axial pull to said one end of the tube and thereby forcibly drawing it through said sizing die while rotating the tube and holding said forming rolls in fixed radially-opposed relation to said die ring so as to effect extrusive rolling of said inner surface in a rolling pass along the length of the tube at a fixed indenting depth while extruding metal of said inner surface ahead of said forming rolls and thereby enlarging the internal diameter of the tube, reducing its wall thickness, and simultaneously elongating the tube while absorbing displaced metal into its wall structure with the assistance of said axial pull, and effecting a sizing and burnishing action against its outer surface.

16. The method defined in claim **15**, including the further steps of returning the tube without extrusive rolling thereof, to the position of starting of said rolling pass; then effecting further adjustment of said forming rolls outwardly under radial pressure while rotating the tube to develop another internal annular channel adjacent said one end of the tube, at a selected depth of further indentation; and then again applying an axial pull to said one end of the tube so as to again draw it axially through the die while continuing to rotate the tube, thus effecting a second pass of extrusive rolling of the interior of the tube at said second selected indenting depth, whereby to further enlarge the internal diameter of the tube while further reducing its wall thickness and further elongating it with additional sizing and burnishing of its outer surface as it is drawn through the die.

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