WORK PIECE
4130 STEEL, AS-QUENCHED
1.00" O.D. X 0.035" WALL

DRAW SPEED
8 INCHES/MINUTE

LUBRICANT
IVORY SOAP

SYMBOL  DIE-SHAPE  DIE MATERIAL
O  3-CIRCLE  BRONZE
□  3-CIRCLE  TOOL STEEL
△ CONVENTIONAL  CARBIDE

PERCENT REDUCTION IN AREA BY DRAWING

Fig. 1.

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METAL DRAWING METHOD AND APPARATUS

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ABSTRACT OF THE DISCLOSURE

A method of drawing elongated metal articles and a novel die configuration which implements the method, assuring the establishment and optimum performance thereof. According to the invention, tube, bar, rod or sheet stock is drawn to a reduced diameter or wall thickness, or both, through the die or between the die and a mandrel or other supporting surface. The die in longitudinal section has entrance and land arcs, preferably segments of circles, which intersect with a common tangent, and has an outwardly flaring exit that is preferably an arc tangential with the land arc. The stock upon entering the die is deflected inwardly or laterally a large amount at a primary deflection point on the entrance arc, to be intercepted and further deflected a small, precisely controlled amount at a secondary deflection point on the land arc, thereby creating and perpetuating a natural serpentine bend in the stock as it moves under the die, greatly reducing redundant work and friction and providing a lubrication chamber between stock and die for improved lubrication, whereby the required drawing force is substantially reduced, and producing more uniform final dimensions, as well as improved quality of the material, both internally and externally.

BACKGROUND OF THE INVENTION

The present invention relates in general to the drawing of various types of elongated metal stock, including but not limited to tube, rod, bar, wire and sheet stock, to reduce the transverse dimension of the stock and increase the longitudinal dimension thereof. For the purpose of this application the term "drawing" is hereby defined to include tube sinking, wherein a tube is moved through a closed die without internal support such as a mandrel, to reduce the diameter of the tube usually without a major change in the wall thickness; tube sizing, wherein the tubing is confined between a closed die and a mandrel which either moves with the tube or "floats" within the tube proximate the region of the die, for the principal purpose of reducing the wall thickness of the tubing, and usually incidentally also reducing the diameter of the tube; bar, rod or wire drawing through a closed die to reduce the diameter and correspondingly increase the length thereof; and the drawing of sheet stock between a die and a backup plate to reduce the thickness and extend the length of the sheet.

In most instances the term "drawing" as employed in this application refers to an arrangement wherein the stock is moved through or under the die principally by pulling or by a combination of pulling and pushing, although it is to be understood that the term "drawing" as employed herein is intended to also cover the circumstance where the entire moving force is a pushing force, which is sometimes referred to as extrusion.

The present invention will be described herein primarily in connection with tube drawing, although the applicant has found in practice that the principles of the invention apply equally as well to bar, rod, wire and sheet drawing. In this connection, the two types of tube drawing, namely, tube sinking and tube sizing, represent the two extremes of drawing insofar as the support of the work-piece is concerned. Thus, in tube sinking the tubing itself presents the only resistance to inward deformation, while in tube sizing the deformation is opposed by a rigid mandrel which may be treated as non-deformable. What might be considered as in between these two extremes is the drawing of rod, bar and wire stock, which may be considered as comprising an outer shell like a tube, with an inner structure that is partially supporting but is also deformable. Sheet sizing is similar to tube sizing, a relationship which can be best understood by thinking of the sheet as a tube which has been split longitudinally and opened out, the sheet sizing die as a closed tube sizing die which likewise has been longitudinally split and opened out, and the sheet backup plate as a generally flat mandrel.

Conventional drawing dies have a long, gradual funnel-like entrance that is usually substantially conical, which terminates in a long land of specified length that is usually substantially cylindrical, but may have a constricting angle on the order of from 1° to 3°. Maximum wear in such prior art dies occurs at the land, which is the most critical region of the die dimensionally as it is the part of the die which controls the final diameter. In other words, the maximum wear in such prior art dies is at exactly the most disadvantageous place in the die. Thus, the final size tolerance is, and has for a long time been, a major problem in the use of such conventional dies. Nevertheless, the use of a long land is the accepted means in the art for controlling the final diameter of the drawn article.

In operation, such conventional dies with the long, gradual entrance and generally straight land gradually guide and force the stock inwardly by a wedging or camming action, and in conformity with this operation of conventional dies the conventional concept of drawing is that the plastic flow to accomplish the desired change in cross section of the workpiece is caused by compressive forces set up by the reaction between the workpiece metal and the die.

There has been some prior art awareness of an effect termed "cascading" in tube sinking, wherein the tubing tended to shrink inwardly at a faster rate than that directed by the die contour. However, prior to the present invention, there has been no drawing die configuration which could assure the establishment of cascading, or which could, after cascading commenced, provide any satisfactory control over the final diameter of the drawn tube. Conventional dies inhibit the establishment or continuation of any cascading effect by forcing the stock inwardly through a gradual entrance and controlling the final diameter by means of a long land.

It is generally considered that three separate force components make up the total drawing force: (1) the force required to decrease the diameter uniformly, as in uniform tensile elongation, (2) redundant work, sometimes hereinafter referred to as non-uniform shear deformation, and (3) the force required to overcome friction between the die and the workpiece. There is also a fourth force that may be considered to be present, which is the increase in the drawing force that is required because of work hardening in the part. This fourth force actually represents increases in each of the other three forces resulting from work hardening of the part during the drawing operation.

While the first force, i.e., the force required to decrease the diameter uniformly, is necessarily present regardless of the die configuration, the drawing force required with the use of conventional dies is greatly increased by the second and third forces, i.e., shear deformation and friction factors, respectively, and these increases in the second and third forces cause a progressive increasing in the forth force, i.e., the increase from work...
hardening, as the drawing progresses. In drawing with conventional dies the workpiece is forced inwardly in an unnatural flow pattern which involves a relatively large minimum non-uniform shear deformation, or redundant work, and substantial friction is usually present. Because of this the prior art has been severely limited as to how far the stock can be drawn down in a single pass. The theoretical maximum reduction in a single pass is limited by the simple formula:

\[ A_{\text{min}} = \frac{P}{T} \]

where:

\[ A_{\text{min}} = \text{Minimum cross sectional area of the part which can be achieved during the draw} \]

\[ P = \text{Load or draw force} \]

\[ T = \text{Ultimate tensile strength of the workpiece} \]

It is seen from the above formula that the minimum cross sectional area of the workpiece, to which the workpiece can be drawn increases proportionally to increases in the drawing force P over and above the basic drawing force required to decrease the diameter uniformly, as in simple tensile elongation. Accordingly, the additional drawing force required with the use of conventional dies to overcome non-uniform shear deformation and friction, and to compensate for work hardening in the part, seriously limit the amount that the part can be drawn down in a single pass. Because of this, large reductions generally required repeated intermediate annealing, with consequent increases in manufacturing costs.

A number of additional undesirable results generally occur with the use of conventional prior art drawing dies as described above, for the most part resulting from the undesirably large amounts of non-uniform shear deformation and friction which are present. Sometimes unfavorable residual stresses were present in the drawn product, resulting in the possibility of stress-corrosion cracking therein, and reduction of the fatigue life. Also, surface damage was frequently present, the surface often being marred, striated, or galled, and substantial cracks frequently being present in the wall if an attempt was made to draw the part down too far in a single pass. In tube sinking, the tube wall tended to be thickened, such thickening usually being noticeable starting about one-third of the way down the die entrance incline or wedge. Additionally, the undesirably large shear forces operating between the workpiece and the die tended to damage the die, which usually required that the die be made of a very hard and expensive material, such as tungsten carbide or diamond.

It is well established in the art that a minor change in either interfacial shear resistance or surface lubrication can result in a major change in the overall friction force which must be overcome during a drawing operation. For this reason, both die material and lubrication are critical with the use of conventional prior art drawing dies where interfacial shear resistance is inherently high. As one means to minimize friction, most conventional drawing dies are made with the working parts composed of very hard and expensive materials that are capable of taking a high polish, such as tungsten carbide and diamond. Even with such highly polished die materials, lubrication is generally essential. However, with prior art dies, simple, economical approaches to lubrication have generally failed. Thus, the most practical way to provide lubrication, which is simply to coat the undrawn part of the workpiece with a film of lubricant, does not materially help with conventional dies, because such lubricant is substantially completely extruded back or otherwise wiped out prior to the abrupt engagement between the workpiece and the die entrance funnel, preventing a continuous film of lubricant from being maintained through the work zone. This has resulted in the frequent employment together with conventional drawing die shapes of various complex and expensive, and frequently die weakening, schemes to direct the lubricant to the work area, such as multiple, tandem die arrangements with lubricating pressure chambers therebetween, lubricating channels cut right into the die working surfaces, lubrication pumping arrangements, and the like.

The lubrication problem with conventional dies is compounded where hard, high-strength materials are being drawn. In this case, the higher drawing load and correspondingly higher friction make lubrication even more critical than usual, yet in this circumstance the extra contacting pressure tends to even further wipe out the lubricating film.

**SUMMARY OF THE INVENTION**

In view of these and other problems in the metal drawing art, it is a general object of the present invention to provide a novel drawing method and a novel drawing die configuration employed to effect such method, which either completely overcome or greatly minimize the various problems in the drawing art discussed hereinafter, thereby permitting, other factors being equal, a much larger drawing increment to be taken in one pass, thus reducing the need for intermediate annealing, producing a final product with more uniform overall dimensions and more uniform wall thickness in the case of tubing, and leaving the material of the formed article in better structural condition, both internally and on the surface thereof.

According to the method aspect of the present invention, the elongated workpiece, while being moved axially relative to the die, is first deflected at a ring or line in the entrance portion of the die so as to be turned radially inwardly or laterally in a continuous, uninterrupted curve, this first, primary deflection causing the major part of the reduction that is to be taken in the workpiece during the drawing operation. Then, the workpiece material is allowed to follow a natural bending pattern back toward the axial direction and is intercepted and deflected a second time at a ring or line in the land portion of the die in advance of the land apex. This second deflection diverts the workpiece material a small, accurately controlled amount further radially inwardly or laterally so that it bypasses the minimum diameter part of the land, producing an accurately controlled final diameter or thickness of the part. By this means a stable flow pattern is achieved in the workpiece, in the form of a continuous, uninterrupted curving of the workpiece shaped as an S or serpentine bend. This S-bend in the workpiece adjusts naturally to its shape of minimum strain energy thereby adjusting to the optimum primary and secondary deflection rings on the die, the deflection rings becoming highly polished, low friction regions which, because of the low amount of stress in the workpiece, suffer minimal wear.

The overall geometry of the S-bend in the workpiece, and the positions of the primary and secondary deflection rings or lines on the die which control the same, are highly stable, and determine the final outer dimensions of the drawn article, so that the article has an extremely uniform final dimensional tolerance as compared with conventionally drawn articles. The method greatly reduces redundant work, friction and consequent work hardening, thereby materially reducing the drawing force permitting the article to be drawn down a much larger amount in a single pass than with conventional drawing. A lubricant chamber is automatically formed between the die and workpiece surfaces in the region intermediate the deflection rings serving to entrap and meter surface lubricant on the workpiece so that it is not wiped away.

According to the structural aspect of the invention, a novel die configuration is employed which automatically establishes and predictably and stably maintains the aforesaid continuous curving of the workpiece, with the attendant formation and stabilization of the aforesaid two deflection rings on the die entrance and land portions, respectively. In this novel die configuration, the entrance portion of the die is arcuate in longitudinal section, preferably in the form of a segment of a circle. Accordingly,
the entrance portion of the die will sometimes herein be referred to as the entrance circle or circular entrance surface, and it is to be understood that such terms refer to the general longitudinal sectional shape of the entrance portion of the die. The land portion of the die is likewise arculate in longitudinal section, preferably in the form of a segment of a circle, and likewise hereinafter will sometimes be referred to as the land circle or circular land surface. The land arc has a smaller radius of curvature than the entrance arc, i.e., has a greater rate of curvature, and the land and entrance arcs intersect with a common tangent, a relationship sometimes hereinafter referred to as intersecting.

The exit portion of the die flares outwardly or falls away from the land arc, and is preferably but not necessarily arculate and tangential with the land arc, the preferred cross-sectional configuration of the exit also being a segment of a circle.

The manner in which these entrance, land and exit portions of the present invention cooperate to deform an elongated workpiece moved axially relative thereto with reduced shear deformation and friction, and hence reduced drawing force, will be described in detail hereinafter in the "Detailed Description" portion of this specification.

Briefly summarizing some of the ultimate results achieved by the new die configuration of the present invention, it reduces the force necessary to prop the workpiece past the die, and it reduces the danger of workpiece overstressing and rupture while drawing, allowing workpiece materials and shapes to be drawn that have not in the past been amenable to fabrication by drawing. The new die frequently makes it possible to eliminate heat treatments both between drawing passes and after final fabrication. In general, the new die produces a better quality, closer tolerance drawn part.

Further objects and advantages of the present invention will appear during the course of the following part of the specification, wherein the details of construction, mode of operation and novel method steps of a presently preferred embodiment are described with reference to the accompanying drawings, in which:

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a fragmentary, axial section illustrating a tube sinking operation employing the die configuration and method of the present invention.

FIG. 2 is a fragmentary, axial section similar to FIG. 1, but illustrating a conventional tube sinking operation employing a conventional drawing die and method.

FIG. 3 is an axial section of the die shown in FIG. 1, but with the tube removed therefrom.

FIG. 4 is a diagrammatic representation, in axial section, of the structure of a drawing die embodying the features of the present invention, illustrating entrance, land and exit parameters.

FIGS. 5a and 5c are diagrammatic illustrations of variations in the land radius of dies embodying the present invention.

FIGS. 6a, 6b and 6c are diagrammatic illustrations similar to FIGS. 5a, 5b and 5c, but showing variations in the steepness of the entrance portions of dies embodying the present invention.

FIGS. 7 and 8 are graphs illustrating the substantial reduction in drawing force required with drawing dies made in accordance with the present invention, as compared to conventional drawing dies.

**DETAILED DESCRIPTION**

Referring to the drawings, and at first to FIGS. 1 and 3 thereof, in these figures the present method and die apparatus are illustrated in connection with a tube sinking operation. This is because in tube sinking the die entrance, land and exit arcs are relatively large, and a relatively large amount of forming occurs in the tubing, so that the principles of the present invention are more conveniently illustrated. However, the various novel relationships of the present invention which will be described in some detail in connection with the sinking die and operation illustrated in FIGS. 1 and 3 also hold true, although on a somewhat more reduced scale, for the various other types of drawing to which the present invention relates, namely, tube sizing, rod, bar and wire drawing, and sheet sizing.

The drawing die 10 according to the present invention includes a block or body 12 having generally flat, parallel front and rear surfaces 14 and 16, respectively. The outer periphery of the die body 12 is usually circular, but may be of any desired configuration, and is adapted to be gripped in a suitable supporting structure, as for example a support on a draw bench.

Since the drawing die 10 is adapted for tube sinking, it will be a closed type of die which, for the sinking of round tubing, will have an axial passage 17 therethrough which is also round in cross sectional shape at any given point in the axial direction thereforth. It is to be understood, however, that for the drawing of tubing having other cross-sectional shapes, the die passage 17 will correspondingly have other cross-sectional shapes. Also, it is to be understood that the die may have a configuration in passage 17 wherein the entrance portion is adapted to receive round tubing, and is then formed to other cross-sectional shapes as it is reduced, as for example into square, hexagonal, octagonal or other shapes, without departing from the present invention.

Although some drawing operations according to the present invention may not employ a closed die such as the drawing die 10, as for example where sheet is drawn against a rigid backup plate and an open or linear type of die is employed, nevertheless, the axial-sectional configuration of the functional portions of the die, i.e., the entrance, land and exit portions, will be similar to those illustrated for the closed die 10, and the novel drawing method employed in connection with such open dies will likewise be similar.

The axial passage 17 through the die is defined by entrance, land and exit portions of the die which, in axial section, include an entrance arc 18 which extends radially inwardly and rearwardly from the front surface 14 and is preferably an arc of a circle; a land arc 20 which tangentially intersects the entrance arc 18 so as to be smoothly and continuously faired into the entrance arc 18, this intersection between the land arc 20 and entrance arc 18 being somewhat forward and radially outward of the line of minimum diameter in the die; and an exit portion 22 of the die which flares outwardly from the land arc 20, and is preferably but not necessarily also an arc, preferred to be a segment of a circle, which is tangentially intersecting with the land arc 20.

The I.D. of the die, which is the apex of the land, is shown as a line 24. Similarly, the line of tangential intersection between the entrance arc 18 and the land arc 20 is designated by the numeral 26, while the line of tangential intersection between the land arc 20 and the exit arc 22 is designated by the numeral 28.

The metal tube which is illustrated as being drawn through the die 10 in FIG. 1 is generally designated 30, with the undrawn or large diameter portion 32 thereof shown to the left of die 10 in FIG. 1, and the drawn, reduced diameter portion 34 thereof shown to the right of die 10 in FIG. 1. The drawing force is applied by pulling the small end 36 of the tube to the right relative to the die 10, or by pushing the large end 32 of the tube to the right relative to the die 10, or by a combination of such pulling and pushing. In order to start the drawing operation, the free right-hand end of the tube 30 is "pointed" or reduced down to a sufficiently small diameter by any of a variety of pointing procedures for insertion thereof from the left to the right through the die passage 17 to a sufficient extent so that the drawing operation can commence, and preferably so that the right-hand end can be "gripped" by conventional gripping means form-
The actual drawing operation may be effected by moving the tube to the right and holding the die stationary, or by holding the tube stationary and moving the die to the left, or by a combination of such movements. However, for illustrative purposes it will be assumed that the die is stationary and the tube is moving to the right relative thereto.

As the tube advances, the drawing die is turned and deflected outwardly off a narrow primary deflection ring or band 36 on the entrance arc 18 of the die to form an inwardly curving shoulder 38 in the tube 30 having a continuous, uninterrupted character. The curvature 38 commences in the tube 30 substantially in advance of the actual contact of the tube with the die at the primary deflection ring or band 36, and the deflection of the tubing at ring or band 36 is of a generally tangential nature, the tubing being deflected inwardly sufficiently steeply off of the ring or band 36 so as to skip past a substantial portion of the entrance arc 18 inwardly of the ring or band 36.

In this region of the tubing inwardly of the ring 36 where the tubing is free of the die, the tubing is allowed to curve back toward the axial direction, i.e., back toward what may be considered the condition of repose of the tubing, in a reverse curve 40. However, the complete return of the tubing to its normal, axial direction is controlled by engagement of the tube with the die a second time, at secondary deflection ring or band 42 on a forwardly facing portion of the entrance arc 26 between the entrance arc 18 and the land arc 29. The tube is further inwardly deflected at this secondary deflection ring or band 42 so as to skip inwardly past the smallest diameter point 24 in the land defining the outside of the die, the tube then straightening out in the small diameter, drawn portion 34 thereof which will normally have an O.D. a few thousandths of an inch smaller than the L.D. of the die at line 24.

Most of the actual reduction of the tubing is accomplished by the initial deflection at the primary deflection ring or band 36, and the final deflection at secondary deflection ring or band 42 involves a relatively minor inward increment of deflection which has the principal function of accurately controlling the return of the tubing from the major deflection to the normal axial direction of the tubing so as to accurately define the final diameter thereof.

After a drawing operation or a series of drawing operations has been completed and the tubing removed from the die so that the die is seen as in Fig. 3, the primary and secondary deflection bands 36 and 42 are seen as narrow, highly polished rings in the die. Usually, the primary band 36 will be somewhat wider than the secondary band 42, confirming that the principal forming effort is accomplished at the primary band 36, and that the secondary band 42 serves primarily as a control band for accurately defining the final tube diameter. There does not appear to be any substantial movement or displacement of die material relative to the body 12 of the die at either the primary band 36 or the secondary band 42 after a drawing operation, so that the geometric relationship between the bands 36 and 42 remains substantially identical throughout a drawing operation or a series thereof within a very close tolerance. It will be apparent from the following discussion that with the present die and method, it is this geometric relationship, rather than the L.D. of the land as indicated at line 24, which serves to determine the final O.D. of the drawn tube section 34, and it is the close tolerance stability of this geometric relationship which therefore is apparently the cause for a very close tolerance final diameter of tubes which are drawn in accordance with the present invention.

The exact positions of the primary and secondary deflection bands 36 and 42, respectively, need not be predetermined before any particular drawing operation.

In fact, the exact optimum positions of the bands 36 and 42 will tend to vary slightly in the die according to changes in such variables as the material of which the tubing is made, the condition of temper of the tubing material, the initial diameter of the tube, the wall thickness of the tube material, and the amount of deformation which is to be achieved. Other factors which will, of course, influence the exact positions of the deflection bands 36 and 42 in the die are the radii of the entrance and land arcs 18 and 29, respectively, and the steepness of the entrance arc 18. Nevertheless, despite such a multitude of variable circumstances which can result in literally thousands of different specific combinations of physical circumstances, dies made in accordance with the present invention which include the entrance and land arcs 18 and 29 that are fairing smoothly together, and the outwardly flaring rearward portion 22, have the unique capability of automatically deflecting the workpiece at primary and secondary deflection bands 36 and 42, respectively, in the die, so that the wall portion of the workpiece that engages the die at these two bands will be smoothly and continuously formed into a double bend which is best described as an S bend, which includes the inward-curling band 38 which is primarily an advance of the primary deflection band 36, and the return band 40, the final extent of which is accurately determined by the secondary deflection band 42.

Once this continuously curving S-bend is thus established in the workpiece, it quickly adjusts automatically to its most natural flow shape, which appears to be the particular S-bend curvature involving substantially the least possible amount of non-uniform shear deformation or redundant work. This appears to be a highly stable flow pattern which remains during an entire drawing operation, with fixed, stable positions of the primary and secondary deflection bands 36 and 42, respectively, and with a resulting overall geometric relationship which is so stable as to produce a very close tolerance final outside dimension of the product.

Accordingly, despite the many possible variables, a die which is made in accordance with the present invention, having the entrance arc and the land arc 29, will dependably establish and perpetuate the double-deflection method of the present invention for an entire drawing operation. On the other hand, once a particular workpiece is drawn in a particular die, to produce a particular final dimension, such a drawing operation can be repeated many times in a single die or in other dies of the same dimensions with predictable and substantially identical end results.

The cavity 44 which is defined between the workpiece, the die, and the deflection bands 36 and 42, serves an important function as a lubrication chamber wherein lubricant applied to the surface of the undrawn portion 32 of the workpiece is accumulated and appears to become pressurized and subsequently metered forwardly between the workpiece and the secondary deflection band 42, so that a continuous film of lubricant appears to be preserved during the entire drawing operation at the contacting regions, i.e., at the deflection bands 36 and 42. The localized engagement between the workpiece and the die at only the two narrow deflection bands 36 and 42 causes the deflection bands to quickly become highly polished so that they become, in effect, low friction bearing surfaces which present a minimum of frictional retarding force on the workpiece, and additionally they polish out the close-fitting lubricant sealing surfaces at the ends of the lubrication chamber 44 which tend to promote the entrainment and metering action of the lubrication chamber 44 during the drawing operation.

Although the exact manner in which surface lubricant that is applied to the outer surface of the undrawn workpiece 32 prior to the drawing operation is enabled to be fed past the primary deflection band 36 into the lubrication chamber 44 is not known, it is believed that the
gradual, tangential nature of the approach of the workpiece curve 38 toward the entrance arc 18, without any abrupt or sharp break in the workpiece as it comes into contact with the die entrance surface, allows the surface lubricant to become gradually wedged and secured between the tangentially approaching surfaces so as to be carried on past the primary deflection ring or band 36 into the lubrication chamber 44. Since the engaging force between the tubing and the die is considerably higher at the primary deflection ring or band 36 than it is at the secondary deflection ring or band 42, the lubricant can more readily escape from the lubrication chamber 44 in the forward direction past the secondary deflection ring 42, and thus the forward movement of the workpiece past the die carries the lubricant out through the secondary deflection ring or band 42.

A solid or dry type of lubricant such as soap is preferred for use with the present invention, and typically the lubrication can be accomplished by simply rubbing bar soap onto the outside of the undrawn tube 32. A substantial film thickness will normally thus be applied to the undrawn part 52 of the tubing, and because of the reduced surface area on the drawn tubing section 544, as well as the close-fitting relationship between the tubing and the secondary deflection band 42, which tends to leave a relatively thin film of the lubricant on the drawn part of the tube, the lubricant tends to become compacted and pressurized within the lubrication chamber 44 to assure continued lubrication despite irregularities which may occur in the application of lubricant to the undrawn part 32 of the tube. Furthermore, it appears that this pressurization of lubricant within the lubrication chamber 44 tends to help the double-deflection, S-bend method of the present invention in that it tends to hold the return bend portion 49 of the bend inwardly away from portion of the entrance arc 48, thereby opposing any tendency for the workpiece to simply slide down along the die entrance surface.

FIG. 2 of the drawings is a diagrammatic illustration of a tube sinking operation employing a conventional type of drawing die 46 and the conventional drawing method. The drawing die 46 includes a body or block 49 which, in general, is much longer than the novel die 10 employed in the present invention as illustrated in FIGS. 1 and 3. The body 48 of the conventional die has front and rear surfaces 50 and 52, respectively, and the die has axial passage 53 extending therethrough between the surfaces 50 and 52. The entrance portion 54 of the die 46 is generally funnel-shaped, in this case being conical, and is typically quite gradual in slope, even more so than the die that is illustrated in FIG. 2. For example, conventional wire drawing dies have been shown to have an optimum die semicircle between about 6° and 9°; i.e., an included angle for the entrance funnel 54 between about 12° and 18°, for minimum required drawing force.

In contrast to this, typically in the present invention the semicircle for the tangential engagement between the tube and die entrance arc 18 at primary deflection band 36 will be greater than about 40°; i.e., the included angle will normally be greater than about 80°. However, as will be discussed more fully hereinafter, this angle of inclination will vary depending on the strength level and thickness of the tubing wall relative to its initial diameter, and according to the amount of reduction that is taken in the tube.

Returning to the conventional die and method illustrated in FIG. 2, the entrance funnel continues inwardly to an abrupt intersection with the long and generally straight or cylindrical land surface 56, which terminates at the point of about an abrupt break at the die entrance. The die 46, includes the undrawn, large diameter portion 62 thereof to the left of the die, and drawn, reduced diameter portion 64 thereof to the right of the die. At the point of engagement of the undrawn portion 62 of the tube with the die entrance funnel 54, the tube breaks sharply inwardly along the annular ring or line 66, and the tube is thence guided and forced inwardly in a conical diminishing formation 68 until it reaches the long land 56, wherein the portion 70 of the tube is stabilized to provide control over the final O.D. dimension in the reduced or drawn portion 64.

While in practice there is a variety of specific entrance and land shapes for conventional dies which differ somewhat from the diagrammatically illustrated conventional die shape in FIG. 2, nevertheless, the various conventional die shapes have in common the feature that they are designed to gradually funnel and guide and force the workpiece inwardly, with the plastic flow to accomplish the desired change in shape caused by compressive forces set up by the reaction of the workpiece metal with the entrance portion of the die, and then the final O.D. of the drawn part as determined by means of a long land, which may be a straight, cylindrical land such as the land 56 shown in FIG. 2, or may have a slight taper, as for example about 1° to 3° included angle. This long land was deemed necessary in the art, as experience had taught that the land was subjected to so much wear that the long land with lots of material "beeping" it up was absolutely essential for any degree of tolerance or accuracy in the final dimension of the drawn part.

It will be apparent from an inspection of FIG. 2 that the general flow pattern of the workpiece as it is constrained in the diminishing formation 68 thereof is not a natural flow pattern for the metal. The metal in this region is being forced all of the way in what may be analogized to a pressure-forming operation. Thus, in the region of the diminishing formation 68 there is a continual cold-working of each successive increment of the metal as it is forced down the incline of the die contrary to its natural tendency to remain straight. This continued and repeated cold working involves a considerable amount of non-uniform shear deformation, or redundant work, which adds substantially to the amount of drawing force that is required.

In tests which the applicant has performed employing such a conventional die and method, the applicant has observed that the wall of the tube becomes noticeably thicker about the middle of the tube before the incline of the die, down the incline or funnel, and that the final wall thickness of the drawn portion 64 is generally greater than the initial wall thickness of the undrawn portion 60. Additionally, this tendency for the wall of the tube to thicken during drawing by conventional means is a rather uncertain factor, and generally results in substantial variations in the wall thickness either along the length of the drawn tube or around the periphery thereof, or both, so that the thickness tolerance is generally rather poor.

The conventional funneling procedure is illustrated in FIG. 2 tends to build up substantial residual stresses in the drawn tubing, so that typically when the tubing departs rearwardly from the confinement of the land surface 56 into the back relief 58, the tubing will spring back outwardly on the order of from about .001 inch to about .004 inch O.D. This outward springing further limits the tolerance of the drawn part which can be achieved, this time in regard to O.D. instead of wall thickness, as it is somewhat unpredictable. It has the very serious disadvantage that when a tube is not drawn through a die, and must be removed rearwardly from the die, a large amount of force is required to strip the die off of the formed end 64 of the part, resulting in some further working of the part, and a likelihood of galling and scratching of the part. Such damage is in addition to the tendency for the tubing to become rounded during the continued cold working which occurs in the region of the diminishing formation 68, which frequently involves surface damage and even cracks in the wall of the part.

Reference will now be made to FIG. 4 which shows...
schematically the entrance circle $C_1$ which defines the entrance arc 18, the land circle $C_2$ which defines the land arc 20, and the exit circle $C_3$ which defines the exit arc 22. The radii of the three circles $C_1$, $C_2$, and $C_3$, are respectively designated $R_1$, $R_2$, and $R_3$. The parameters for the entrance, land, and exit circles $C_1$, $C_2$, and $C_3$, respectively, are defined in FIG. 4 relative to an $X$ axis shown in phantom which is normal to the central longitudinal axis of the die opening and a $Y$ axis also shown in phantom which is essential with such central longitudinal axis of the die. The $X$ and $Y$ axial coordinates of the centers of the three circles $C_1$, $C_2$, and $C_3$, are designated respectively as $(X_1, Y_1)$, $(X_2, Y_2)$, and $(X_3, Y_3)$.

Bearing in mind that the relationship between $C_1$ and $C_2$ is tangential for a smooth transition from entrance arc 18 to land arc 20, the critical parameters to define any die are the I.D., $R_1$, $X_1$, and $R_2$.

FIGS. 5a, 5b, and 5c illustrate the effect on the cross sectional configuration of the die caused by variations in the land radius $R_2$ where $R_1$ and $X_1$ remain constant. In FIG. 5a, $R_2$ is approximately one and a half times $R_1$. In FIG. 5c, $R_2$ is approximately two times $R_1$. These are approximately the preferred parameters for the relative sizes of $R_1$ and $R_2$; i.e., the preferred range for the relationship between $R_1$ and $R_2$ is from about $R_1=2R_2$ to about $R_1=5R_2$. Nevertheless it is to be understood that a critical relationship which exists between $R_1$ and $R_2$ in dies made according to the present invention is that $R_1$ must at least be greater than $R_2$. This same relationship could be illustrated by maintaining the radius $R_2$ of land circle $C_2$ constant and varying the radius $R_1$ of the entrance circle $C_1$.

FIGS. 6a, 6b, and 6c illustrate variations in the entrance angle of the die by varying the coordinate $X_1$ of the center of the entrance circle $C_1$. The $X_1$ coordinate shown in FIG. 6b is of intermediate length, and accordingly the entrance angle is of intermediate steepness or incline relative to the longitudinal or $Y$ axis. The $X_1$ coordinate $X_1'$ in FIG. 6c is shorter than the coordinate $X_1$ in FIG. 6b, and accordingly the entrance angle illustrated in FIG. 6a is steeper than that shown in FIG. 6b; i.e., the entrance has a greater angle of inclination relative to the longitudinal or $Y$ axis of the die in FIG. 6a as compared with FIG. 6b. Conversely, the coordinate $X_1''$ in FIG. 6c is longer than the coordinate $X_1$ in FIG. 6b, causing the entrance angle to be more gentle in FIG. 6c than in FIG. 6b; i.e., the entrance has less angle of inclination relative to the longitudinal or $Y$ axis in FIG. 6c than in FIG. 6b. It is preferred that the angle of inclination of the entrance arc at the primary deflection ring or band 36 be at least about $40^\circ$ relative to the longitudinal or $Y$ axis; i.e., have an included angle at least about $80^\circ$.

Referring again to FIG. 4, it is not essential that the exit portion of the die be of arcuate or circular configuration; it is only necessary that the exit surface face outwardly or fall away sufficiently so that no portion of the exit surface will be obstructed by the workpiece to the rear of the land arc 20. However, it is preferred that the exit surface be arcuate in longitudinal section, tangentially intersecting the land arc 20, and the most desirable configuration for the exit arc 22 is a segment of a circle such as the circle $C_3$ illustrated in FIG. 4, which has a radius $R_3$. The exit circle radius $R_3$ is preferably greater than the land circle $R_2$, and it is also preferred that the exit parameters be within the same range as the preferred entrance parameters relative to the land circle. By this means the die becomes, in effect, a double-ended or reversible die so that drawing can be accomplished by movement of the workpiece in either direction axially through the die.

In such a reversible die, if desired the entrance and exit arcs 18 and 22, respectively, may be of the same curvature, and have the same relationship relative to the land arc 20, so that identical drawing operations can be performed in both directions through the die. This has the effect of doubling the useful life of the die.

On the other hand, if one end of the die is made steeper than the other end, then different drawing operations can be performed in the opposite directions. For example, the applicant has found that in tube sinking, where the wall of the tubing is of increased thickness, it is desirable to have a steeper entrance angle. Conversely, the applicant has found in practice that in any drawing operation, the greater the percentage reduction for a single pass, the less steep the entrance angle is required to be.

A critical factor which enables dies made in accordance with the present invention to be thus employed as reversible dies, despite the fact that conventional dies cannot be so used, is that the two points of contact of the workpiece with the die for drawing in one direction, namely, the primary and secondary deflection bands 36 and 42, respectively, will be located entirely on one side of the apex of the land, while the two points of contact for drawing in the other direction will lie entirely on the other side of the apex of the land. Thus, a drawing operation or a series thereof in one direction through the die will not adversely affect the surface portions of the die that will be used for a drawing operation or series thereof in the opposite direction.

Referring again to FIG. 1, it will be noted that the first point of contact of the tubing 30 with the die is at a diameter that is substantially smaller than the O.D. of the undrawn portion of the tubing. Accordingly, during the course of a drawing operation it is not essential that the entrance arc 18 extend all of the way out to the same diameter as the O.D. of the tube portion 32. However, at the beginning of a drawing operation there is likely to be some "hunting" of the shoulder 38 in and out along the convex surface of the entrance arc 18 until the optimum S-bend configuration is established, and for this reason it is desirable to have the entrance arc 18 extend radially outwardly somewhat beyond the primary deflection ring or band 36. It is preferred that the entrance arc 18 extend outwardly to approximately the same level as the outside of the workpiece. Thus, in the case of a tube sinking operation as illustrated in FIG. 1, it is preferred that the entrance arc 18 extend radially outwardly at least to approximately the O.D. of the undrawn tubing section 32.

While the accompanying drawings illustrate the present invention in connection with tube sinking, the applicant has found in practice that the same method and structural relationships hold true for tube sizing, and for bar, rod, and sheet drawing. The only major difference is that since such sizing and drawing of solid stock involves substantially smaller increments of reduction than the typical tube sinking operation, the overall size of the die entrance, land and exit arcs is much smaller. In other words, dies according to the present invention are substantially the same for tube sizing and for bar, rod, wire, and sheet drawing as they are for tube sinking, except that they are on a much smaller scale. The die arcs for such solid material reductions are in some proportion to the amount of reduction of the solid material as are the corresponding die arcs of a tube sinking die to the amount of sinking. The only difference is that sometimes the applicant has found it desirable to employ a land arc 20 having a somewhat smaller radius of curvature relative to the curvature of the entrance arc 18 for solid material drawing than for tube sinking. The discrete primary and secondary deflection rings or...
bands 36 and 42, respectively, are observed both on dies used for tube sinking and in dies used for the drawing of solid material, as for example tube sizing and bar, rod, wire and sheet drawing.

The convexity of the arcuate entrance surface 18 is far more likely to establish and maintain the primary deflection band 38 in the tubing than a straight conical or other conventional configuration, and the varying rate of curvature inherent in the entrance arc 18 allows the desired automatic "hunting" or shifting to stabilize the bend to the optimum S-band of minimum strain energy. Preferably, but not necessarily, the workpiece will be oriented prior to a drawing operation to an approximation of the S-band configuration that it will ultimately assume when being drawn through the die. This starts the correct S-band configuration most easily, the outer, convex shoulder corresponding to the shoulder 38 on the workpiece engaging the entrance arc 18 at approximately the region of the final primary deflection ring or band 36, to initiate the major deflection at the shoulder 38. Then, the minor deflection is automatically established from a pointed size that is initially smaller than the final size of the drawn part, and the two deflection bands 36 and 42 are typically adapted to the optimum positions for minimum strain energy.

Conventional pointing produces a relatively long, gradual cone, which first hits the die way down in the throat proximate or on the land arc 20. With a die configuration according to the present invention, even such a long, gradual cone will, at the onset of a drawing operation, be forced by the unique entrance and land circle configuration of the present die into a curvature that is close enough to the natural S-band of the present invention so that the applicant's S-band, two-deflection band system will become operative. Thus, the novel die configuration of the present invention has the capability of picking up any kind of conventional point on an elongated workpiece, and shaping such point at the beginning of the drawing operation sufficiently close to the ultimate shape utilized in the drawing operation so as to bring the method aspect of the invention into play.

The applicant has found in experimental practice of the invention that for relatively small reductions in the workpiece, as for example on the order of 20%, it is desired to employ a relatively steep entrance arc proximate the primary deflection band 36, with a relatively large entrance circle-to-land ratio. This appears to be desirable because with the lesser amount of total deflection that is admitted, the higher load is necessary to turn the workpiece inwardly more quickly at the shoulder 38 in order to obtain a sufficient amount of deflection in the more limited space that is available. Again, because of the limited space available, a relatively small land circle is preferable for the final size control. In contrast, for a relatively large reduction, as for example a 40% reduction in the workpiece, the entrance arc need not be so steep; proximate the primary deflection band 36, and the ratio of the entrance circle radius of curvature to the land circle radius of curvature need not be so large.

Similarly, the applicant has found in experimental practice that the higher the strength level of the material of the workpiece, the steeper should be the entrance arc proximate the primary deflection band 36, so as to deflect the workpiece inwardly more rapidly. In like fashion, in the drawing of tubing it is desirable to compensate for an increase in initial wall thickness of the tubing by a steeper than the entrance arc proximate the primary deflection band 36, to obtain a more rapid deflection at the shoulder 38. In both of these circumstances, the drawing of tougher materials and drawing of tubing having increased wall thickness, it is also preferable to have a relatively large entrance circle-to-land ratio. Applicant has found that in a typical drawing operation in accordance with his invention the final drawn part will invariably be deflected further than the die land apex, and the extent of this deflection beyond the land apex usually will run from about .004 inch to about .020 inch. Thus, for example, in a typical tube sinking operation, the final O.D. of the drawn portion 34 of the tube will be on the order of from about .004 inch to about .020 inch smaller than the I.D. of the land as indicated by the line 24 in FIG. 1.

Similar results occur in the drawing of bar or wire stock. In one example, one-half inch diameter carbon steel bar stock was drawn down approximately 20% in a single pass, and the die deflection portion 34 of the tube invention which was composed of aluminum bronze. The final diameter of the reduced part was .006 inch less than the I.D. of the die, and the polished primary and secondary deflection bands were apparent on the die.

The larger differentials in the relative size between the final drawn part diameter and the I.D. of the die, as for example in the neighborhood of .020 inch, have been observed in the sinking of such tubing as 304 stainless steel and 4130 steel of nominal 1.00 inch O.D. and .035 inch wall thickness. In such sinking, the applicant has usually observed that the greater the amount of reduction taken in a pass, the larger the differential between the final O.D. of the reduced part and the I.D. of the die.

While the differences between the dimension of the final drawn part and the I.D. of the die which have been thus observed by the applicant have for the most part been in the neighborhood of from about .004 inch to about .020 inch, such differences have been for relatively small stock, in the neighborhood of about one-half inch O.D. to one inch O.D. in initial size. However, this differential appears to increase with larger diameter parts and corresponding larger amounts of reduction.

In a drawing operation according to the present invention wherein a tube is drawn down onto a solid mandrel, the mandrel prevents the tube from collapsing down all of the way to the diameter which is substantially smaller than the I.D. of the die. However, when the tube is then stripped off of the mandrel after completion of the drawing operation, the tube springs inwardly to an O.D. that is in fact substantially less than the I.D. of the die. This coupled with observation of the polished primary and secondary deflection bands in the die after a drawing operation, confirms that the applicant's double-deflection process of the present invention occurs in such a sizing operation.

Variations in the hardness of the workpiece do not generally require different dies according to the present invention, either as to the die configuration or as to the material of which the die is made. One of the advantages of the present invention over conventional drawing dies is that with the present invention it is generally not necessary to resort to such hard die materials as tungsten carbide, which is usually required in conventional drawing dies. For most purposes under the present invention, it has been found that dies made of such material as aluminum bronze, are completely adequate, even for drawing such materials as 4130 steel and 6-4 titanium. Ampco bronze having a hardness of Rockwell C-40 appears to be quite adequate for most purposes. Tool steel dies having the novel configuration of the present invention appear also to work satisfactorily.

The two polished deflection rings serve as a good indicator that the method of the present invention has been operative. Thus, a method step of the invention for assuring that a particular die configuration will be suitable for performing the method of the invention, is to take a
test draw of the particular type of workpiece that is to be drawn in that die, and then to inspect the die for the polished primary and secondary deflection bands 36 and 42.

All available engineering formulae which the applicant has been able to find concerning drawing appear to relate strictly to the usual type of drawing die which simply guides and forces the workpiece inwardly in a conical diminishing formation. An accepted formula which describes the stress pattern in wire drawing, which is essentially the same as the stress pattern for the other types of drawing with which the present invention is concerned, and which contemplates use of a conventional die configuration, is as follows:

\[ \frac{P}{A_2} = (1 + \mu \cot \alpha) \phi Y_m \ln \frac{A_1}{A_2} \]

where:
- \( P \) = the pull in pounds, required to draw the wire through the die
- \( A_1 \) = the cross-sectional area of the wire before drawing through the die
- \( A_2 \) = the cross-sectional area of the wire after drawing through the die
- \( \mu \) = the mean coefficient of friction between the wire and the die
- \( \alpha \) = the half angle of taper of the die bore
- \( \phi \) = the index of inhomogeneity of deformation
- \( Y_m \) = the mean or average yield stress of the wire before and after drawing.

This formula illustrates the relationship between the three separate factors hereinabove discussed which directly contribute to the drawing force, as follows:

1. The quantity \( Y_m \ln \frac{A_1}{A_2} \) represents the stress in the absence of friction and redundant deformation.

2. The quantity \( 1 + \mu \cot \alpha \) represents the contribution of friction to the drawing process at the area of contact between the workpiece and the die.

3. The quantity \( \phi \) is a factor which takes into account non-uniform shear deformation.

It is seen from this formula that the drawing force \( P \) increases in direct proportion to an increase in the frictional force, and also increases in direct proportion to an increase in the non-uniform shear deformation or redundant work. It is therefore apparent from this formula that the substantial reductions in both friction and non-uniform shear deformation by employing the drawing dies and method of the present invention will result in a substantial reduction of the drawing force required, all other factors being equal, with a consequent capability of drawing much further in a single pass, and the requirement of less interstage annealing.

FIGS. 7 and 8 graphically illustrate the large amount of reduction in drawing force where the present invention is used as compared with the drawing force for conventional dies. FIG. 7 illustrates this comparison for tube sizing of a workpiece in the form of hardened (as quenched) type 4130 steel tubing having a nominal O.D. of 1.00 inch and wall thickness of 0.035 inch. In each case a mandrel of hardened tool steel was employed having a diameter of between 0.8831 and 0.8836 inch, the drawing speed was approximately eight inches per minute, and the lubricant was Ivory soap, employed both inside and outside the tube. The upper curve in FIG. 7 represents the drawing force in pounds versus the percent reduction in cross-sectional area for conventional commercial drawing dies which might well be described as "horn-shaped," and made of tungsten carbide. The lower curve, showing greatly reduced drawing force, also shows drawing force in pounds versus percent reduction in area of cross section, for dies made in accordance with the present invention both of Grade 25 Ampco bronze and hardened tool steel. It is interesting to note that there is substantially no difference in the drawing force as a result of this substantial difference in the die material where the dies have the novel configuration of the present invention.

FIG. 8 shows a similar tube sizing comparison employing the same mandrel size and lubricant as for FIG. 7, and also employing conventional carbide dies purchased on the open market and dies according to the present invention made of both aluminum bronze and tool steel. The drawing speed was also approximately eight inches per minute for the data on FIG. 8. The workpiece material for FIG. 8 was annealed 304 stainless steel, having a nominal O.D. of 1.00 inch and wall thickness of 0.035 inch. The upper curve is a plot of the drawing force in pounds for the conventional, commercial tungsten carbide dies versus the percent reduction in area of cross section. The lower curve illustrates the greatly reduced drawing force for both bronze and tool steel dies made according to the present invention, and also represents the drawing force in pounds versus the percent reduction in area of cross section.

It appears that the wall thickening which tends to occur in prior art tube drawing, as pointed out hereinabove in connection with FIG. 2 of the drawings, is caused by the undesirably large amount of working such as non-uniform shear deformation that is involved in the drawing. In contrast, the applicant has found that with the process of the present invention there is not only a tendency for the initial wall thickness dimension to be retained in the drawn part, but this dimension appears to be averaged out to an even more uniform, closer tolerance dimension than tubing stock commercially obtained.

Instead of the usual surface damage such as galling that is frequently present after conventional drawing, the surface of elongated stock that has been drawn according to the present invention usually appears substantially the same as the surface did before the drawing operation except simply for elongation of surface characteristics. If there is any quality change, it appears to be an improvement in the quality of the surface and of the metal adjacent to the surface.

In an experimental comparison utilizing annealed 304 stainless tubing of nominal O.D. 1.00 inch and wall thickness 0.035 inch, sizing with conventional dies to a reduction of between 30% and 45% produce severe gall marks on the tube, and the dies were severely damaged. In contrast, a 60% reduction was obtained in a single pass with dies according to the present invention with no material galling or damage to either the tube or the dies.

In tube sinking according to the present invention, the wear on the die is so small and has such a minimal effect on the ultimate dimensions of the tubing that the applicant has found during his experimentation that many feet of tubing can sometimes be sunk through a single die in one direction while maintaining close tolerance final dimensions, without requiring that the die be re-formed. Then, when the wear finally becomes substantial, if the die is reversible as aforesaid, a further similar quantity of tubing can be drawn through the die in the opposite direction. Then, if desired, it is relatively simple to machine a worn die of the configuration of the present invention open a small amount, retaining the same general die configuration, but opening the die out to the next larger drawing size. In this manner, a series of dies can be gradually worked from a small size through a stepped sequence of larger sizes, so as to minimize production costs.

Once the natural S-bend configuration has been established under the present invention, the continued
drawing operation may be analogized to the longitudinal movement of a wave, the S-bend being simply pushed along the workpiece by pushing at an optimum position on the shoulder 38 of the workpiece, at a substantial distance inwardly from the initial point of turn-in of the shoulder from the O.D. of the undrawn stock 32. Pushing the S-bend along in such wave-like longitudinal movement appears to be a highly stable method of drawing which can be perpetuated throughout a drawing operation provided the workpiece is deflected or glanced off of the die where the shoulder is being pushed, i.e., at the primary deflection band 36, and provided the workpiece is not "snatched" in which it is not when the second deflection of the present invention is effected at the secondary deflection band 42.

While the instant invention has been shown and described herein in what is conceived to be the most practical and preferred embodiment, it is recognized that departures may be made therefrom within the scope of the invention, which is therefore not to be limited to the details disclosed herein, but is to be accorded the full scope of the appended claims.

1. A die for use in drawing an elongated metal workpiece, said die having a forward entrance surface portion, an intermediate land surface portion having an apex, and a rearward exit surface portion, said entrance surface portion in axial sectional profile including a forwardly facing convex arc, said land surface portion in axial sectional profile including a convex arc extending inwardly and rearwardly from said entrance arc at least to said apex, and said exit surface portion flaring outwardly from said land surface portion, said entrance arc having a greater average radius of curvature than said land arc, at least one of said entrance and land arcs being a segment of a circle.

2. A die as defined in claim 1, wherein said entrance arc is a segment of a circle.

3. A die as defined in claim 1, wherein said land arc is a segment of a circle.

4. A die as defined in claim 1, wherein each of said entrance and land arcs is a segment of a circle.

5. A die as defined in claim 1, wherein said entrance and land arcs are substantially tangentially intersecting.

6. A die as defined in claim 1, wherein said entrance arc has an average radius of curvature from about 2 to about 5 times that of said land arc.

7. A die as defined in claim 1, wherein said land arc extends rearwardly beyond said apex, and said exit surface portion in axial sectional profile includes a convex arc extending outwardly and rearwardly from said land arc, whereby the die is reversible.

8. A die as defined in claim 1, wherein said entrance and exit arcs are each substantially tangentially intersecting with said land arc.

9. A die as defined in claim 1, wherein said entrance and exit arcs have substantially different radii of curvature.

10. A die as defined in claim 1, wherein said entrance and exit arcs have substantially different radii of curvature.

11. A die for use in drawing an elongated metal workpiece, said die having a forward entrance surface portion, an intermediate land surface portion having an apex, and a rearward exit surface portion, said entrance surface portion in axial sectional profile including a forwardly facing convex arc, said land surface portion in axial sectional profile including a convex arc extending inwardly and rearwardly from said entrance arc at least to said apex, and said exit surface portion flaring outwardly from said land surface portion having a greater average radius of curvature than said land arc, said die including a transverse, polished, primary deflection band on said forward entrance surface portion of the die spaced outwardly and forwardly from said land surface portion, and a transverse, polished, secondary deflection band on said land surface portion of the die forward of said land apex, said primary and secondary deflection bands being adapted to deflect the workpiece inwardly in major and minor increments, respectively, in a continuously curving double bend generally in the shape of an S.

12. A die as defined in claim 11, wherein the angle between the axis of the die and a straight line tangent to said entrance arc proximate said primary deflection band is at least about 40°.

13. A die as defined in claim 4, wherein said entrance arc extends outwardly at least substantially as far as the undrawn portion of said workpiece.

14. The method of drawing an elongated metal workpiece to a reduced transverse dimension which comprises the steps of arranging the workpiece for axial movement rearwardly relative to a die having generally forwardly facing surface means terminating at an apex and having exit surface means to the rear of said apex, deflecting the workpiece laterally off of a first surface portion of said forwardly facing surface means in a continuously curving inward bend so as to cause a major amount of lateral diversion in the workpiece, allowing the workpiece to curve continuously back from said inward bend toward the axial direction in a reverse bend, deflecting the workpiece laterally a second time in the region of said bend off of a second surface portion of said forwardly facing surface means located rearwardly and laterally inwardly of said first surface portion to cause a minor amount of further lateral diversion in the workpiece, said second deflection being sufficient to cause the workpiece to bypass said apex and exit surface means.

15. The method of claim 14, wherein said inward and reverse bends in the workpiece are substantially unrestrained tangentially proximate the engagement of said bends with the die at said first and second surface portions, respectively, thereby allowing the workpiece in the region of the die to adjust to an S-bend configuration of substantially minimum stress.

16. The method of claim 14, wherein the engagement of said inward and reverse bends with the die is at spaced, discrete, polished, primary and secondary deflection bands, respectively, on the respective said first and second surface portions of the die.

17. The method of claim 16, wherein the reverse bend in the workpiece has greater curvature than the complementary portion of said forwardly facing surface means of the die whereby to define a lubrication chamber between the workpiece and die intermediate said primary and secondary deflection bands, and applying a film of lubricant onto the surface of the workpiece ahead of the die, at least a material portion of said lubricant being passed between the workpiece and said primary deflection band to be captured in said lubrication chamber and then metered rearwardly from said chamber between the workpiece and said secondary deflection band.

18. The method of claim 16, wherein said continuously curving inward bend commences in the workpiece substantially in advance of said primary deflection band.

19. The method of claim 16, wherein the workpiece is engaged with the die only at said primary and secondary deflection bands.

20. The method of claim 16, wherein the overall geometric relationship between the primary and secondary deflection bands and the double bend configuration of the workpiece proximate the die is held substantially constant during substantially an entire drawing operation whereby to achieve a close-tolerance transverse dimension in the portion of said surface arc having a greater average radius of curvature than said land arc, said die including a transverse, polished, primary deflection band on said forward entrance surface portion of the die spaced outwardly and forwardly from said land surface portion, and an entrance part of the die which is arcuate and convex in axial sectional profile to provide substantial tangential...
clearance between the workpiece and the die on opposite sides of said deflection at said inward bend, whereby to assure the establishment and perpetuation of said inward bend during a given drawing operation.

22. The method of claim 21, wherein said second surface portion of said forwardly facing surface means, including said apex, is a land part of the die which is also arcuate and convex in axial sectional profile, having a smaller radius of curvature than said entrance part of the die, to provide substantial tangential clearance between the workpiece and the die on opposite sides of said second deflection, whereby to assure that said second deflection will carry the workpiece on past said apex.

23. The method of claim 16, wherein the angle defined between the axis of the die and the surface of the die proximate said primary deflection band is at least about 40°.

24. The method of claim 14, which includes the initial step of pointing the workpiece to a configuration generally similar to the double bend of said inward and reverse bends.

25. The method of claim 14, wherein said first surface portion of said forwardly facing surface means is an entrance part of the die which is arcuate and convex in axial sectional profile, and said second surface portion of said forwardly facing surface means, including said apex, is a land part of the die which is also arcuate and convex in axial sectional profile, having a smaller radius of curvature than said entrance part of the die, said method including the initial steps of pointing the workpiece to a configuration substantially different than the double bend of said inward and reverse bends, and reforming such point to a configuration generally similar to said double bend by forcing said point into said arcuate entrance and land parts of the die.

26. The method of claim 14, which includes the step of inspecting said first and second surface portions of the die for the presence of a respective polished deflection band on each thereof to confirm the operation of said method.

27. The method of drawing an elongated metal workpiece to a reduced transverse dimension which comprises the steps of establishing a continuous double bend generally in the shape of an S in the workpiece including an inward bend commencing at the undrawn part of the workpiece and curving inwardly toward the drawn portion of the workpiece, said inward bend presenting a generally outwardly and rearwardly facing shoulder, and including a reverse bend in the workpiece curving from said inward bend back to the axial direction, and pushing said S-bend axially along the workpiece by the continuous application of a generally forwardly and inwardly directed force against said shoulder.

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