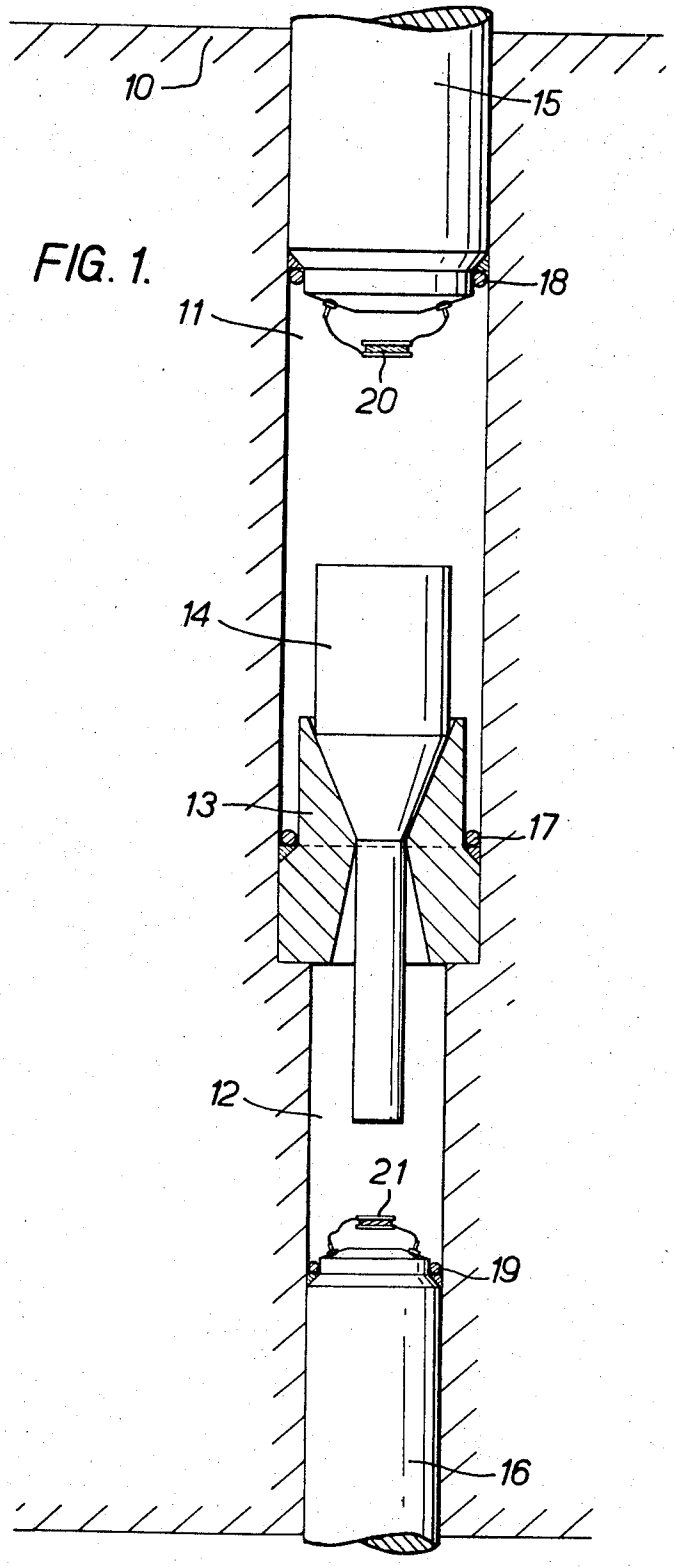
Oct. 3, 1967 H. L. D. PUGH 3,344,636

EXTRUSION OF METALS

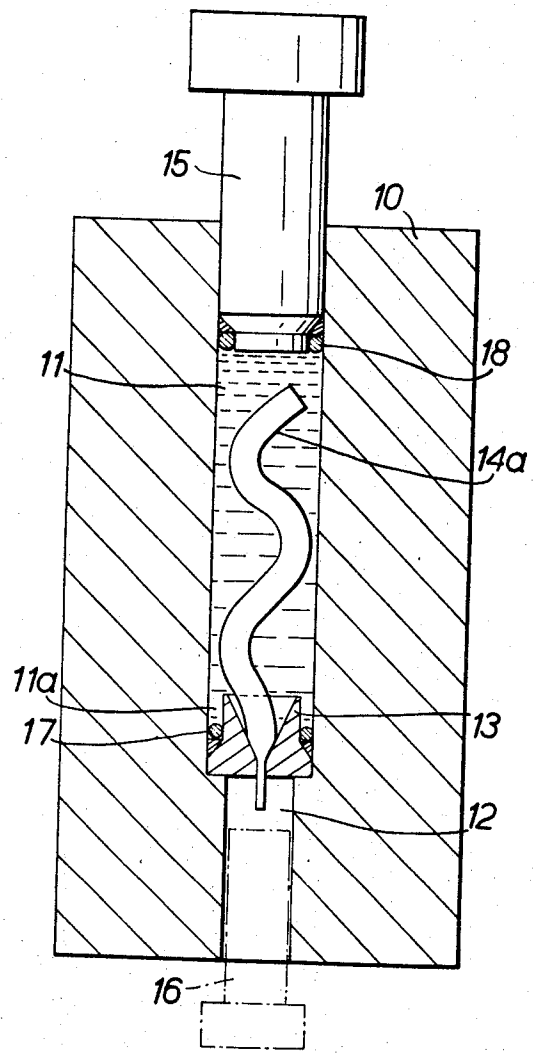
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FIG. 1.



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FIG. 2.

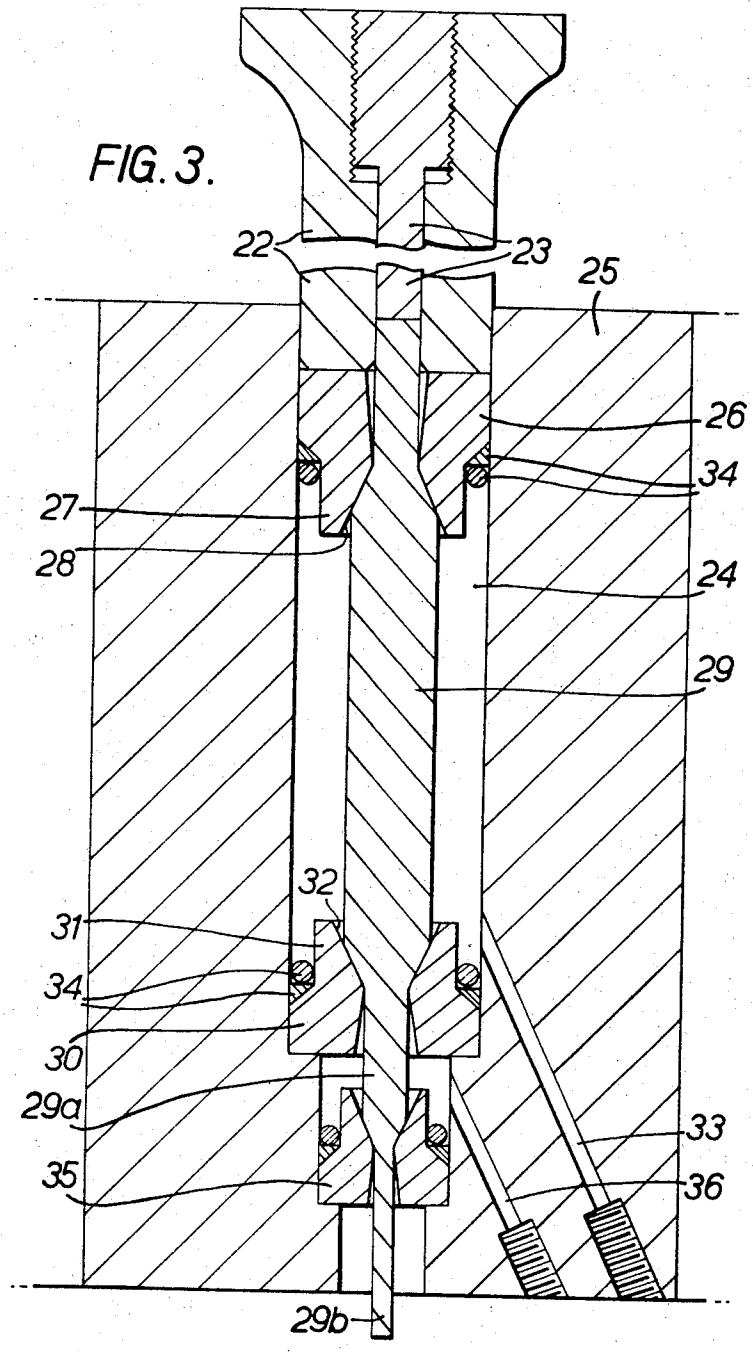


Oct. 3, 1967 H. L. D. PUGH 3,344,636

EXTRUSION OF METALS

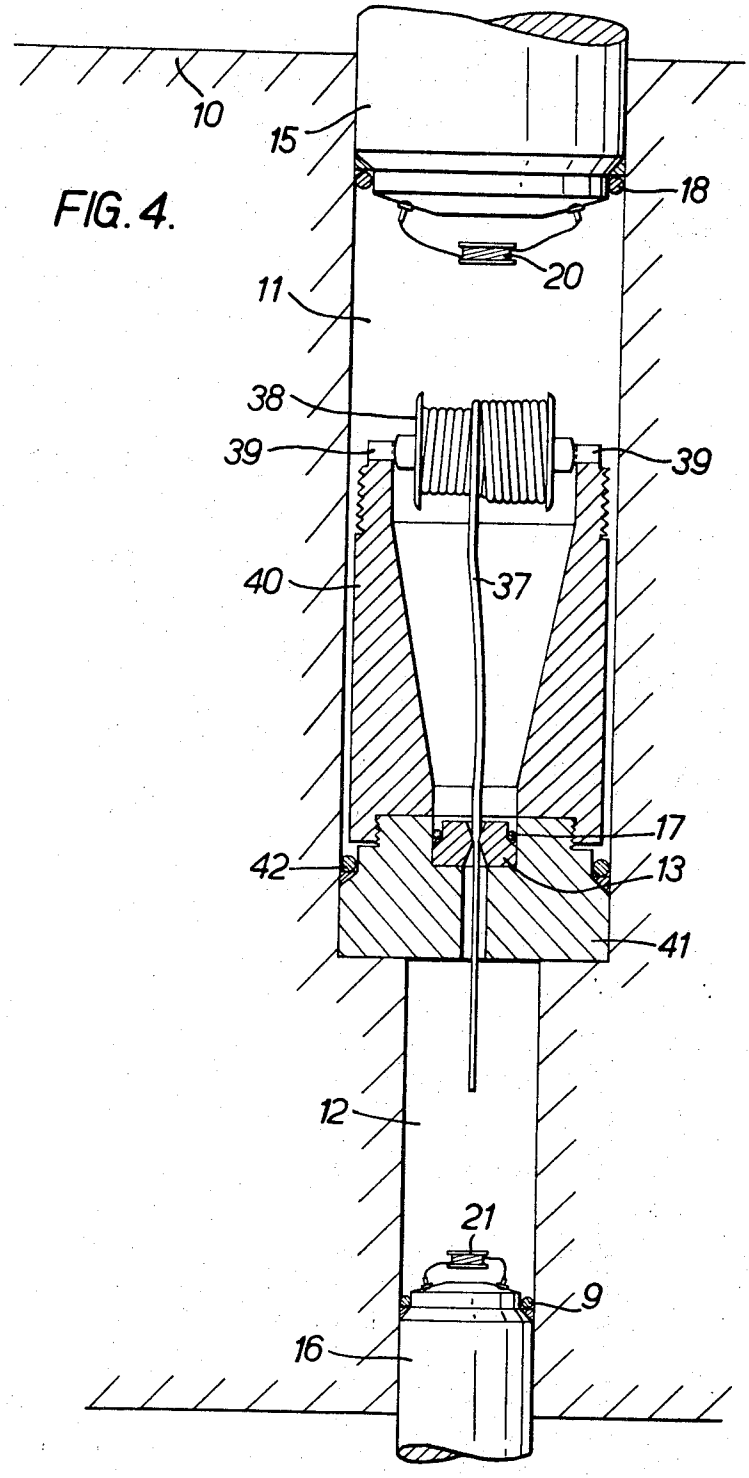
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FIG. 3.



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FIG. 4.



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EXTRUSION OF METALS

Hubert L. D. Pugh, East Kilbride, Glasgow, Scotland, assignor to Council for Scientific and Industrial Research, London, England, a corporate body

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16 Claims. (Cl. 72—60)

ABSTRACT OF THE DISCLOSURE

A process for extruding long and/or brittle metal billets is accomplished by subjecting them to high fluid pressure on the entry side of the extrusion die and maintaining on the outlet side of the die a lower positive pressure sufficient to minimize surface cracking or to eliminate it entirely. The high pressure is established in a chamber in which the billet is not closely confined by the chamber walls, permitting long billets to be bent, coiled or reeled, and then extruded under differential hydrostatic pressure developed across the die. Billets can also be extruded in both directions simultaneously or in succession by closing opposite ends of the high pressure chamber with dies.

This invention relates to the extrusion of solid plastically deformable materials such as metals, and has for an object to enable extrusions to be made from slugs or billets of unusual shape or aspect ratio. Thus, for example, the invention aims at enabling extrusions to be made from relatively long slugs or billets without unduly increasing the size of the extrusion press. It also aims at making such extrusions from elongated billets in helical form or wound on reels.

The invention also has for an object the production of extrusions of intricate or complex shape from billets which can be either of conventional or of unusual shape.

In this specification, the term "intricate or complex shape" is used to define shapes which have an intermediate section of maximum diameter or transverse dimension and an adjacent reduced section at each end thereof. There may be additional reduced sections, at one or both ends, of progressively decreasing diameters or transverse dimensions. Thus, proceeding in either direction lengthwise of the product from the intermediate section, the shape of each end of the product is such as can be formed by the extrusion, through one or more dies, of a slug or billet of diameter or transverse dimension not less than that of the said intermediate section. The slug or billet may have an irregular or non-circular cross-section.

Examples of products having intricate or complex shapes are axles having reduced diameter journals or spigots at each end; pillars or like spacing members having tapered or shouldered ends of reduced cross-section compared with an intermediate section, and so on.

Another object is to facilitate the formation of extrusions from metals having a low ductility at ordinary temperature and pressure, or the production, in a single pass or fewer passes, of components which it is normally possible to produce only in numerous passes. For example, the production of very fine wires normally requires a number of successive drawings each effecting a relatively small reduction in diameter, this being due to the low tensile strength of the finished product. It is an object of the present invention to produce such wires in a single pass, or at least in a much reduced number of passes.

A further object of the invention is to reduce redundant work during extrusion, i.e. work done in reversed shear during extrusion.

A still further object is to produce products as a result

of more homogeneous deformation and therefore to avoid heavy surface shears.

When extruding billets by the conventional method using a ram working in a container or chamber whose outlet is constituted by a die, the billet is normally a close fit within the chamber to prevent lateral distortion and to ensure that the force exerted by the plunger constrains the billet to pass through the die. This normally imposes an upper limit on the ratio of length to diameter of the billet, since the compressive force applied by the ram distorts the billet laterally into tight contact with the walls of the container or chamber and sets up friction which opposes the forward movement of the billet as extrusion proceeds.

Normally the practical limit of the ratio of length to diameter in a conventional extrusion press is about 4:1. Beyond this figure, the forward pressure of the ram tends to become increasingly absorbed by friction between the billet and its container so that extrusion becomes prohibitively difficult.

Another limitation on the length of a billet in a conventional ram extrusion press is that the ram itself, which must have a diameter which is a good working clearance within the billet container, must not be required to have a length sufficient to cause buckling under the compressive load.

The present invention overcomes these drawbacks by substituting a high pressure hydraulic fluid or soft solid for the ram and providing a high pressure chamber having at least one die outlet in which the slug or billet is exposed to the high pressure fluid on all sides. The chamber is also of a length which will accommodate an elongated billet. By this means, when the pressure of the hydraulic fluid is raised to a value sufficient to cause the billet to extrude through the die, this pressure is exerted equally in all directions on the billet, which is thereby prevented from deforming into contact with the walls of the container, and the lateral component of the equilateral pressure at the same time prevents the billet from buckling under the end load so that there is no theoretical limit to the length of the billet which can be extruded. For example, billets of aluminum and lead having a length/diameter ratio of 40 have been successfully extruded by the method of the present invention.

Furthermore, in order to keep the dimensions of the pressure chamber down to reasonable proportions, a long slug or billet can be coiled into helical or spiral form, or even wound on a reel or bobbin, with its leading end forming a fluid-tight seal in the die aperture, and then extruded as a straight product by the application of the necessary hydrostatic pressure.

The hydrostatic pressure may be provided either by a ram working in the container itself, or from an outside source which may include an intensifier.

Where certain normally brittle metals are required to be extruded—such as bismuth, magnesium, zinc, molybdenum, beryllium, chromium and others which normally exhibit, on extrusion under normal circumstances, at least a more deeply cracked external surface than can be removed by a mere sizing or finishing operation—the die opens on its outlet side into a second pressure vessel into which is introduced hydraulic fluid at a positive back pressure less than the forward pressure above the die causing extrusion of the metal. In some cases, this back pressure is critical for the elimination of surface cracking. For example, in the case of bismuth which is extruded through a square-entry die at ambient temperature, the critical or transition value of back pressure has been found to vary with extrusion ratio, and to show a maximum of about 1.5 tons/in.^{2} at a ratio of approximately 2.0, falling to about 0.6 ton/in.^{2} at an extrusion ratio of 4.0. For magnesium, the comparable figures are a

naximum critical pressure of about 2.0 tons/in.² at an extrusion ratio of approximately 2.2, falling to substantially zero at a ratio of 4.0. The extrusion of 60/40 brass to form tubes at an extrusion ratio of 3.9 into atmospheric pressure results in such severe cracking that the product is usually a large number of fragments. The same material can, however, be extruded in one piece—though not always without surface cracks—at the same extrusion ratio when the product emerges into a closed fluid-filled chamber, the back pressure rising during extrusion from 18 tons/in.² to 60 tons/in.². Higher back pressures would doubtless remove any cracks in the product.

Billets wound on bobbins can be extruded in the form of wire by forward hydrostatic pressure in accordance with the present invention, and successful extrusions have been achieved where a rod of 0.045 inch diameter and 30 feet length was so wound, the ratio of length to diameter in this case being 8000.

An important advantage of the method of the invention is that the pressurised hydraulic fluid affords lateral support to the die and thus enables thin-walled dies to be successfully used.

Successful extrusions according to the invention into atmospheric pressure have been made as follows:

A low alloy nickel-chrome molybdenum steel (250 Vickers hardness) was extruded at a ratio of 2 to 1 through a 45° die at a pressure of 55 tons/in.². A complex 10% chrome manganese silicon steel (330 Vickers hardness) was extruded through a 45° die at a ratio of 2 to 1 at a pressure of 69 tons/in.². Nimonic 80 (210 Vickers hardness) extruded under the same conditions required a pressure of 56 tons/in.². A complex aluminum alloy of the Duralumin type (71 Vickers hardness) extruded through a 45° die at a ratio of 6¼ required 44 tons/in.². An aluminium magnesium titanium alloy (250 Vickers hardness) was extruded through a 45° die at a ratio of 2 to 1 at a pressure of 70 tons/in.². Aluminum tin titanium alloy (310 Vickers hardness) required 74 tons/in.² for extrusion under the same conditions. Magnox, i.e. 1% aluminum magnesium alloy, was extruded through a 45° die at a ratio of 4 to 1 by a pressure of 26 tons/in.². This gave a product which, compared with the conventional hot extrusion, had a strength which was twice as high and a grain size which was ten times as fine as hitherto known for this material.

Similarly, successful results have been obtained on other materials e.g. molybdenum, beryllium and chromium, using positive hydrostatic back pressure.

It has already been proposed to extrude metal products having intricate or complex shapes by placing a slug or billet between a pair of dies each adapted to form an adjacent section of the product and causing the dies to approach each other so as to produce simultaneous "forward" and "backward" extrusions of the slug or billet. In this arrangement, the slug or billet is normally supported in a close-fitting chamber which constrains the slug or billet in the radial direction during extrusion. Hence, either the extrusion ratio at each die must be low so as to keep the axial compressive load on the billet between the dies below its buckling load, or the slug or billet must be short relative to its diameter, or preferably both.

It is also known to form a product of complex shape by the extrusion method by first extruding one end in conventional manner and then extruding the other end under a force exerted on an external shoulder of the first extruded portion by means of a tubular ram or punch. This method has the disadvantage that the intermediate section of the product must be radially constrained in the conventional close-fitting chamber of a ram extrusion press, and consequently the thickness of the tubular ram or punch is limited to the radial height of an external shoulder formed on the slug or billet during the first extrusion step or stage. Hence, either the second extrusion stage must be limited to a low extrusion ratio, or the stroke of the tubular second extrusion ram must be short, in order to avoid the risk of collapse of the tubular ram or punch. Hence, the variety of the complex shapes which can be produced by this method is strictly limited.

It is a still further object of the present invention to enable relatively long slugs or billets to be extruded at both ends without risk of buckling so as to produce relatively long products of complex shape.

In a method of extrusion according to the present invention, one end of a slug or billet is extruded in the first stage through one or more dies to form one end of the product and the other end is extruded in the second stage through a die or dies under hydrostatic pressure applied to the slug or billet in a pressure-tight chamber of which the second stage extrusion die forms an outlet.

The first and second extrusion steps or stages may be carried out separately, in which case any conventional method of first stage extrusion may be adopted. For example, the initial slug or billet may be placed in a conventional ram-type extrusion machine to form one end of the product. The partly formed product is then transferred to an extrusion press having a pressure-tight chamber for containing the partly formed product, the unextruded end of the said product being located in the mouth of a second stage extrusion die constituting the outlet of the pressure-tight chamber. The latter is then filled with oil or other convenient hydraulic fluid which is then subjected to sufficient pressure to cause the required second stage extrusion of the other end of the slug.

Alternatively, the slug or billet may initially be placed in a hydrostatic extrusion chamber having the appropriate dies at each end. The chamber is then filled with hydraulic fluid under the appropriate pressure to cause simultaneous first and second stage extrusion of the slug or billet.

The terms "first stage" and "second stage" as used herein are chosen arbitrarily for convenience of separate identification of the extrusion operations carried out at opposite ends of the same billet. They do not imply any order of time sequence or technical importance, but whereas one of the stages may be carried out, if desired, in a conventional mechanical ram press, the other must, in accordance with the present invention, be carried out by means of hydrostatic pressure in a fluid or soft solid. In this specification the stage which is essentially a hydrostatic pressure extrusion is designated the second stage.

A soft solid is a material such as rubber, lead or a pressure-frozen liquid which, at the working pressure, behaves in such a manner as to transmit that pressure substantially equally in all directions. For the purposes of the present specification, the term "hydraulic fluid" is deemed to include such a soft solid material. It also includes a gas, since the criterion of suitability of the fluid is ability to transmit pressure substantially equally in all directions. The problems of sealing against leakage of gases, however, are normally greater than for liquids, and their compressibilities are greater, both of which factors can lead to complications in design of the press.

In the latter method, the dies at opposite ends of the pressure chamber can be different shapes and produce different extrusion ratios. It is immaterial to the production of the finished article whether first and second stage extrusion takes place simultaneously and at equal rates through the respective dies, or whether extrusion takes place first at the die offering lower resistance until the necessary length of extruded product has emerged and is then positively stopped and followed by extrusion through the other die.

In a method according to the present invention, the use of hydraulic fluid under hydrostatic pressure for at least the second stage of extrusion ensures that the slug or billet is compressed on all sides throughout its unextruded length so that there is no resultant force tending to cause buckling. Hence, there is no theoretical upper limit to

the length of the initial billet or the final product. Furthermore, the use of hydrostatic pressure, at least for the second stage extrusion, eliminates the necessity for specially shaped tubular rams having reduced rigidity as in the above-mentioned known process. Aluminium products have been thus formed in which the intermediate section of maximum diameter or transverse dimension was first extruded to give a shape having an elongated splined end section separated from the intermediate section by a larger diameter land whose diameter was only slightly less than that of the intermediate section. A different shape was then extruded at the other end of the slug or billet by hydrostatic pressure to produce a finished product of acceptable finish and dimensions.

If the length to diameter ratio of the slug or billet exceeds quite a low value—conventionally taken as about 4:1—neither of the above-mentioned known processes could be used to form the above product, since the slug or billet would have buckled in the first-mentioned approaching-die process; whilst in the second process, the small difference in diameter between the land section and the adjacent intermediate section would have required the use of a tubular ram whose walls would have been too thin to withstand the extrusion load.

The slug or billet may initially be coiled—that is to say, it longitudinal axis is other than straight—and placed in the pressure chamber of a hydrostatic extrusion press, the chamber having the appropriate fixed dies at each end. The chamber is then filled with hydraulic fluid under the appropriate pressure to cause simultaneous first and second stage extrusion of the slug or billet. Such extrusion will continue until the axis of the intermediate portion of the slug or billet—i.e. that portion lying between the extruded end portions—becomes straight. Any further attempt at extrusion beyond this point by increasing the hydrostatic pressure in the extrusion chamber is liable to cause non-uniform deformation or "necking" of the intermediate portion of the slug between the dies. If further extrusion is required, the dies themselves must then be made to approach each other within the extrusion chamber.

By way of example only, methods of performing the invention will now be described in greater detail with reference to the accompanying drawings in which each of FIGURES 1–4 is a fragmentary diagrammatic section through a respective extrusion press.

Referring first to FIGURE 1, a hydrostatic extrusion press incorporates a main block or body **10** having upper and lower chambers **11** and **12** which are separated by a conical entry die **13** abutting a shoulder at the end of chamber **11**. A long billet **14** of material to be extruded is shaped at one end to fit the conical entrance to the die. Pressure is built up in hydraulic fluid in the chambers **11** and **12** by moving rams or plungers **15** and **16** in those chambers towards the die, the difference in pressure above and below the billet being sufficient to cause extrusion of the material through the die. The pressure in chamber **12** is sufficient to minimise defects in the surface and structure of the extruded product. A seal **17** is provided between the die **13** and the wall of the chamber **11** to prevent leakage of liquid around the die from the chamber **11** to the chamber **12**, while the shaped billet is a sufficiently good fit in the conical die entry that special sealing arrangements are unnecessary there. Seals **18** and **19** are provided between the plungers and the chamber walls, and conventional electrical pressure-sensitive elements **20**, **21** are carried by the respective rams **15**, **16** for measuring or recording the extrusion and back pressures during operation of the press.

The pressure exerted by the hydraulic fluid around the billet **14** and die **13** provides lateral support to the die, so that relatively thin-walled dies can be used and it is not necessary to provide support in the usual way by shrunk-on steel rings.

Instead of applying pressure to the fluid by the movement of plungers as described above, the required pressures may be obtained in the chambers by connecting them through pipes to a source of pressure fluid, if necessary, through the intermediary of a make-up pump.

Using the apparatus described above, cold extrusion of beryllium may be carried out with a pressure of 16 tons/sq. in. in the chamber **11** and a back pressure of 100 tons/sq. in. in the chamber **12**. Zirconium-berylliu alloy may be cold extruded with a pressure of 100 tons sq. in. in the chamber **11** and a back pressure of 4 tons/sq. in. in the chamber **12**. Lower pressures may b used if satisfactory extrusions are still obtained thereby

The hydraulic fluid used in the chambers **11** and **1** must not react with the material being extruded and mus not rigidify under the applied pressures. High pressur liquids which may be used include glycerine and wate glycerine and 40% aqueous glycol; Shell DTD 585 castor oil; castor oil and methylated spirits; and paraffin With the materials and pressures specifically mentione above, a particularly suitable hydraulic fluid is isopentane

FIGURE 2 illustrates the extrusion of a bent or coile billet, with or without a fluid back-pressure at the di outlet.

The press illustrated is similar to that shown in FIG URE 1, like parts carrying the same reference numerals The upper chamber **11** accommodates an elongated ben or coiled slug **14***a* the lower end of which is preformed t fit the mouth or entry of the die **13** and provide a pressure tight seal. The dimensions of the slug or billet **14***a* ar such as to give a ratio of length to diameter which i considerably in excess of the conventional maximun value of 4:1, and the actual profile can vary from gen erally bent to a close-coiled helix or spiral. The term "bent" includes a nominally straight slug or billet whic is not dead true either as to straightness or constancy o diameter, such a distorted slug or billet being unextrud able in a conventional ram press without prior rectifica tion. This preliminary step, however, can be dispensed with in the process according to the present invention because there is no danger of buckling under the three-dimensional fluid-applied extrusion loading.

The provision of back pressure in the lower cavity **12** at the outlet from the die **13** is optional, depending on the characteristics of the metal being extruded and the final product to be obtained.

The ability of a press according to the invention to accommodate and extrude bent or coiled slugs or billets can be further developed by providing a coiling machine below the outlet from the die **13** which accepts the extruded product from a preceding extrusion stage and coils it into a form in which it can be stored or handled. Thus a very long product, such as a fine wire, can be produced in a compact apparatus from a relatively heavy initial slug or billet **14** or **14***a* in fewer passes than could be tolerated in conventional ram extrusion presses followed by conventional wire-drawing machines. The operation is more economic and the first cost of the plant and equipment can be substantially lessened.

Various other advantages follow from the process according to the present invention. First, the power consumption for the extrusion of a given volume of a given metal at a given extrusion ratio is markedly lessened due to the absence of friction between the slug or billet and the container wall.

Secondly, when a product of given dimensions is to be obtained, there is flexibility in the choice of initial dimensions and extrusion ratio.

Thirdly, so long as a billet can be accommodated in the pressure chamber **11** with its leading end sealed in the die entry, no further rectifying process is required for the product than is normally necessary in conventional methods.

The pressure-producing ram need not, of course, operate in the same direction as that of the extrusion of the billet. The ram can operate in a lateral pressure

eader which may feed a multiple chamber unit, so enbling a plurality of simultaneous extrusions to be made. Means is preferably provided for arresting any one extrusion as required—for example, before the billet has been completely extruded through the die—so as to prevent loss of pressure fluid through an open die.

A suitable press for carrying out the simultaneous extrusion of both ends of a billet consists of a relatively large diameter chamber to which fluid at the appropriate hydrostatic pressure can be introduced, the opposite ends of the chamber being closed by dies, one of which is reciprocable in the chamber by means of an external ram.

A schematic arrangement of such a machine is illustrated in FIGURE 3 of the accompanying drawings, in which a tubular ram or plunger **22** having an internal coaxial stop **23** works in the upper end of a high pressure chamber **24** constituted by a through cylindrical bore in a high-duty alloy steel block **25**. This plunger bears on an upper externally necked die **26** slidable in the bore **24**, the necked part **27** being coextensive with at least the inlet taper **28** and surrounded by the high pressure liquid. The upper end of a billet **29** (here shown straight for illustration purposes only, but having a length/diameter ratio much in excess of the normal maximum for billets extruded in conventional mechanical ram extrusion presses) registers with the inlet to the upper die **26** and its lower end registers with the inlet to a generally similar lower die **30** having a necked portion **31**, and entry taper **32**. The die **30** is here shown as immovable in the lower end of the chamber **24**. High pressure hydraulic fluid is introduced into the chamber **24** through an inlet passage **33** to which is connected the necessary pump and pressure relief valve (not shown).

Both dies have conventional external pressure seals **34** to prevent leakage of high pressure liquid around their outer peripheries, and at least their entry tapers **28, 32** are formed in the respective necked sections **27, 31** of the dies whose reduced wall thickness enables the cost of production of each die to be reduced.

Since the billet **29** between the dies **26, 30** is surrounded by the liquid pressure, the chamber **24** can be much larger than in conventional mechanical ram extrusion presses since the walls of the chamber are not required to support the unextruded billet. Hence, the wall thickness of the tubular ram or plunger **22** where it engages the upper die **26** can be made sufficiently great to avoid buckling under the maximum extrusion loading.

The billet **29** extrudes simultaneously through both dies **26, 30**, though not necessarily at the same rate. The necessary extrusion through each die can be controlled by the adjustable stop **23**, the whole of the extrusion force on the billet being transferred to the lower end when the upper end has extruded to the limit determined by the stop.

As shown, two stages of extrusion at one end can be accommodated by placing a second lower die **35** below the first lower die **30** at the appropriate spacing, a second fluid inlet passage **36** being provided for the access of hydrostatic pressure to the intermediate extruded product **29*a*** between the dies **30, 35** if necessary. The resultant product then has two reduced diameter sections **29*a*, 29*b*** at one end. Consequently, by subjecting the billet to high hydrostatic pressure over the initial or unextruded length, complex shapes having two or more reduced diameter sections at one or both ends can be extruded in a single operation, thus saving operating time and economising in apparatus.

FIGURE 4 illustrates a form of hydrostatic extrusion press according to the invention for extruding very long billets in the form of reeled material **37**. This machine closely resembles, in essential particulars, the machine of FIGURE 1 in that a main block or body **10** has upper and lower chambers **11, 12** between which lies a conical entry die **13**. Upper and lower rams or plungers **15, 16** are reciprocable in fluid-tight manner in the upper and lower chambers **11, 12**, the pressure difference between the chambers during use causing the extrusion of the reeled material **37**.

The material **37** to be extruded is initially supplied reeled on a bobbin **38**. This bobbin is designed for mounting by low-friction trunnion bearings **39** on a heavy yoke or support tube **40** located with radial clearance within the upper chamber **11**. The tube **40** is stepped on a die holder **41** which also serves to support the die **13**. A conventional seal **42** prevents leakage of hydraulic fluid between the wall of the upper chamber **11** and the periphery of the die holder **41**, and the latter locates the tubular support **40** coaxially with the die **13**.

In operation, after the bobbin **38** has been placed in position on the yoke or support tube **40**, the leading end of the material **37** to be extruded is fitted in fluid-tight manner in the taper entry of the die **13**. The main ram or plunger **15** is then advanced to build up the pressure in the chamber **11**, and when this exceeds by the appropriate amount the value of the back pressure in the chamber **12**, the material **37** begins to extrude through the die and continues to do so for as long as the pressure difference is maintained across the die **13**.

In all embodiments of the present invention, extrusion is produced by an hydrostatic pressure difference across the extrusion die itself, as distinct from arrangements in which the same high hydrostatic pressure is maintained on both sides of the die and the extruded product is either gripped and pulled or is passed through a pressure seal into a lower ambient pressure.

Materials other than metals have been successfully extruded by the present invention where no satisfactory extrusion had hitherto been possible. For example, successful extrusions of polytetrafluorethylene have been achieved without fracture of the material.

I claim:

1. Hydrostatic extrusion process which comprises inserting a non-straight billet into a hydrostatic pressure chamber; sealing extrusion dies into opposite ends of said chamber; inserting each end of said billet in fluid-tight manner into the adjacent die, and establishing a high hydrostatic pressure in said chamber between said dies while maintaining a lower pressure in a chamber on the outlet side of each of said dies whereby to cause extrusion of the opposite ends of said billet through the respective dies.

2. Hydrostatic extrusion process comprising inserting a billet into a hydrostatic pressure chamber; sealing opposite end outlets of said chamber with extrusion dies; introducing each end of said billet into a respective die in fluid-tight manner; establishing a high hydrostatic pressure in said chamber between said dies; maintaining a lower pressure in a chamber on the outlet side of each die, and effecting mutual axial approach of said dies to cause extrusion of the opposite ends of said billet through the respective dies.

3. Hydrostatic extrusion process for long billets having high ratios of length to diameter—for example, upwards of 100:1—comprising reeling a billet on a bobbin; supporting said bobbin in a hydrostatic pressure chamber for free rotation about its axis; closing an end of said chamber in pressure-tight manner by an extrusion die; inserting an end of said billet into said die to form a fluid-tight seal therein; establishing a high hydrostatic pressure in said chamber, and maintaining a lower pressure in a chamber at the outlet side of said die to cause extrusion of said billet.

4. Hydrostatic extrusion process as claimed in claim **3** including continuously reeling the extruded product onto another bobbin.

5. Hydrostatic extrusion process for normally brittle materials comprising inserting an extrusion die in pressure-tight manner into a high pressure chamber; introducing a billet of normally brittle material into said chamber; inserting an end of said billet into said die to

form a fluid-tight seal therein; establishing a high hydrostatic pressure in said chamber on the entry side of said die; and establishing a lower but substantial positive hydrostatic back pressure in a chamber on the outlet side of said die such that the difference in pressure across said die causes extrusion of said billet therethrough while the value of said back pressure is sufficient to inhibit unacceptable cracking of the extruded product.

6. In a hydrostatic extrusion press incorporating a high pressure chamber, an extrusion die located in an open end of said chamber; a pressure-tight seal between said die and the wall of said chamber; means for establishing within said chamber a high hydrostatic pressure; a second pressure chamber enclosing the outlet from said die; and means for maintaining a substantial positive but lower hydrostatic pressure in said second pressure chamber around the extruded product as it emerges from said die.

7. Apparatus as claimed in claim 6 wherein a plunger is reciprocable in fluid-tight manner within said second chamber for displacement in synchronism with the extrusion of said billet for maintaining the pressure around said extruded product within predetermined limits.

8. In a hydrostatic extrusion press, a high pressure chamber for accommodating a billet to be extruded; an extrusion die located in the outlet from said chamber in pressure-tight manner; a coaxial lower pressure chamber communicating with said high pressure chamber solely through the die aperture; a ram reciprocable in said high pressure chamber for establishing a high hydrostatic pressure therein; a plunger reciprocable in said lower pressure chamber for maintaining a predetermined substantial positive but lower pressure therein, and means for measuring the pressure in each chamber.

9. In a hydrostatic extrusion press, a high pressure chamber for accommodating a reeled billet to be extruded; a bobbin having axial trunnions; bearings for said trunnions fixed within said high pressure chamber; an extrusion die mounted in pressure-tight manner in one end of said high pressure chamber; and means for establishing a high hydrostatic pressure in said chamber.

10. Apparatus as claimed in claim 9 wherein the trunnion bearings are carried on the one end of a tubular support located with radial clearance within said chamber.

11. Apparatus as claimed in claim 10 wherein the extrusion die is mounted in pressure-tight manner in a die holder adapted to carry said tubular support coaxially with said die.

12. Hydrostatic extrusion process applicable to the working of normally brittle metals which comprises introducing a billet of the normally brittle metal into a hydrostatic pressure chamber having at least one outlet defined by the aperture of an extrusion die; inserting one end of said billet into said die to form a fluid tight seal; establishing a high hydrostatic pressure in said chamber on the entry side of said die, and maintaining a lower but substantial positive pressure in a chamber on the outlet side of said die such that the difference in pressure across the die causes extrusion of the material of said billet through said die aperture, while the value of the said lower positive pressure is sufficient to inhibit unacceptable cracking of the extruded product.

13. Hydrostatic extrusion process as claimed in claim 12 wherein extrusion is terminated after a predetermined length of material has been extruded; the hydrostatic pressure in said chamber and the lower positive pressure are released; the partially extruded billet is reversed end-for-end in said chamber and the unextruded end is sealed into said die, and the hydrostatic pressure in said chamber and the lower positive pressure are reestablished to cause extrusion of said unextruded end.

14. Hydrostatic extrusion process as claimed in claim 12 wherein a billet having one end already extruded is inserted in said pressure chamber with its unextruded end sealed in fluid tight manner in said die, and the high hydrostatic pressure in said chamber and the lower positive pressure are established to cause extrusion of said unextruded end.

15. Hydrostatic extrusion process for long billets having high ratios of length to diameter and applicable to the working of normally brittle metals comprising coiling a billet of the normally brittle metal to an overall size such that it can be accommodated in a hydrostatic pressure chamber; inserting an end of said billet into an extrusion die to form a fluid tight seal therein; locating said die in said chamber so as to form a pressure-tight closure therefor; and establishing a high hydrostatic pressure in said chamber around said billet while maintaining a substantial positive but lower pressure in a chamber at the outlet side of said die such that the difference in pressure there across causes extrusion of the material of said billet through said die, while the value of said lower pressure is sufficient to inhibit unacceptable cracking of the extruded product.

16. Hydrostatic extrusion process as claimed in claim 1 wherein the billet is coiled to an overall size such that it can be inserted into the high pressure chamber closed by respective dies and the opposite ends of said coiled billet are introduced into the adjacent dies in fluid-tight manner.

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RICHARD J. HERBST, *Primary Examiner.*

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,344,636 October 3, 1967

Hubert L. D. Pugh

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

In the heading to the printed specification, lines 4 and 5, for "assignor to Council for Scientific and Industrial Research, London, England, a corporate body" read -- assignor, by mesne assignments, to Minister of Technology, a corporation --.

Signed and sealed this 8th day of April 1969.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents