United States Patent [19]

Green

[11] **3,884,062**

[45] **May 20, 1975**

[54] **FORMING OF MATERIALS**

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[73] Assignee: **United Kingdom Atomic Energy Authority,** London, England

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[21] Appl. No.: **357,531**

Related U.S. Application Data

[62] Division of Ser. No. 880,127, Nov. 26, 1969, abandoned.

[30] **Foreign Application Priority Data**

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Dec. 9, 1968	United Kingdom	58493/68
Jan. 21, 1969	United Kingdom	3489/69
Jan. 29, 1969	United Kingdom	4996/69
Feb. 19, 1969	United Kingdom	9096/69

[52] **U.S. Cl.** **72/60**

[51] **Int. Cl.** **B21c 23/08**

[58] **Field of Search** 72/41, 60, 68, 71, 256, 72/262, 270, 271, 273; 425/371, 381

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Primary Examiner—Richard J. Herbst
Attorney, Agent, or Firm—Larson, Taylor & Hinds

[57] **ABSTRACT**

A process for producing an extrusion of small cross section from a workpiece in which the workpiece is subjected to a bulk compressive stress in a container so that the end of the workpiece is forced into a reducing die at the end of the container. The material of the workpiece in the reducing die is subjected to an additional localised compressive stress by a tool member having a working face which is applied to the material of the workpiece in the reducing die. Under the combined compressive stresses the material of the workpiece is formed through a die orifice. In one arrangement a rotary tool member is employed which is moved in a circular path through the workpiece material in the reducing die. In another arrangement the tool member is in the form of a reciprocating punch.

16 Claims, 23 Drawing Figures

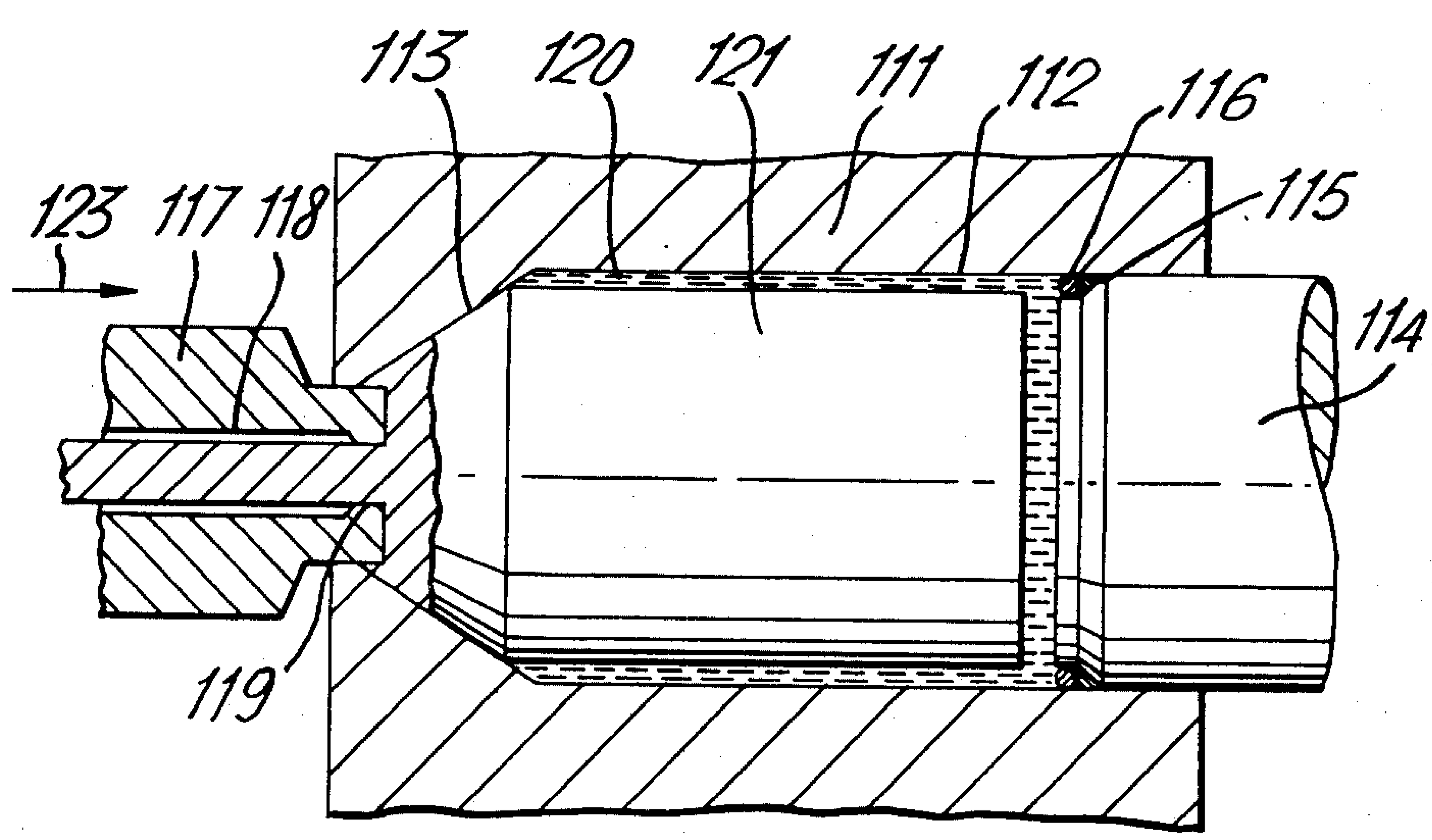


Fig. 1.

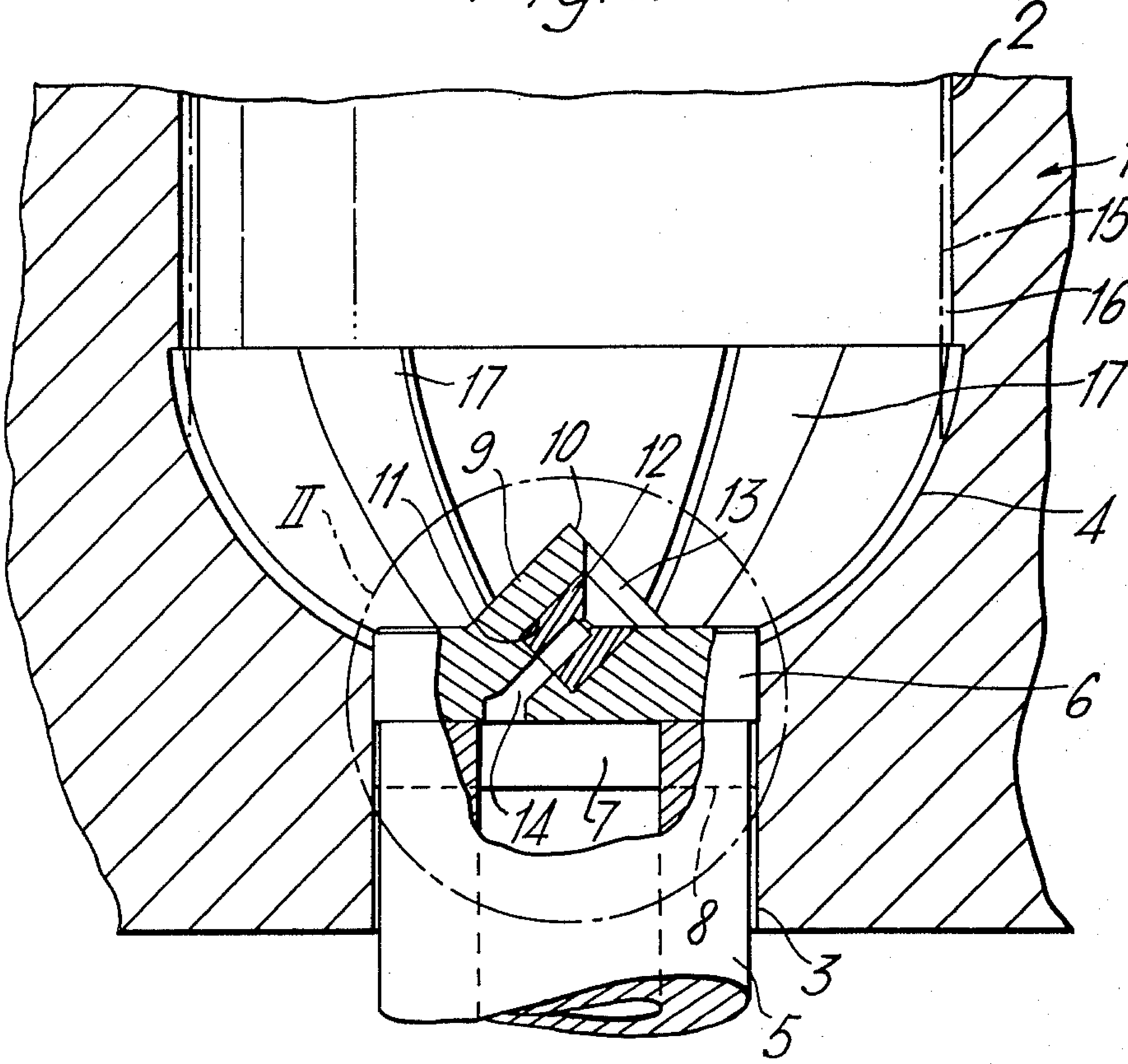


Fig. 2.

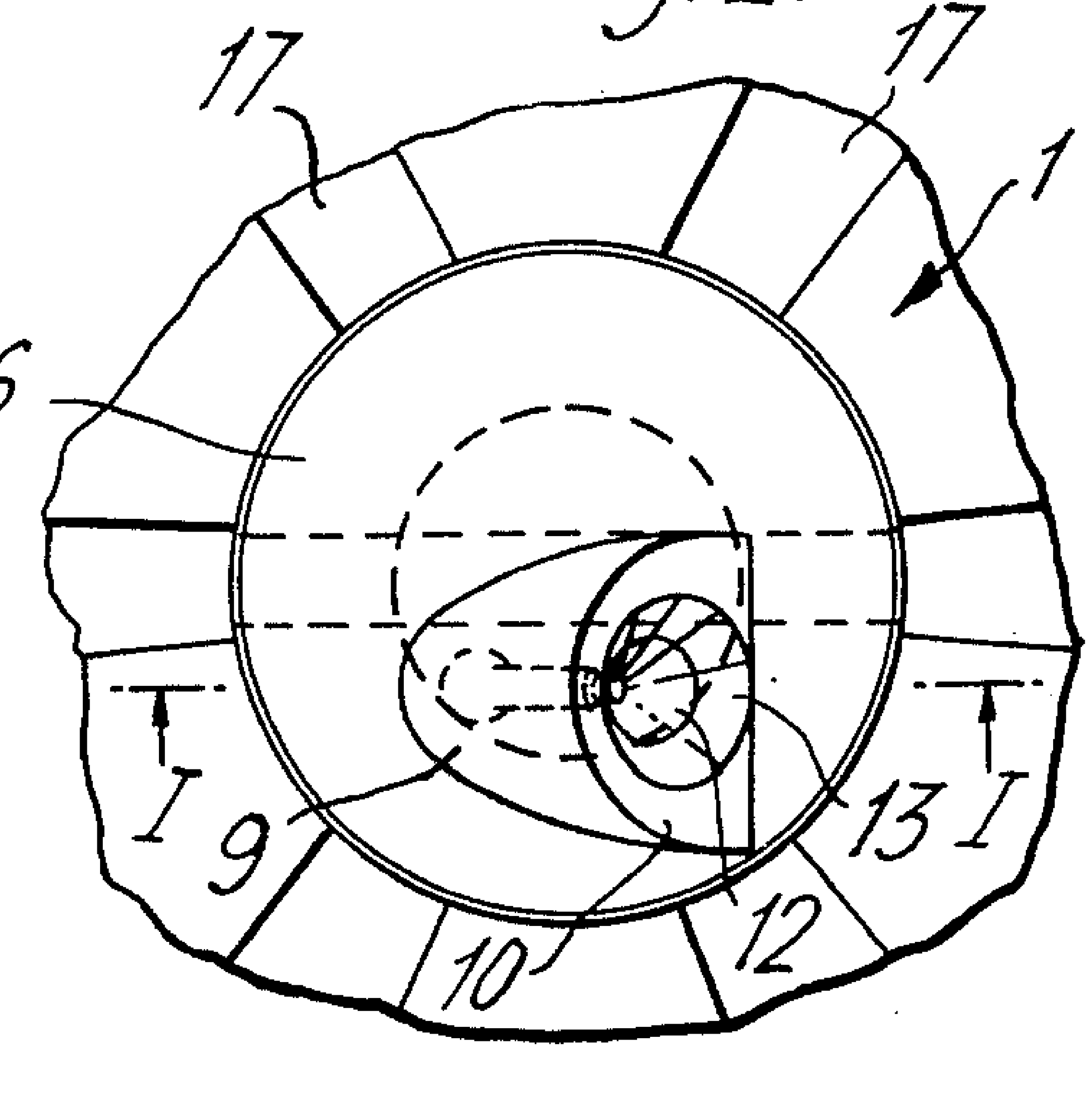
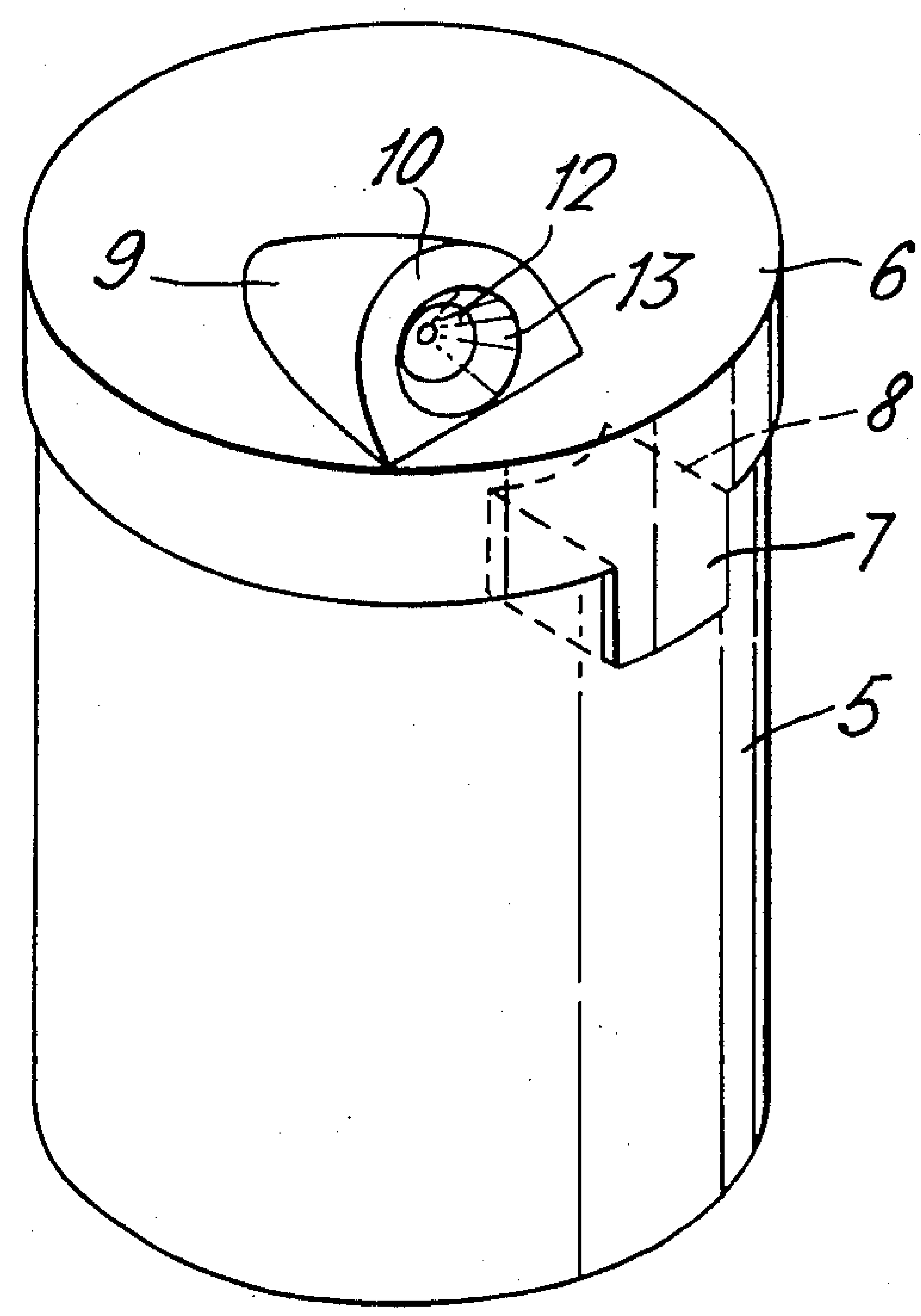


Fig. 3.



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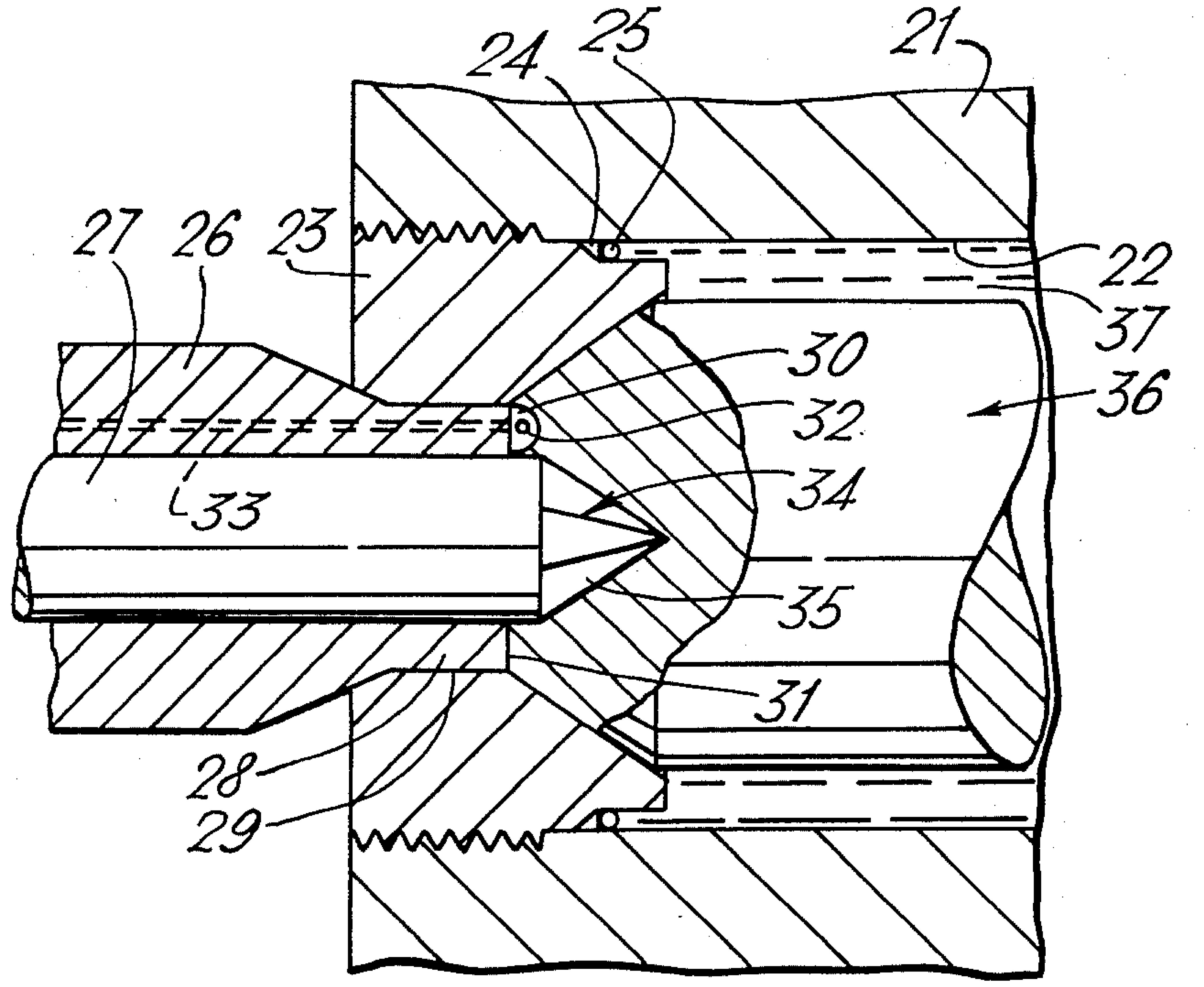
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Fig. 5.

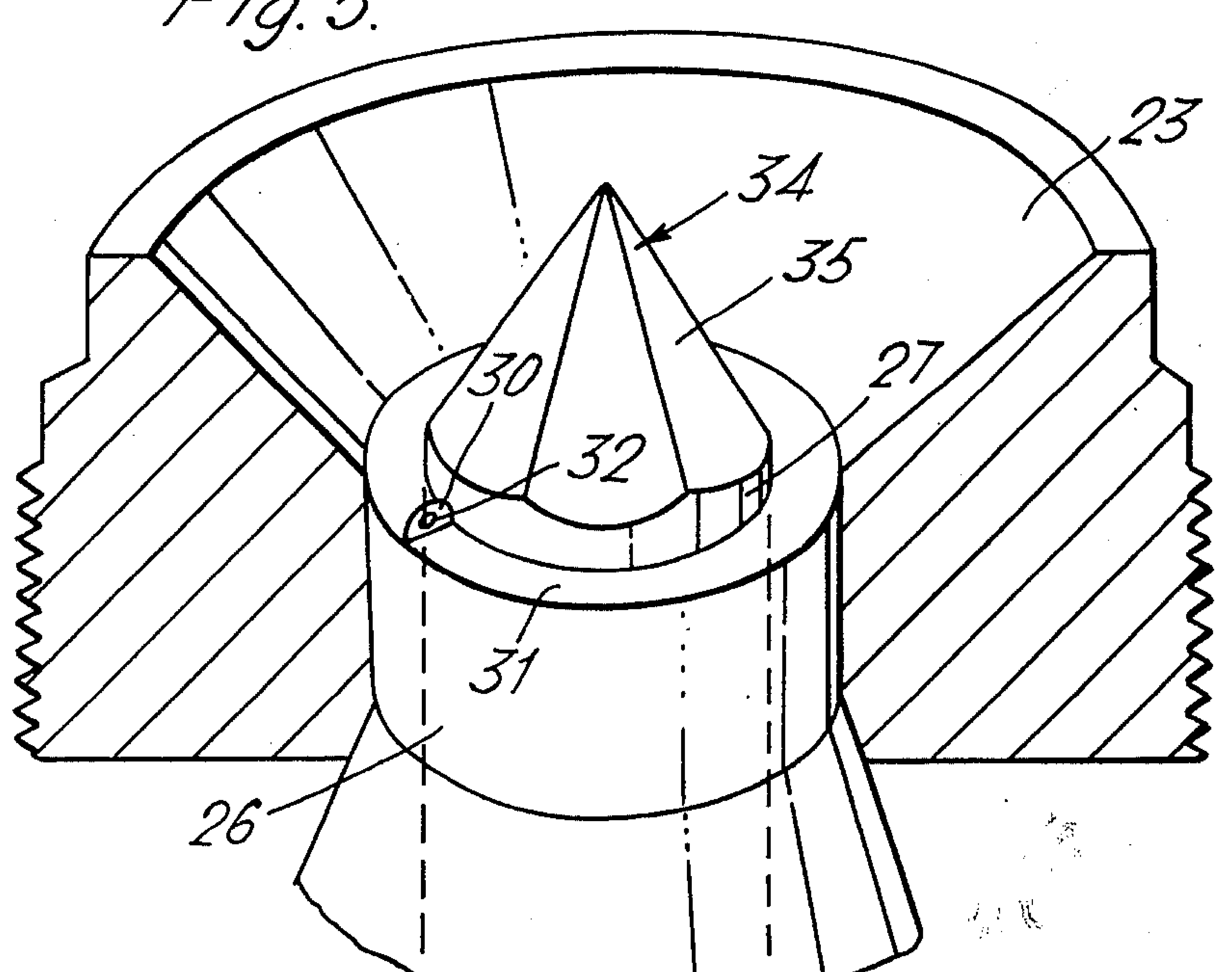
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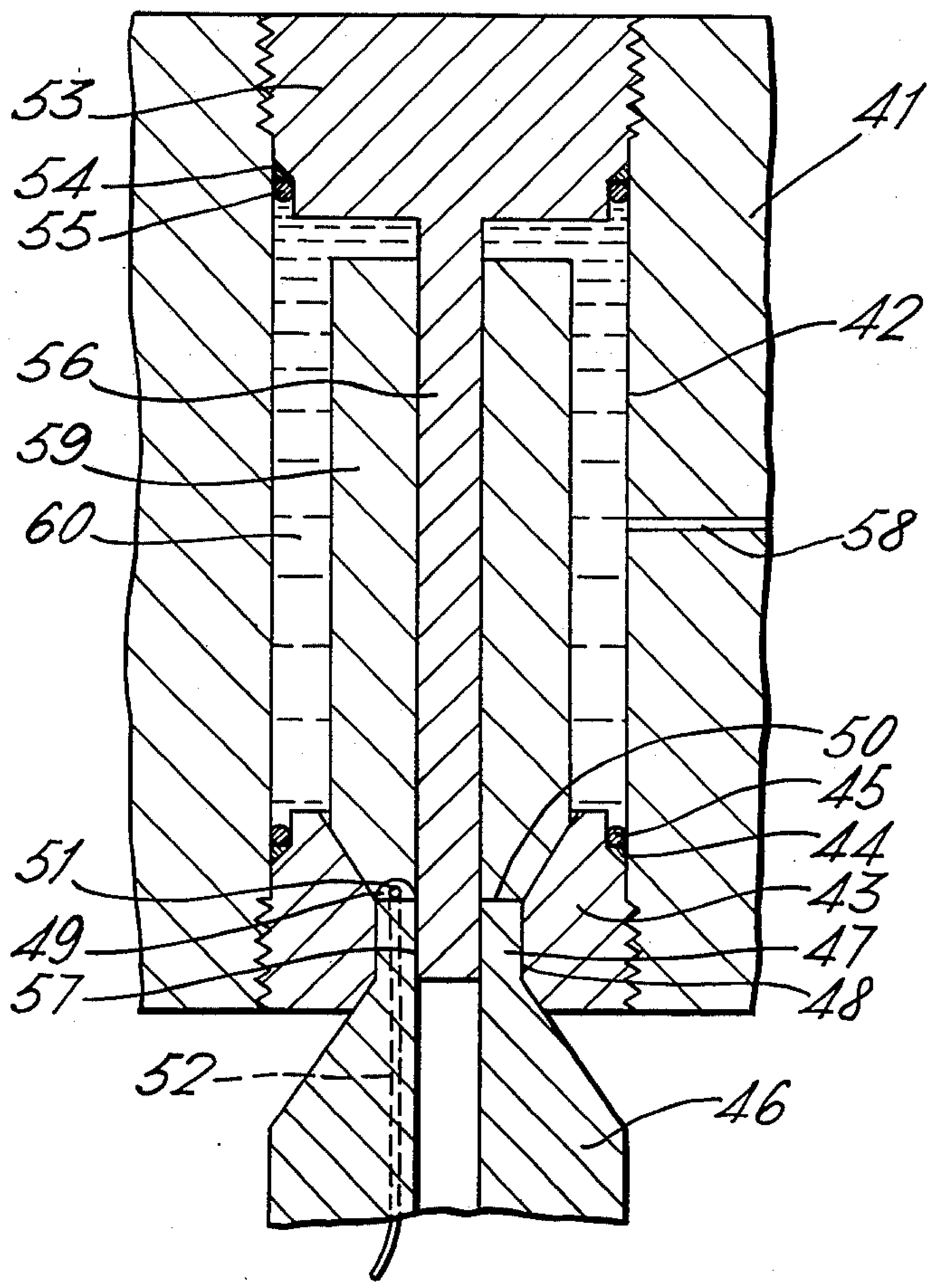
Fig. 6.



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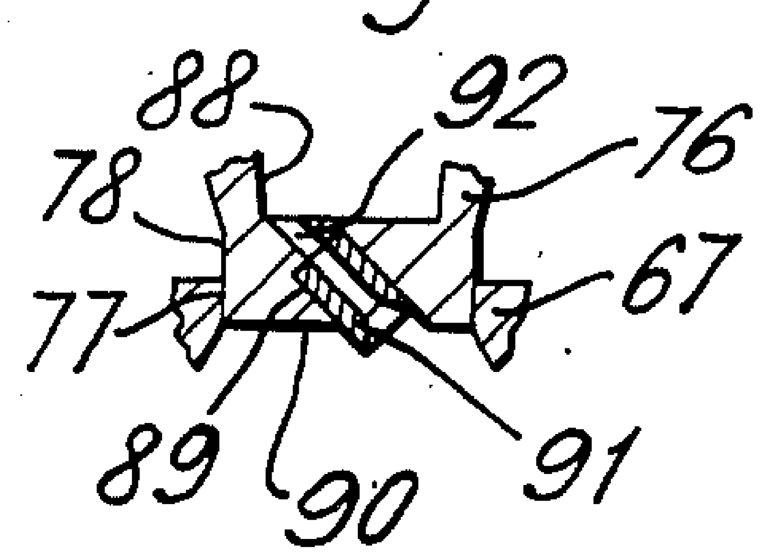

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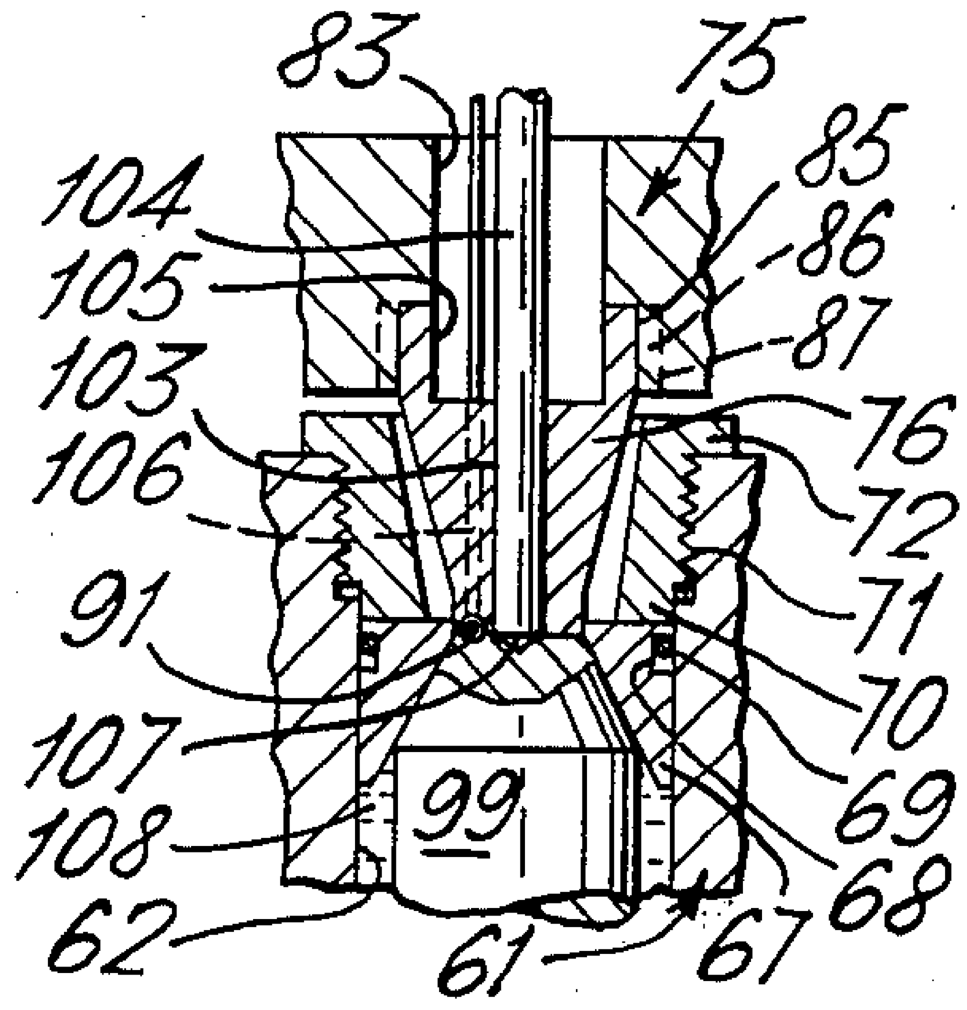

Fig. 7

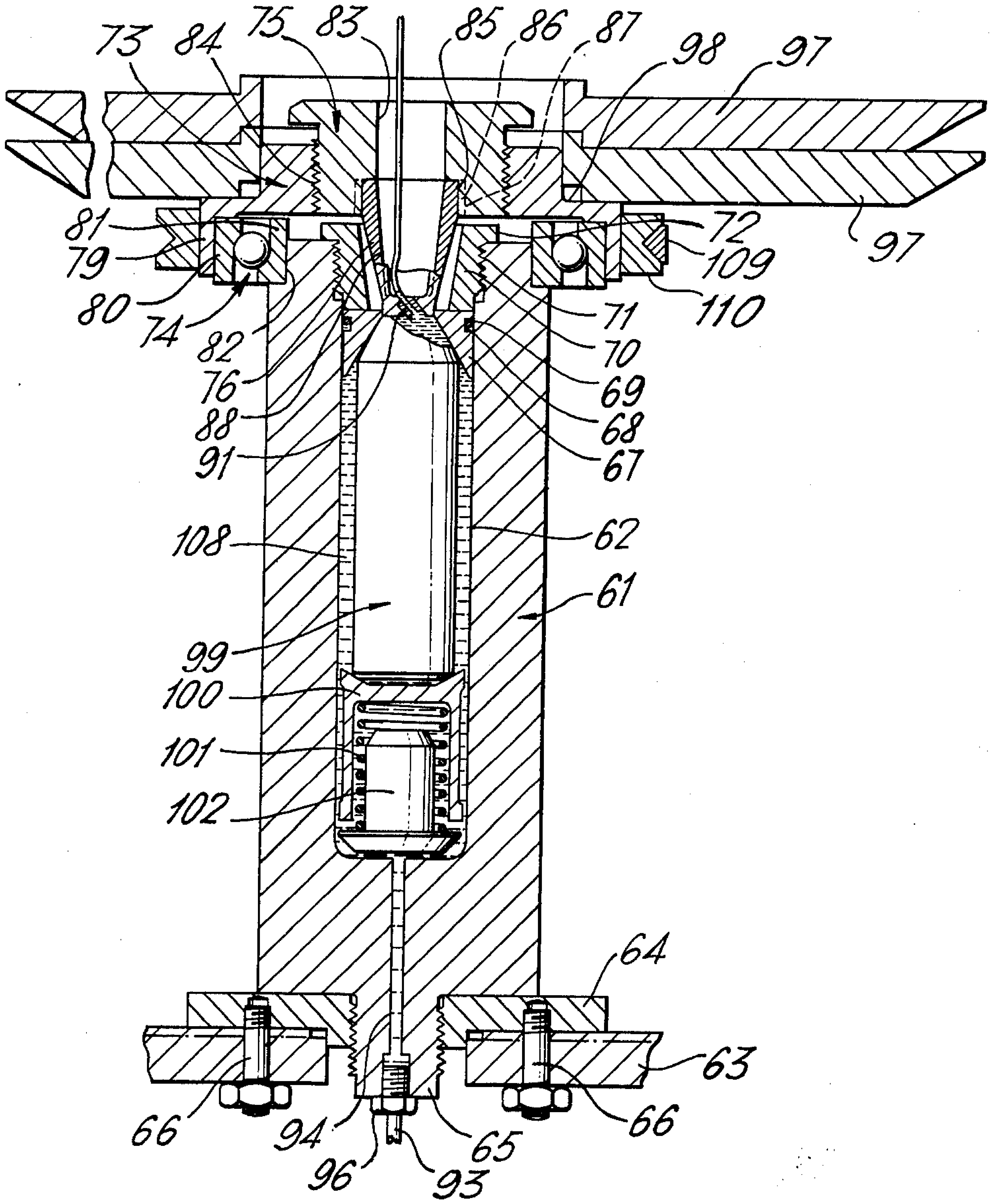
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Fig. 10.

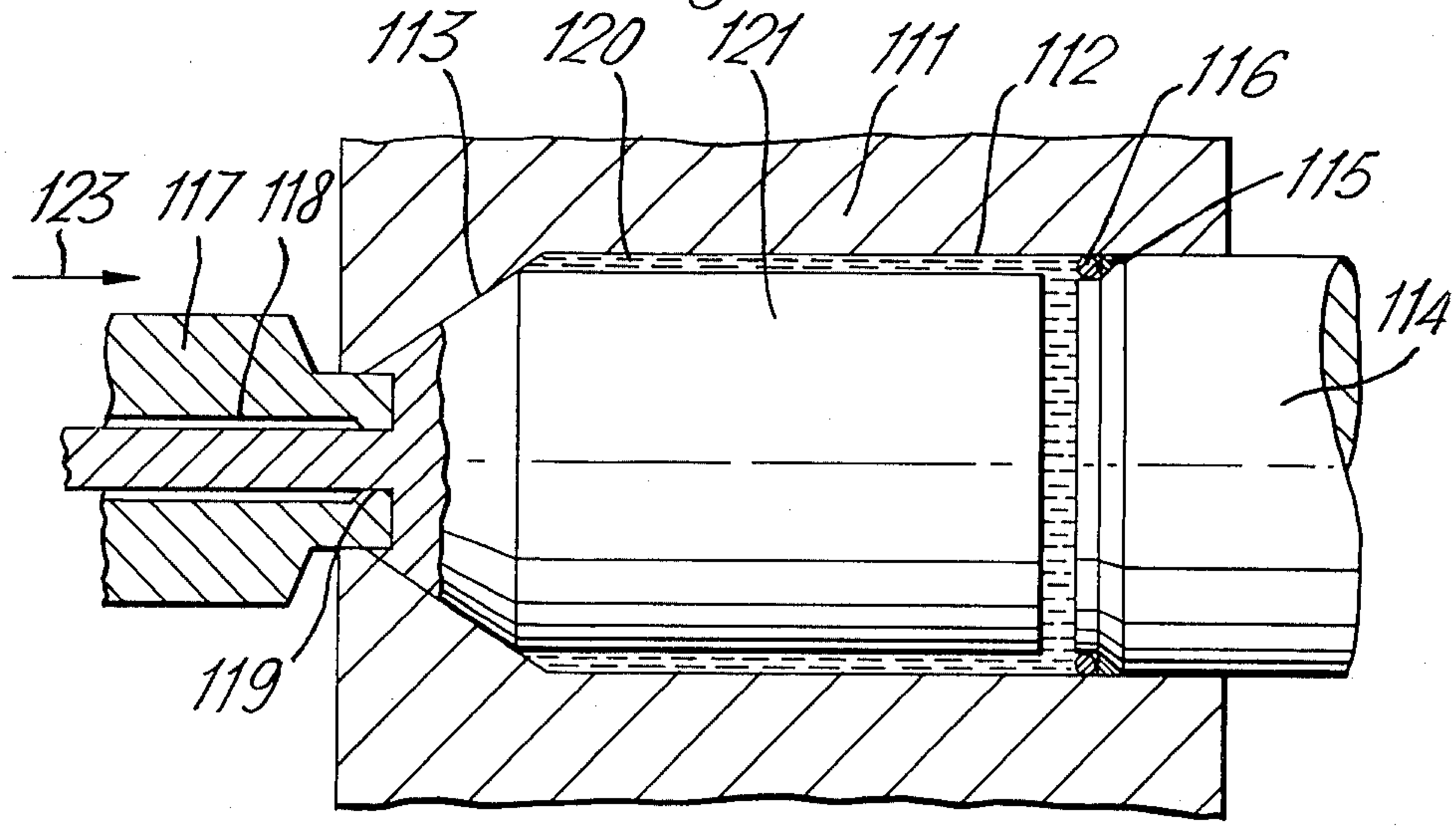
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Fig. 11.

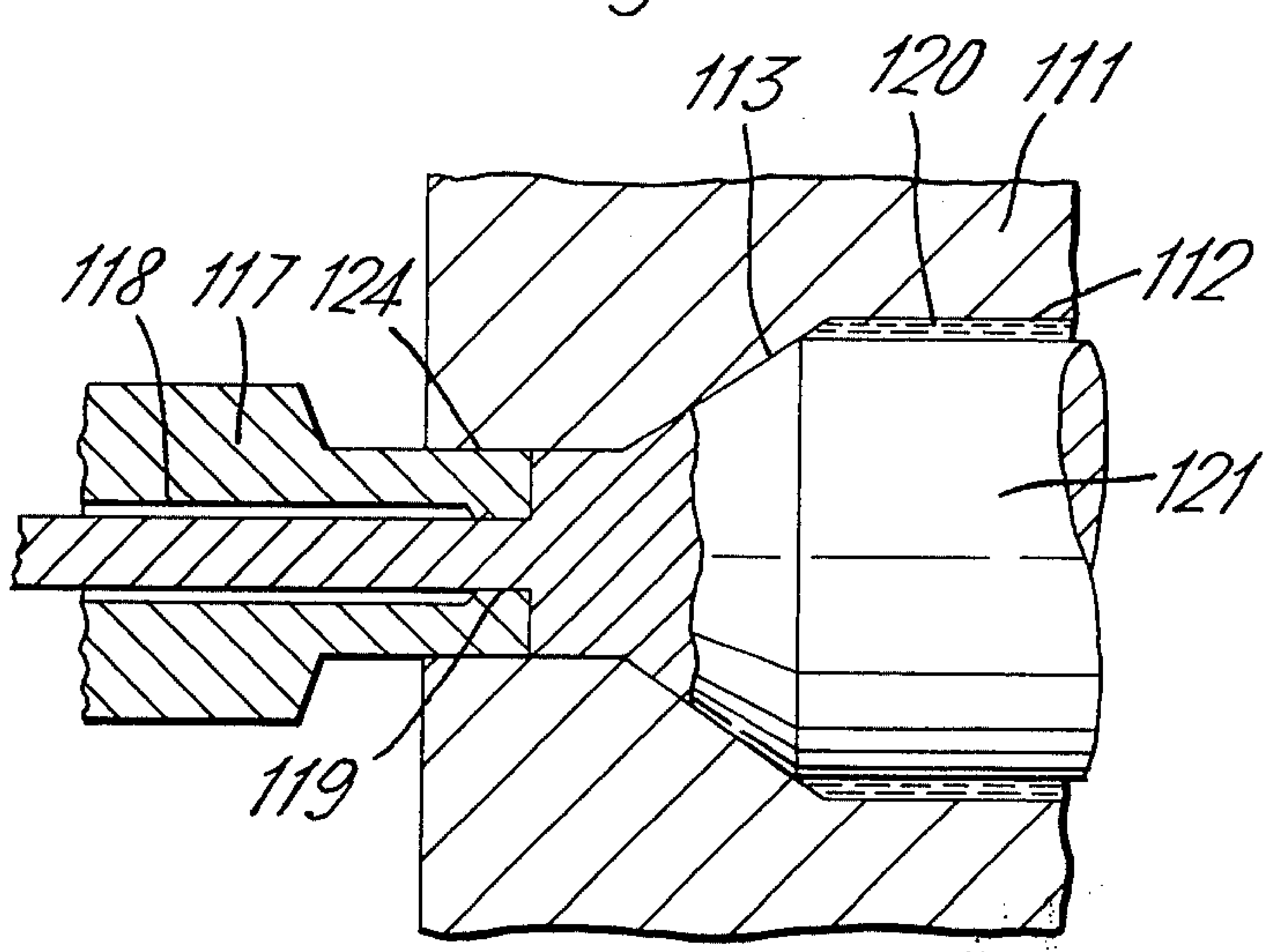
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Fig. 12.

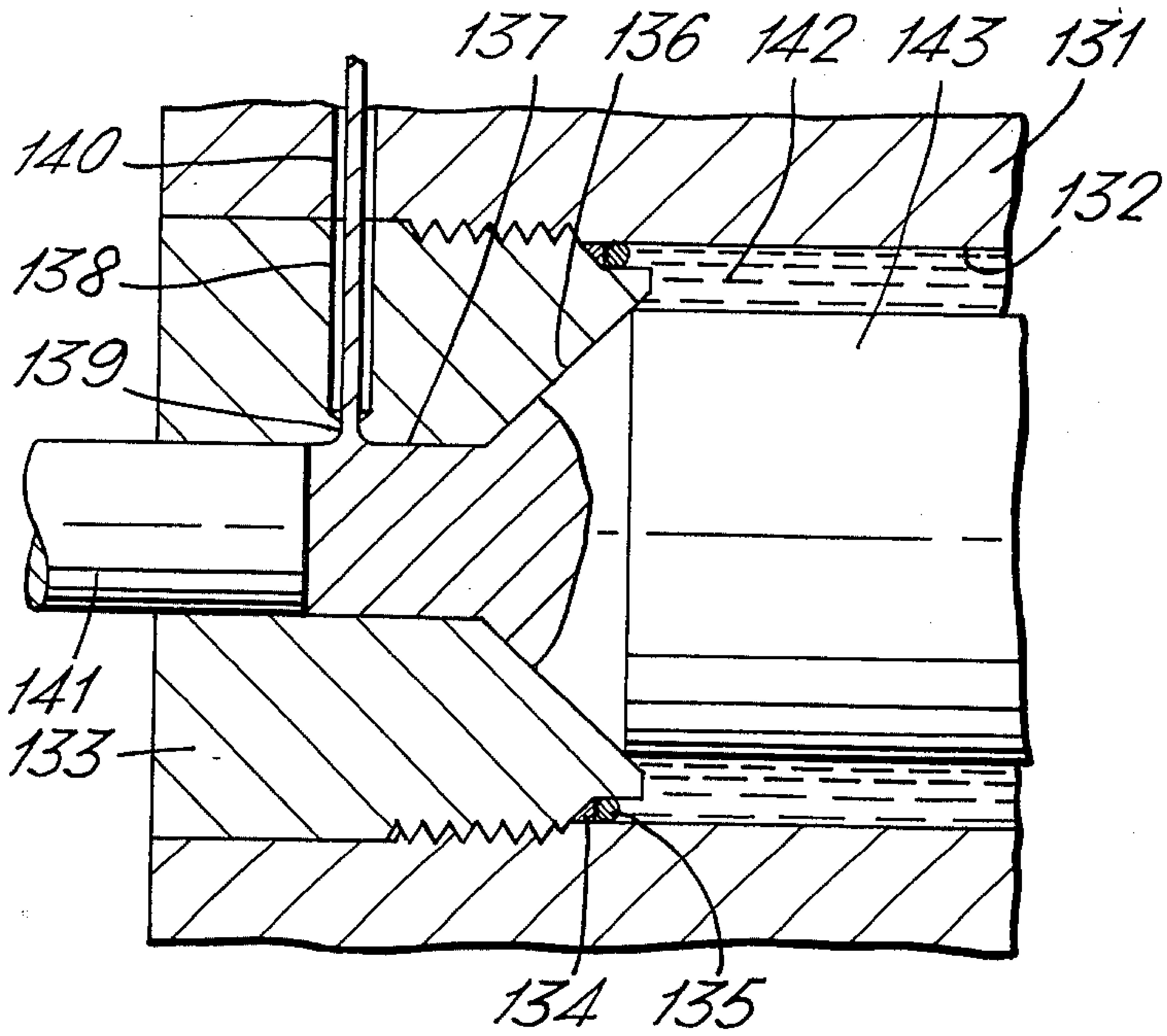
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Fig. 13.

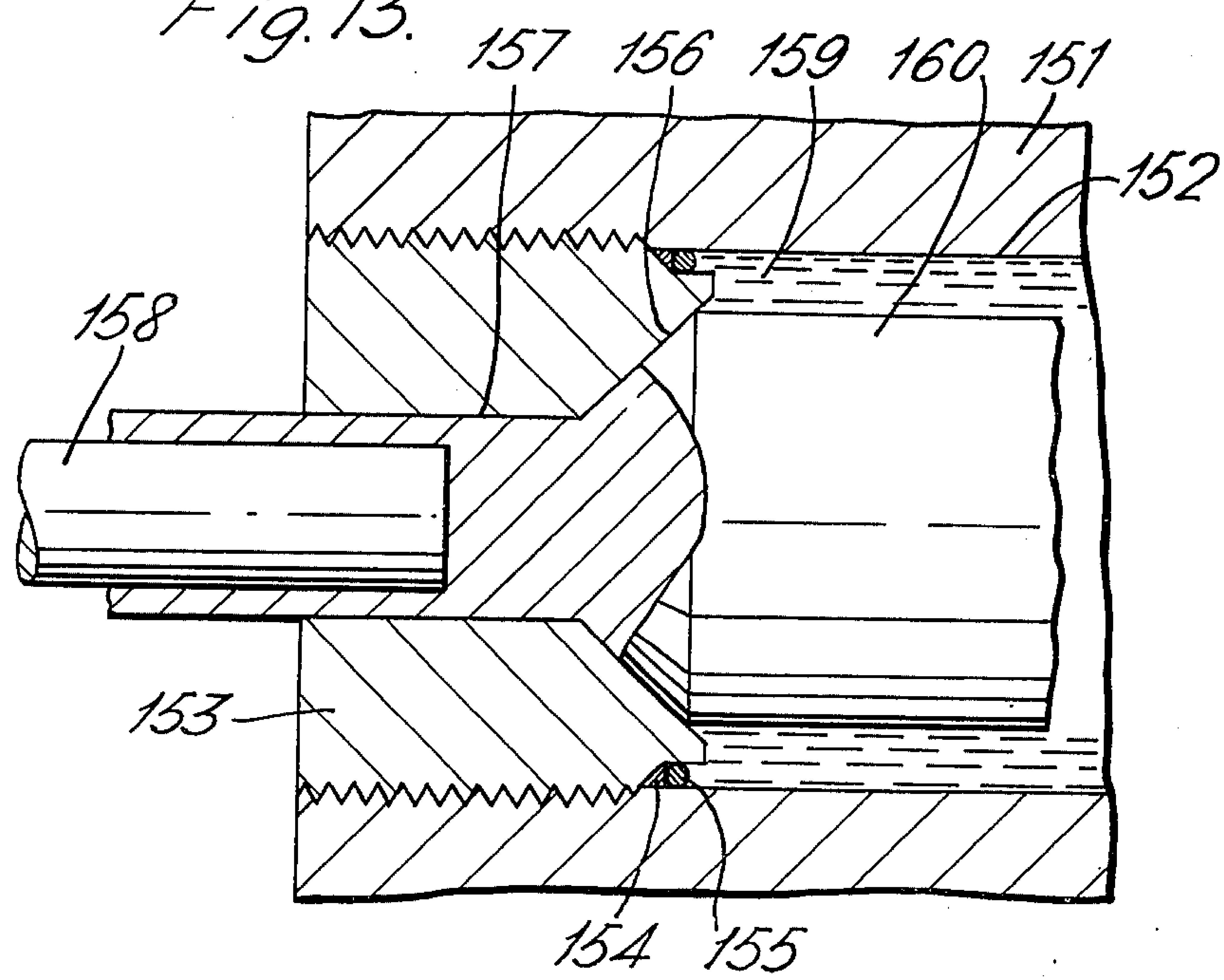
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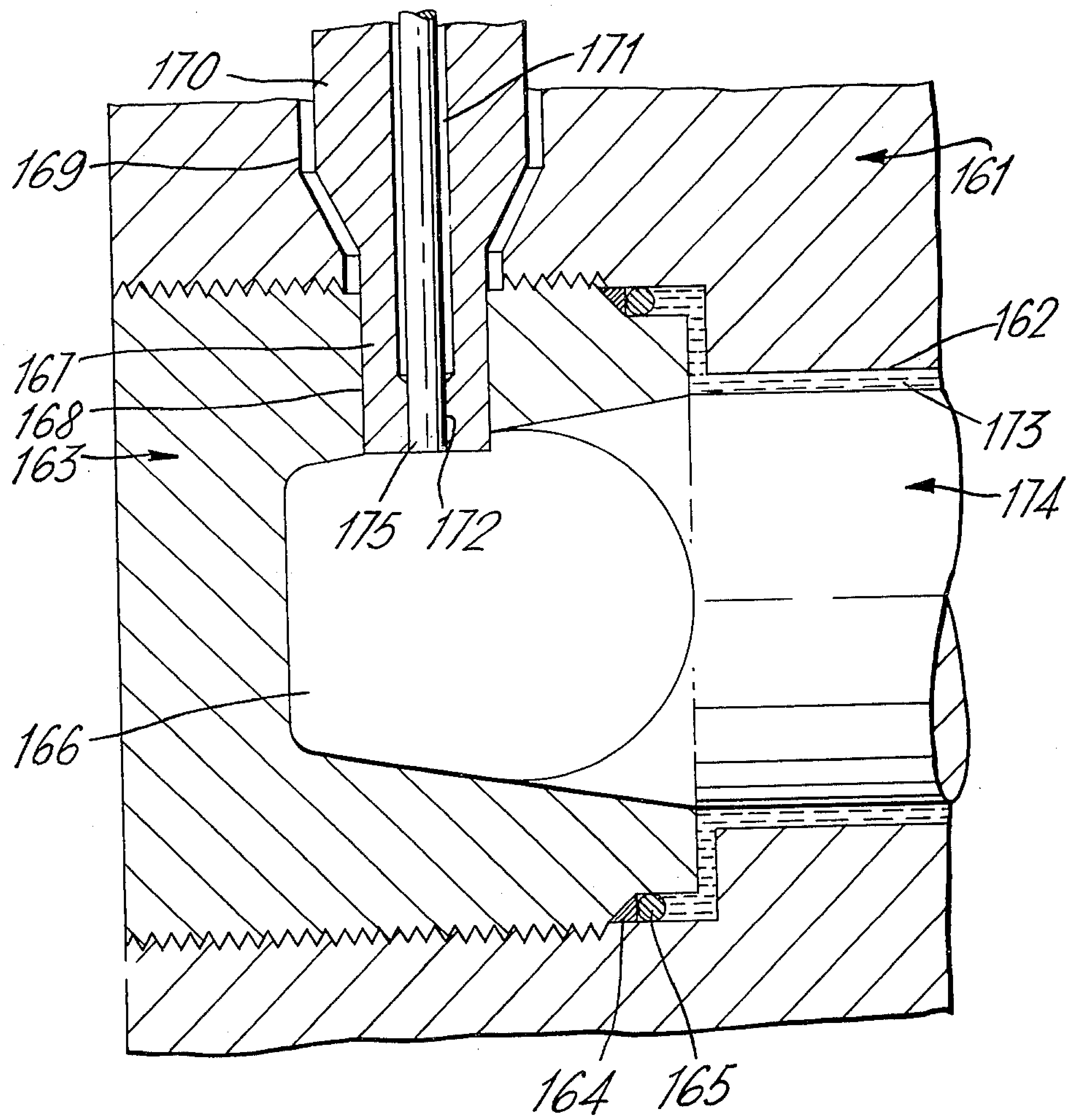
Fig. 14.



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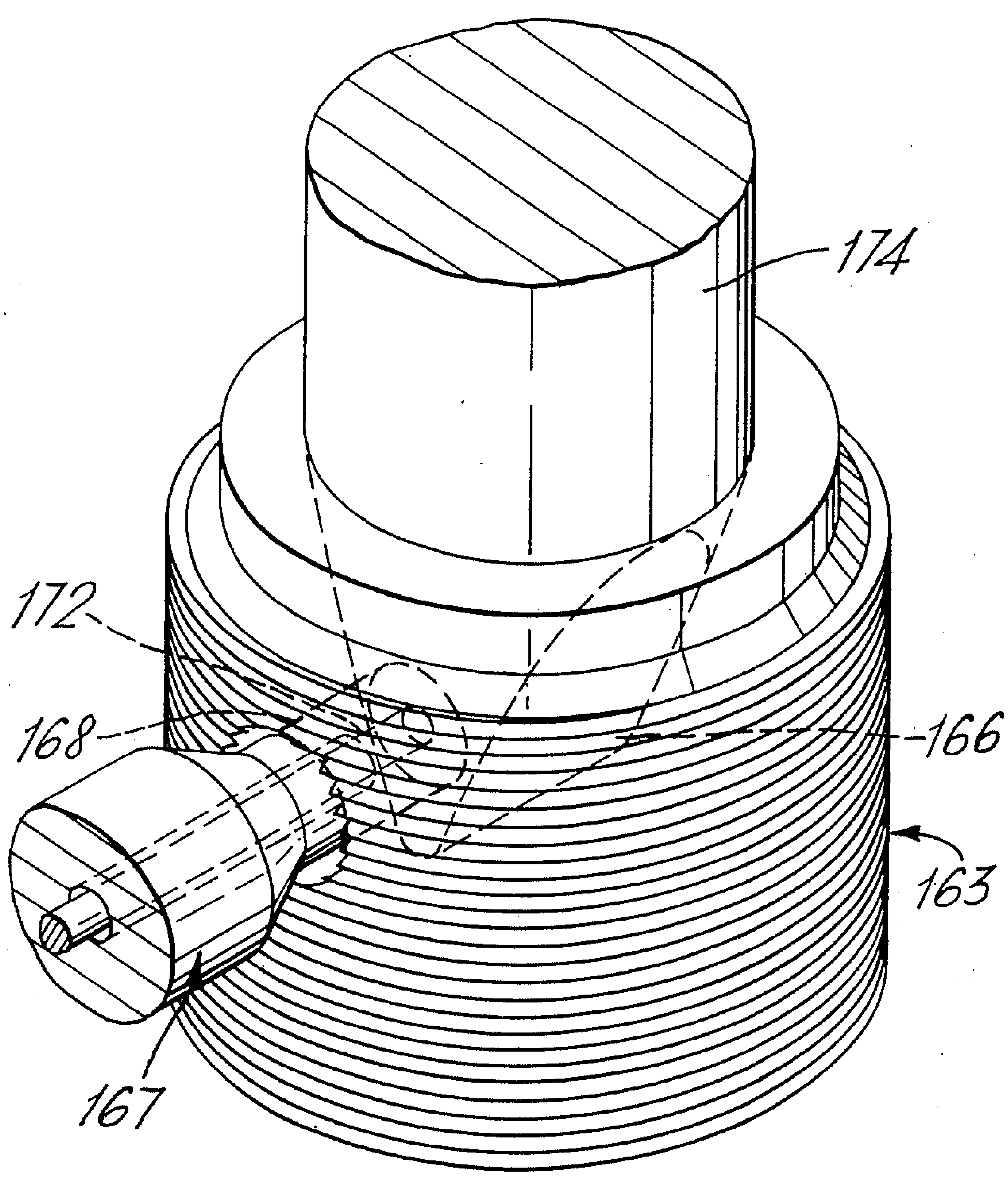


Fig. 16.

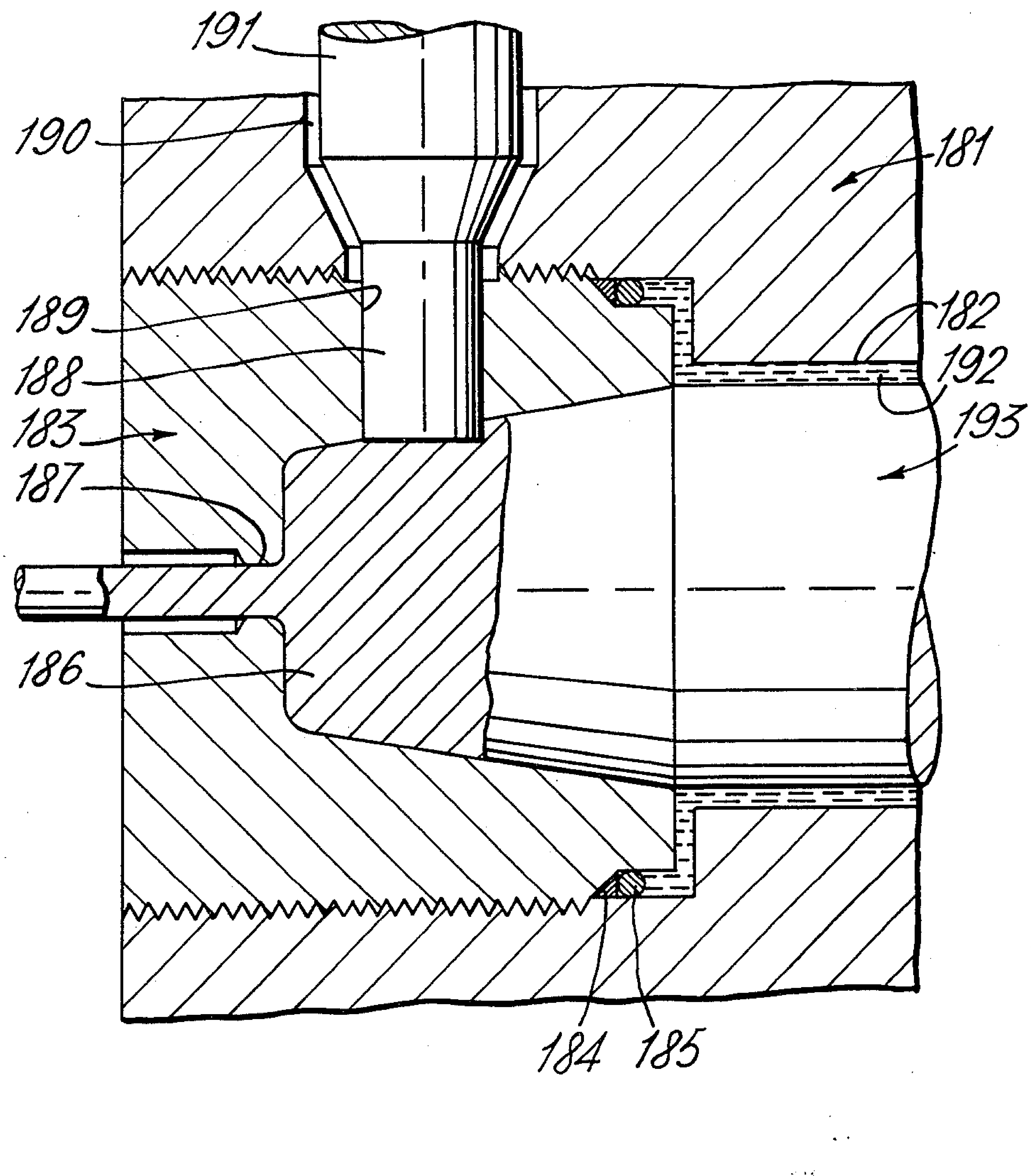
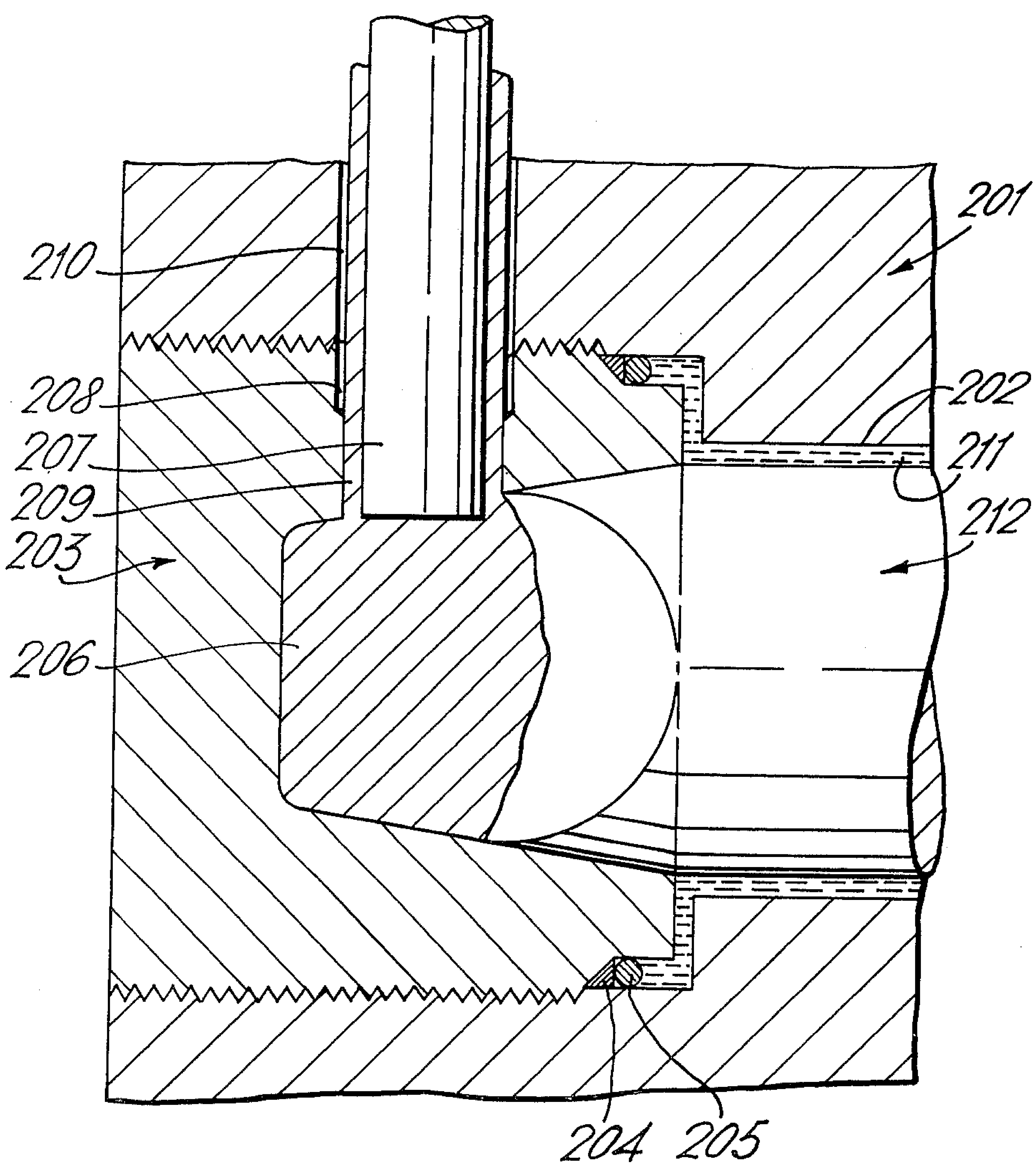


Fig. 17.



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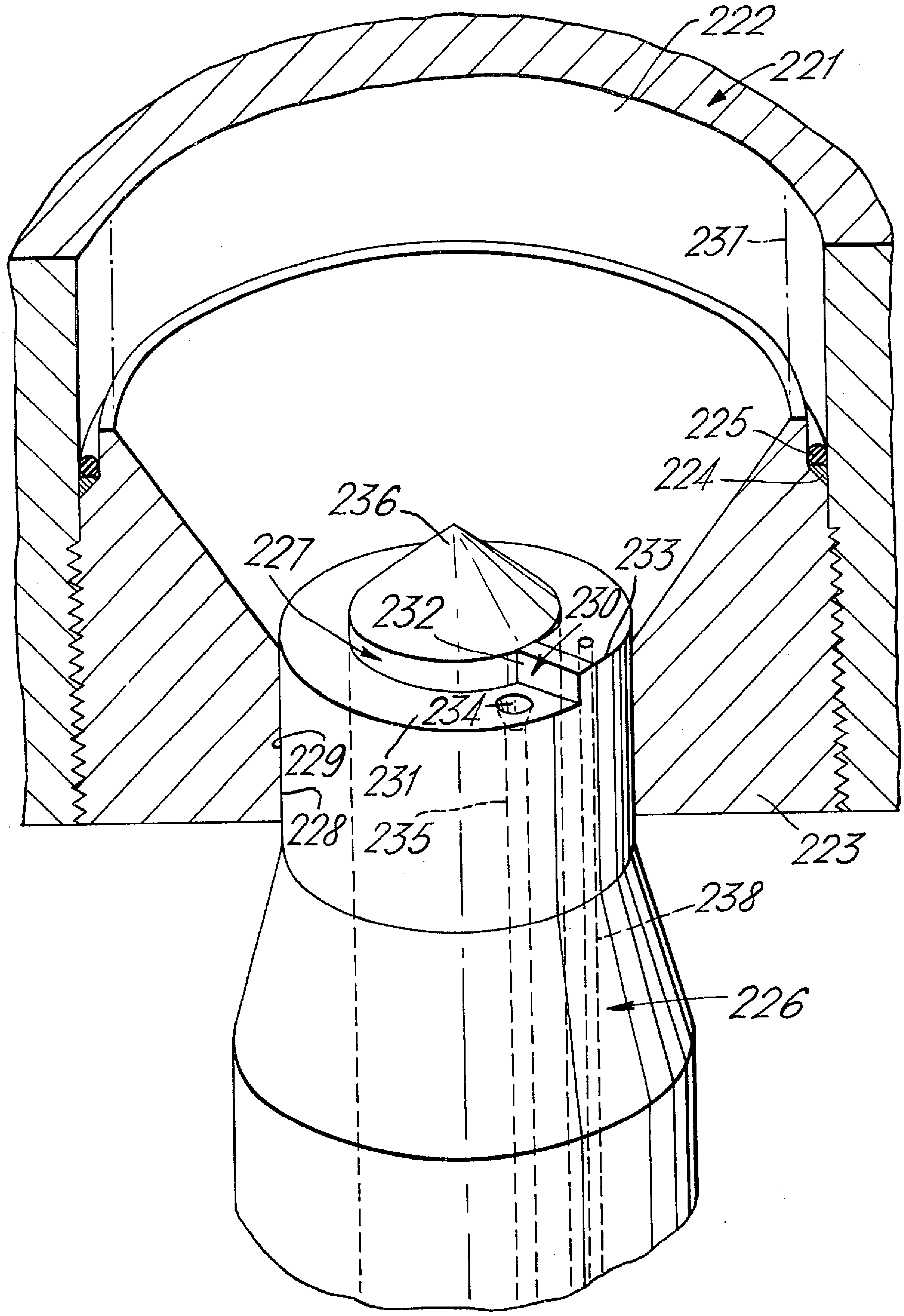
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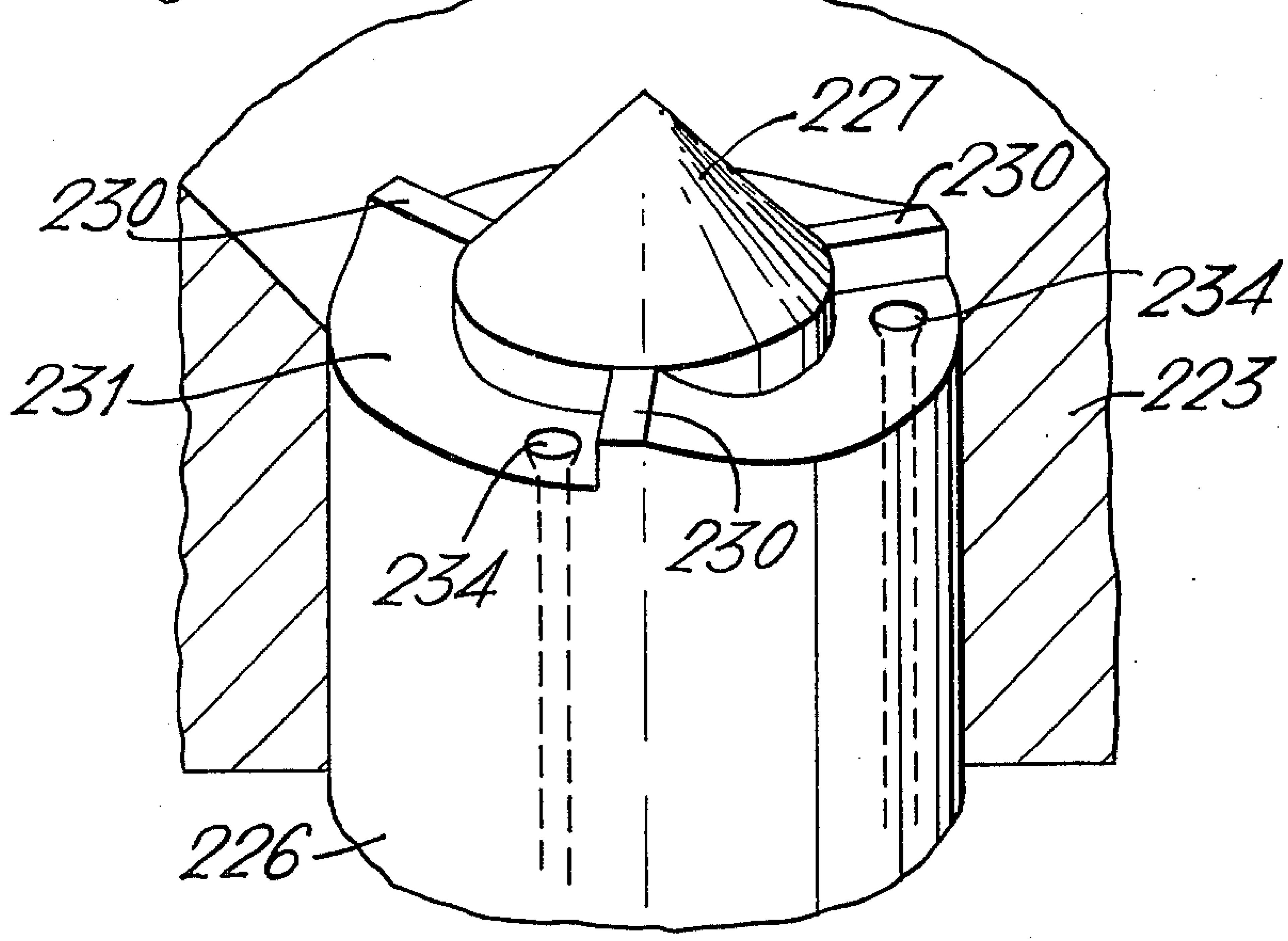
Fig. 19.



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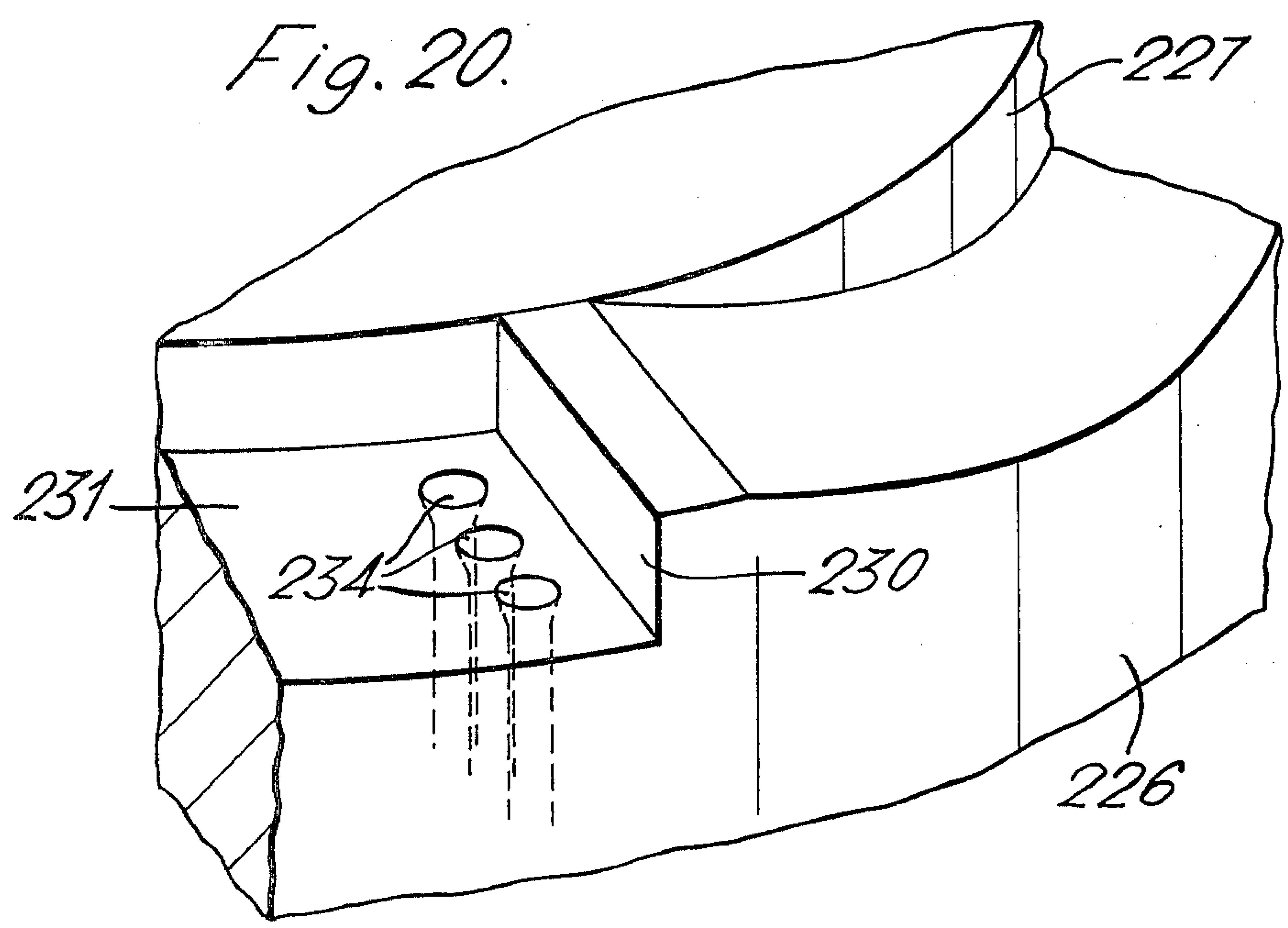


Fig. 21.

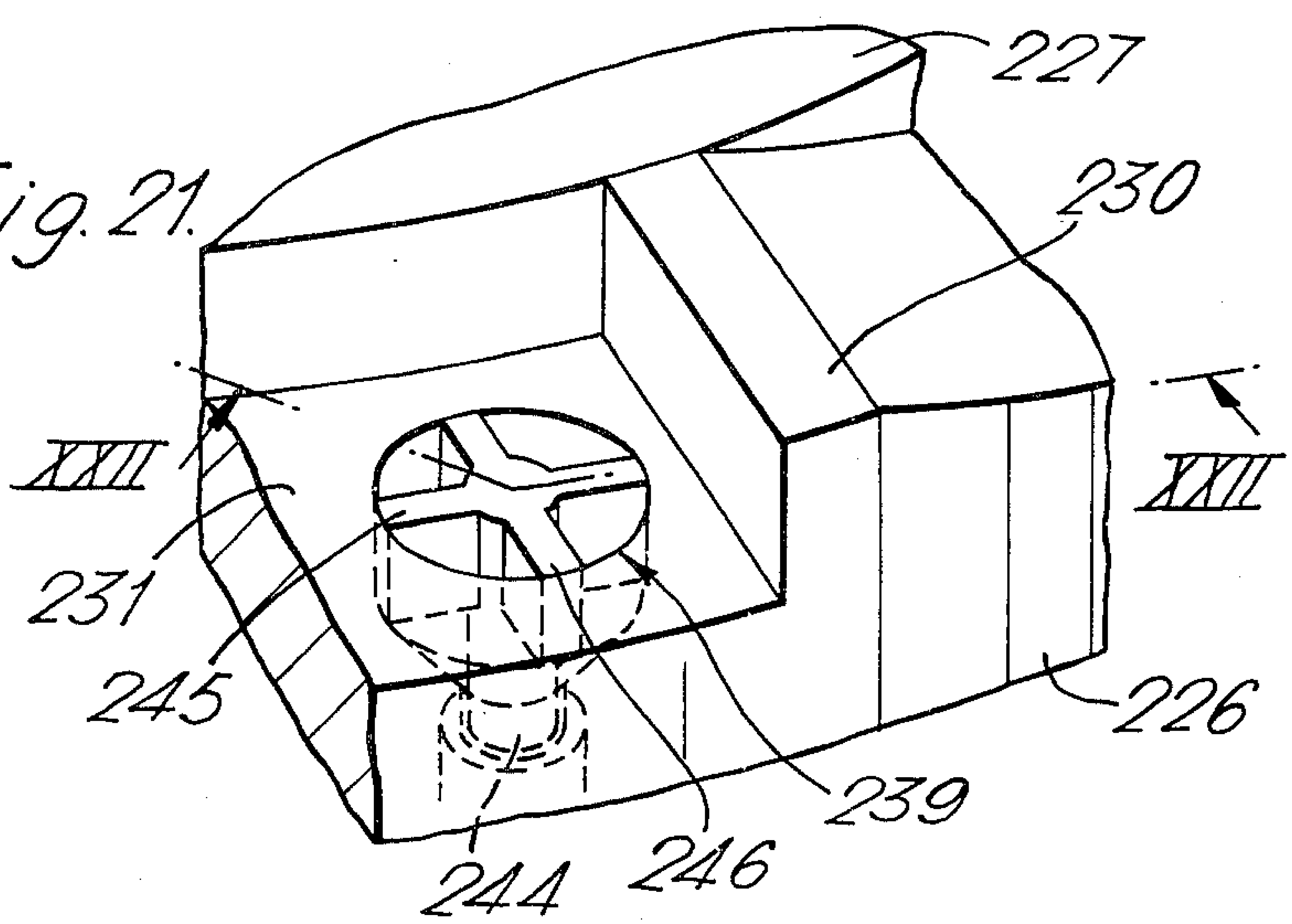
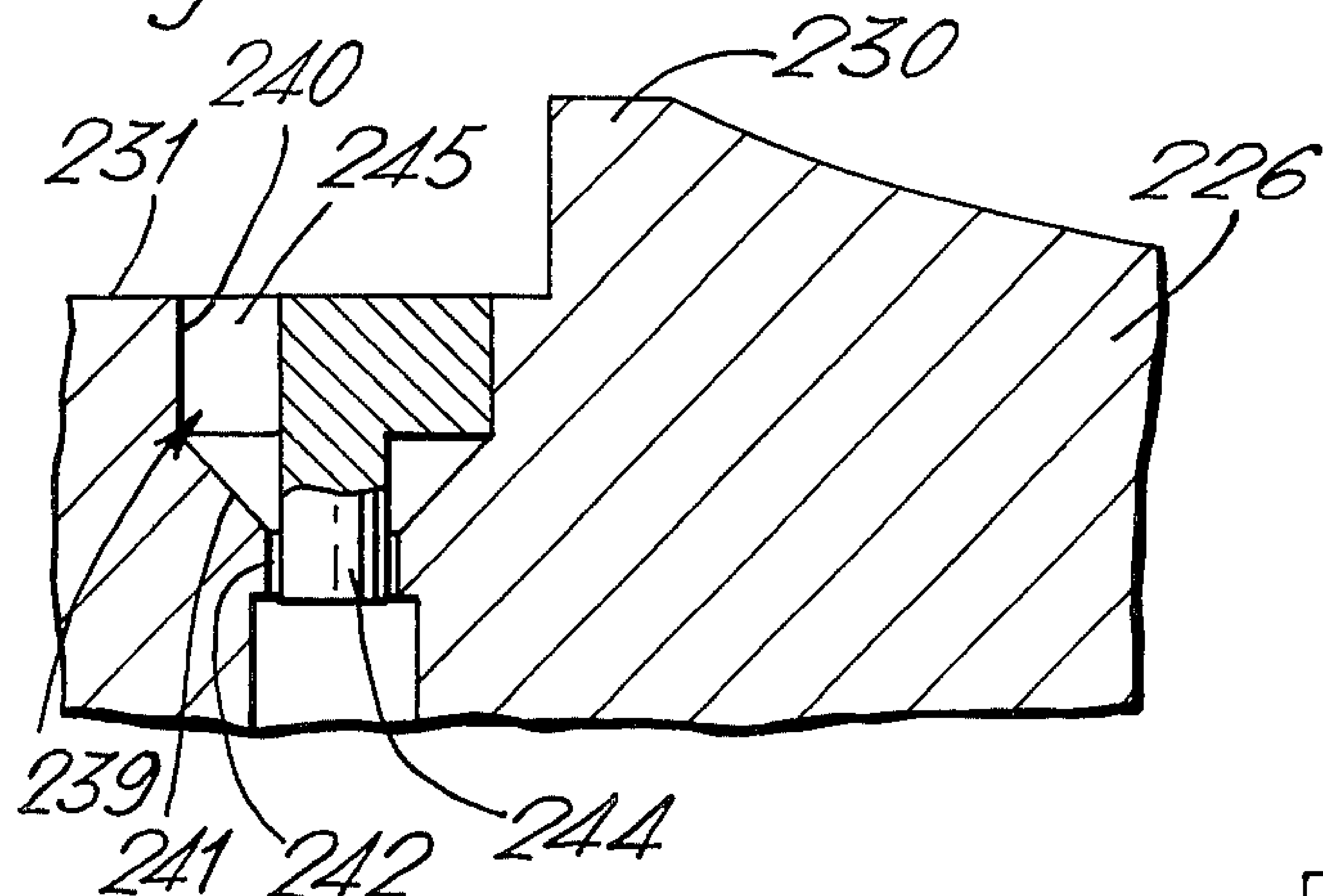


Fig. 22.



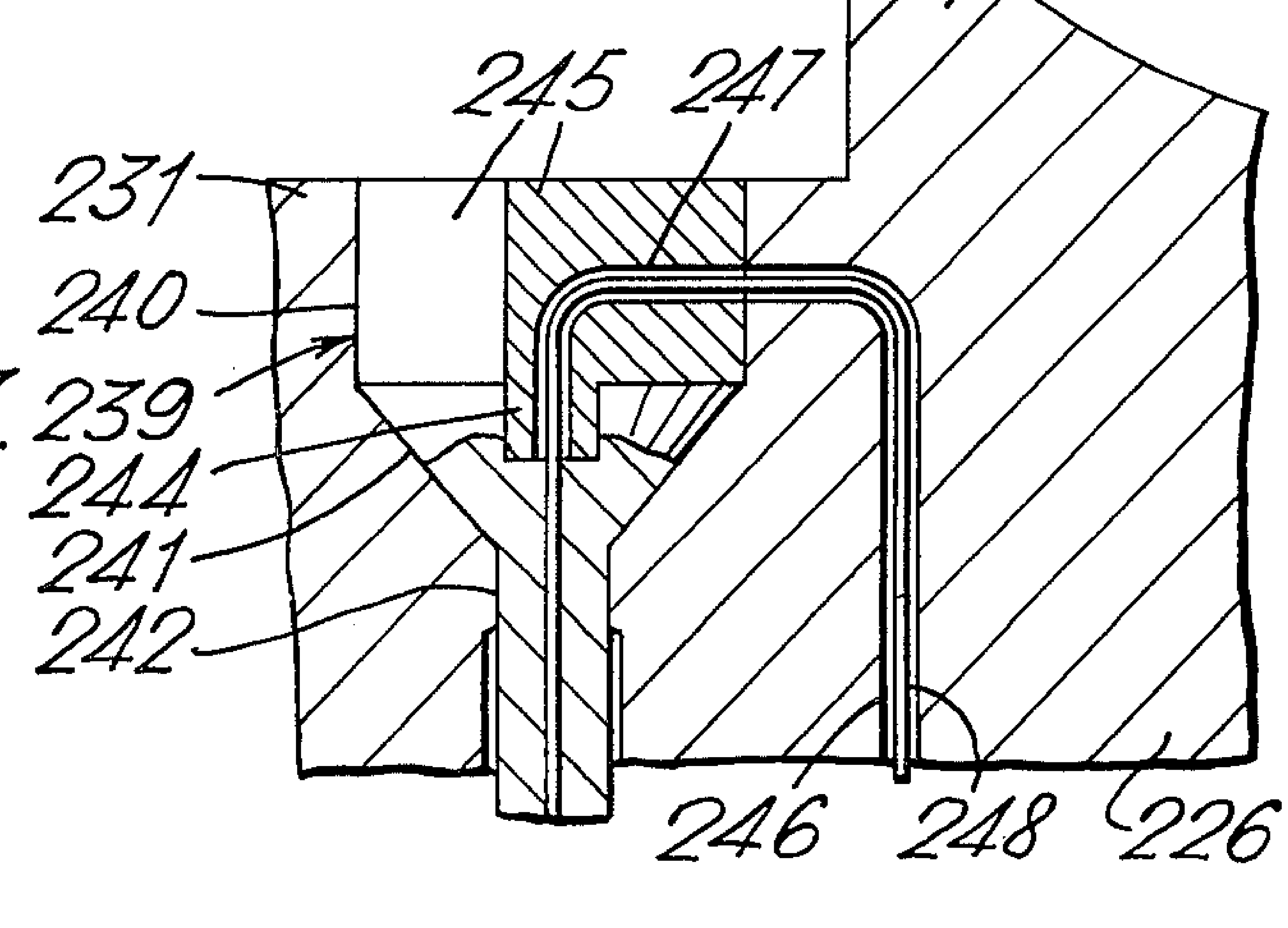


Fig. 23.

FORMING OF MATERIALS

This is a division, of application Ser. No. 880,127 filed Nov. 26, 1969 now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to the forming of materials and in particular relates to the forming of a product of reduced cross section from a workpiece by an extrusion process.

In extrusion a workpiece is subjected to pressure in a container so that the workpiece is extruded from the container through an orifice defining the product cross section. Pressure may be applied on the workpiece mechanically, as in conventional extrusion, by a ram acting on the workpiece in the container. Alternatively, as in hydrostatic extrusion liquid may be pressurised about the workpiece in the container to effect extrusion of the workpiece.

One feature which is a practical limitation in carrying out such an extrusion process is that the pressure required to carry out extrusion is dependant on the extrusion ratio, the extrusion ratio being defined as the cross sectional area of the workpiece relative to the cross sectional area of the extruded product.

Even in the case of soft materials very high extrusion ratios (for example in the region of 500 : 1) can only be achieved by the application of extremely high pressures (for example 150–200 tons per square inch) on the workpiece in the container. The manufacture of containers which can withstand such high pressures is difficult and costly.

It is one of the objects of the present invention to provide a method and apparatus capable of producing extruded products at such high extrusion ratios with the application of only moderate pressure to the workpiece in the extrusion container.

SUMMARY OF THE INVENTION

According to the present invention a method of producing from a workpiece a product of reduced cross section comprises applying a compressive stress to the bulk of the workpiece and applying an additional compressive stress at a localised region of the workpiece so that the workpiece is stressed in the localised region to an extent causing it to flow through an orifice defining the product cross section.

The additional compressive stress may be produced in the localised region of the workpiece by applying a tool to the workpiece having a working face of smaller cross section then the workpiece, the tool being moved in a closed cyclic path with the working face of the tool maintained in pressure contact with the workpiece during at least part of the cyclic path so that the material of the workpiece in the localised region forward of the working face of the tool is subjected to an additional compressive stress and is formed through an orifice defining the product cross section.

According to the invention a method of producing from a workpiece a product of reduced cross section also comprises applying pressure to the workpiece so as to set up a compressive stress in the bulk of the workpiece and so as to produce a reduction in cross section in a region of the workpiece, applying a tool having a material working face to said region of the workpiece and moving the tool so that the material of the workpiece in said region forward of the working face of the tool is subjected to an additional compressive stress and is formed through an orifice defining the product cross section.

In accordance with the invention one form of apparatus for producing a product of smaller cross section from a workpiece comprises a container, pressure means for applying a compressive stress to the bulk of the workpiece within the container, a rotary member with a projecting tool member having a material working face, means for rotating the rotary member so that the tool member is moved in a circular path with the working face of the tool member in pressure contact with the material of the workpiece, whereby the material of the workpiece in the localised region forward of the working face of the tool member is subjected to an additional compressive stress and is formed through an orifice defining the product cross section.

An alternative form of apparatus for carrying out a method according to the invention comprises a container, pressure means for applying a compressive stress to the bulk of the workpiece within the container, a tool in the form of a reciprocable punch and means for reciprocating the punch between limits whereby on the forward stroke of the punch the face of the punch is forced under pressure into the workpiece so that the material of the workpiece in the localised region forward of the face of the punch is subjected to an additional compressive stress and is thereby formed through an orifice leading from the container and whereby on the backward stroke of the punch the compressive stress applied to the bulk of the workpiece feeds the material of the workpiece to replace the material extruded during the previous forward stroke of the punch.

In both the above forms of apparatus the container may have a bore tapered at one end to a reduced cross section, the pressure applied to the workpiece in the container also acting to force the end of the workpiece into the tapered end of the bore of the container and the tool being applied to operate on the material of the workpiece in the tapered end of the bore of the container.

DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described by way of example with reference to the accompanying drawings in which:

FIG. **1** is a longitudinal sectional elevation of one embodiment of the invention, the area bounded by the chain dotted circle II being along the line I — I in FIG. **2.**

FIG. **2** is a partial plan view of the arrangement shown in FIG. **1.**

FIG. **3** is a detail of FIG. **1** isometric form.

FIG. **4** is a longitudinal sectional elevation of a second embodiment of the invention.

FIG. **5** is a detail of FIG. **4** in isometric form.

FIG. **6** is a longitudinal sectional elevation of a third embodiment of the invention.

FIG. **7** is a longitudinal sectional elevation of a fourth embodiment of the invention.

FIG. **8** is a detail of FIG. **7** on a larger scale.

FIG. **9** is a detail showing a modified form of the arrangement shown in FIG. **7.**

FIG. **10** is a longitudinal sectional elevation of a fifth embodiment of the invention.

FIG. 11 is a detail showing a modified form of the arrangement shown in FIG. **10.**

FIG. 12 is a longitudinl sectional elevation of a sixth embodiment of the invention.

FIG. 13 is a longitudinal sectional elevation of a seventh embodiment of the invention.

FIG. 14 is a longitudinal sectional elevation of an eighth embodiment of the invention.

FIG. 15 is a detail, in isometric form of the arrangement shown in FIG. **14.**

FIG. 16 is a longitudinal sectional elevation of a ninth embodiment of the invention.

FIG. 17 is a longitudinal sectional elevation of a tenth embodiment of the invention.

FIG. 18 shows an eleventh embodiment of the invention in isometric form.

FIG. 19 is a detail, in isometric form, showing a modification of the arrangement of FIG. **18.**

FIG. 20, is a detail, in isometric form, showing another modification of the arrangement of FIG. **18.**

FIG. 21 is a detail, in isometric form, showing a further modification of the arrangement of FIG. **18.**

FIG. 22 is a cross section along the line XXII — XXII in FIG. 21.

FIG. 23 is a cross sectional detail showing a fourth modification of the arrangement of FIG. **18.**

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIGS. **1** and **2** of the drawings there is shown a pressure container **1**, having a bore **2**. The bore **2** leads to a narrower outlet opening **3** through a curved section **4** at the end of the bore **2**. Alternatively the section **4** may be of straight conical taper or instead of being a concave curvature as shown in the drawing may be of convex curvature somewhat as the shape of a trumpet bell. A tubular shaft **5** projects into the opening **3** from outside the container **1**. The shaft **5** is supported in the opening **3** by a heavy duty thrust bearing carried by a hydraulic ram (not shown) so that the shaft **5** can be moved into and out of the opening **3**. The shaft **5** is arranged to be driven by an electric motor. A die block **6** is mounted on the upper end of the shaft **5**. The die block **6** has a transverse key **7** which fits in slots **8** in the upper end of the shaft **5**. As shown in FIG. **3** a die support member **9** is formed projecting from the upper face of the die block **6**. The die support member **9** has an inclined flat face **10**. A housing **11** in the die support member is fitted with a die insert **12**. The housing **11** has a conical lead in **13** from the face **10** of the die support member **9** to the mouth of the die insert **12**. The die insert **12** is connected with the bore of the shaft **5** by a passageway **14**.

In use of the arrangement shown in the drawings a billet **15** (shown in chain dotted outline in FIG. **1**) is held in the container **1**. Hydraulic liquid in the interspace **16** surrounding the billet **15** is pressurised to apply an overall compressive stress on the billet **15** so that the end of the billet is forced into the curved section **4** at the end of the bore **2** of the container **1**. The shaft **5** is rotated to drive the die block **6**. The material of the billet **15** forward of the face **10** of the die support member **9** is subjected to an additional localised compressive stress system arising from the mechanical loading applied by the face **10** of the die support member **9** on the billet material, as the die block **6** is rotated. The material of the billet traversed by the die support member during each rotation of the die block **6** is extruded through the die insert **12**. Extrusion of the billet material is under the additive effect of the overall compressive stress applied in the billet by pressurisation of the hydraulic liquid about the billet and the localised additional compressive stress which is set up forward of the face **10** of the die support member **9**. The extruded wire product passes from the die insert **12** through the passageway **14** and out through the bore of the tubular shaft **5**. Extrusion is continuous whilst the shaft **5** is rotated, the billet **15** being fed continuously downwards by the pressure of the hydraulic liquid into the region of the die block **6**.

To prevent rotation of the billet **15** in the container **1**, the curved section **4** of the container bore **2** may be formed with grooves **17** as shown in FIG. **1**, the material of the billet **15** being forced into engagement with the grooves **17**.

As disclosed in copending British application No. 30277/64 cognate with 28823/65 a direct mechanical loading may also be applied on the billet **15** by a ram entered into the rear end of the bore **2** of the container **1**. The mechanical loading applied by the ram supplements the axial forces feeding the material of the billet into the region of the die block **6** and also contributes to the stress system giving rise to extrusion of the material of the billet through the die insert **12**.

Particularly in the case of soft materials the overall compressive stress may be set up in the billet by direct mechanical loading of the billet for example by a ram as in conventional mechanical extrusion.

By way of example an arrangement for extruding a 2½ inch diameter lead billet has the following parameters:

Internal diameter of die insert 12 — 0.1 inches
Ratio of area of face **10** of the die support member to the area of the die insert orifice — 4 : 1
Pressure in hydraulic liquid — 4 tons/square in
Ratio of area of container bore **2** area to die block **6** — 7 : 1

The reduction of a 2½ inch diameter lead billet to a wire of 0.1 inch diameter entails a reduction ratio of 625:1. At the pressure used, i.e., 4 tons per square inch a reduction ratio of only 6 : 1 could be achieved using simple hydrostatic extrusion. Thus at the same pressures of operation the process of the present invention enables a hundred fold increase in the extrusion ratio which can be achieved. From another point of view in order to achieve a reduction ratio of 625 : 1 in a lead billet by simple hydrostatic extrusion a pressure of 60 tons per square inch would be required. This represents a reduction in pressure in the region of a factor of 10.

As a further example an arrangement capable of handling a 4 inch diameter copper billet would have the following parameters:

Diameter of die insert 12 — 0.125 inches
Ratio of area of face **10** of die support member to area of die insert orifice — 9:1
Pressure in hydraulic liquid 50 tons per square in.
Power of drive motor for shaft **5** — 25 - 30 H.P.
Ratio of bore **2** diameter to die block **6** diameter 4:1
Rate of revolution of shaft **5** — 200 R.P.M.

In an arrangement having the above parameters a 4 inch diameter billet is reduced to a wire of 0.125 inches diameter. If this were carried out by a simple hydrostatic extrusion process the extrusion ratio entailed would be approximately 1000:1 and in the case of a copper billet a prohibitively high liquid pressure of 165 tons per square inch would be required for simple hydrostatic extrusion.

Although the invention has its main application to the extrusion of harder metals such as copper it may also be used for the extrusion of softer metals such as aluminium. Although a soft metal such as aluminium can be directly reduced to wire by simple hydrostatic extrusion at practical extrusion pressures use of the invention enables a considerable reduction in pressure with saving in cost of pressure vessels and pressure generating equipment which are expensive items.

In FIGS. 4 and 5 of the drawings there is shown a chamber **21** having a bore **22**. A reducing die **23** is screw fitted in the end of the bore **22**.

The die **23** is sealed in the bore **22** by a copper mitre ring **24** and a rubber O-ring **25**. A sleeve shaped rotary die block **26** is fitted on a stationary stem **27**. The end **28** of the sleeve shaped die block **26** is reduced to fit in the parallel outlet **29** of the reducing die **23**. A die member **30** is formed projecting from the annular end face **31** of the die block **26**. A die orifice **32** in the die member **30** connects with a passageway **33** leading through the sleeve shaped die block **26**. The stationary stem **27** has a pointed end **34** with flats **35**. The stationary stem **27** is fixedly supported on a main base frame and the sleeve shaped die block **26** is rotatably supported on the stationary stem **27** by a heavy duty bearing (not shown).

In use of the arrangement described above a billet **36** is subjected to the pressure of hydraulic liquid **37** surrounding the billet **36** in the bore **22** of chamber **21**. The pressure of the liquid **37** subjects the billet to an overall compressive stress system and also loads the billet **37** longitudinally into the reducing die **23**. The nose of the billet **36** is forced into the reducing die **23** over the pointed end **34** of the stationary stem **27**. The sleeve shaped die block **26** is driven on the stationary stem **27** thus driving the die member **30** through the billet material at the mouth of the reducing die **23**. The material of the billet forward of the face of the die member **30** is subjected to an additional localised compressive stress system arising from the mechanical loading applied on the billet material in the reducing die **23** by the face of the die member **30**. The material of the billet traversed by the die member **30** is extruded through the die orifice **32**. Extrusion of the billet material is under the additive effect of the overall compressive stress applied in the billet by the pressure of the hydraulic liquid and the localised additional compressive stress which is set up in the billet material at the mouth of the reducing die **23** forward of the face of the die member **30**.

The wire product extruded through the orifice **32** passes through the passageway **33** in the die block **26** and is coiled on a spool concentric with the stationary stem **27**. Under the pressure of the hydraulic liquid **37** the billet **36** is continually fed into the reducing die **23** to replace the billet material which is extruded through the orifice **32** in the die member **30**. The pointed end **34** of the stationary steam **27** acts as a guide for feeding of billet material into the region of the annular end face **31** of the sleeve shaped die block **36**. The engagement of the flats **35** on the pointed end **34** of the staionary stem **27** with the end of the billet **36** assists in preventing the billet **36** rotating with rotation of the sleeve shaped die block **26**.

The sleeve shaped die block **26** has to be driven under a load sufficient to provide the additional compressive stress in the billet material required to achieve extrusion. In addition part of the driving load applied to the sleeve shaped die block **26** is used in overcoming the friction between the annular end face **31** of the die block **26** and the billet material. As the die block **26** is in frictional contact with the billet material only over the relatively small area of its annular end face **31** only a minor proportion of the driving load applied to the die block **26** is used in overcoming friction.

This is to be compared with the arrangement of FIG. **1** in which the full end face of the die block **6** is in contact with the billet. In the arrangement of FIG. **1** there is a greater loss of power as more redundant work has to be done in overcoming the friction between the full end face of the die block **6** and the billet.

During each rotation of the die block **6** the die member **30** removes a semi toroidal section of the billet material. Depending on the mean diameter (D) of the pitch circle of the rotating die member **30**, the pressure (P) in the billet material ahead of the rotating die member **30** and the shear strength (6s) of the billet a maximum area (a) can be defined for the end face of the die member **30** above which the semi toroidal section will shear from the billet instead of extruding. In the case of a die member **30** having an area (a) less than this maximum the semi toroid is "clamped" i.e., it is of a circumferential length giving a surface area which will not shear.

FIG. **6** shows an alternative arrangement to that shown in FIGS. **4** and **5**. In FIG. **6** there is shown a chamber **41** having a bore **42**. A reducing die **43** is screw fitted in the end of the bore **42**. The die **43** is sealed in the bore **42** by a copper mitre ring **44** and a rubber O-ring **45**. A tubular rotary die block **46** has an end part **47** reduced to fit in the parallel outlet **48** of the reducing die **43**. A die member **49** is formed projecting from the annular end face **50** of the die block **46**. A die orifice **51** in the die member **49** connects with a passageway **52** leading through the die block **46**. The other end of the bore **42** of the chamber **41** is closed by a screwed plug **53** which is sealed in the bore **42** by a copper mitre ring **54** and a rubber O-ring **55**. A mandrel **56** integral with the screwed plug **53** extends coaxially through the bore **42** of the chamber **41**. The lower end of the mandrel **56** extends into the bore **57** of the die block **46**. A passageay **58** leads radially through the wall of the chamber **41** into the bore **42**. The rotary die block **46** is supported by a heavy duty bearing (not shown).

In use of the arrangement shown in FIG. **6** a tubular billet **59** is fitted on the mandrel **56** in the bore **42** of the chamber **41**. Hydraulic liquid **60** surrounding the billet **59** in the chamber **41** is pressurised through the radial passageway **58** in the wall of the chamber **41**. The pressure of the liquid **60** subjects the billet **59** to an overall compressive stress system and also loads the billet **59** longitudinally into the reducing die **43**. The rotary die block **46** is driven to drive the die member **49** through the billet material at the mouth of the reducing die **43**.

The billet material forward of the face of the die member **49** is subjected to an additional localised compressive stress system arising from the mechanical loading applied by the face of the die member **49** on the billet material as the die block **46** is rotated. The material of the billet at the mouth of the reducing die **43** is extruded through the die orifice **51** in the die member **49** under the additive effect of the overall stress applied in the billet material by the pressure of the hydraulic liquid **60** and the localised compressive stress set up in the billet material at the mouth of the reducing die **43** by the loading of the die member **49.** The wire product extruded through the die orifice **51** passes through the passageway **52** in the die block **46** and is coiled on an external take up spool. In the arrangement of FIG. **6,** as in the arrangement of FIGS. **4** and **5** power losses due to friction between the annular end face **50** of the die block **46** and the billet are reduced as compared with the arrangement of FIGS. **1** to **3** in which the die block **6** has a full circular end face in contact with the billet.

The arrangement shown in FIG. **7** of the drawings comprises a pressure container **61** having a longitudinal bore **62.** The container **61** is mounted vertically on a base plate **63** by a flange **64** which is screwed onto a boss **65** at the base of the container **61.** The flange **64** is secured to the base plate **63** by threaded studs **66.** A reducing die **67** is fitted in the upper end of the container bore **62.** A circumferential groove **68** around the outside of the reducing die **67** contains an O-ring **69** which seals the die **67** in the container bore **62.** The die **67** seats on a base ring **70** which is screwed into the threaded upper end **71** of the container bore **62** up to the limit of an external flange **72** on the base ring **70.** A carrier plate **73** rotatably mounted on the upper end of the container **71** by a thrust bearing **74** is fitted with a holder **75** for a rotary die block **76.** As shown in FIG. **8** the reducing die **67** has a parallel outlet **77** and the rotary die block **76** has an end section **78** of reduced diameter fitting in the parallel outlet **77** of the reducing die **67.**

The carrier plate **73** is circular and has an outer rim **79** housing the outer race **80** of the thrust bearing **74.** The inner race **81** of the thrust bearing **74** is fitted in a circumferential step **82** around the upper end of the container **61.** The holder **75** for the rotary die block **76** is cylindrical with a central drilling **83** and is externally threaded to screw into a central aperture **84** in the carrier plate **73.** The rotary die block **76** is fitted in a counterbore **85** at the lower end of the central drilling **83** in the holder **75.** The rotary die block **76** has longitudinal splines **86** engaging in keyways **87** in the counterbore **85** of the holder **75.** The rotary die block **76** has a blind ended bore **88** corresponding to the central drilling **83** in the holder **75.** As also shown in FIG. **8** an oblique drilling **89** in the lower end face **90** of the rotary die block **76** houses an extrusion die **91** which partially projects from the lower end face **90** of the rotary die block **76.** A smaller diameter extension **92** of the drilling **89** connects with the bore **88** of the rotary die block **76.**

Connection of the bore **62** of the container **61** with a pipe **93** for carrying liquid under high pressure is provided by passageway **94** in the container **61** leading from the boss **65** to the bore **62.** The pipe **93** is connected with the passageway **94** at the boss **65** by a union nut **96.**

Disc shaped weights **97** are stacked on the carrier plate **73** to load the rotary die block **76.** The lowermost weight seats in a step **98** around the upper face of the carrier plate **73.**

FIG. **7** of the drawings also shows an arrangement for supporting a billet **99** in the bore **62** of the container **61.** This billet support arrangement comprises a blind ended nylon sleeve **100** supported by a coil spring **101** which is mounted on a flanged boss **102** at the bottom end of the bore **62** in the container **61.**

FIG. **9** of the drawings shows a modification of the arrangement of FIG. **7.** In the arrangement of FIG. **9** the rotary die block **76** has a through drilling **103** fitting about a stationary stem **104** which is mounted from a main frame member of the equipment (not shown). The drilling **103** of the rotary die block **76** has a counterbore **105** at its upper end corresponding to the central drilling **83** in the holder **75.** A passageway **106** leads from the extrusion die **91** to the counterbore **105** in the rotary die block **76.** The lower end **107** of the stationary stem **104** is pointed and projects below the lower end face **90** of the rotary die block **76.**

In use of the arrangement shown in FIG. **7** of the drawings liquid **108** surrounding the billet **99** in the bore **62** of the chamber **61** is pressurised to subject the billet **99** to compression. Under the action of the pressurised liquid **48** the billet **69** is subjected to an upward thrust so that the nose of the billet **99** is forced into the reducing die **67.** The weights **97** load the carrier plate **73** to hold the rotary die block **76** against the upward thrust of the billet **99.** Sufficient of the weights **97** are used so as to slightly overload the carrier plate **73,** the majority of the weight acting to resist the upward thrust of the billet **99** on the end face of the rotary die block **76.** The assembly of the carrier plate **73,** the rotary die block **76** and the weights **97** is rotated bodily. The carrier plate **73** may be driven as shown in FIG. **7** by a V-belt **109** driving a V grooved ring **110** fitted around the rim **79** of the carrier plate **73.** Rotation of the die block **76** drives the die member **91** in a circular path through the material at the reduced end face of the billet **99.** The billet material in the path of the die member **91** is extruded through the die member **91** and the extruded product emerges from the die member **91** through the extension **92** of drilling **89** and is removed through the bore **88** of the rotary die member **16** and the central drilling **83** in the holder **75.**

As the die block **76** is rotated the billet **99** is fed continually upwards into the reducing die **67** to replace the material extruded on each rotation of the die block **76.**

The arrangement of FIG. **9** operates in a similar manner except that the rotary die block **76** rotates on the stationary stem **104,** the lower pointed end **107** of which penetrates the end face of the billet **99.** The extruded product passes from the die member **91** through the longitudinal passageway **106** in the rotary die member **76** and is removed through the counterbore **105** of the rotary die member **76** and the central drilling **83** in the holder **75.** In the arrangement of FIG. **8** the sliding friction between the annular end face of the rotary die member **76** and the end face of the billet **99** is less than in the arrangement of FIG. **7** wherein the whole circular end face of the rotary die member **76** is in sliding frictional contact with the end face of the billet **99.** Therefore in the arrangement of FIG. **8** the work required to overcome friction between the end face of the rotary die member **76** and the end face of the billet, which requires the use of additional power in driving the rotary die member **76,** is less than in the arrangement of FIG. **7.** Also in the arrangement of FIG. **8** the lower pointed end **107** of the stationary stem **104** feeds the billet material into the path of the die member 91 and static friction between the lower pointed end 107 of the stationary stem 104 and the end face of the billet 99 assists in preventing rotation of the billet 99 in the chamber 61.

In FIG. 10 of the drawings there is shown a chamber 111 having a bore 112. A reducing die 113 is formed at one end of the bore 112 of chamber 111. A plunger 114 is entered into the other end of the bore 112 of chamber 111. The plunger 114 is sealed in the bore 112 by a copper mitre ring 115 and a rubber O-ring 116. A reciprocable plunger 117 is mounted at the mouth of the reducing die 113 in axial alignment with the bore 112 of the chamber 111. The plunger 117 has a bore 118 which is restricted at its end to form a die orifice 119.

In operation of the apparatus shown in FIG. 10 liquid 120 enveloping a billet 121 in the chamber 111 is pressurised by loading the plunger 114. The liquid 120 is held at a constant pressure sufficient to cause extrusion of the end of the billet 111 into the reducing die 113 up to the end face of the plunger 117. However the pressure in the liquid 120 is insufficient to cause extrusion of the billet 111 through the die orifice 119 in the plunger 117. The plunger 117 is loaded against the reduced end face of the billet 121 at the mouth of the reducing die 113 so that the material of the billet 121 is extruded through the die orifice 119 in the plunger 117 as the plunger 117 moves forward into the billet 127 in the direction of the arrow 123.

The material of the billet at the mouth of the reducing die 113 extrudes through the orifice 119 under the additive effect of the overall compressive stress applied in the billet by the pressure of the liquid 120 and the localised additional compressive stress applied at the reduced end of the billet by the mechanical loading of the plunger 117. The plunger 117 is advanced to a forward limit and is then retracted tending to leave a void in the end of the billet of the same diameter as the plunger 117. However as the plunger 117 is retracted the pressure of the liquid 120 acting on the billet 121 feeds the billet 121 forward into the reducing die 113 to close up the void left by withdrawal of the plunger 117. This cycle is repeated until the majority of the bllet 121 has been extruded.

Typically the operating parameters of such a form of apparatus for extrusion of a copper billet are as follows:

Diameter of billet 121 4 inches.

Diameter of plunger 117 at the mouth of the reducing die 113 1 inch.

Diameter of die orifice 119 ¼ inch.

Pressure applied in liquid 120, 75 Ton/in^2.

Loading of plunger 117 on forward extrusion stroke 70 Tons/in^2.

The movement of the plunger 117 will be small, e.g., ¼ inches in the example above and the speed of reciprocation will be rapid, e.g., 2 cycles per second.

The limiting condition is reached when the face stress on the plunger 117 during its forward stroke is approximately equal to the pressure in the liquid 110. Higher face stresses will cause leakage of liquid through the reducing die 113. However at this limiting condition the overall extrusion ratio will be approaching the square of the ratio normally possible with simple hydrostatic extrusion at the liquid pressure employed in the present method.

FIG. 11 shows a modified form of apparatus in which the mouth of the reducing die 113 leads into a chamber 124. The plunger 117 operates in the chamber 124 and during retraction of the plunger 117 the billet 121 is extruded through the reducing die 113 into the chamber 124 by the pressure of the liquid 120 in the main chamber 111. On the forward stroke of the plunger 117 the material present in the chamber 124 is extruded through the die orifice 119 in the pluger 117.

FIGS. 12 and 13 show further variants of the arrangement shown in FIG. 10.

In FIG. 12 here is shown a chamber 131 having a bore 132. A reducing die 133 is screw fitted in one end of the bore 132 of the chamber 131. The reducing die 133 is sealed in the bore 132 by a copper mitre ring 134 and a rubber O-ring 135. The reducing die 133 has a conical throat 136 leading into a cylindrical section 137. A radial passageway 138 leading from the cylindrical section 137 of the reducing die 133 has an extrusion die orifice 139 formed at its inner end. The radial passageway 138 in the reducing die 133 connects with a corresponding radial passageway 140 in the chamber 131. A reciprocable plunger 141 is entered into the cylindrical section 137 of the reducing die 132.

In operation of the apparatus shown in FIG. 12 liquid 142 enveloping a billet 143 in the chamber 131 is pressurised for example by means of a plunger operating in the bore of the chamber 131 behind the billet 143. The liquid 142 is raised to a pressure sufficient to cause extrusion of the billet through the throat 136 into the cylindrical section 137 of the reducing die 133. However the pressure of the liquid 142 is arranged to be insufficient to cause extrusion of the billet 143 through the die orifice 139. The plunger 141 is reciprocated in the cylindrical section 137 of the reducing die 133. On the forward stroke of the plunger 141 the billet material in the cylindrical section 137 of the reducing die 133 is subjected to an additional compressive stress by the loading of the plunger 141. The billet material in the cylindrical section 137 of the reducing die 133 extrudes through the die orifice 139 under the combined stress system arising from the overall compressive stream applied in the billet material by pressurisation of the liquid 142 about the billet 143 and the additional localised stress applied on the billet material in the cylindrical section 137 of the reducing die 133 by the loading of the plunger 141.

The plunger 141 is advanced to a forward limit and is then retracted. As the plunger 141 is retracted the pressure of the liquid 142 feeds further billet material through the throat 136 into the cylindrical section 137 of the reducing die 133. This cycle is repeated until the majority of the billet 143 has been extruded. The extruded product passes out through the radial passageways 138 and 140 in the reducing die 133 and the chamber 131.

In FIG. 13 there is shown a chamber 151 having a bore 152. A reducing die 153 is screw fitted in one end of the bore 152 of the chamber 151. The reducing die 153 is sealed in the bore 152 by a copper mitre ring 154 and a rubber O-ring 155. The reducing die 153 has a conical throat 156 leading into a cylindrical section 157. A reciprocable plunger 158 is entered concentrically into the cylindrical section 157 of the reducing die 153. The plunger 158 is of smaller diameter than the internal diameter of the cylindrical section 157 of the reducing die 153.

In operation of the apparatus shown in FIG. 13 liquid **159** is pressurised in the chamber **151** about a billet **160.** The liquid **159** is raised to a pressure sufficient to cause extrusion of the billet **160** through the throat **156** into the cylindrical section **157** of the reducing die **153** but of insufficient pressure to cause extrusion of the billet material from the cylindrical section **157** of the reducing die about the plunger **158.** The plunger **158** is reciprocated in the cylindrical section **157** of the reducing die **153.** On the forward stroke of the plunger **158** the billet material in the cylindrical section **157** of the reducing die **153** is subjected to an additional compressive stress by the loading of the plunger **158.** The billet material in the cylindrical Section **157** of the reducing die **153** extrudes as a tube about the advancing plunger **158** under the combined stress system arising from the overall compressive stress applied by pressurisation of the liquid **159** about the billet **160** and the additional localised compressive stress applied on the billet material in the cylindrical section **157** of the reducing die **153** by the loading of the plunger **158.** The plunger **158** is advanced to a forward limit and is then retracted. As the plunger **158** is retracted the pressure of the liquid **159** feeds further billet material through the throat **156** into the cylindrical section **157** of the reducing die **153.** This cycle is repeated until the majority of the billet **160** has been extruded.

In FIG. **14** of the drawings there is shown a chamber **161** having a bore **162.** A reducing die **163** is screw fitted in the end of the bore **162** of the chamber **161.** The die **163** is sealed in the bore **162** of chamber **161** by a copper mitre ring **164** and a rubber O-ring **165.** The throat of the reducing die **163** is wedge shaped having two flat converging surfaces **166** (See FIG. **15**). A reciprocable plunger **167** is fitted in a radial drilling **168** in the reducing die **163** and the chamber **161** has a corresponding radial drilling **169** to accommodate the main shank **170** of the plunger **167.** The plunger **167** has a bore **171** which is restricted at its end to form a die orifice **172.**

In operation of the apparatus shown in the drawings liquid **173** enveloping a billet **174** in the bore **162** of chamber **161** is pressurised. The liquid **173** is held at constant pressure sufficient to cause extrusion of the end of the billet **173** into the reducing die **163.** The plunger **167** is then driven in a forward stroke into the side face **175** of the reduced end of the billet **174** so that the material of the billet is extruded through the die orifice **172** in the plunger **167** as the plunger **167** moves forward. The material of the billet in the reducing die **163** extrudes through the die orifice **172** under the additive effect of the overall compressive stress applied in the billet by the pressure of the liquid **173** and the localised additional compressive stress applied on the billet material in the reducing die **163** by the mechanical loading of the plunger **167.**

The plunger **167** is advanced to a forward limit and is then retracted, tending to leave a cavity in the reduced end of the billet of the same diameter as the plunger **167.** However as the plunger **167** is retracted the pressure of the liquid **173** acting on the billet **174** feeds further billet material into the reducing die **163** to fill up this cavity as the plunger **167** is retracted. This cycle is repeated until the majority of the billet **174** has been extruded.

As in the arrangement shown in FIG. **10** the movement of plunger **7** will be small (e.g., ¼ inch stroke) and the speed of reciprocation will be rapid (e.g., 2 cycles per second).

In the arrangement shown in FIG. **10** the thrust of the plunger **117** tends to lift the nose of the billet **121** away from the reducing die **113.** The limiting condition is reached when the loading of the plunger **117** on the forward stroke is sufficient to lift the nose of the billet **121** away from the reducing die **113.** This condition arises when the face stress on the plunger **117** during its forward stroke is approximately equal to the pressure of the liquid surrounding the billet. Higher loading of the plunger **117** will cause leakage of liquid between the nose of the billet and the reducing die **113.** Although the arrangement of FIG. **10** enables higher extrusion ratios to be achieved than are possible in simple hydrostatic extrusion the limiting extrusion ratio which can be achieved is approximately the square of the ratio possible in single hydrostatic extrusion at the same pressure.

In the arrangement of FIGS. **14** and **15** there will be a small component of force tending to lift the reduced end of the billet away from the reducing die **163.** This is because the plunger **167** subjects the material to a main stress **6** greater than the yield stress Y of the material and under these conditions a transverse stress acting at right angles to the direction of movement of the plunger **167** must be present in the material of the billet. The component of this transverse stress acting towards the bottom of the reducing die **163** will tend to lift the billet off the reducing die **163.** However the absolute value of the transverse stress is only equal to the difference between the main stress 6 and the yield stress Y of the material i.e.,

$$\text{Transverse stress} = 6 - \mathbf{Y}.$$

The axial stress **6** acting in the billet material in the direction of movement of the plunger **167** dies away along the path which the plunger **167** takes that is it is a maximum immediately in front of the plunger **167.** So of course, the transverse stress in the billet material dies away at a similar rate and it is the mean transverse stress which tends to lift the billet away from the reducing die. However in the arrangement described above in which the plunger **167** is entered at right angles into the billet the force tending to lift the billet away from the reducing die is much smaller than in the arrangement shown in FIG. **10** in which the plunger **117** is entered axially into the end face of the billet. Hence in the arrangement of the present invention higher extrusion ratios are possible than in the arrangement shown in FIG. **10** wherein, due to the loading of the plunger **117** on the billet, a limiting extrusion ratio is reached when lift off of the billet from the reducing die **113** occurs.

In FIG. **16** of the drawings there is shown a chamber **181** having a bore **182.** A die **183** is screw fitted in the end of the bore **182** of the chamber **181.** The die **183** is sealed in the bore **182** by a copper mitre ring **184** and a rubber O-ring **185.** The die **183** has a conical reducing section **186** and an extrusion orifice **187.** A reciprocable plunger **188** is fitted in a radial drilling **189** in the die **183** leading from the reducing section **186** of the die **183.** The chamber **181** has a corresponding radial drilling **190** to accommodate the main shank **191** of the plunger **188.**

In operation of the apparatus shown in FIG. **16,** liquid **192** enveloping a billet **193** in the bore **182** of the chamber **181** is pressurised. The liquid **192** is raised to a pressure sufficient to force the end of the billet **193** into the reducing section **186** of the die **183** but of insufficient pressure to cause extrusion of the billet **193** through the extrusion orifice **187**. The plunger **188** is then reciprocated between the position shown in FIG. **16** and a forward position in which the plunger **188** projects into the reducing section **186** of the die **183**. On the forward stroke of the plunger **188** the billet material in the reducing section **186** of the die **183** is subjected to an additional compressive stress by the loading of the plunger **188**. The billet material in the reducing section **186** of the die **183** is extruded through the orifice **187** under the combined stress system arising from the overall compressive stress applied in the billet material by pressurisation of the liquid **192** about the billet **193** and the additional localised compressive stress applied on the billet material in the reducing section **186** of the die **183** by the loading of the plunger **188**. The plunger **188** is advanced to its forward limit and is then retracted. As the plunger **188** is retracted the pressure of the liquid **192** on the billet **193** feeds further billet material into the reducing section **186** of the die **183**.

This cycle is repeated until the majority of the billet **193** has been extruded.

In FIG. **17** of the drawings there is shown a chamber **201** having a bore **202**. A reducing die **203** is screw fitted in the end of the bore **202** of the chamber **201**. The reducing die **203** is sealed in the bore **202** by a copper mitre ring **204** and a rubber O-ring **205**. The throat of the reducing die **203** is wedge shaped having two flat converging surfaces **206**. A reciprocable plunger **207** is fitted concentrically in a radial drilling **208** in the reducing die **203**. The drilling **208** is of reduced diameter at its inner end to form an extrusion orifice **209**. The plunger **207** is of smaller diameter than the internal diameter of the extrusion orifice **209**. The chamber **201** has a radial drilling **210** corresponding to the radial drilling **208** in the reducing die **203**.

In operation of the apparatus shown in FIG. **17** liquid **211** is pressurised in the chamber **201** about a billet **212**. The liquid **211** is raised to a pressure sufficient to cause extrusion of the end of the billet **212** into the throat of the reducing die **203** but of insufficient pressure to cause extrusion of the billet material from the throat of the reducing die **203** through the extrusion orifice **209** about the plunger **207**. The plunger **207** is reciprocated between the position shown in FIG. **17** and a forward position in which the plunger **207** projects into the throat of the reducing die **203**. On the forward stroke of the plunger **207** the billet material in the throat of the reducing die **203** is subjected to an additional compressive stress by the loading of the plunger **207**. The billet material in the throat of the die **203** is extruded as a tube through the extrusion orifice **209** about the plunger **207**. Extrusion of the billet material on the forward stroke of the plunger **207** occurs under the combined stress system arising from the overall compressive stress applied in the billet material by pressurisation of the liquid **211** about the billet **212** and the additional localised compressive stress applied on the billet material in the throat of the reducing die **203** by the loading of the plunger **207**. The plunger is advanced to its forward limit and is then retracted. As the plunger **207** is retracted the pressure of the liquid **211** on the billet **212** feeds further billet material into the throat of the reducing die **203**. The cycle is repeated until the majority of the billet has been extruded.

In FIG. **18** of the drawings there is shown a chamber **221** have a bore **222**. A reducing die **223** is screw fitted in the end of the bore **222**. For the sake of clarity the chamber **221** and the reducing die **223** are shown in half section. The die **223** is sealed in the bore **222** by a copper mitre ring **224** and a rubber O-ring **225**. A sleeve shaped rotary die block **226** is fitted on a stationary stem **227**. The end **228** of the rotary die block **226** is reduced to fit in the parallel outlet **229** of the reducing die **223**. A solid abutment member **230** is formed projecting from the annular end face **231** of the die block **226**. The abutment member **230** has a vertical leading face **232** and a sloping trailing face **233**. A die orifice **234** is formed in the annular end face **231** of the die block **226** in front of the leading face **232** of the abutment member. A longitudinal passageway **235** in the die block **226** leads from the die orifice **234**. The stationary stem **227** has a pointed end **236** and is fixedly supported on a main base frame while the die block **226** is rotatably supported on the stationary stem **227** by a heavy duty bearing (not shown).

In use of the arrangement described above a billet **237** (indicated by the chain dotted lines in the drawing) is subjected to the pressure of hydraulic liquid surrounding the billet **237** in the bore **222** of chamber **221**. The pressure of the liquid subjects the billet **237** to an overall compressive stress system and also loads the billet longitudinally into the reducing die **223**. The nose of the billet **237** is forced into the reducing die **223** over the pointed end **236** of the stationary stem **227**. The rotary die block **226** is driven on the stationary stem **227** thus driving the abutment member **230** through the billet material at the mouth of the reducing die **223**. The billet material forward of the abutment member **230** is subjected to an additional compressive stress system by the loading of the abutment member **230**. The billet material traversed by the abutment member **230** is extruded through the die orifice **234** under the combined effect of the overall compressive stress applied in the billet **237** by the pressure of the hydraulic liquid and the additional compressive stress applied in the billet material at the mouth of the reducing die **223** by the loading of the abutment member **230**. The stress applied by the abutment member **230** which is effective in contributing to extrusion is that acting in the billet material towards the die orifice **234** parallel to the vertical leading face **232** of the abutment member **230**. This stress is approximately the face stress (**6**) applied in the billet material by the abutment member **10** less the yield stress ($\bar{Y}$) of the billet material.

In the arrangements shown in FIGS. **1, 4, 6** and **7** in which the die orifice is formed in the die member projecting from the face of the rotary die block the extrusion ratio achieved at the die member is equal to the ratio of the area of the face of the die member to the area of the die orifice. An extrusion ratio at the die member approaching 1 : 1 would require the area of the die orifice to be approximately equal to the area of the face of the die member which would mean that the die member would be impractically thin walled. Expressed in another way in the arrangements of FIGS. **1,** 4, 6 and 7 the size of the die orifice and hence the extrusion ratio which can be achieved is limited by the size of the die member. This limitation does not apply in the arrangement of FIG. **18** as the die orifice **234** is separate from the abutment member **230** so that the size of the die orifice **234** is not governed by the size of the abutment member **230.** Thus in the arrangement of FIG. **18** an extrusion ratio of 1 : 1 or even less can be achieved at the die orifice **234.**

The extrusion ratio achieved at the die orifice **234** depends on the area of the leading face **232** of the abutment member **230** relative to the area of the die orifice **234.** It is the area of the leading face **232** of the abutment member **230** which is significant and within limits the shape of the face **232** of the abutment member **230** does not matter. This factor provides an advantage in the arrangement of FIG. **18** which can best be explained by consideration of two examples.

a. The first case is where the leading face **232** of the abutment member **230** is high and of narrow width for example where the height of the face **232** is approximately equal to or greater than its width. In this case the outlet end of the reducing die **223** will be narrow compared with its inlet end and the billet must undergo considerable initial reduction in the reducing die **223** requiring the application of a relatively high pressure in the liquid acting on the billet in the chamber **221.**

b. In the second case the face **232** of the abutment member **230** may be made of the same area as in case (a) (To achieve the same extrusion ratio at the die orifice **234**) but the face **232** is made of low height and extended width (e.g., as shown in FIG. **18**). In this case the width of the outlet end of the reducing die **223** will be greater than the case (a) and the initial reduction of the billet in the die **223** will be less. Hence the pressure required in the liquid acting on the billet in the chamber **221** will be less than in case (a) whilst the same overall billet to product extrusion ratio is achieved in both cases. The decrease in the pressure required in the liquid in the chamber **221** results in a saving in cost of the chamber **221.**

In the arrangement of FIG. **18** a drilling **238** extends longitudinally through the die block **226.** The drilling **238** leads to the trailing face **233** of the abutment member **230.** During operation of the arrangement of FIG. **18** lubricant is fed through the drilling **238** at a low pressure. A space will exist between the material of the billet and the trailing face **233** of the abutment member **230** as the billet is extruded. Lubricant enters this space from the drilling **238** and is swept around the annular end face **231** of the die block **226** to lubricate the end face **231** and the material extruding through the die. This form of lubrication is also applicable in the arrangements shown in FIGS. **1, 4, 6** and **7.**

FIGS. **19** and **20** of the drawings show modifications of the arrangement of FIG. **18.**

In FIG. **19** the die block **226** has three abutment members **230** on its annular end face **231.** A die orifice **234** is provided in front of each of the abutment members **230.** Multiple die members may also be employed in the arrangements of FIGs. **2, 4, 6** and **7.**

In FIG. **20** three die orifices **234** are provided in the annular end face **231** of the die block **226** forward of the abutment member **230.**

FIGS. **21** and **22** show the adaptation of an arrangement such as shown in FIG. **18** to the production of tubing.

In the arrangement of FIGS. **21** and **22** a bridge type die assembly is employed. A die cavity **239** is formed in the annular end face **231** of the die block **226** forward of the abutment member **230.** As shown in FIG. **22** the die cavity **239** comprises a cylindrical inlet **240** and a conically tapered throat **241** leading to a die orifice **242.** A passageway **243** leads from the die orifice **242** through the die block **226.** A mandrel **244** has spider arms **245** which seat in the cylindrical inlet **240** of the die cavity **239,** so that the mandrel **244** is located concentrically in the die orifice **242.** In use of the arrangement billet material extrudes into the die cavity **239** passing over the spider arms **245** of the mandrel **244.** The billet material comes together in the throat **241** of the die cavity **239** and extrudes through the die orifice **242** about the mandrel **244** to form a tube.

FIG. **23** shows the adaptation of the bridge type die of FIGS. **21** and **22** to the production of clad wire.

As in FIGS. **21** and **22** a die cavity **239** having cylindrical inlet **240,** a conically tapered throat **241** and a die orifice **242** is formed in the annular end face **231** of the die block **226** forward of the abutment member **230.** A mandrel **244** is supported by spider arms **245** seating in the cylindrical inlet **240** of the die cavity **239.** However in the arrangement of FIG. **23** the mandrel **244** terminates in the throat **241** of the die cavity **239** short of the die orifice **242.** A longitudinal passageway **246** in the die block **226** connects with a passageway **247** leading radially through one of the spider arms **245** of the mandrel **244** and then longitudinally through the mandrel **244.**

In use of the arrangement shown in FIG. **23** wire **248** to be clad, is fed through the longitudinal passageway **246** in the die block **226** and then through the passageway **247** in the spider arm **245** and the mandrel **244.** The wire **248** may be fed from a spool located below the die block **226.** Billet material extrudes into the die cavity **239** passing over the spider arms **245** of the mandrel **244.** The billet material comes together in the throat **241** of the die cavity **239** and extrudes through the die orifice **242** about the wire **248.** The wire **248** is drawn along by the extruding billet material.

I claim:

1. A method of producing from a workpiece a product of reduced cross section by extruding through an orifice defining the reduced product cross-section, comprising applying an initial bulk compressive stress to the whole of the workpiece to influence the workpiece to extrude through the orifice and applying a tool having a working face of smaller cross section than the workpiece to a localized region of the workpiece adjacent the orifice, and moving the tool in a repetitive closed cyclic path with the working face of the tool maintained in pressure contact with the localized region of the bulk-stressed workpiece during at least part of the cyclic path to apply an additional compressive stress at said localized region to influence the localized region to extrude through said orifice, so that the material of the workpiece in the localized region forward of the working face of the tool is subjected to an additional compressive stress and is thereby formed through the orifice defining the product cross section under the influence of the bulk compressive stress acting in combination with the additional compressive stress in the material of the workpiece in the region forward of the working face of the tool.

2. A method of producing from a workpiece a product of reduced cross section comprising applying pressure to the workpiece in a container having a region of smaller cross-section than the workpiece so as to set up an initial bulk compressive stress in the whole of the workpiece and so as to force a part of the workpiece into the region of smaller cross-section to produce a reduction of cross section in a part of the workpiece, applying a tool having a material working face to said part of the workpiece, and moving the tool relative to the workpiece and relative to said region of the container in a repetitive closed cyclic path with the working face of the tool maintained in pressure contact with said part of the workpiece during at least part of the cyclic path, so that the material of the workpiece in said part forward of the working face of the tool is subjected to an additional compressive stress and is thereby formed through an orifice opening into said region of smaller cross-section and defining the product cross section under the influence of the bulk compressive stress acting in combination with the additional compressive stress in the material of the workpiece in the part forward of the working face of the tool.

3. Apparatus for producing from a workpiece a product of reduced cross section comprising a workpiece, an orifice defining the reduced product cross-section, means for applying an initial bulk compressive stress to the whole of the workpiece to influence the workpiece to extrude through said orifice, a tool having a working face of smaller cross section than the workpiece, the tool being mounted for application to a localized region of the bulk-stressed workpiece adjacent said orifice and so as to be movable in a repetitive closed cyclic path with the working face of the tool maintained in pressure contact with the workpiece during at least part of the cyclic path, and means for effecting relative movement between the tool and the workpiece to apply an additional compressive stress at said localized region to influence the localized region to extrude through said orifice, whereby the material of the workpiece in the localized region forward of the working face of the tool is subjected to an additional compressive stress and is thereby formed through the orifice defining the product cross section under the influence of the bulk compressive stress acting in combination with the additional compressive stress in the material of the workpiece in the localized region forward of the working face of the tool.

4. Apparatus for producing from a workpiece a product of reduced cross section comprising a container having a region of smaller cross section than the workpiece, means for applying pressure to the workpiece in the container so as to set up an initial bulk compressive stress in the whole of the workpiece and so as to force a part of the workpiece into the region of smaller cross section of the container, an orifice opening into said region and defining the reduced product cross-section, a tool having a working face and mounted for application of the working face to the part of the bulk-stressed workpiece in said region of smaller cross section of the container, and means for moving the tool in a repetitive closed cyclic path with the working face of the tool maintained in pressure contact with the workpiece during at least part of the cyclic path so that the material of the workpiece in the region of smaller cross section of the container forward of the working face of the tool is subjected to an additional compressive stress and is thereby formed through the orifice defining the product cross section under the influence of the bulk compressive stress acting in combination with the additional compressive stress in the material of the workpiece in the region of small cross section of the container forward of the working face of the tool.

5. Apparatus as claimed in claim **3** wherein said means for applying a bulk compressive stress comprises a container, and pressure means for applying a compressive stress to the bulk of the workpiece within the container, said tool comprising a reciprocable punch, and means for reciprocating the punch between limits, the apparatus being constructed and arranged such that on the forward stroke of the punch the face of the punch is forced under pressure into the bulk-stressed workpiece, so that the material of the workpiece in the localized region forward of the face of the punch is subjected to an additional compressive stress and is formed through the orifice leading from the container, and whereby on the backward stroke of the punch the compressive stress applied to the bulk of the workpiece feeds the material of the workpiece to replace the material formed during the previous forward stroke of the punch.

6. Apparatus as claimed in claim **4** wherein the bore of the container has a tapered end reducing to said smaller cross section, and said means for applying pressure to the workpiece in the container sets up a compressive stress in the bulk of the workpiece so as to force the corresponding end of the workpiece into the tapered end of the bore of the container, said tool comprising a reciprocable punch, and said means for moving the tool comprising means for reciprocating the punch between limits such that on the forward stroke of the punch the face of the punch is forced under pressure into the material of the workpiece in the tapered end of the bore of the container so that the material of the workpiece in the localized region forward of the face of the punch is subjected to an additional compressive stress and is formed through the orifice leading from the tapered end of the container, and such that on the backward stroke of the punch the compressive stress acting in the bulk of the workpiece feeds further material into the tapered end of the bore of the container to replace the material formed during the previous forward stroke of the punch.

7. Apparatus as claimed in claim **4** wherein the bore of the container has a tapered end leading to a secondary chamber of smaller cross section, and said means for applying pressure to the workpiece in the container sets up a compressive stress in the bulk of the workpiece so as to force the corresponding end of the workpiece through the tapered end of the bore of the container into the secondary chamber, said tool comprising a reciprocable punch, and said means for moving the tool comprising means for reciprocating the punch between limits such that on the forward stroke of the punch the face of the punch is forced under pressure into the material of the workpiece in the secondary chamber so that the material of the workpiece in the secondary chamber is subjected to an additional compressive stress and is formed through the orifice leading from the secondary chamber and defining the product cross section, and such that on the backward stroke of the punch the compressive stress acting in the bulk of the workpiece feeds further material from the workpiece into the secondary chamber through the tapered end of the bore of the container.

8. Apparatus as claimed in claim **6** wherein the punch is entered axially along the container axis into the said corresponding end of the work piece at the forward part of the tapered end of the bore of the container.

9. Apparatus as claimed in claim **7** wherein the punch is entered axially along the container axis into the said corresponding end of the material of the workpiece in the secondary chamber.

10. Apparatus as claimed in claim **6** wherein the punch is entered through the side wall of the tapered end generally normal to the bore axis of the container.

11. Apparatus as claimed in claim **5** wherein the orifice defining the product cross section is provided in the reciprocable punch leading from the face of the punch.

12. Apparatus as claimed in claim **8** wherein the orifice defining the product cross section is provided in the side wall of the tapered end of the bore of the container.

13. Apparatus as claimed in claim **10** wherein the orifice defining the product cross section is provided leading axially from the forward end of the tapered end of the bore of the container.

14. Apparatus as claimed in claim **9** wherein the punch is of smaller diameter than the internal diameter of the secondary chamber and the orifice defining the product cross section is provided by the annular space defined between the punch and the wall of the secondary chamber.

15. Apparatus as claimed in claim **10** wherein the punch is entered into the tapered end of the bore of the container through a passageway in the wall of the container and the punch is of smaller diameter than the internal diameter of said passageway, the orifice defining the product cross section being provided by the annular space defined between the punch and the wall of the passage way.

16. Apparatus as claimed in claim **4** wherein said tool comprises a reciprocable punch, and said means for moving the tool comprises means for reciprocating the punch between limits, the apparatus being constructed and arranged such that on the forward stroke of the punch the face of the punch is forced under pressure into the workpiece, so that the material of the workpiece in the localized region forward of the face of the punch is subjected to an additional compressive stress and is formed through the orifice leading from the container, and whereby on the backward stroke of the punch the compressive stress applied to the bulk of the workpiece feeds the material of the workpiece to replace the material formed during the previous forward stroke of the punch.

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