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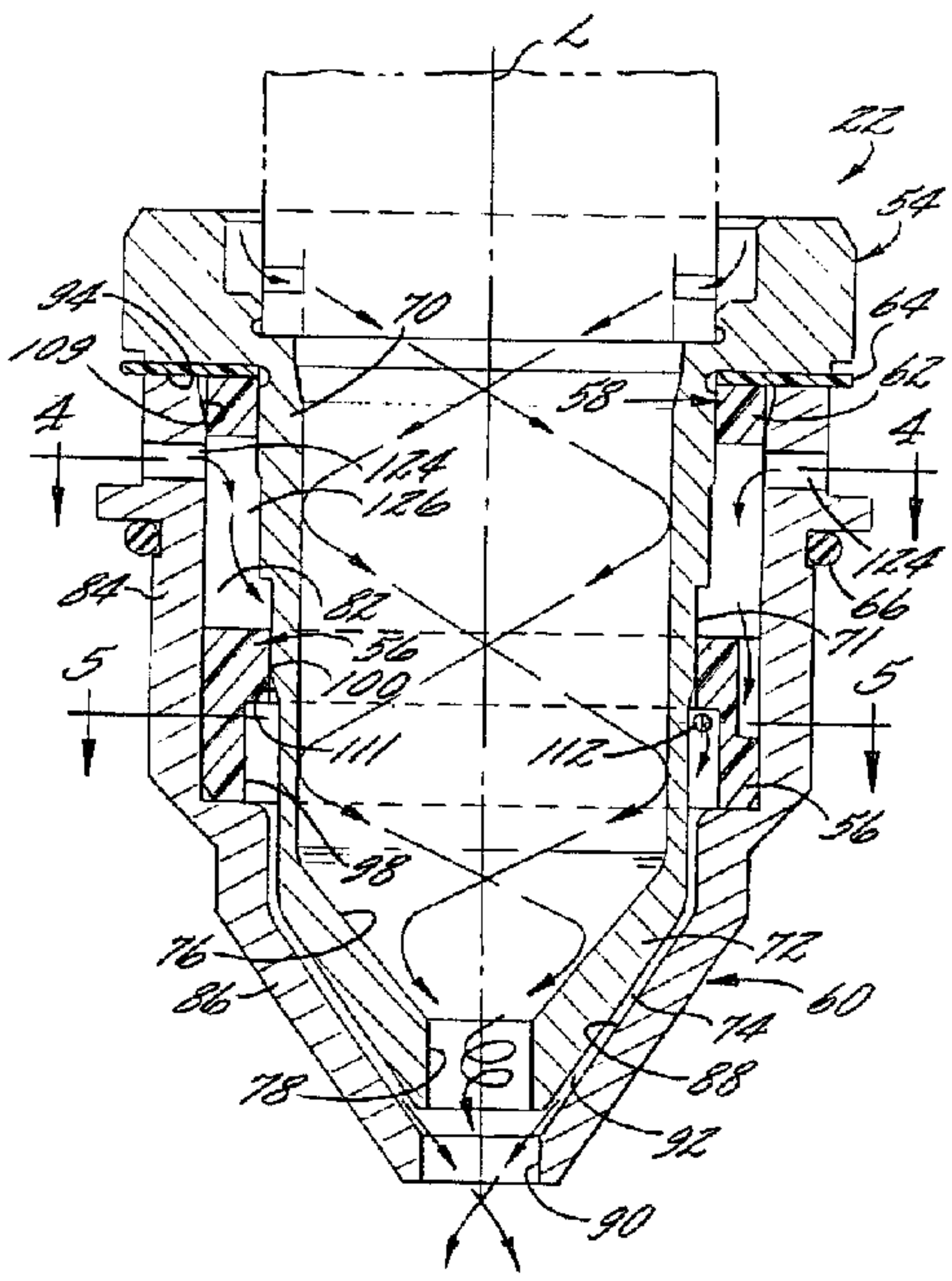

(57) Abrégé/Abstract:

A nozzle assembly for a plasma arc torch includes inner and outer metal nozzle members and an annular insulating element press-fit between the inner and outer nozzle members so that the nozzle members are electrically insulated from one another and bores of the nozzle members are coaxial. Additionally, the annular insulating element is constructed such that the inner and outer nozzle members are secured together to define a water passageway between the interior surface of the outer nozzle member and the exterior surface of the inner nozzle member. The nozzle assembly may further include an outer insulating element secured onto the exterior surface of the outer nozzle member, in which case the annular insulating element between the nozzle members may not be press-fit to the nozzle members. The annular insulating element may define at least one port for introducing water into the water passageway. The port extends in a direction that is generally tangential to an imaginary circle around the longitudinal discharge axis so that the water swirls in the water passageway. Alternatively, the nozzle assembly includes an annular insulating swirl ring press-fit between the inner and outer nozzle members. The swirl ring is displaced along the longitudinal discharge axis from the first annular insulating element and is positioned between the first annular insulating element and the bore of the inner nozzle member.

WATER-INJECTION NOZZLE ASSEMBLY WITH INSULATED FRONT END

ABSTRACT OF THE DISCLOSURE

A nozzle assembly for a plasma arc torch includes inner and outer metal nozzle members and an annular insulating element press-fit between the inner and outer nozzle members so that the nozzle members are electrically insulated from one another and bores of the nozzle members are coaxial. Additionally, the annular insulating element is constructed such that the inner and outer nozzle members are secured together to define a water passageway between the interior surface of the outer nozzle member and the exterior surface of the inner nozzle member. The nozzle assembly may further include an outer insulating element secured onto the exterior surface of the outer nozzle member, in which case the annular insulating element between the nozzle members may not be press-fit to the nozzle members. The annular insulating element may define at least one port for introducing water into the water passageway. The port extends in a direction that is generally tangential to an imaginary circle around the longitudinal discharge axis so that the water swirls in the water passageway. Alternatively, the nozzle assembly includes an annular insulating swirl ring press-fit between the inner and outer nozzle members. The swirl ring is displaced along the longitudinal discharge axis from the first annular insulating element and is positioned between the first annular insulating element and the bore of the inner nozzle member.

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WATER-INJECTION NOZZLE ASSEMBLY WITH INSULATED FRONT END

FIELD OF THE INVENTION

The invention relates to a water-injection nozzle assembly for a plasma arc torch, and more particularly to a water-injection nozzle assembly with an insulated front end.

BACKGROUND OF THE INVENTION

Plasma arc torches are commonly used for cutting, welding, surface treating, melting, or annealing a metal workpiece. Such working of the workpiece is facilitated by a plasma arc that extends from the plasma arc torch to the workpiece. In one type of plasma arc torches, a shielding gas is used to surround and control the plasma arc. In contrast, in another type of plasma arc torches, water is used to surround and control the plasma arc. The gas or water that is used to surround and control the plasma arc generated by a plasma arc torch is typically also used to cool a nozzle assembly of the plasma arc torch. Water has a higher coefficient of heat transfer than gas; therefore, plasma arc torches that utilize water to cool their nozzle assemblies can typically operate at higher currents and therefore provide higher quality cuts than torches that utilize gas for cooling their nozzle assemblies. Plasma arc torches that utilize water as discussed above typically include water-injection nozzle assemblies. Examples of plasma arc torches with water-injection nozzle assemblies are disclosed in U.S. Patent Numbers 5,747,767; 5,124,525 and 5,023,425, which are assigned to the assignee of the present invention.

A typical plasma arc torch that includes a water-injection nozzle assembly may further include a torch body defining a longitudinal discharge axis and an electrode secured to the torch body and having a discharge end. The water-injection nozzle assembly is mounted adjacent to the discharge end of the electrode. A typical water-injection nozzle assembly may include a metal inner nozzle member and a metal outer nozzle member that is radially outward from the inner nozzle member. The inner nozzle member defines a gas-constricting bore and the outer nozzle member defines a water-constricting bore. The nozzle members are fit together so that the bores are coaxially aligned with the longitudinal discharge axis defined by the torch body, and a water passageway is defined between the interior surface of the outer nozzle member and the exterior surface of the inner nozzle member.

A typical plasma arc torch includes an electrical source for generating an electrical arc that extends from the discharge end of the electrode. The water-injection nozzle assembly is separated from the electrode by a gas passage proximate to the discharge end of the electrode, and a vortical flow of a gas is provided through the gas passage. The electrical arc ionizes the gas to create the plasma arc, which extends along the longitudinal discharge axis and through the bores of the nozzle members to the workpiece. A water flow source supplies a vortical flow of water to the water passageway defined between the inner and outer nozzle members. The vortical flow of the water exits the water-constricting bore and constricts the plasma arc.

Concentricity of the inner and outer nozzle members is very important to proper operation of a plasma arc torch. U.S. Patent Numbers 5,747,767 and 5,124,525 disclose inner and outer nozzle members that are press-fit together, by way of metal-to-metal contact, to center and maintain concentricity between the bores of the inner and outer nozzle members.

Avoiding "double arcing" is also important to proper operation of a plasma arc torch. Double arcing may occur when the workpiece, or molten splatter from the workpiece, accidentally contacts the metal outer nozzle member. When this happens, a second plasma arc, in addition to the main plasma arc, extends from the electrode through the inner nozzle member and the outer nozzle member, and ultimately to the workpiece. Insulating the outer nozzle member can reduce double arcing. For example, U.S. Patent Number 5,124,525 discloses an outer nozzle member having a radially exterior surface and an outer insulating element secured onto the exterior surface of the outer nozzle member. These types of insulating elements are often formed of a ceramic material. Such ceramic insulating elements are somewhat brittle and are therefore subject to being broken when they come into contact with the workpiece or molten splatter from the workpiece.

Accordingly, there is a need for a water-injection nozzle assembly with an insulated front end that is less prone to breakage.

SUMMARY OF THE INVENTION

The present invention solves the problems identified above and provides other advantages, and comprises a water-injection nozzle assembly for a plasma arc torch, wherein the nozzle assembly includes inner and outer metal nozzle members and an annular insulating element press-fit between the inner and outer nozzle members. The annular insulating element is constructed such that the metal inner and outer nozzle members are electrically insulated from one another. Further, the annular insulating element is constructed so that a water-constricting bore of the outer nozzle member and a gas-constricting bore of the inner nozzle member are coaxial. The nozzle assemblies of the present invention may be mounted adjacent to a discharge end of an electrode mounted to a torch body, which defines a longitudinal discharge axis. The annular insulating element is constructed so that the water-constricting bore of the outer nozzle member and the gas-constricting bore of the inner nozzle member are coaxial with the longitudinal discharge axis of the torch body. Additionally, the annular insulating element is constructed such that the inner and outer nozzle members are secured together to define a water passageway between at least portions of an interior surface of the outer nozzle member and an exterior surface of the inner nozzle member. The water passageway is for communicating a flow of water to the water-constricting bore of the outer nozzle member.

In accordance with another aspect of the invention, the water-injection nozzle assembly further includes an outer insulating element secured onto an exterior surface of the outer nozzle member. The outer insulating element extends around and proximate to the water-constricting bore of the outer nozzle member. The outer insulating element is preferably constructed of a ceramic or plastic material.

In accordance with another aspect of the invention, the annular insulating element defines one or more ports for introducing water into the water passageway. Preferably the ports extend in a direction that is generally tangential to an imaginary circle around the longitudinal discharge axis, so that the ports introduce a vortical flow of water into the water passageway.

In accordance with another aspect of the invention, the water-injection nozzle assembly includes a second annular insulating element press-fit between the inner and outer nozzle members. The second annular insulating element is displaced along the longitudinal discharge axis from the first annular insulating element and is positioned between the first annular insulating element and the gas-constricting bore of the inner nozzle member. Preferably the second annular insulating element is a swirl ring, meaning that it defines one or more ports for introducing a vortical flow of water into the water passageway.

Advantageously, the present invention increases the service life of water-injection plasma arc torches by decreasing the likelihood of double arcing. This is achieved by insulating the metal inner and outer nozzle members from one another while at the same time providing superior concentricity of the outer and inner nozzle members. The advantages achieved by insulating the metal inner and outer nozzle members from one another are unexpected since water, which is typically thought of as being electrically conductive, flows through the water passageway defined between the nozzle members.

According to an aspect of the invention, a water-injection nozzle assembly for a plasma arc torch, comprises:

an inner nozzle member formed of metallic material and comprises a radially exterior surface, wherein the inner nozzle member defines a bore therethrough;

an outer nozzle member formed of metallic material and comprises a radially interior surface, wherein the outer nozzle member is radially outward of the inner nozzle member and defines a bore therethrough that is coaxially aligned with the bore of the inner nozzle member; and

an annular insulating element press-fit between the inner and outer nozzle members such that the inner and outer nozzle members are pressed together in a manner that a water passageway is defined between at least portions of the interior surface of the outer nozzle member and the exterior surface of the inner nozzle member for communicating a flow of water to the bore of the outer nozzle member, wherein the annular insulating element is constructed such that the metallic inner and outer nozzle members are electrically insulated from one another.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of this invention reference should now be had to the exemplary embodiments illustrated in the accompanying drawings, which are described below.

FIG. 1 is a sectional elevation view of a plasma arc torch including a water-injection nozzle assembly, in accordance with a first embodiment of the invention.

FIG. 2 is an exploded perspective view of the water-injection nozzle assembly of FIG. 1.

FIG. 3 is a sectional elevation view of the water-injection nozzle assembly of FIG. 1.

FIG. 4 is a cross-sectional view of the water-injection nozzle assembly of FIG. 1, taken along line 4-4 of FIG. 3.

FIG. 5 is a cross-sectional view of the water-injection nozzle assembly of FIG. 1, taken along line 5-5 of FIG. 3.

FIG. 6 is a cross-sectional view of a water-injection nozzle assembly in accordance with an alternative embodiment of the invention, wherein the nozzle assembly of FIG. 6 is sectioned similarly to the nozzle assembly of FIG. 5.

FIG. 7 is a sectional elevation view of a plasma arc torch including a water-injection nozzle assembly, in accordance with a second embodiment of the invention.

FIG. 8 is a sectional elevation view of the water-injection nozzle assembly of FIG. 7.

FIG. 9 is a cross-sectional view of the water-injection nozzle assembly of FIG. 7, taken along line 9-9 of FIG. 8.

FIG. 10 is a sectional elevation view of a water-injection nozzle assembly in accordance with a third embodiment of the invention.

FIG. 11 is a partial, sectional elevation view of a water-injection nozzle assembly in accordance with a fourth embodiment of the invention.

FIG. 12 is a partial, cross-sectional view of a water-injection nozzle assembly taken along line 12-12 of FIG. 13, in accordance with a fifth embodiment of the invention.

FIG. 13 is a partial, cross-sectional view of the water-injection nozzle assembly of FIG. 12, taken substantially along line 13-13 of FIG. 12.

FIG. 14 is a partial, cross-sectional view of a water-injection nozzle assembly in accordance with a sixth embodiment of the invention, wherein the view of FIG. 14 is from a perspective substantially similar to the perspective of FIG. 13.

FIG. 15 is a partial, cross-sectional view of a water-injection nozzle assembly taken along line 15-15 of FIG. 16, in accordance with a seventh embodiment of the invention.

FIG. 16 is a partial, cross-sectional view of the water-injection nozzle assembly of FIG. 15, taken substantially along line 16-16 of FIG. 15.

DETAILED DESCRIPTION OF THE INVENTION

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that the disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

FIRST EMBODIMENT

FIG. 1 illustrates a plasma arc torch, indicated generally at **20**, according to a first embodiment of the invention. The torch **20** includes a torch body **24**, an electrode **25**, a water-injection nozzle assembly **22** and a nozzle assembly retaining cup **26**. As discussed in greater detail below, the nozzle assembly **22** includes a pair of axially displaced annular insulating elements **56, 58** press-fit between a metal inner nozzle member **54** and a metal outer nozzle member **60**. These press-fits are such that the nozzle members **54, 60** are coaxially aligned. These press-fits are also such that the metal nozzle members **54, 60** are electrically insulated from one another, so that the possibility of double arcing between nozzle members **54, 60** is reduced.

The torch body **24** is generally cylindrical, elongate and defines a longitudinal discharge axis L. At its lower end, the torch body **24** has a generally cylindrical cavity **28** therein for housing the electrode **25** and the water-injection nozzle assembly **22**. The torch body **24** includes an electrode holder **30**, a water inlet passageway **32** and a gas inlet passageway **34**. The electrode holder **30** is generally cylindrical and is disposed within the cavity **28** of the torch body **24** and coaxially along the longitudinal discharge axis L. At its upper end, the electrode holder **30** includes an externally threaded portion **36** for engaging internal threads provided on the torch body **24**, to secure the electrode holder to the torch body.

At its lower end, the electrode holder **30** preferably includes an internally threaded lower portion **38** for securing the electrode **25** on the torch body **24**. Preferably, the electrode **25** includes an externally threaded portion **40** adjacent to an upper end **42** of the electrode for engaging the internally threaded lower portion **38** of the electrode holder **30**. In other embodiments, however, the electrode **25** may be secured to the electrode holder **30** in any manner, for example by press-fit, that permits the electrode to be readily removed for replacement and ensures that the electrode is in good electrical contact with a conductor from an external power source (not shown). The electrode **25** is secured to the torch body **24** adjacent to the lower portion **38** of the electrode holder **30** and coaxially along the longitudinal discharge axis L.

The electrode **25** is electrically conductive and includes a generally cylindrical, elongate body **44** having a lower discharge end **46**. Preferably, the discharge end **46** includes an emissive element **48** which acts as the cathode terminal for an electrical arc extending from the discharge end of the electrode **25** and along the longitudinal discharge axis L in the direction of a workpiece (not shown) positioned beneath the torch **20**. An electrode including an emissive element is disclosed in United States Patent No. 5,023,425, the entire disclosure of which is incorporated herein by reference, and which is assigned to the assignee of the present invention.

The emissive element **48** is composed of a material which has a relatively low work function, defined in the art as the potential step, measured in electron volts, that permits thermionic emission from the surface of a metal at a given temperature. In view of its low work function, the emissive element **48** readily emits electrons in the presence of an electric potential. Commonly used materials for fabricating these elements include hafnium, zirconium, tungsten, and alloys thereof.

A gas baffle **50** is preferably positioned adjacent to the upper end **42** of the electrode **25** and the lower portion **38** of the electrode holder **30**. The gas baffle **50** has at least one, and preferably multiple radially inwardly directed, circumferentially-spaced holes **52** therein that direct gas from the gas inlet passageway **34** around the periphery of the body **44** of the electrode **25**. As indicated by the arrows, gas from an external source (not shown) flows through the gas inlet passageway **34** into an annular chamber in the cavity **28** between the gas baffle **50** and the torch body **24**. The pressurized gas encircles the gas baffle **50** and is forced through the holes **52** into a generally cylindrical chamber between the electrode **25** and the water-injection nozzle assembly **22** to form a swirling vortex of gas. The swirling flow of gas ionizes in the electrical arc extending from the discharge end **46** of the electrode **25** to create a plasma arc extending in the direction of the workpiece.

The electrode **25**, upon being connected to the torch body **24** causes the gas baffle **50** and an elongate member **53** to be held in their assembled configuration. The gas baffle is constructed of an electrically insulating ceramic material and the elongate member **53** is constructed of an electrically insulating plastic material. The gas baffle **50** and the elongate member **53** electrically insulate the water-injection nozzle assembly **22** from the electrode **25**.

The water-injection nozzle assembly **22** is positioned adjacent to the electrode **25** and coaxially along the longitudinal discharge axis L of the torch body **24**. As mentioned above, the nozzle assembly **22** includes the inner nozzle member **54**; the annular insulating element **56**, which is preferably in the form of a insulating swirl ring **56**; the annular insulating assembly **58**, and the outer nozzle member **60**. Those components of the nozzle assembly **22** are press-fit together such that the metal nozzle members **54**, **60** are coaxially aligned and electrically insulated from one another, so that the possibility of double arcing between the nozzle members **54**, **60** is reduced.

As illustrated in the exploded perspective view of FIG. 2, the insulating swirl ring **56** and the annular insulating assembly **58** are positioned over the inner nozzle member **54**, and the outer nozzle member **60** is positioned in turn over the insulating swirl ring **56** and the annular insulating assembly **58**. The annular insulating assembly **58** may consist of a lower insulating ring **62** and a upper insulating ring **64** that extends at least partially radially outwardly from the lower insulating ring **62**. Alternatively, the annular insulating assembly **58** may be a unitary element that is absent of separate parts. For example, the lower and upper insulating rings **62**, **64** may be molded together as a single piece. An annular ring **66**, which may be in the form of an O-ring, is positioned over the outer nozzle member **60** for accepting the nozzle assembly retaining cup **26** (FIG. 1), as will be described.

As best shown in the sectional elevation view FIG. 3, the inner nozzle member **54** has a cavity **68** formed therein and includes a generally cylindrical, upper portion **70**; a generally cylindrical, middle portion **71** and a frusto conical lower portion **72**. The lower portion **72** defines a convergent, frusto conical exterior surface **74** and a convergent, frusto conical interior surface **76** terminating at a gas-constricting bore **78**. The gas-constricting bore **78** extends through the inner nozzle member **54** and is coaxially aligned with the longitudinal discharge axis L of the torch body **24**. As indicated by the arrows, the interior surface **76** directs the swirling vortex of gas in the cavity **68** into the gas-constricting bore **78** to constrict the plasma arc in the direction of the workpiece. As best seen in FIG. 2, the inner nozzle member **54** further includes an annular, radially extending shoulder **80**.

As best seen in FIG. 3, outer nozzle member **60** has a cavity **82** formed therein. The outer nozzle member **60** includes a generally cylindrical, upper portion **84** and a frusto conical, lower portion **86**. The lower portion **86** defines a sharply convergent, frusto conical interior surface **88** terminating at a water-injection bore **90**. The water-injection bore **90** extends through the outer nozzle member **60** and is coaxially aligned with the longitudinal discharge axis L of the torch body **24**. The radially interior surface **88** of the lower portion **86** of the outer nozzle member **60** together with the radially exterior surface **74** of lower portion **44** of inner nozzle member **54** define an annular water passageway **92** for communicating the injection water from the water inlet passageway **32** (FIG. 1) to the water-injection bore **90**. As best seen in FIG. 3, the upper end of the outer nozzle member **54** includes an annular, radially extending shoulder **94**.

As best seen in FIG. 2, the annular insulating swirl ring **56** has a generally cylindrical, exterior surface **96** and a pair of generally cylindrical, radially interior surfaces **98, 100**. The interior surface **98** is at a greater radius from the longitudinal discharge axis L than the interior surface **100**. The lower insulating ring **62** of the annular insulating assembly **58** has a generally cylindrical outer surface **102**, a generally cylindrical inner surface **104** and a radially extending annular upper surface **106**. The upper insulating ring **64** of the annular insulating assembly **58** has annular upper and lower surfaces **108, 110**.

The inner nozzle member **54**, insulating swirl ring **56**, annular insulating assembly **58**, and outer nozzle member **60** are press-fit together so that the nozzle assembly **22** is assembled as illustrated in FIG. 3. That press-fit arrangement is facilitated by numerous surfaces being press-fit together. More specifically, and referring to FIGS. 3 and 4, the generally cylindrical outer surface **102** of the lower insulating ring **62** is in press-fit engagement with the generally cylindrical interior surface of the upper portion **84** of the outer nozzle member **60**, and the generally cylindrical inner surface **104** of the lower insulating ring **62** is in press-fit engagement with the generally cylindrical exterior surface of the upper portion **70** of the inner nozzle member **54**, to provide an upper press-fit connection. The press-fitting of the lower insulating ring **62** to the outer nozzle member **60** is at least partially facilitated by an annular chamfered portion **109** (FIG. 3) of the interior surface of upper portion **84** of outer nozzle member **60**.

In accordance with the first embodiment of the invention, the upper surface **106** of the lower insulating ring **62** abuts a portion of the lower surface **110** of the upper insulating ring **64**. The portion of the upper insulating ring **64** that extends radially away from the lower insulating ring **62** is fit between the shoulder **80** of the inner nozzle member **54** and the shoulder **94** of the outer nozzle member **60**, such that the upper surface **108** of the upper insulating ring **64** abuts the shoulder **80** and the lower surface **110** of the upper insulating ring **64** abuts the shoulder **94**.

The generally cylindrical exterior surface **96** of the insulating swirl ring **56** is in press-fit engagement with the generally cylindrical interior surface of the upper portion **84** of the outer nozzle member **60**, and the generally cylindrical interior surface **100** of the insulating swirl ring **56** is in press-fit engagement with the generally cylindrical exterior surface of the middle portion **71** of the inner nozzle member **54** to provide a lower press-fit connection. The press-fitting of the insulating swirl ring **56** to the inner nozzle member **54** is at least partially facilitated by an annular chamfered portion **111** of the middle portion **71** of the inner nozzle member **54**.

The axially displaced upper and lower press-fit connections are such that the insulating swirl ring **56**, the annular insulating assembly **58**, the inner nozzle member **54**, the gas-constricting bore **78**, the outer nozzle member **60**, and the water-injection bore **90** are coaxially aligned with the longitudinal discharge axis L of the torch body **24**. Further, each of the annular insulating assembly **58** and the insulating swirl ring **56** are constructed of an electrically insulating material, such as plastic or the like, such that the metal inner nozzle member **54** and the metal outer nozzle member **60** are electrically insulated from one another. Therefore, the possibility of double arcing between the metal inner nozzle member **54** and the metal outer nozzle member **60** is reduced. More specifically, the insulating swirl ring **56** and the lower insulating ring **62** may acceptably be constructed of acetal resin, such as that sold under the trademark Delrin by E.I. du Pont de Nemours and Company. The upper insulating ring **64** may acceptably be constructed of paper and/or pressboard insulation sold under the trademark Nomex by E.I. du Pont de Nemours and Company.

It is surprising that the water flowing through the water passageway **92** does not provide a good electrical communication path between the metal inner nozzle member **54** and the metal outer nozzle member **60**. However, the inventor has discovered that the water typically used in water-injection torches is treated to remove contaminates and is of good quality such that the water is a reasonably good electrical insulator. Accordingly, although counterintuitive, it is advantageous to electrically insulate the inner nozzle member **54** and the outer nozzle member **60** from one another by way of the annular insulating assembly **58** and the insulating swirl ring **56**. In this way the inventor has created an insulated press-fit nozzle assembly for a water-injection torch.

Aspects of the insulating swirl ring **56** in addition to those discussed above are best seen in FIG. 2 and the sectional views of FIGS. 4 and 5. The insulating swirl ring **56** defines at least one, and preferably a plurality of tangentially-directed and circumferentially-spaced ports **112** extending inwardly from respective V-shaped notches **114**. The ports **112** are preferably in the form of elongate cylindrical bores that are tangentially-directed with respect to an imaginary circle that is coaxial with the longitudinal discharge axis L. As illustrated, the insulating swirl ring **56** defines twice as many circumferentially arranged V-shaped notches **114** as ports **112**, as will be discussed below. Each port **112** preferably extends from a flat surface defining a V-shaped notch **114** to the interior surface **98** of the insulating swirl ring **56**. The ports **112** may be formed by drilling, and it is advantageous to drill into a flat surface of a V-shaped notch **114**, because it can be difficult to drill into a non-flat surface.

As best seen in FIG. 1, once the water-injection nozzle assembly **22** is configured as illustrated in FIG. 3, the nozzle assembly **22** is then positioned within the cavity **28** of the torch body **24** against an O-ring **116** and over the electrode **25**. Thereafter, the nozzle assembly retaining cup **26** is secured onto the torch body **24** such that the nozzle assembly **22** is held firmly between the lower edge of the gas baffle **50** and a lower shoulder **118** on the nozzle assembly retaining cup **26** against the annular ring **66**. The annular ring **66** abuts an annular attachment shoulder **121** of the nozzle assembly **22**, which in accordance with the first embodiment is defined by the outer nozzle member **60**. The annular ring **66** and the O-ring **116** seal the water inlet passageway **32** and the gas inlet passageway **34**, respectively.

As indicated by the arrows in FIGS. 3-5, the injection water, preferably from an external source (not shown), flows through the water inlet passageway **32** into an annular chamber **122** (FIG. 1) defined between the nozzle assembly **22** and the nozzle assembly retaining cup **26**. The injection water is directed through at least one, and preferably multiple radially extending, circumferentially-spaced holes **124** in the outer nozzle member **60** and into a somewhat cylindrical chamber **126** (FIG. 3) between the inner nozzle member **54** and the outer nozzle member **60** above the insulating swirl ring **56**. The injection water passes through the ports **112** in the insulating swirl ring **56**, and thereafter into the water passageway **92** to form a swirling vortex of water in the water-injection bore **90**. The orientation of the tangentially-directed and circumferentially-spaced ports **112** causes the swirling vortex of water. The swirling vortex of injection water further constricts the plasma arc exiting the gas-constricting bore **78** in the direction of the workpiece to provide "higher quality" cuts, such as cuts having a more square edge.

FIG. 6 is a cross-sectional view of a water-injection nozzle assembly **22** in accordance with an alternative embodiment of the invention. The nozzle assembly **22** of FIG. 6 is sectioned similarly to the nozzle assembly **22** of FIG. 5. The insulating swirl ring **56** may be molded from plastic, and the mold may be constructed such that when the swirl ring **56** is removed from the mold it contains all of the V-shaped notches **114**, but does not contain the ports **112**. Thereafter, the ports **112** may be formed with respect to a first group of the V-shaped notches **114** so that the swirling vortex of water provided by the swirl ring **56** rotates clockwise, as illustrated in FIG. 5. Alternatively, the ports **112** may be formed with respect to a second group of the V-shaped notches **114** so that the swirling vortex of water provided by the swirl ring **56** rotates counter-clockwise, as illustrated in FIG. 6. The first group of V-shaped notches **114** are positioned so that the ports **112** extending perpendicularly from the appropriate flat surfaces of the first group of V-shaped notches are positioned to optimumly provide a clockwise vortex, as illustrated in FIG. 5. The second group of V-shaped notches **114** are positioned so that the ports **112** extending perpendicularly from the appropriate flat surfaces of the second group of V-shaped notches are positioned to optimumly provide a counter-clockwise vortex, as illustrated in FIG. 6. As illustrated in both of FIGS. 5 and 6, the ports **112** are straight and tangential to an imaginary circle centered about the longitudinal discharge axis L. That imaginary circle has a diameter that is smaller than the diameter of the interior surface **98** (FIG. 2) of the insulating swirl ring **56** and larger than the diameter of the portion of the inner nozzle member **54** that is cross-sectioned in FIGS. 5 and 6.

In accordance with an alternative embodiment of the invention, the swirl ring **56** is constructed of an electrically insulating material such as plastic, or the like, and is shaped like the swirl ring disclosed in U.S. Patent Number 5,747,767, which is incorporated herein by reference.

Throughout all of the embodiments of the invention, the inner nozzle member **54** can be constructed of copper and the outer nozzle member **60** can be constructed of brass. Alternatively, however, the inner nozzle member **54** and the outer nozzle member **60** can both be constructed of copper. Brass has a lower melting point than copper and thus damages more easily. In addition, because copper has a higher coefficient of conductive heat transfer than brass, an outer nozzle member **60** constructed of copper more efficiently dissipates heat than an outer nozzle member **60** constructed of brass. Thus, molten material splattered from a workpiece onto an outer nozzle member **60** constructed of copper cools more rapidly than molten material on an outer nozzle member **60** constructed of brass and is less likely to be damaged.

The torch **20** illustrated in FIGS. 1-3 is of a type that is especially useful in forming beveled cuts. More specifically, in accordance with the first embodiment the nozzle members **54, 60** extend a substantial distance along the longitudinal discharge axis L. Further, the angle formed between the exterior surface **74** of the lower portion **44** of the inner nozzle member **54** and the longitudinal discharge axis L is preferably equal to the angle formed between the interior surface **88** of the lower portion **86** of the outer nozzle member **60** and the longitudinal discharge axis L. Those angles are less than about **60** degrees, and preferably less than about 45 degrees. In one specific embodiment, the angles are about 34 degrees, which permits the frusto conical portions of the inner nozzle member **54** and the outer nozzle member **60** to have a significant longitudinal extent. The distance D (FIG. 1) between the lower edge **128** of nozzle assembly retaining cup **26** and the lower end **38** of the extended water-injection nozzle assembly **22** is thus sufficient to permit the torch **20** to produce a bevel cut or weld, and a cut or weld within a sharp concavity on the top surface of the workpiece at a relatively short, predetermined stand-off distance. Typically, the distance D is on the order of 0.9 inches while the predetermined stand-off distance to produce the best quality and speed of cut or weld is typically on the order of 0.375 inches. Accordingly, a plasma arc torch provided with the extended water-injection nozzle assembly **22** illustrated in FIGS. 1-3 has the ability to produce a bevel cut or weld, and a cut or weld within a sharp concavity on the top surface of the workpiece, at a relatively short stand-off distance while centering and maintaining the concentricity of the water-injection bore **90** relative to the gas-constricting bore **78**, and electrically insulating the inner nozzle member **54** from the outer nozzle member **60**. Whereas the advantages relating to concentricity and insulating that are provided by the pair of axially displaced and press-fit annular insulating elements **56**, **58** are illustrated in the context of a torch with a substantial distance D, those advantages can also be achieved in a torch with a smaller distance D.

SECOND EMBODIMENT

FIGS. 7-9 illustrate components of a plasma arc torch **20** and a water-injection nozzle assembly **22** in accordance with a second embodiment of the invention. The components of the plasma arc torch **20** and the nozzle assembly **22** of the second embodiment are substantially similar to the corresponding components of the first embodiment of the invention, except for disclosed variations and variations that will be apparent to those skilled in the art in view of this disclosure.

As best seen in FIG. 8, the nozzle assembly **22** of the second embodiment does not include an insulating swirl ring (for example see the insulating swirl ring **56** of FIGS. 1-6). Further, the annular inner and outer nozzle members **54**, **60** of the second embodiment are shaped differently than in the first embodiment, and the nozzle assembly **22** of the second embodiment further includes an annular outer insulating element **130** attached to and extending substantially along a radially exterior surface **132** of the outer nozzle member **60**. The outer insulating element **130** functions in conjunction with the annular insulating assembly **58** so that the possibility of double arcing between the nozzle members **54**, **60** is even further reduced.

The outer insulating element **130** is coaxial with the longitudinal discharge axis L of the torch **20**. The outer insulating element **130** defines a bore **135** aligned with the longitudinal discharge axis L, and through which the plasma arc extends when the torch **20** is operating. The outer insulating element **130** defines the annular attachment shoulder **121** that cooperates with the annular ring **66** (FIG. 7) and the lower shoulder **118** (FIG. 7) of the nozzle assembly retaining cup **26** to secure the nozzle assembly **22** to the torch body **24**.

The outer insulating element **130** is held into place by an O-ring **134**, which engages an attachment shoulder on the outer insulating element **130** and a corresponding attachment shoulder on the outer nozzle member **60**. The outer insulating element **130** is pressed onto the outer nozzle member **60**, which compresses the O-ring **134** so that the O-ring interacts with the attachment shoulder on the outer insulating element **130** and the attachment shoulder on the outer nozzle member **60** to retain outer insulating element **130** onto the outer nozzle member **60**. The O-ring **134** not only retains the outer insulating element **130** in place, but also seals between the outer insulating element **130** and the exterior surface **132** of the outer nozzle member **60** to prevent water exiting the water-injection bore **90** from passing between the outer nozzle member and the outer insulating element. Additionally or alternatively, the outer insulating element **130** may be attached to the outer nozzle member **60** by an adhesive substance, such as heat-resistant glue, or the like.

The outer insulating element **130** is preferably formed from a thermal and electrically insulating material, such as ceramic or plastic. An acceptable ceramic material is alumina, and an acceptable plastic material is polyetheretherkeytone (PEEK). The O-ring **134** may be formed from a variety of materials, such as silicone rubber or neoprene.

The inner nozzle member **54**, annular insulating assembly **58**, and outer nozzle member **60** are press-fit together so that the nozzle assembly **22** is assembled as illustrated in FIGS. 7 and 8. That press-fit arrangement is facilitated by numerous surfaces being press-fit together. More specifically, and referring to FIG. 8, the generally cylindrical outer surface **102** of the lower insulating ring **62** is in press-fit engagement with a generally cylindrical interior surface **136** of the outer nozzle member **60**, and the generally cylindrical inner surface **104** of the lower insulating ring **62** is in press-fit engagement with a generally cylindrical exterior surface **138** of the inner nozzle member **54**. The press-fitting of the lower insulating ring **62** to the outer nozzle member **60** is at least partially facilitated by the annular chamfered portion **109** of the interior surface of the outer nozzle member **60**. A lower annular surface **140** (also see FIG. 2) of the lower insulating ring **62** abuts an annular shoulder **142** of the outer nozzle member **60**. The annular shoulder **142** extends radially inward from the cylindrical inner surface **136** of the outer nozzle member **60**. The annular shoulder **142** and the cylindrical inner surface **136** at least partially define an annular channel that receives the lower insulating ring **62**.

The upper insulating ring **64** can be characterized as being part of the press-fit connection between the inner and outer nozzle members **54**, **60**, although in some embodiments that press-fit connection may not include the upper insulating ring **64**. In accordance with the second embodiment of the invention, the upper surface **106** of the lower insulating ring **62** abuts a portion of the lower surface **110** of the upper insulating ring **64**. The portion of the upper insulating ring **64** that extends radially away from the lower insulating ring **62** is fit between the shoulder **80** of the inner nozzle member **54** and the shoulder **94** of the outer nozzle member **60**, such that the upper surface **108** of the upper insulating ring **64** abuts the shoulder **80** and the lower surface **110** of the upper insulating ring **64** abuts the shoulder **94**.

The press-fit connection is such that the annular insulating assembly **58**, the inner nozzle member **54**, the gas-constricting bore **78**, the outer nozzle member **60**, and the water-injection bore **90** are coaxially aligned with the longitudinal discharge axis L of the torch body **24**; the metal inner nozzle member **54** and the metal outer nozzle member 60 are electrically insulated from one another; and the annular water passageway **92** is defined between the nozzle members **54**, **60**.

As best seen in FIG. 9, the outer nozzle member **60** defines at least one, or more preferably a plurality of tangentially-directed and circumferentially-spaced ports **144**. The ports **144** are preferably in the form of elongate cylindrical bores that are tangentially-directed with respect to an imaginary circle that is coaxial with the longitudinal discharge axis L. The ports **144** communicate with the annular chamber **122** (FIG. 7) defined between the nozzle assembly **22** and the nozzle assembly retaining cup

26. The injection water from the annular chamber **122** passes through the ports **144** into the water passageway **92** to form a swirling vortex of water in the water-injection bore **90**. The orientation of the tangentially-directed and circumferentially-spaced ports **144** causes the swirling vortex of water. The inlet openings of the ports **144** communicate with the annular chamber **122**.

THIRD EMBODIMENT

FIG. 10 is a sectional elevation view of a water-injection nozzle assembly **22** in accordance with a third embodiment of the invention. The torch **20** and nozzle assembly **22** of the third embodiment of the invention are substantially similar to the torch **20** and the nozzle assembly **22** of the second embodiment, except for disclosed variations and variations that will be apparent to those skilled in the art in view of this disclosure.

As illustrated in FIG. 10, the nozzle assembly **22** of the third embodiment does not include an outer insulating element and associated O-ring (for example see the outer insulating element **130** and O-ring **134** of FIG. 8). Rather, as compared to the outer nozzle member **60** of the second embodiment, the outer nozzle member **60** of the third embodiment is shaped differently and enlarged, and includes the annular attachment shoulder **121**.

FOURTH EMBODIMENT

FIG. 11 is a partial, sectional elevation view of a water-injection nozzle assembly **22** in accordance with a fourth embodiment of the invention. The torch **20** and nozzle assembly **22** of the fourth embodiment of the invention are substantially similar to the torch **20** and the nozzle assembly **22** of the third embodiment, except for disclosed variations and variations that will be apparent to those skilled in the art in view of this disclosure. For example, in accordance with the fourth embodiment the annular insulating element **58** is unitary, meaning that it is absent of separate but joinable parts.

FIFTH EMBODIMENT

FIGS. 12-13 illustrate a water-injection nozzle assembly **22** in accordance with a fifth embodiment of the invention. The torch **20** and nozzle assembly **22** of the fifth embodiment are substantially similar to the torch **20** and the nozzle assembly **22** of the third embodiment, except for disclosed variations and variations that will be apparent to those skilled in the art in view of this disclosure. For example, rather than including bored ports **144** (FIG. 8 and 9) as in the third embodiment, the outer nozzle member **60** has at least one, and preferably multiple (e.g., four) tangentially-directed and circumferentially-spaced slots **146** that extend vertically downward into the outer nozzle member **60** from the annular upper shoulder **94** (also see FIG. 2) of the outer nozzle member **60**. The slots **146** may be formed by milling vertically downward into the outer nozzle member **60** from the annular upper shoulder **94**.

When the nozzle assembly **22** of the fifth embodiment is assembled as illustrated in FIGS. 12-13, the insulating ring **62** partially closes each slot **146**, but does not completely fill each slot **146**. As a result, portions of the lower annular surface **140** (also see FIG. 2) of the lower insulating ring **62** that are opposite from the portions of the outer nozzle member **60** that define the bottom of each slot **146** at least partially define the multiple tangentially-directed and circumferentially-spaced ports **144** of the fifth embodiment.

As mentioned previously, the injection water from the annular chamber **122** (FIG. 13) passes through the ports **144** into the water passageway **92** (FIG. 13) to form a swirling vortex of water in the water-injection bore **90**. The orientation of the tangentially-directed and circumferentially-spaced ports **144** causes the swirling vortex of water. The inlet openings of the ports **144** communicate with the annular chamber **122** when the torch **20** of the fifth embodiment is fully assembled.

In accordance with the fifth embodiment, and other embodiments, it may be preferable for the annular insulating assembly **58** not to include the upper insulating ring **64**. In such a configuration, the vertical thickness of the lower insulating ring **62** may be increased so that the annular upper surface **106** (see FIG. 2) of the insulating ring **62** engages the annular shoulder **80** (see FIG. 2) of the inner nozzle member **54** to maintain a space between the annular shoulder **80** and the annular shoulder **94** (see FIG. 2) of the outer nozzle member **60**.

SIXTH EMBODIMENT

FIG. 14 illustrates a water-injection nozzle assembly **22** in accordance with a sixth embodiment of the invention. The torch **20** and nozzle assembly **22** of the sixth embodiment of the invention are substantially similar to the torch **20** and the nozzle assembly **22** of the third embodiment, except for disclosed variations and variations that will be apparent to those skilled in the art in view of this disclosure. For example, in accordance with the sixth embodiment, the annular insulating assembly **58** does not include the upper insulating ring **64** (FIG. 2), and the vertical thickness of the insulating ring **62** is increased so that the annular upper surface **106** of the insulating ring **62** engages the annular shoulder **80** of the inner nozzle member **54** to maintain an annular space between the annular shoulder **80** and the annular shoulder **94** of the outer nozzle member **60**.

In accordance with the sixth embodiment, rather than the outer nozzle member **60** including the ports **144** (see FIGS. 8 and 9) as in the third embodiment, the insulating ring **62** defines at least one or preferably a plurality (e.g., four) of the ports **144**, and corresponding V-shaped notches **148** that function as inlets to the ports **144**. As mentioned previously, the injection water from the annular chamber **122** (FIG. 7) passes through the ports **144** into the water passageway **92** to form a swirling vortex of water in the water-injection bore **90**. The orientation of the tangentially-directed and circumferentially-spaced ports **144** causes the swirling vortex of water. The inlet openings of the ports **144** (i.e., the V-shaped notches **148**) communicate with the annular chamber **122** when the torch **20** of the sixth embodiment is fully assembled.

The insulating ring **62** of the sixth embodiment can be characterized as being shaped and constructed substantially similarly to the insulating swirl ring **56** (FIGS. 1-6). In this analogy, the ports **144** of the insulating ring **62** correspond to the ports **112** (FIGS. 2-6) of the swirl ring **56**, and the V-shaped notches **148** of the insulating ring **62** correspond to the V-shaped notches **114** (FIGS. 2-6) of the swirl ring **56**. Further, in accordance with the sixth embodiment, the generally cylindrical inner surface **104** of the insulating ring **62** is not radially tiered like the cylindrical inner surfaces **98**, **100** (FIG. 2) of the swirl ring **56**.

SEVENTH EMBODIMENT

FIGS. 15-16 illustrate a water-injection nozzle assembly **22** in accordance with a seventh embodiment of the invention. The torch **20** and nozzle assembly **22** of the seventh embodiment of the invention are substantially similar to the torch **20** and the nozzle assembly **22** of the sixth embodiment, except for disclosed variations and variations that will be apparent to those skilled in the art in view of this disclosure. In accordance with the seventh embodiment, the insulating ring **62** is molded so that the ports **144** and the notches **148** are each exposed along their entire length at the respective outer surface **102** (also see FIG. 3) and lower surface **140** (also see FIG. 3) of the insulating ring **62**. Because the passages **144** are molded and need not be bored, the notches **148** may take on a more rounded shape if desired. Of course in accordance with the seventh embodiment the insulating ring **62** may be molded with a group of the ports **144** and notches **148** that provide clockwise vortical flow, or alternatively a group of ports and notches that provide counter-clockwise vortical flow, as should be understood with reference to FIGS. 5 and 6, and the discussions thereof.

Many modifications and other embodiments of the invention will come to mind to those skilled in the art to which the invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for the purposes of limitation. Additionally, the accompanying drawings are not necessarily to scale; for example, in some cases the chamfered portions **109**, **111** have been exaggerated in an effort to clarify the drawings, and in some cases those chamfered portions are not illustrated.

THAT WHICH IS CLAIMED IS:

1. A water-injection nozzle assembly for a plasma arc torch, comprising:

an inner nozzle member formed of metallic material and comprising a radially exterior surface, wherein said inner nozzle member defines a bore therethrough;

an outer nozzle member formed of metallic material and comprising a radially interior surface, wherein said outer nozzle member is radially outward of said inner nozzle member and defines a bore therethrough that is coaxially aligned with said bore of said inner nozzle member; and

an annular insulating element press-fit between said inner and outer nozzle members such that said inner and outer nozzle members are pressed together in a manner that a water passageway is defined between at least portions of said interior surface of said outer nozzle member and said exterior surface of said inner nozzle member for communicating a flow of water to said bore of said outer nozzle member, wherein said annular insulating element is constructed such that said metallic inner and outer nozzle members are electrically insulated from one another.

2. A water-injection nozzle assembly according to claim 1, wherein said annular insulating element is press-fit to said exterior surface of said inner nozzle member and is also press-fit to said interior surface of said outer nozzle member to provide said press-fit connection between said inner and outer nozzle members.

3. A water-injection nozzle assembly according to claim 1, wherein said inner nozzle member is formed of copper and said outer nozzle member is formed of copper.

4. A water-injection nozzle assembly according to claim 1, wherein said annular insulating element defines at least one port for introducing water into said water passageway, and said port extends in a direction that is generally tangential to an imaginary circle around said longitudinal discharge axis.

5. A water-injection nozzle assembly according to claim 1, wherein:

said outer nozzle member comprises a radially extending shoulder;

said inner nozzle member comprises a radially extending shoulder adjacent to said radially extending shoulder of said outer nozzle member; and

said annular insulating element comprises:

a first ring defining said press-fit connection; and

a second ring extending at least partially radially outwardly from said first ring, wherein said second ring fits between said radially extending shoulder of said outer nozzle member and said radially extending shoulder of said inner nozzle member.

6. A water-injection nozzle assembly according to claim 1, wherein:

said radially interior surface of said outer nozzle member comprises:

a cylindrical surface, and

a shoulder extending radially inward from said cylindrical surface; and

said annular insulating element comprises:

an outer cylindrical surface press-fit to said cylindrical surface of said outer nozzle member, and

a surface extending radially inward from said outer cylindrical surface of said annular insulating element and abutting said shoulder of said outer nozzle member.

7. A water-injection nozzle assembly according to claim 1, further comprising a second annular insulating element press-fit between said inner and outer nozzle members, wherein said second annular insulating element is displaced along said longitudinal discharge axis from said first annular insulating element and is positioned between said first annular insulating element and said bore of said inner nozzle member.

8. A water-injection nozzle assembly according to claim 7, wherein said second annular insulating element is a swirl ring.

9. A water-injection nozzle assembly according to claim 1, wherein:

said outer nozzle member comprises a radially exterior surface; and

said nozzle assembly further comprises an outer insulating element secured onto said exterior surface of said outer nozzle member and extending around and proximate to said bore of said outer nozzle member.

10. A water-injection nozzle assembly according to claim 9, wherein said outer insulating element is constructed of a material selected from the group consisting of ceramic material and plastic material.

11. A water-injection nozzle assembly according to claim 1, wherein said water passageway is in fluid communication with a water inlet passageway that is for receiving said flow of water from an external source.

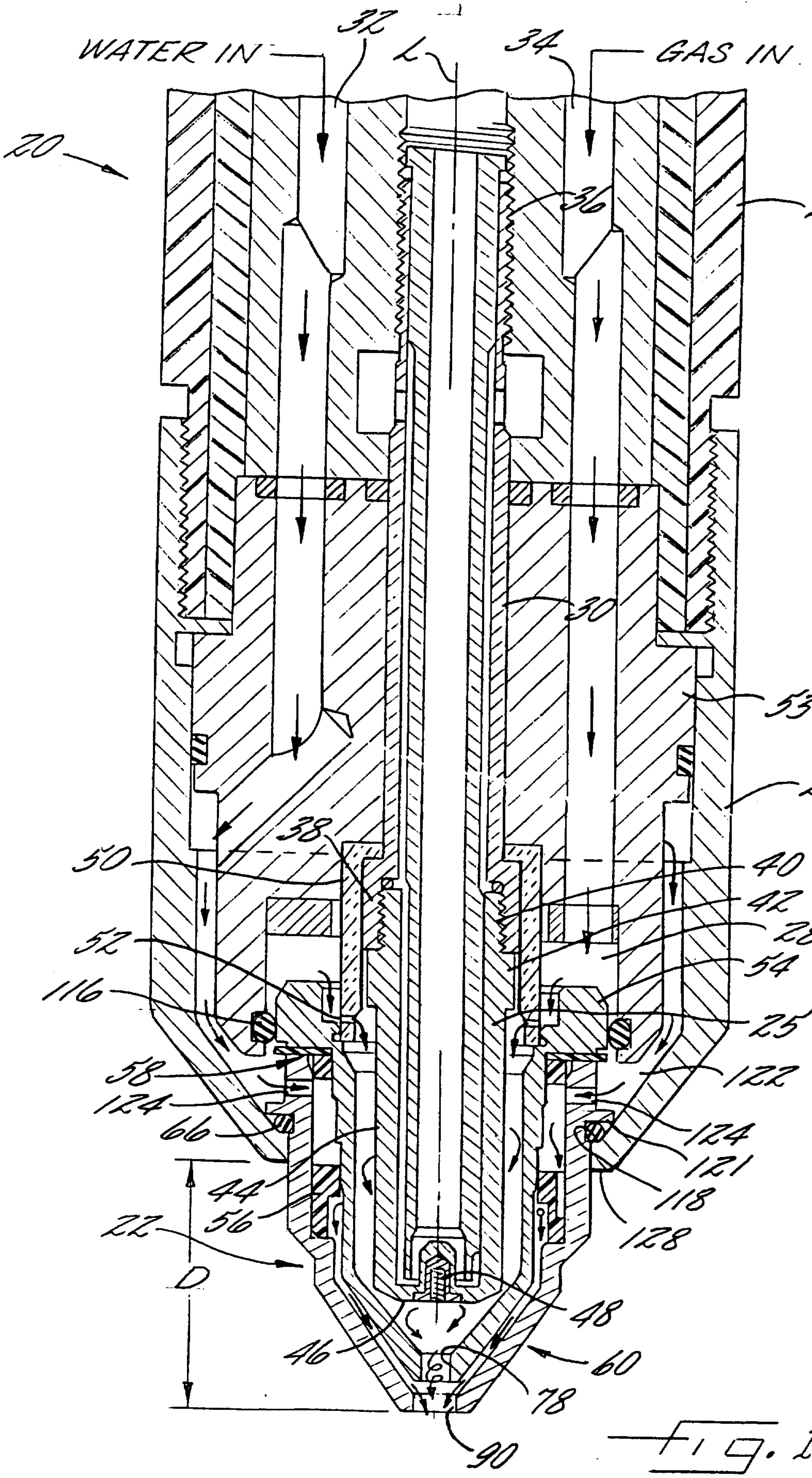
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Fig. 1.

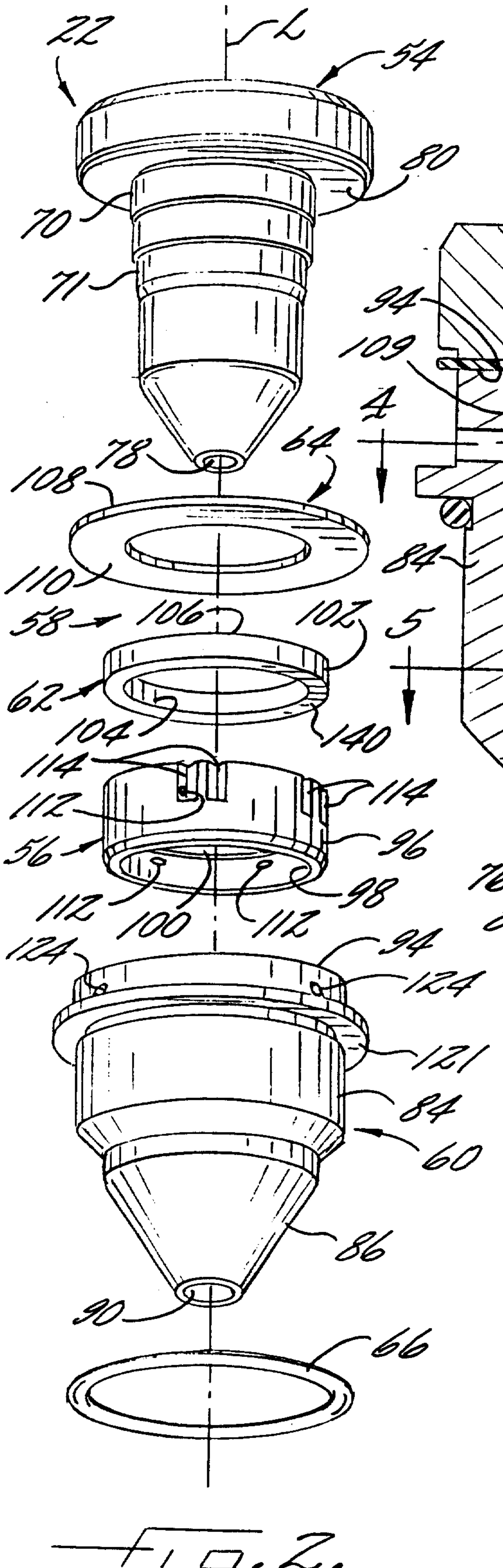

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Fig. 2.

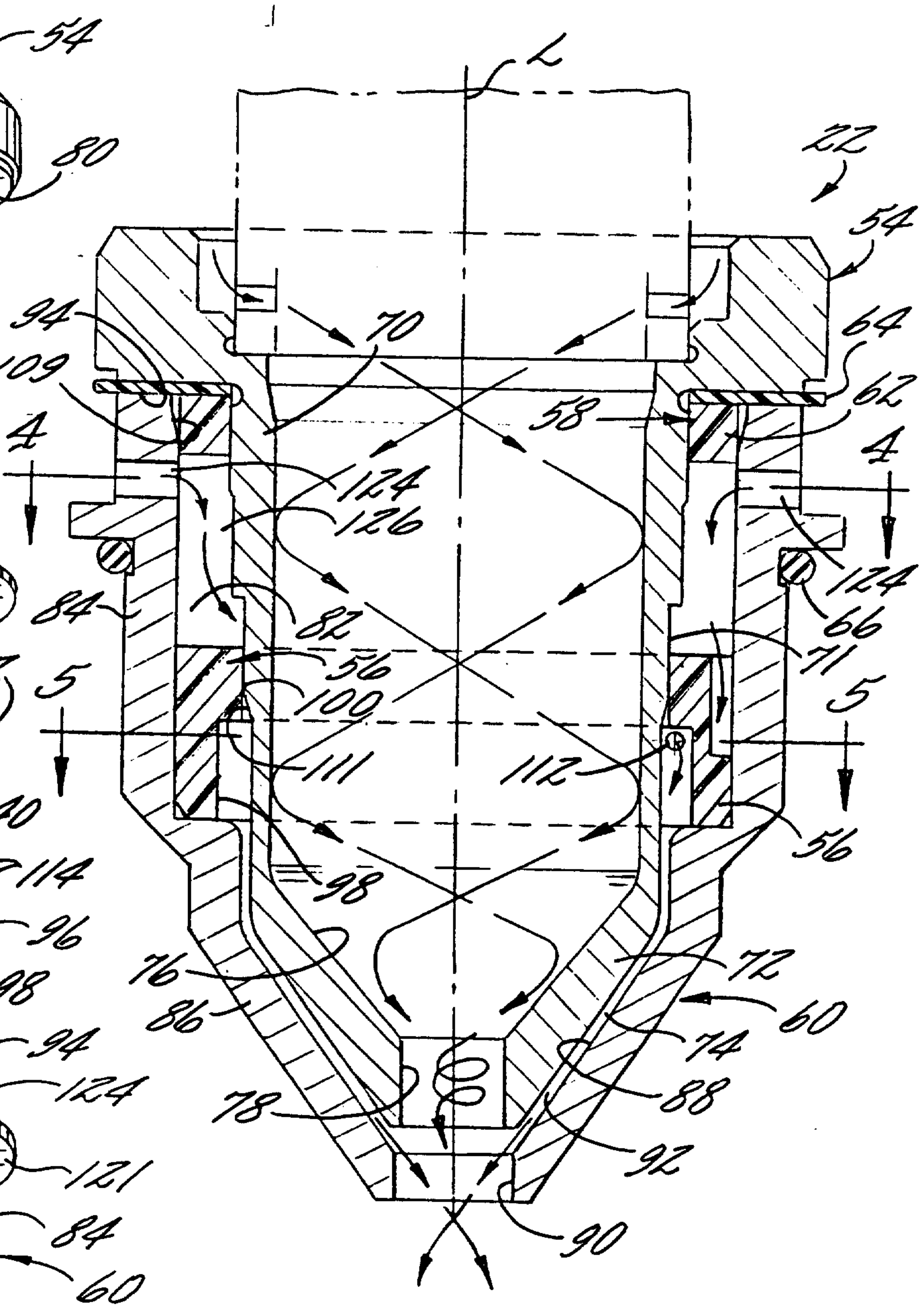

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Fig. 3.

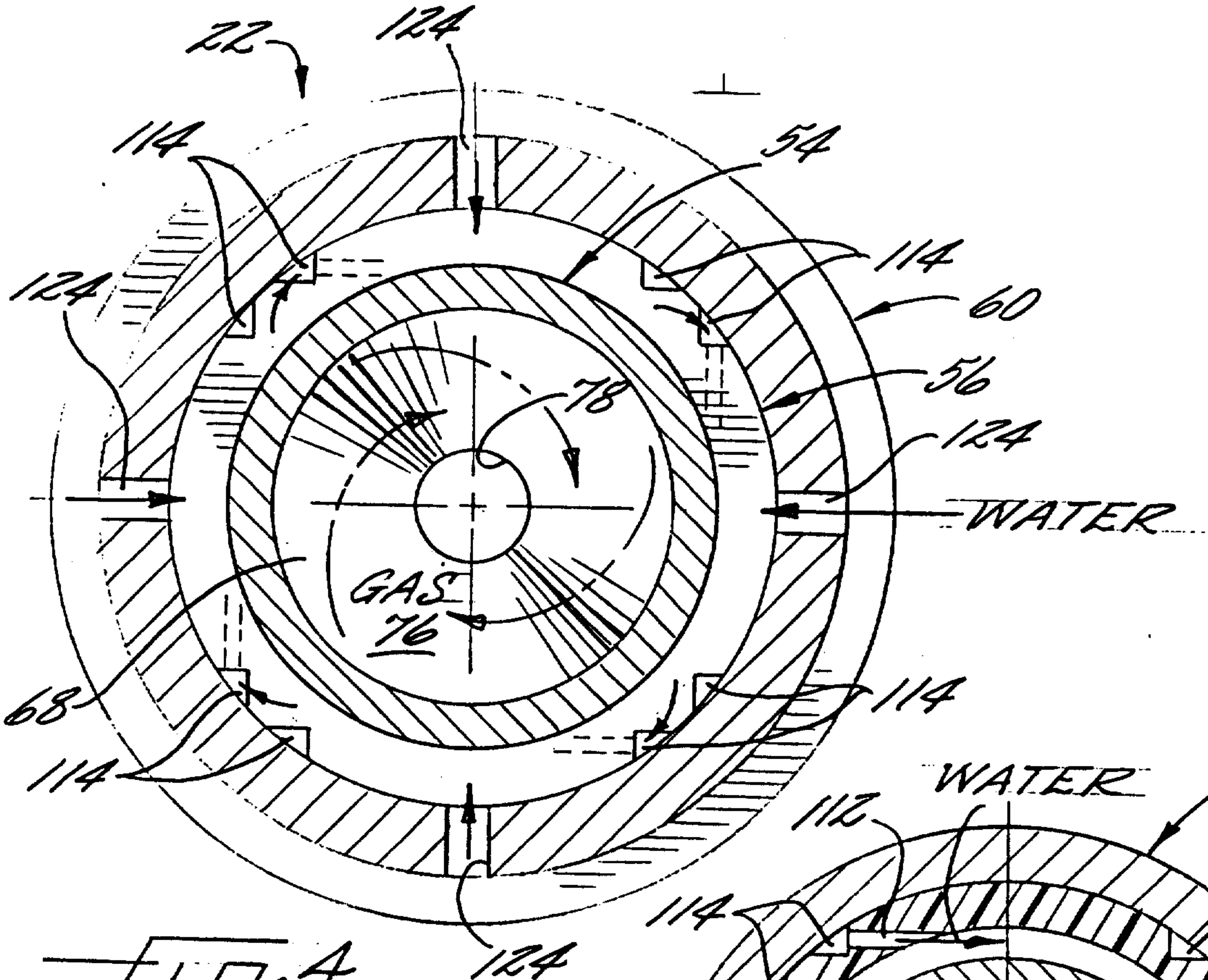

Fig. 4.

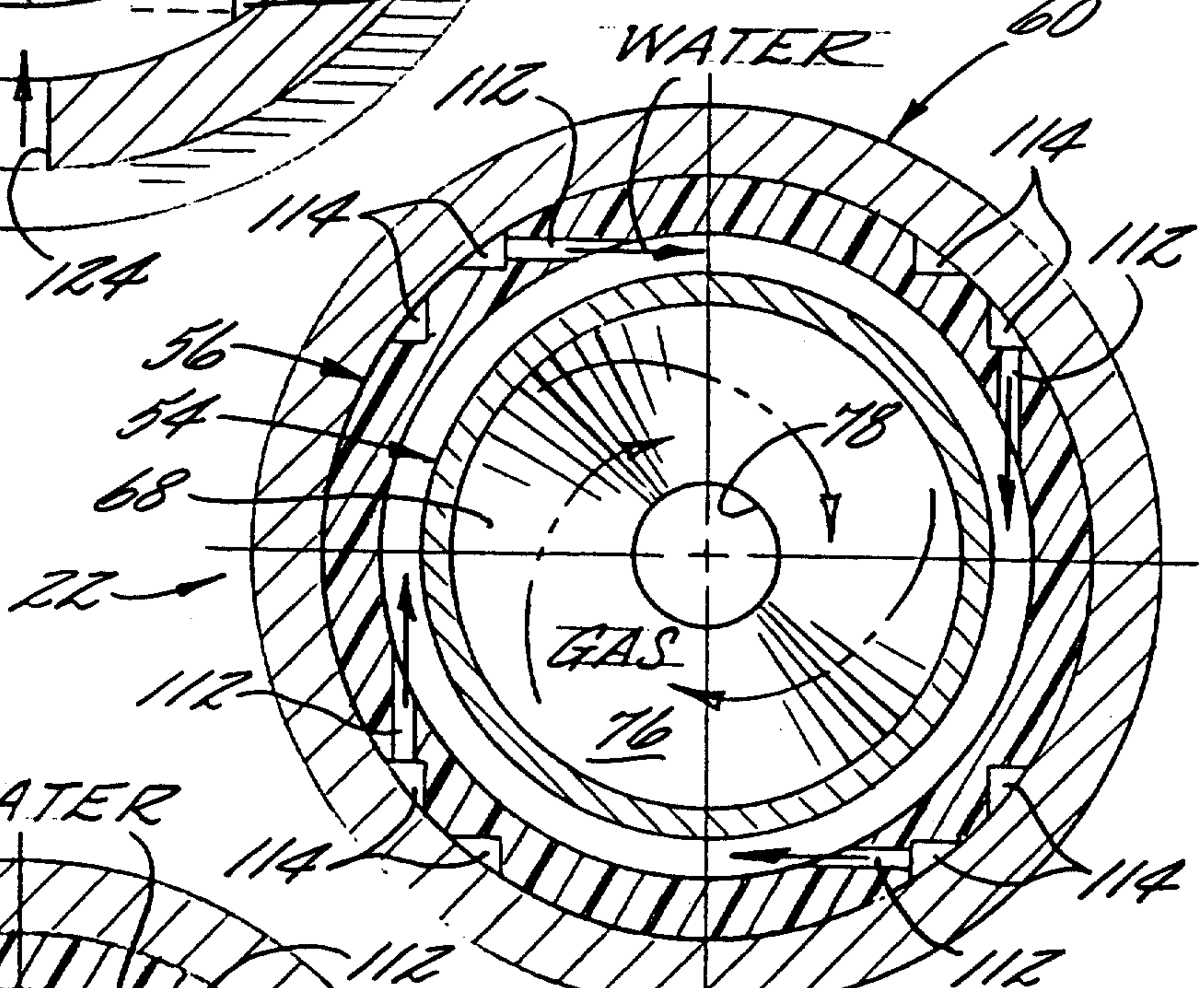

Fig. 5.

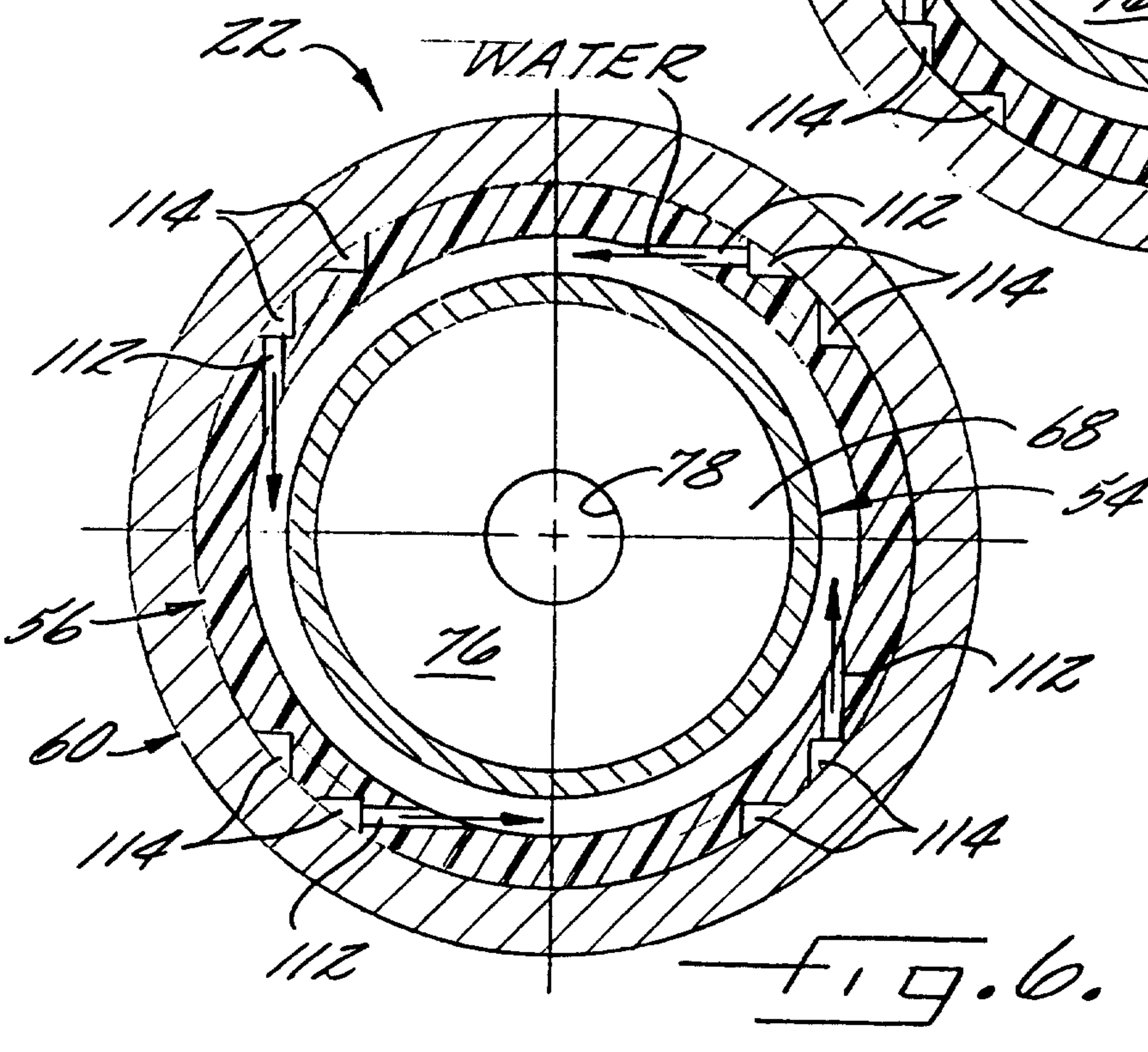

Fig. 6.

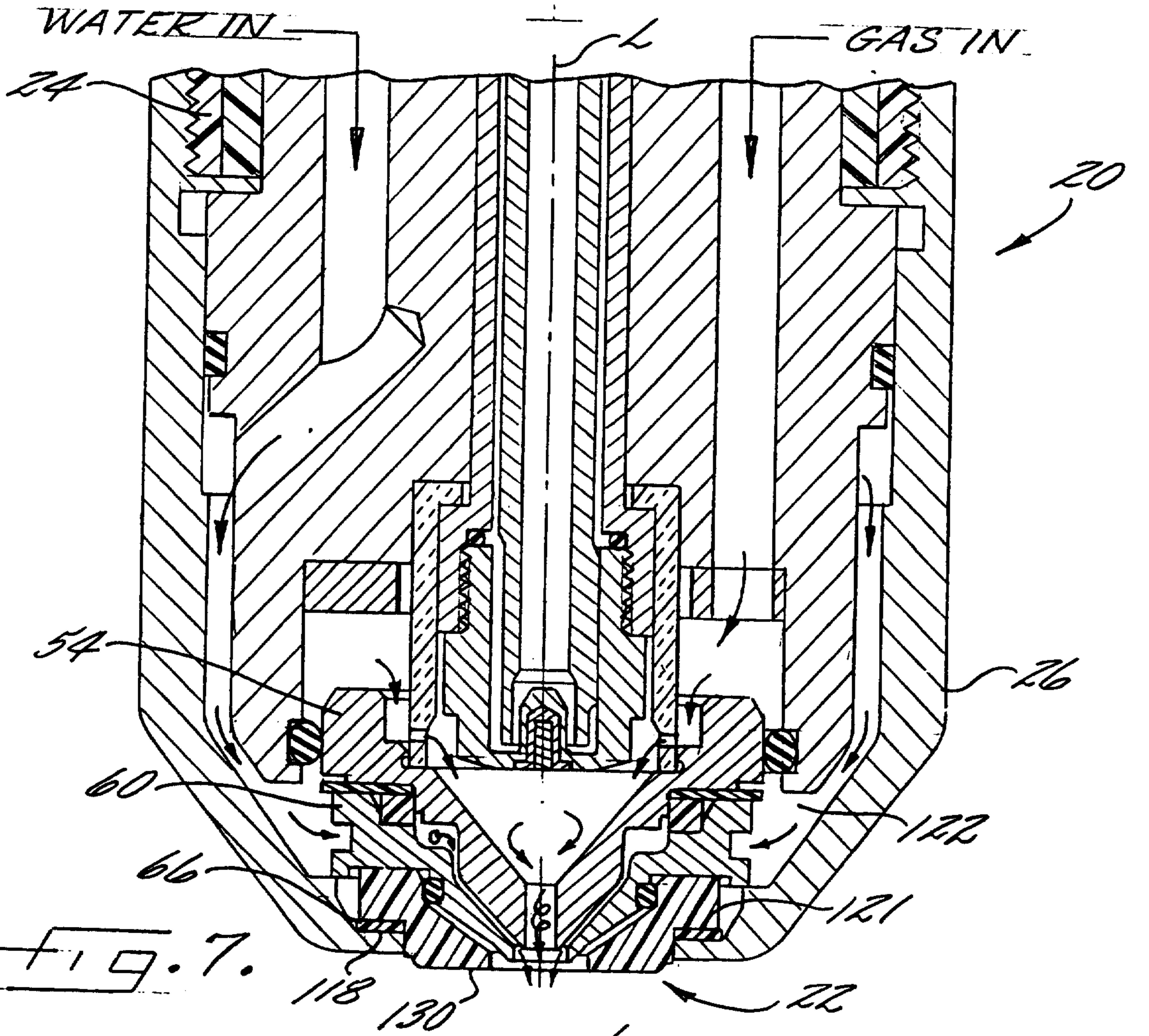
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Fig. 7.

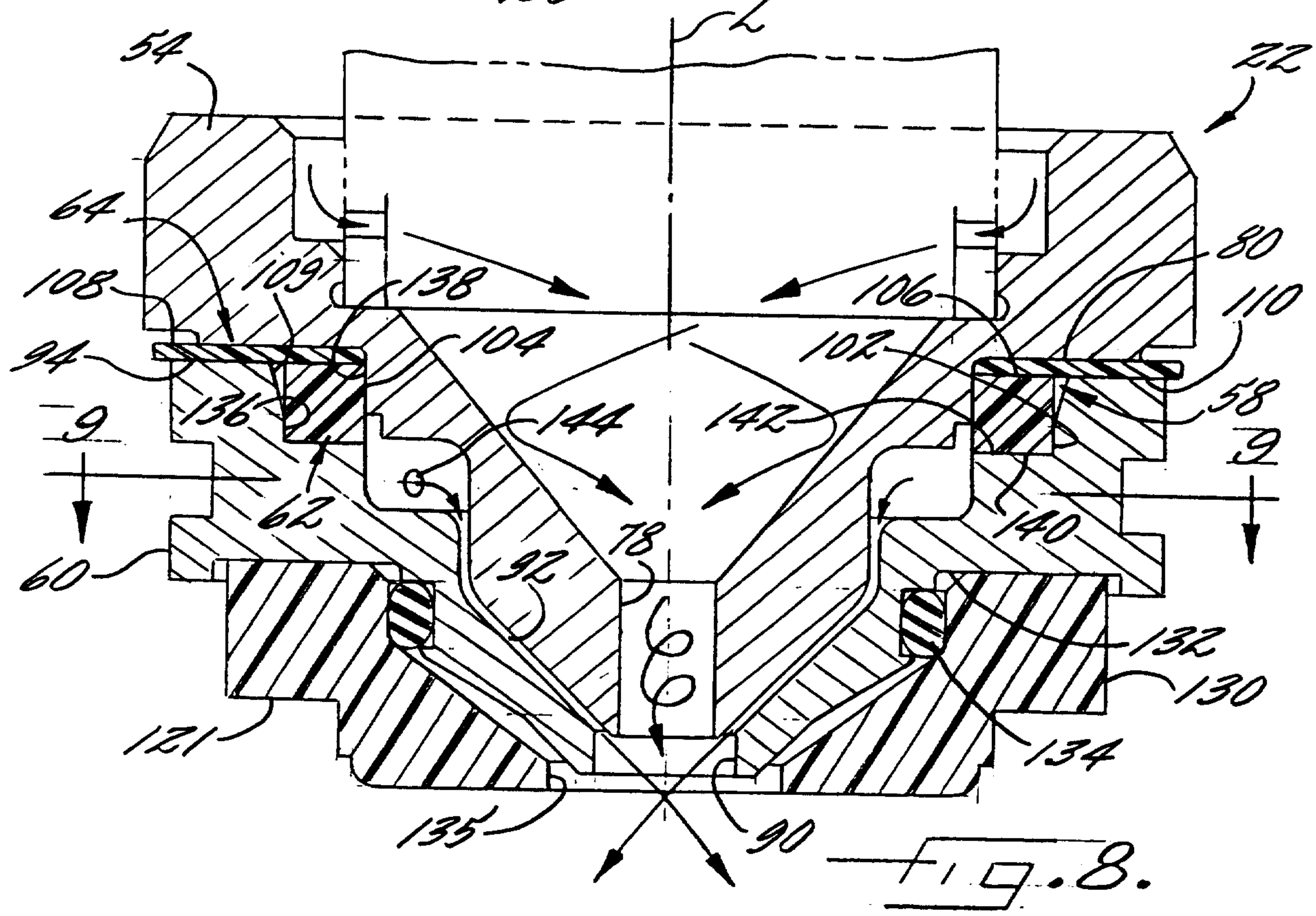
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Fig. 8.

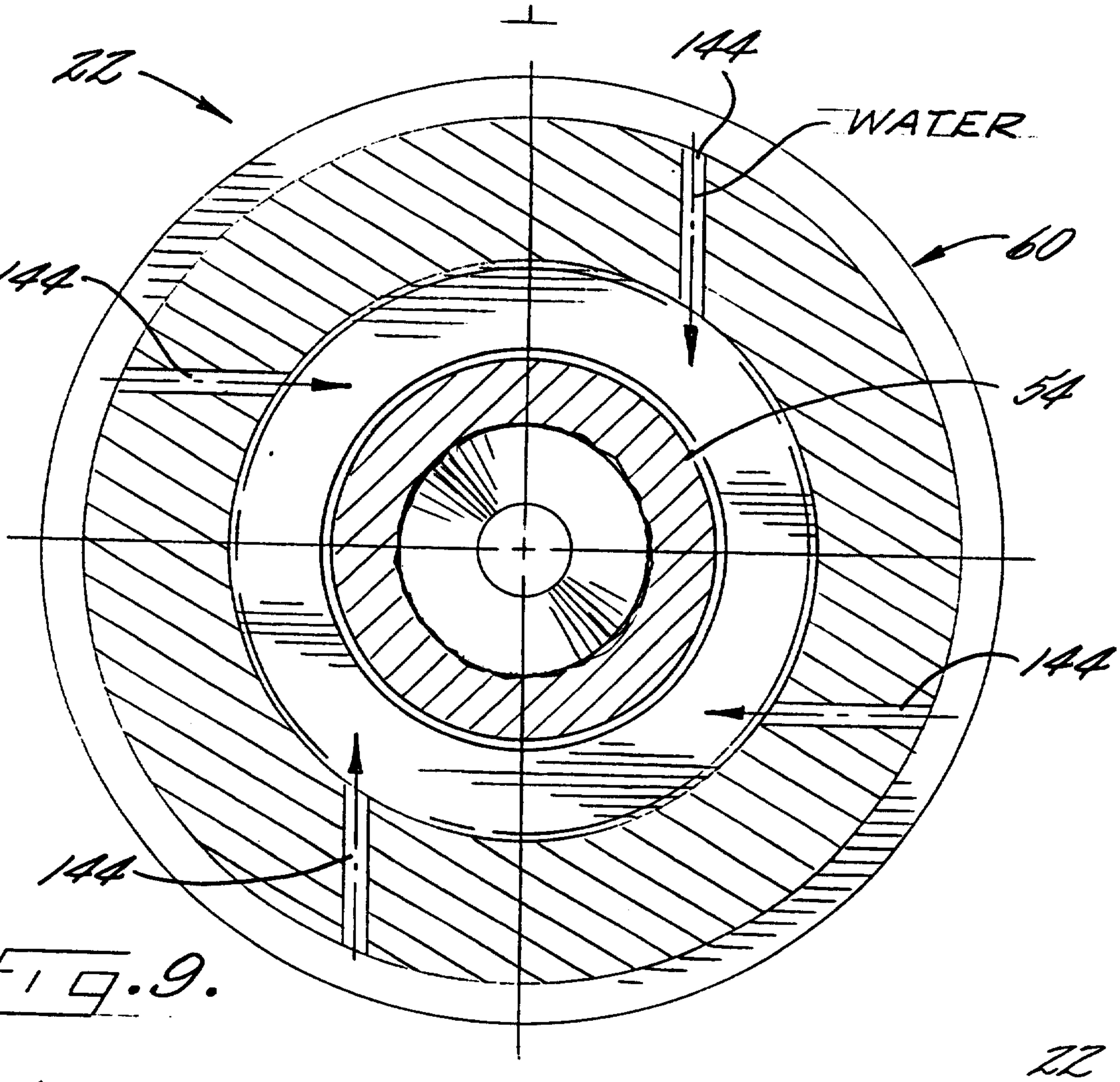


Fig. 9.

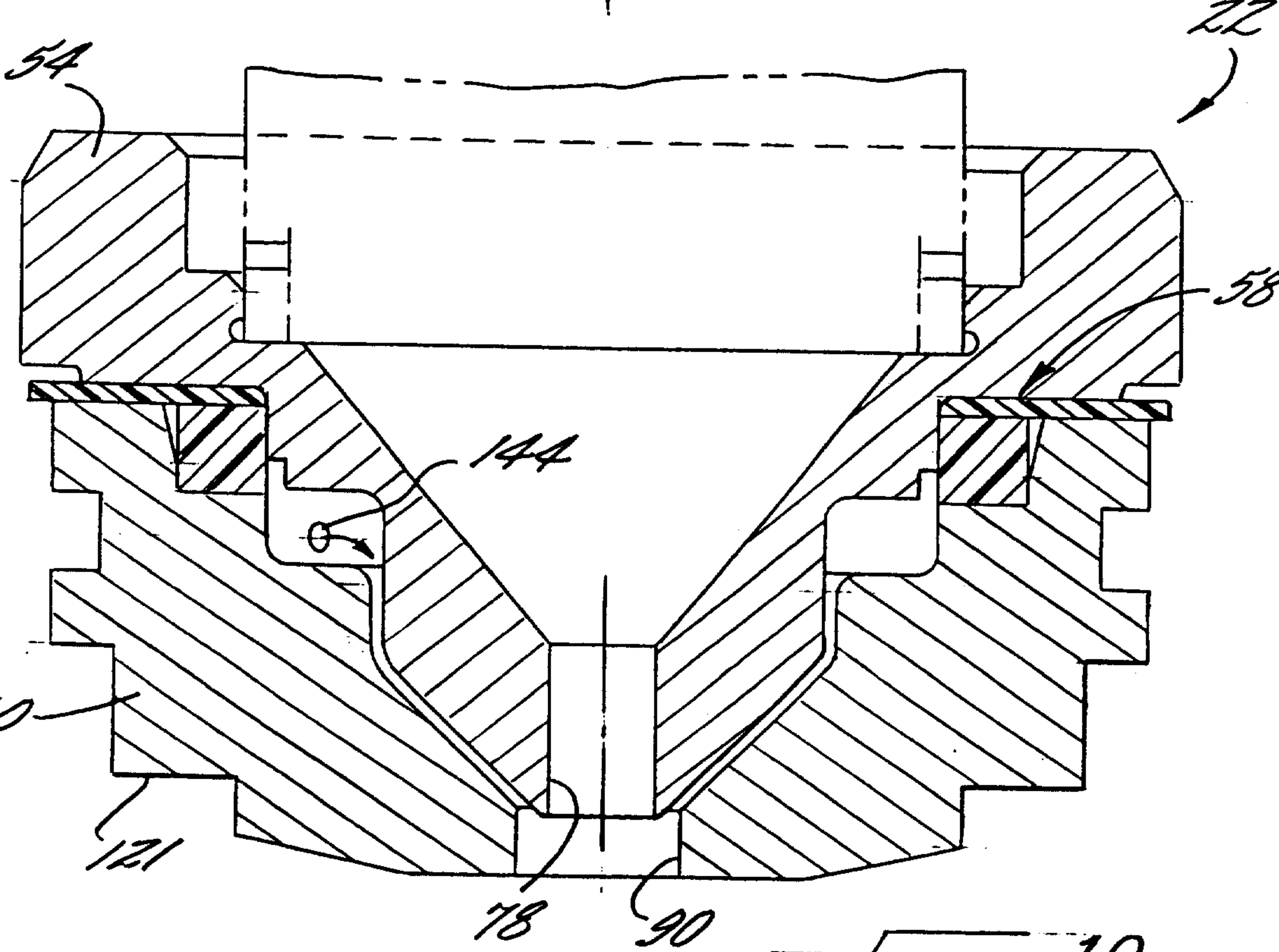


Fig. 10.

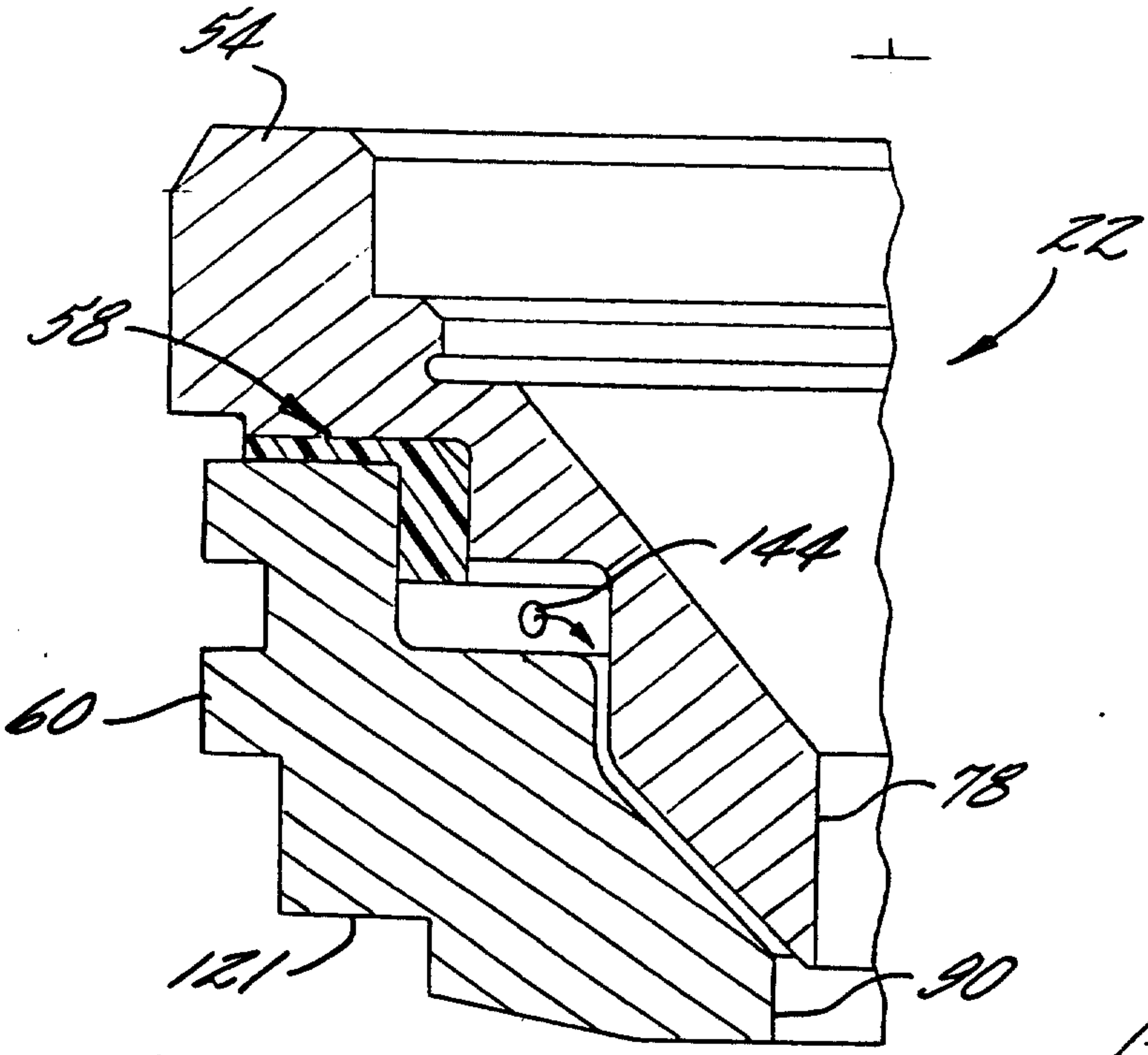


Fig. 11

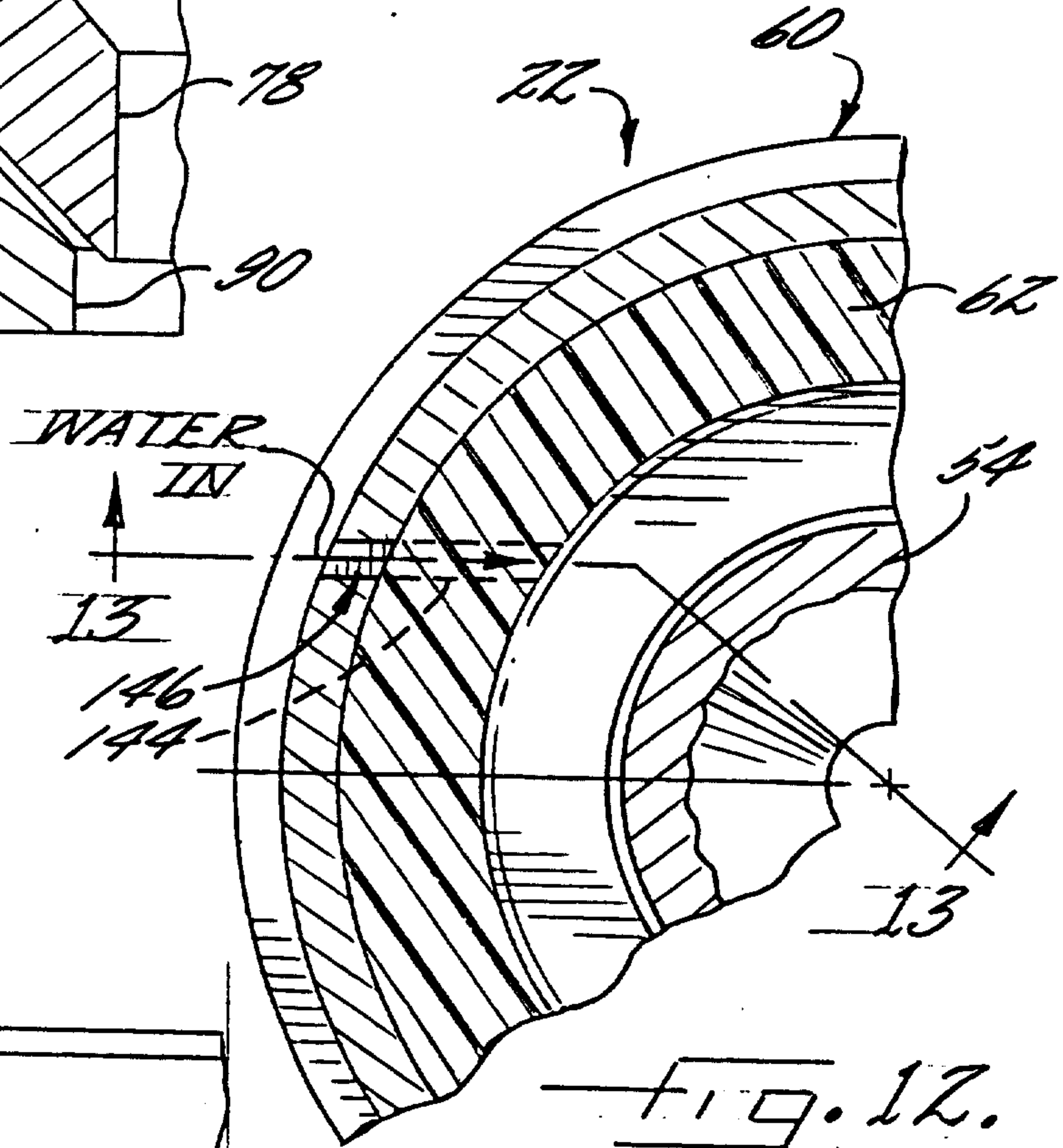


Fig. 12.

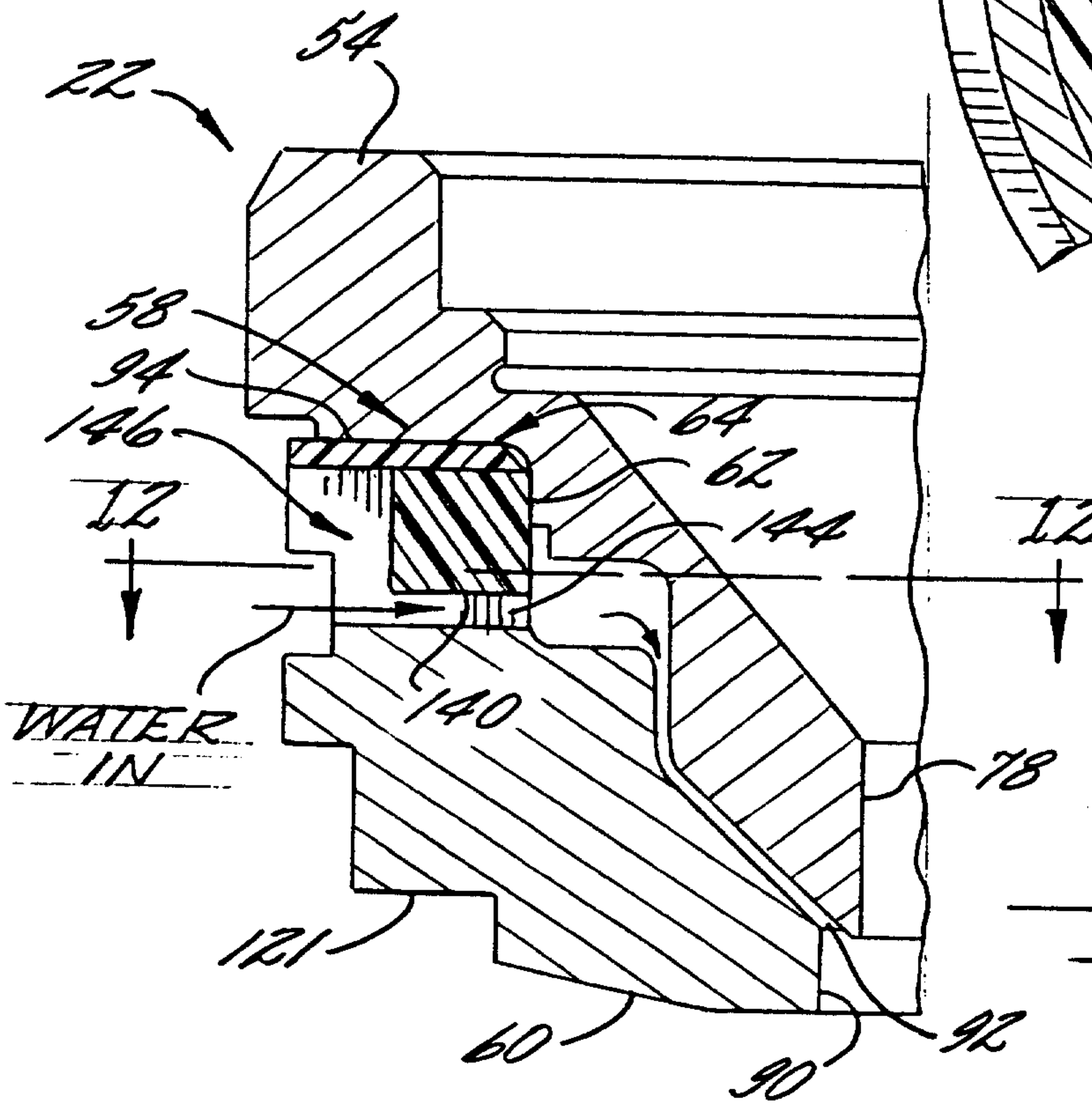


Fig. 13.

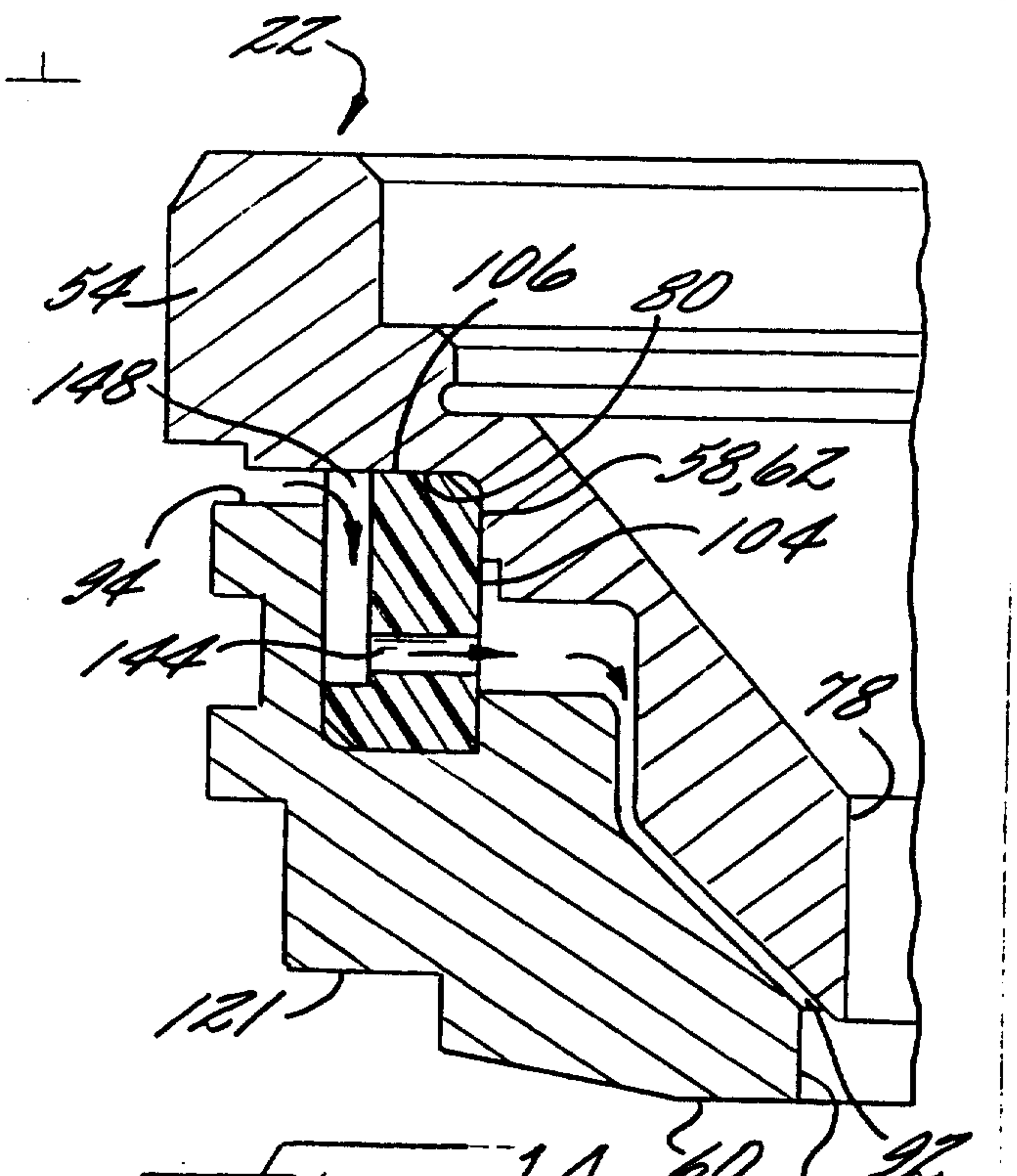


Fig. 14.

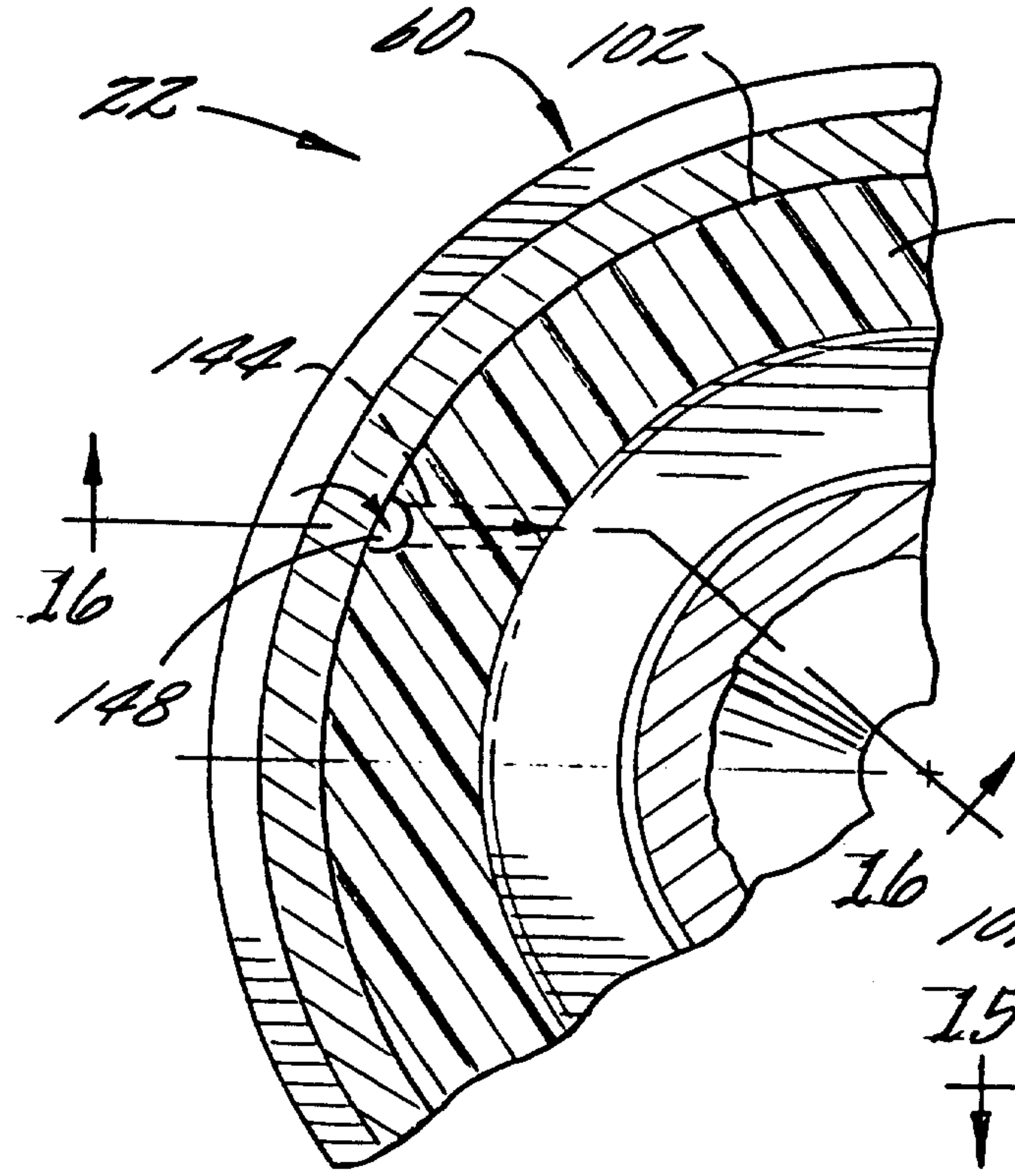


Fig. 15.

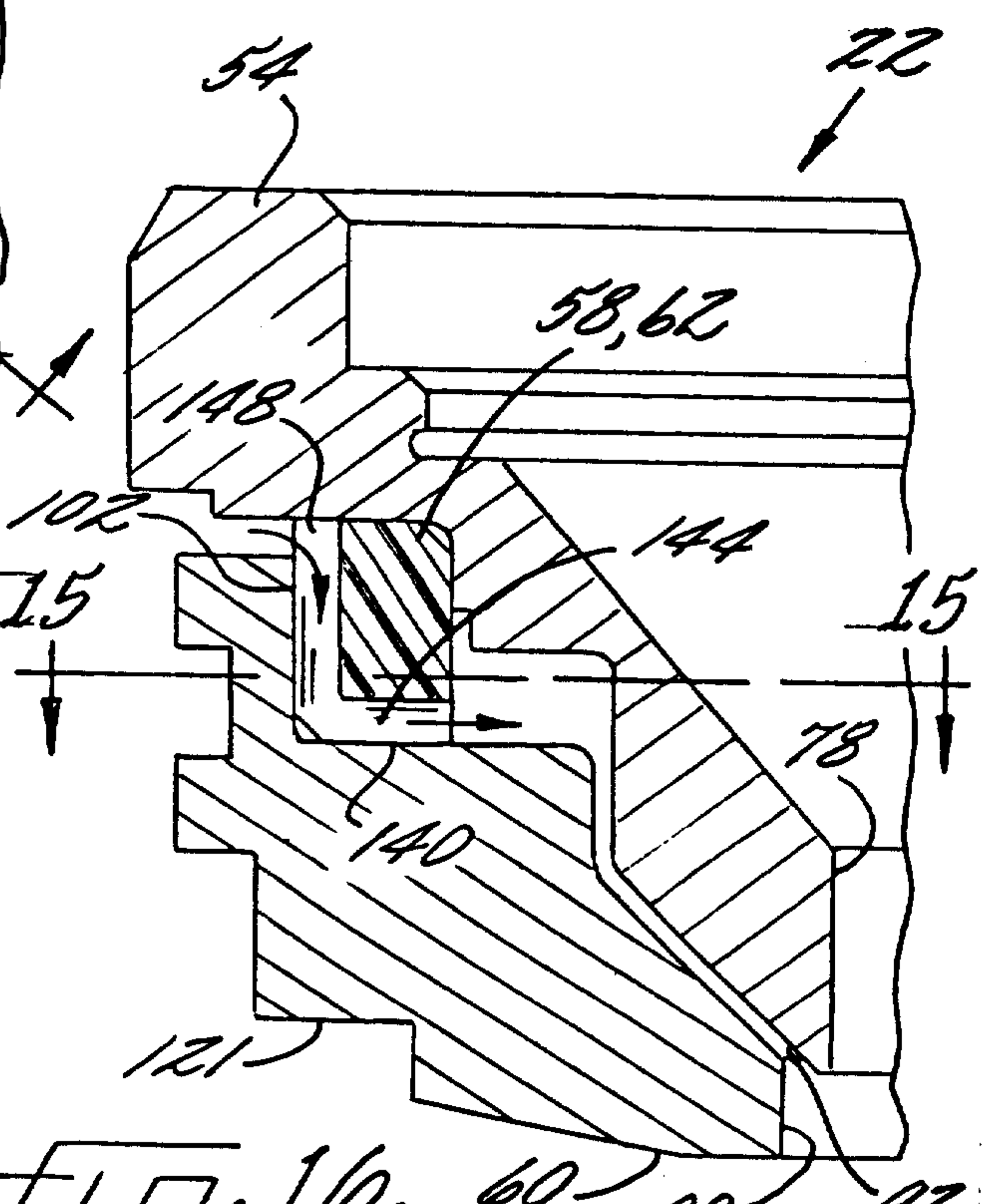
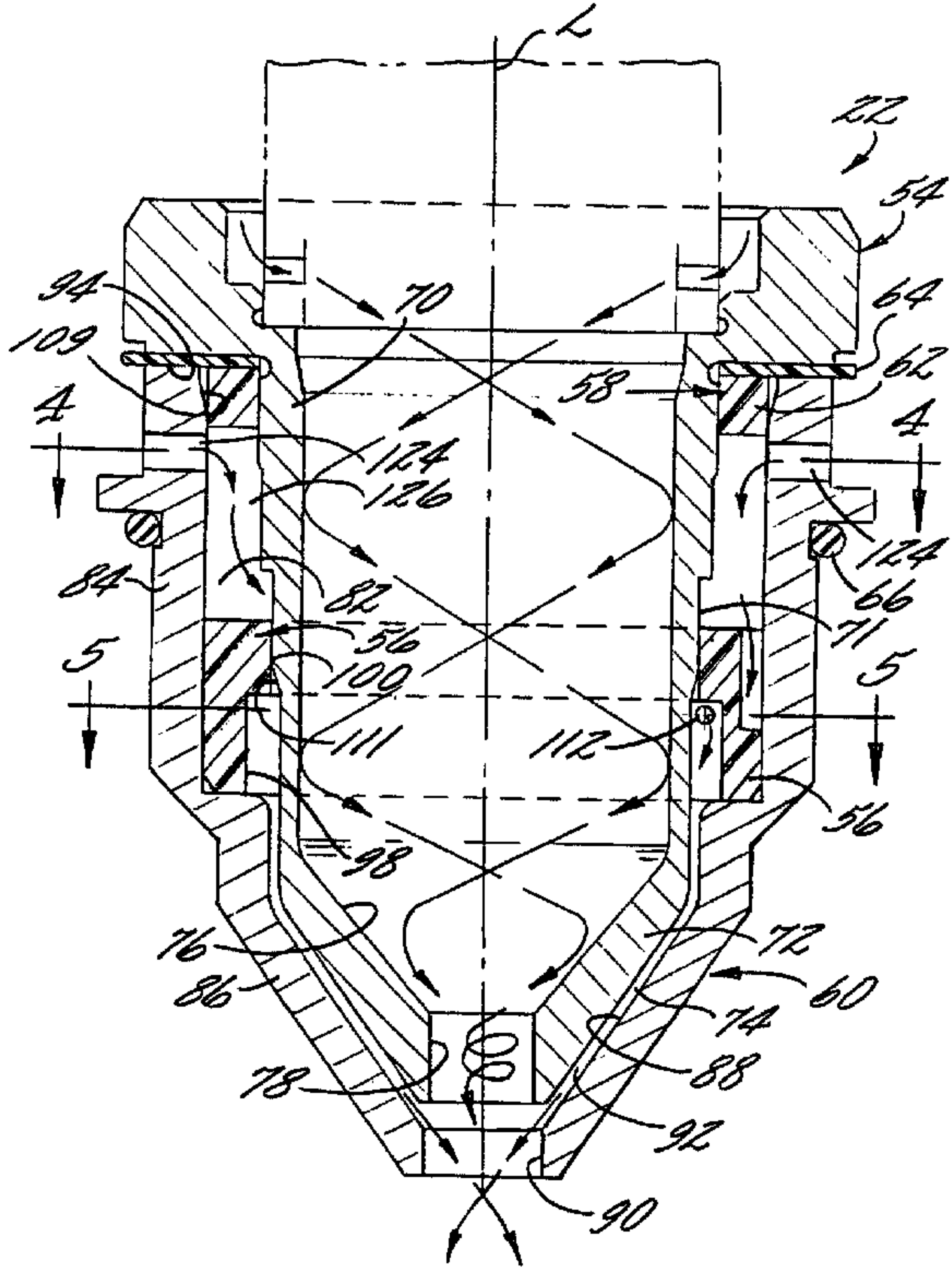


Fig. 16.



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