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(19) **United States**
(12) **Reissued Patent**
Deken et al.

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(45) **Date of Reissued Patent: Nov. 20, 2001**

(54) **DIRECTIONAL MULTI-BLADE BORING HEAD**

(75) Inventors: **Arthur D. Deken**; **Cody L. Sewell**, both of Perry, OK (US)

(73) Assignee: **The Charles Machine Works, Inc.**, Perry, OK (US)

(21) Appl. No.: **09/488,914**

(22) Filed: **Jan. 19, 2000**

Related U.S. Patent Documents

Reissue of:
(64) Patent No.: **5,392,868**
Issued: **Feb. 28, 1995**
Appl. No.: **08/163,756**
Filed: **Dec. 9, 1993**

U.S. Applications:
(

(63) Continuation-in-part of application No. 08/067,298, filed on May 25, 1993, now Pat. No. 5,341,887, which is a continuation-in-part of application No. 07/857,167, filed on Mar. 25, 1992, now Pat. No. 5,242,026, which is a continuation-in-part of application No. 07/575,568, filed on Aug. 31, 1990, now Pat. No. 5,148,880, which is a continuation-in-part of application No. 07/211,889, filed on Jun. 27, 1988, now Pat. No. 4,953,638.

(51) **Int. Cl.**^{7} **E21B 7/00**
(52) **U.S. Cl.** **175/62**; 175/376
(58) **Field of Search** 175/61, 62, 19, 175/73, 385, 398, 400, 376

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Primary Examiner—Thomas B. Will
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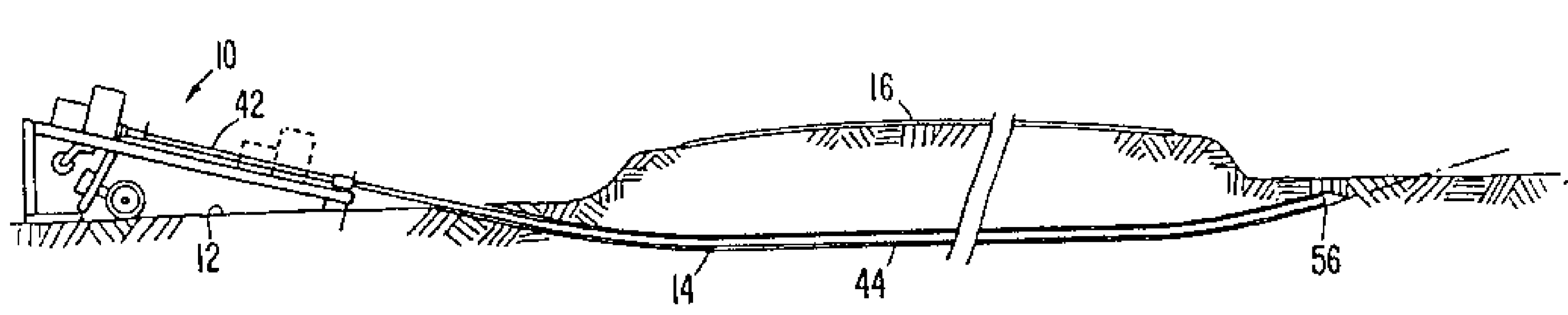
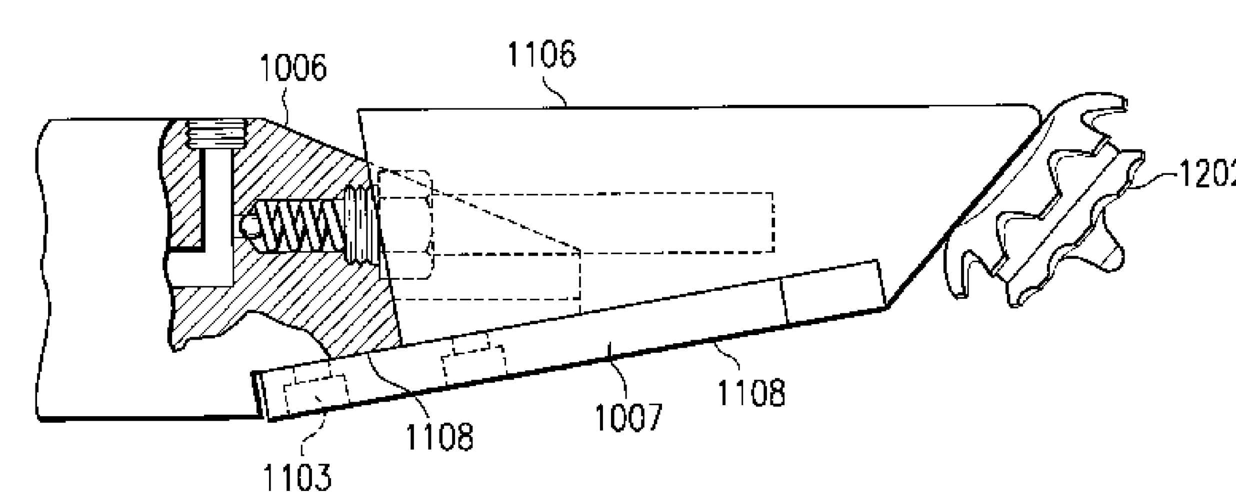
(57) **ABSTRACT**

Directional boring bits (**1100**, **1200**) are disclosed which have at least one roller cone (**1202**, **1104**) and also each define a deflecting surface (**1104**) for deflecting the boring bit when the bit is advanced without rotation. The borehole can be curved by pushing the bit forward without rotation.

5 Claims, 22 Drawing Sheets





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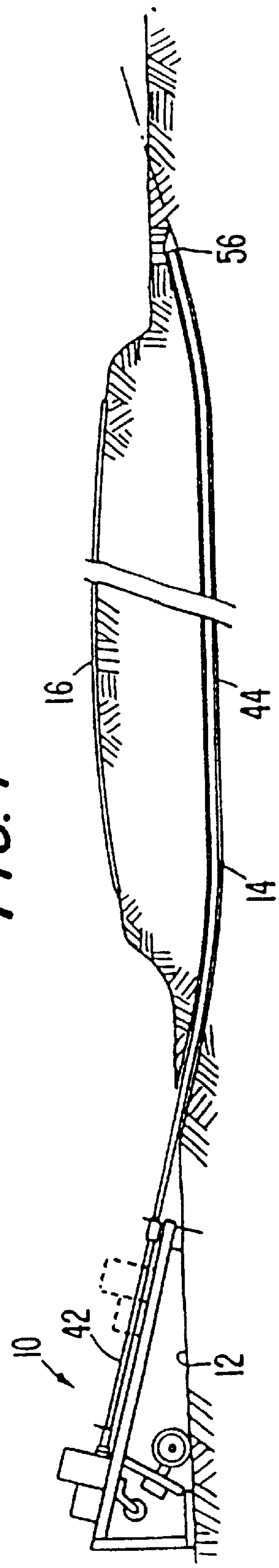
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FIG. 1

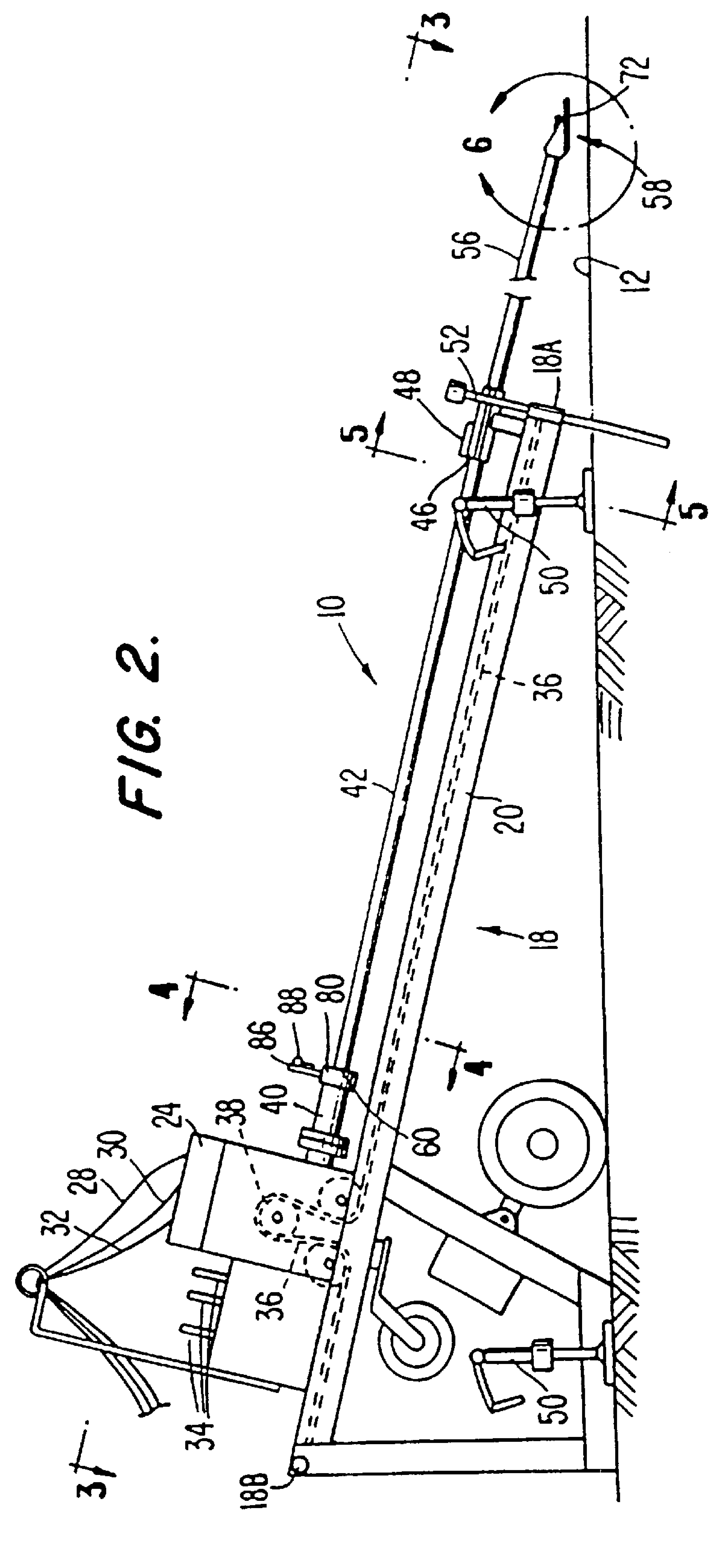
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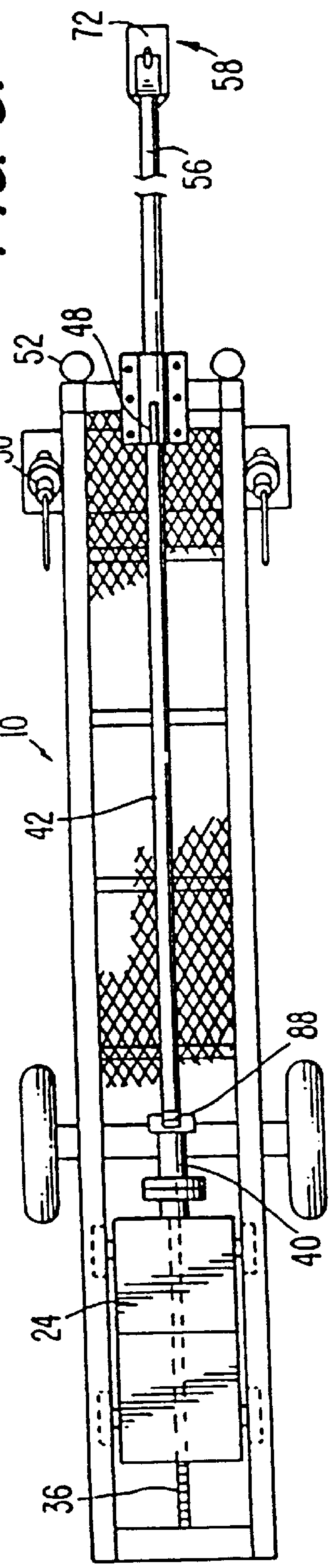
FIG. 2.



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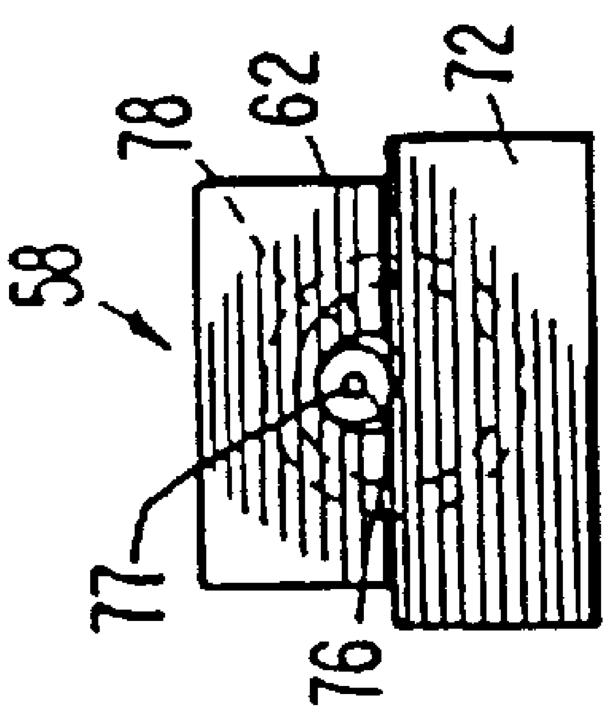

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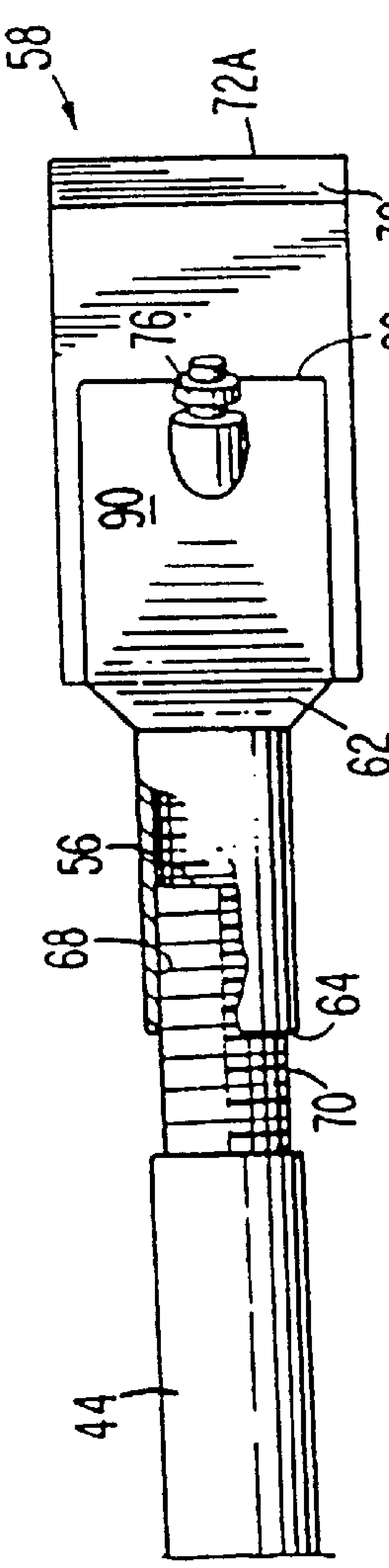

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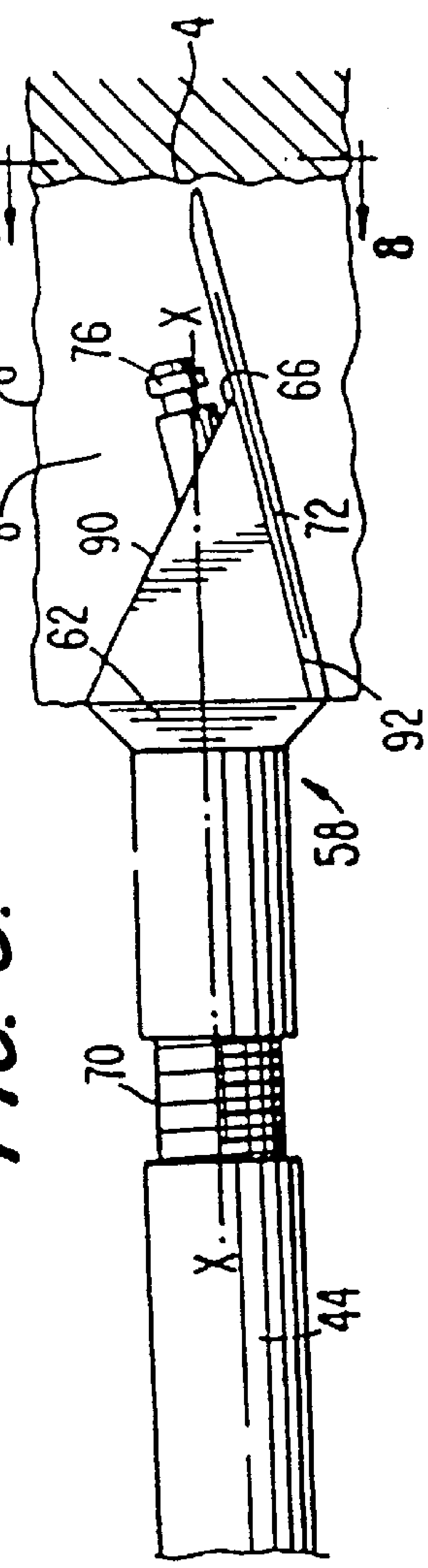

FIG. 6.

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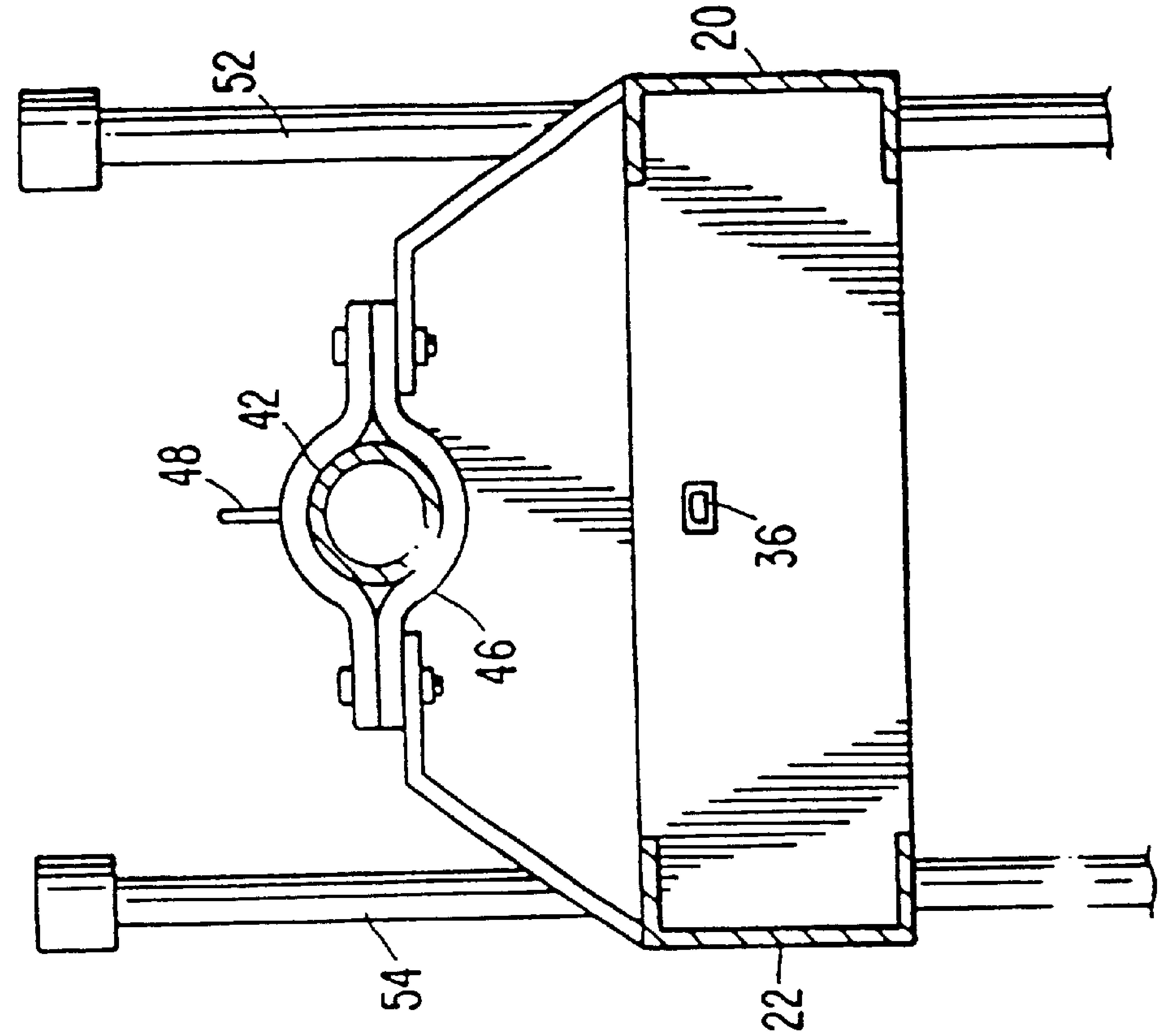

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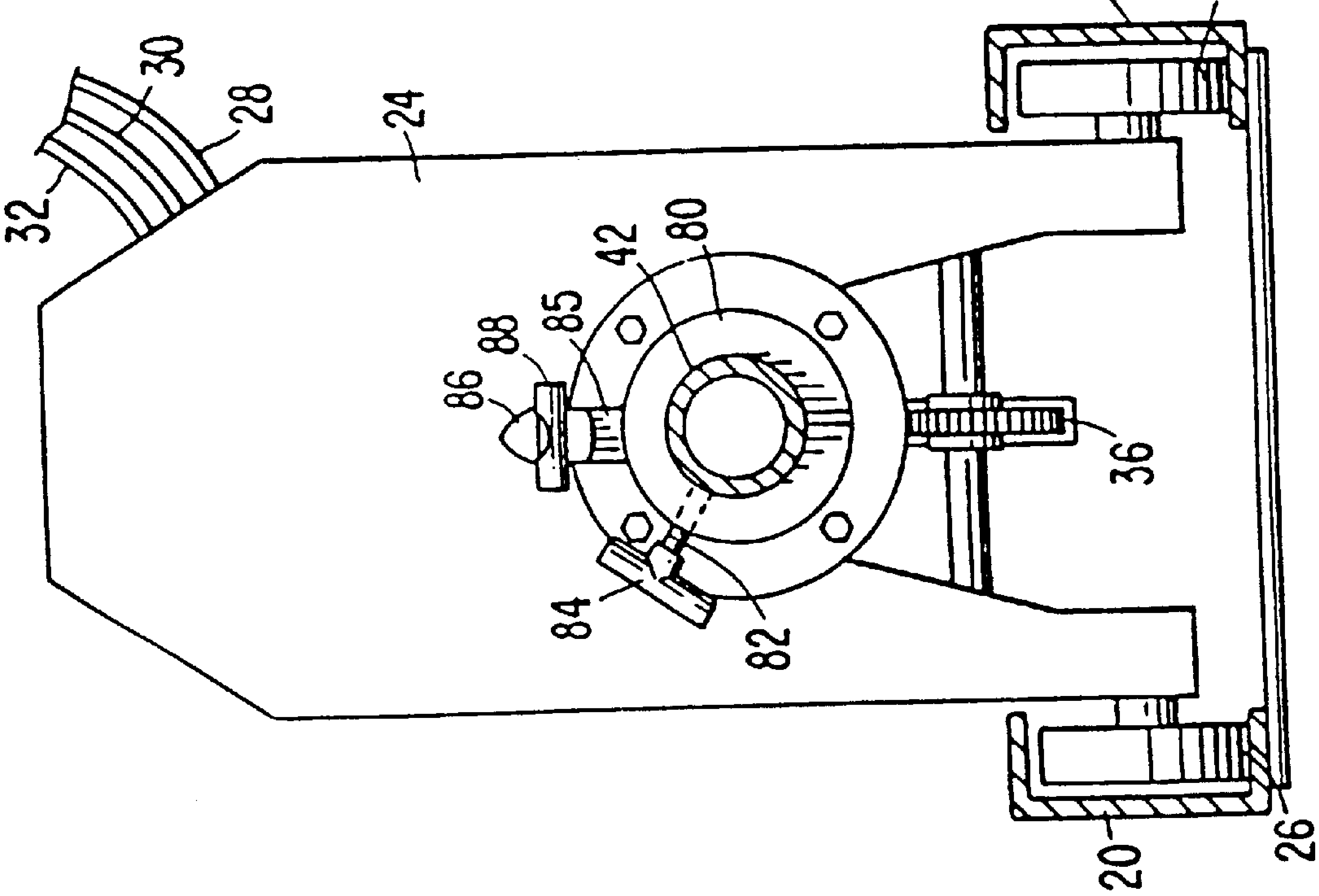

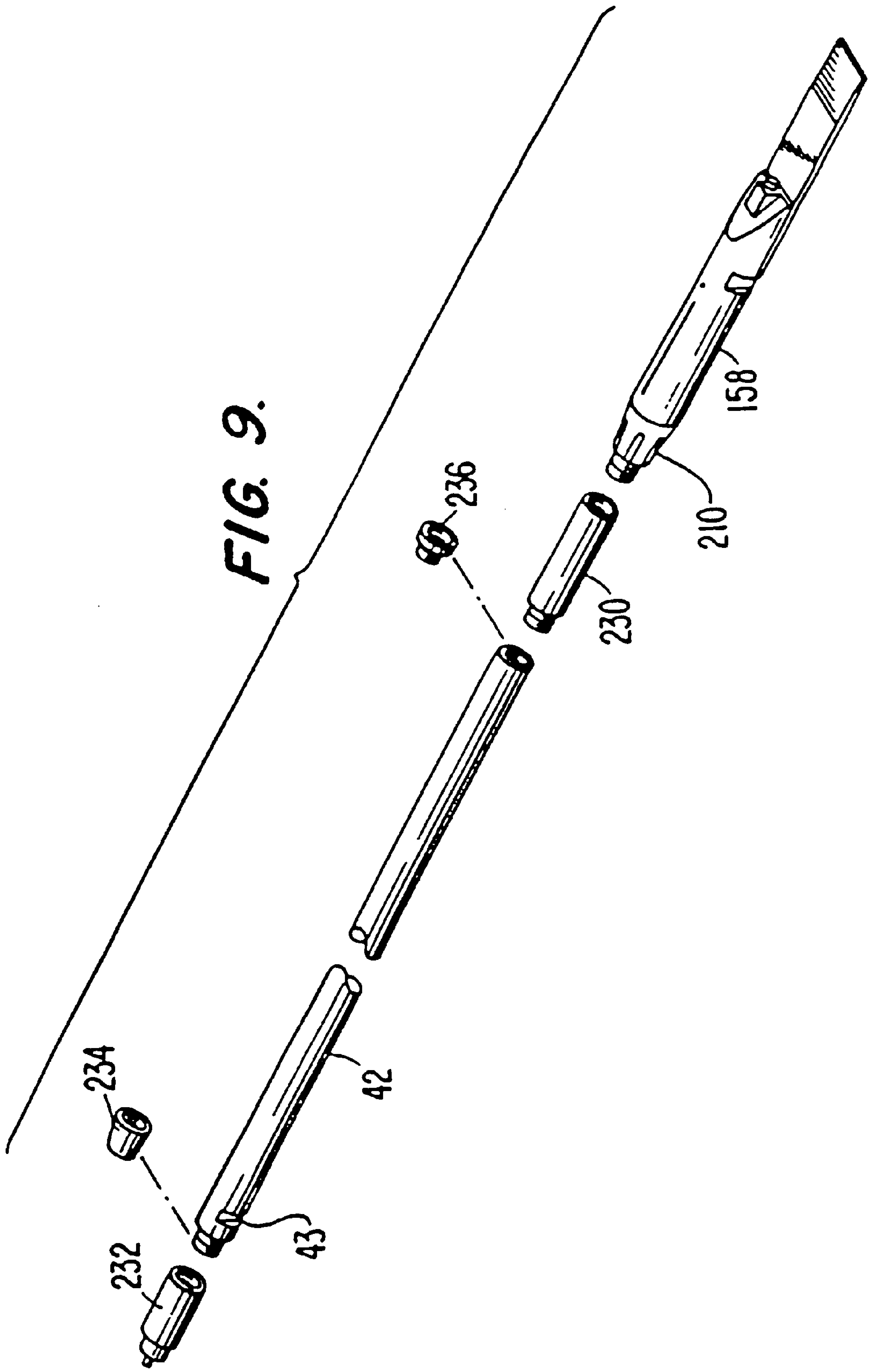

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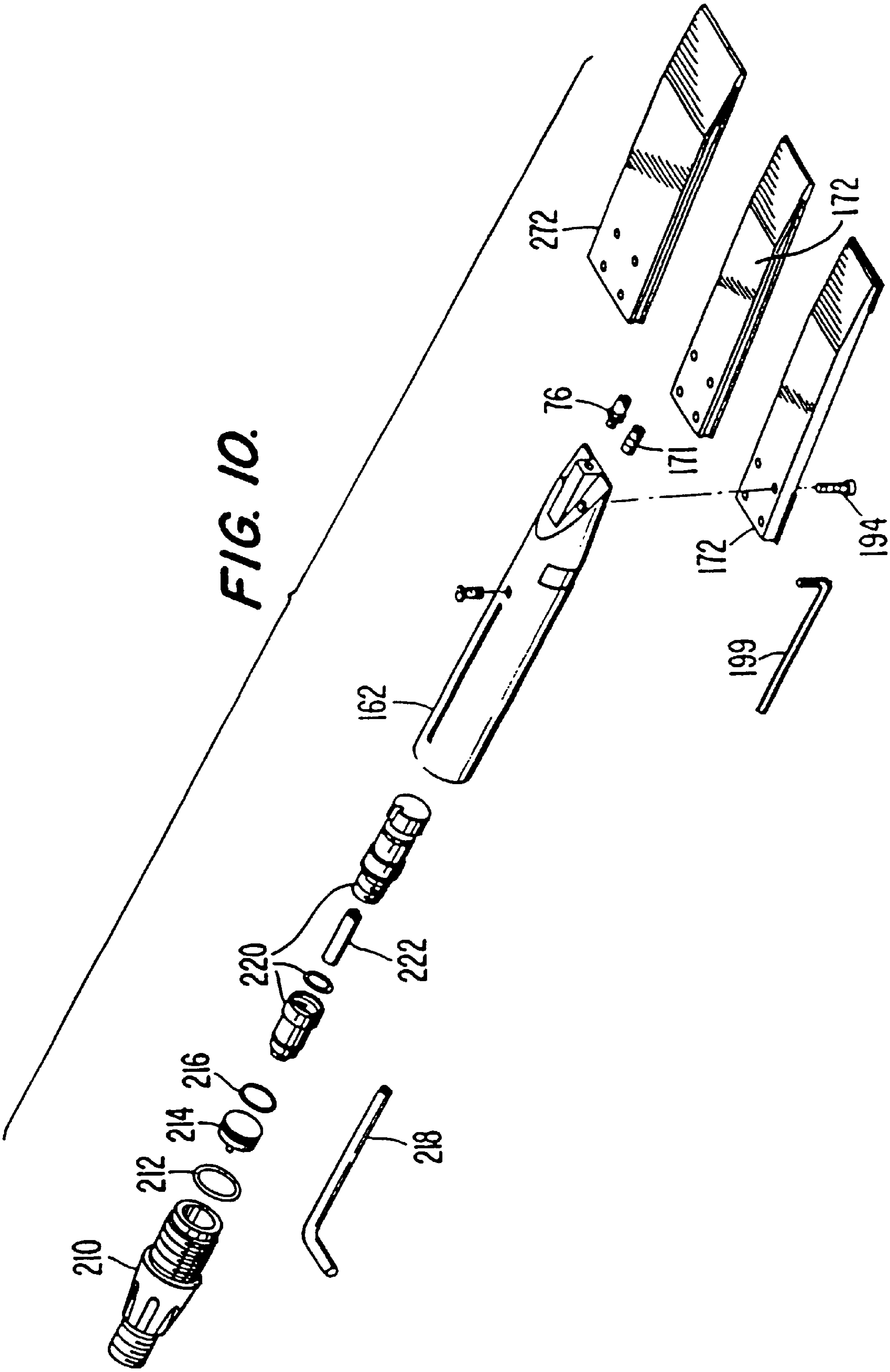

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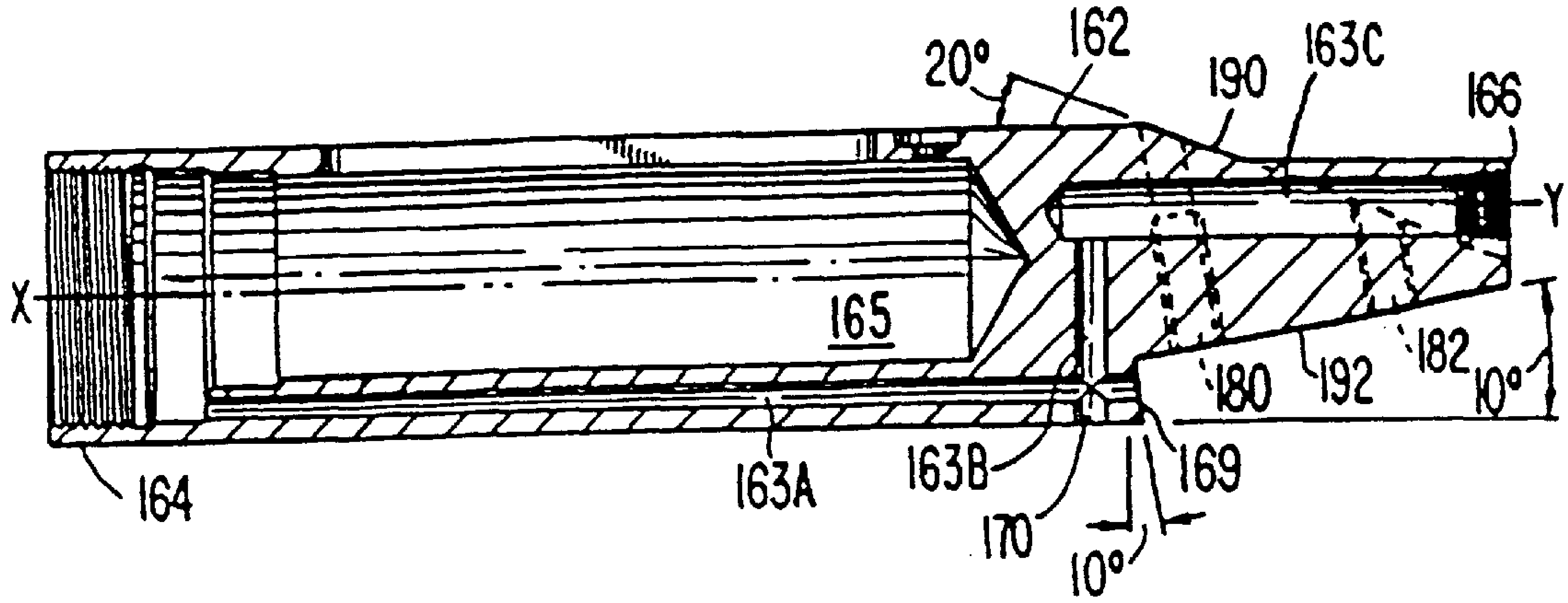

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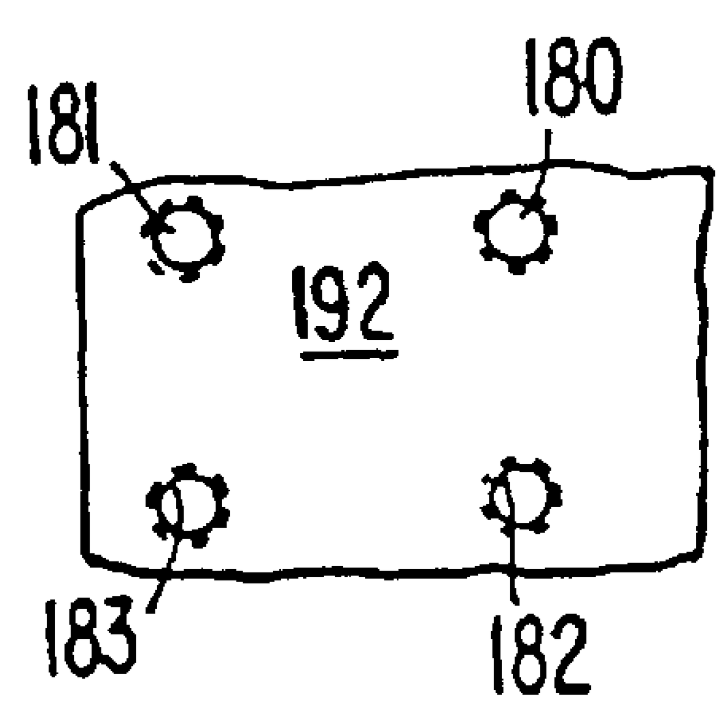

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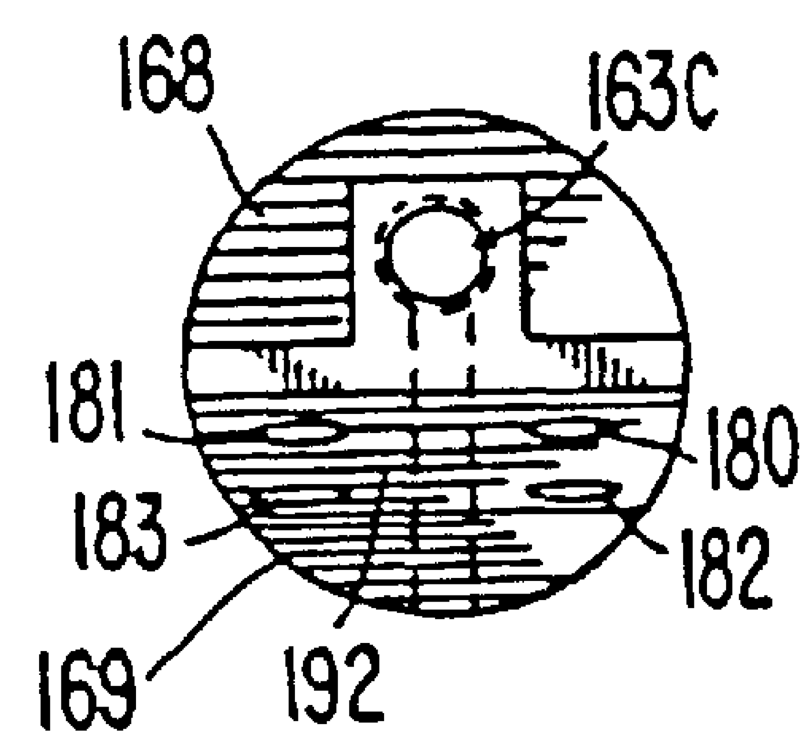

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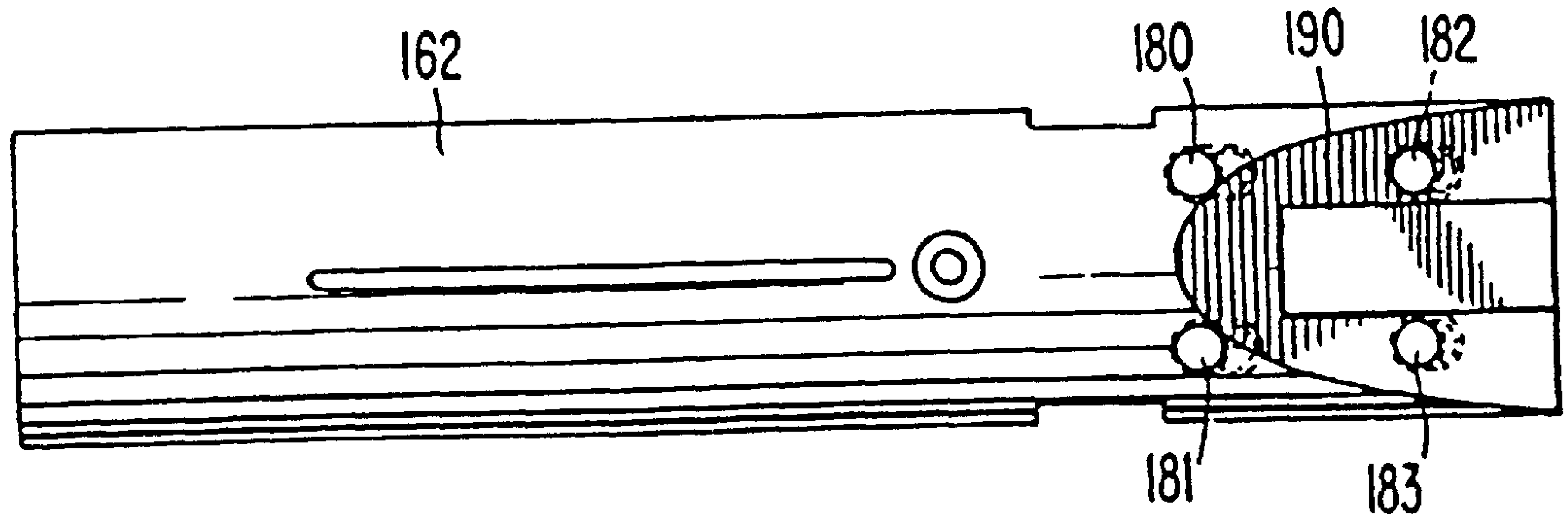


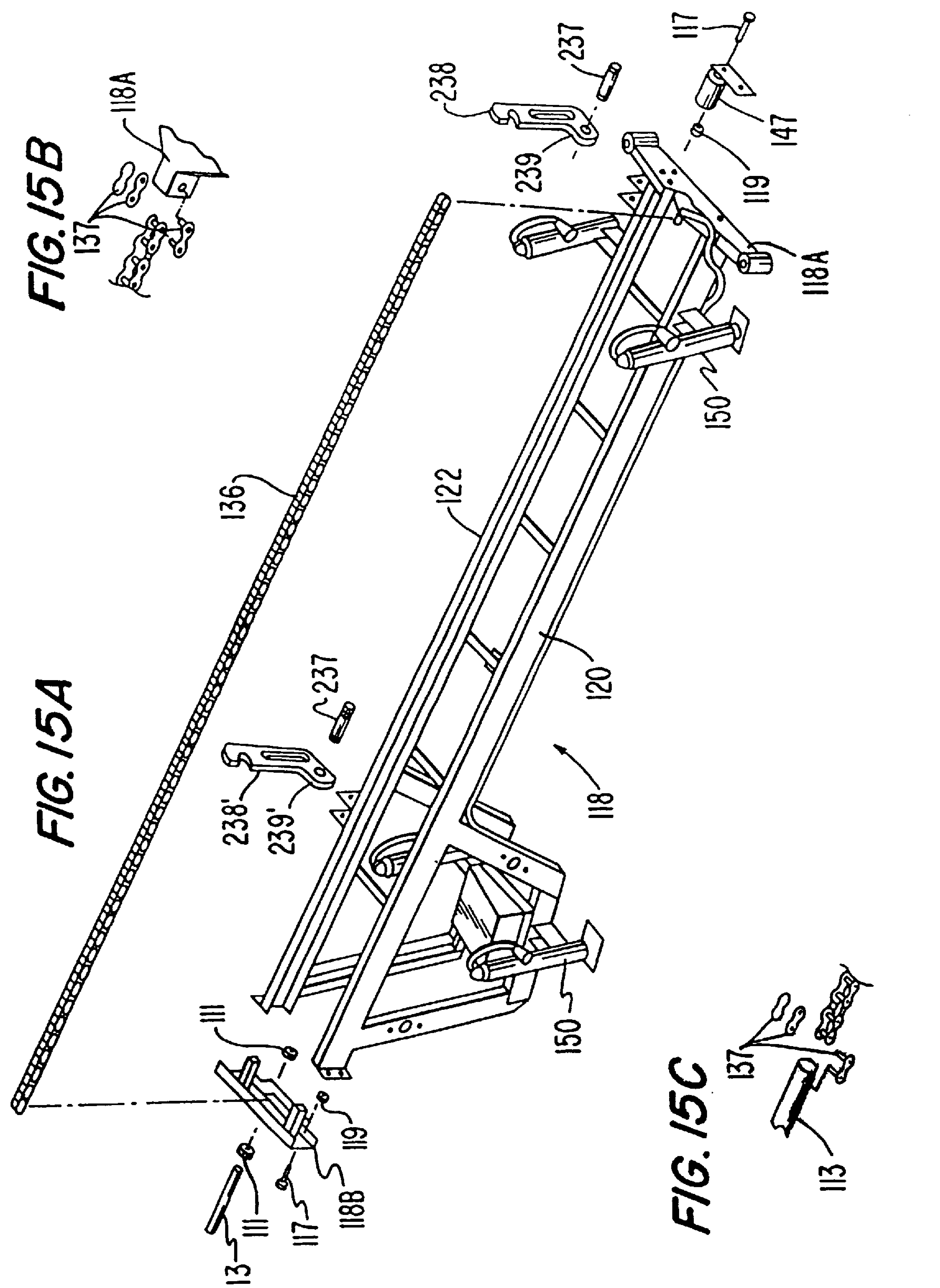
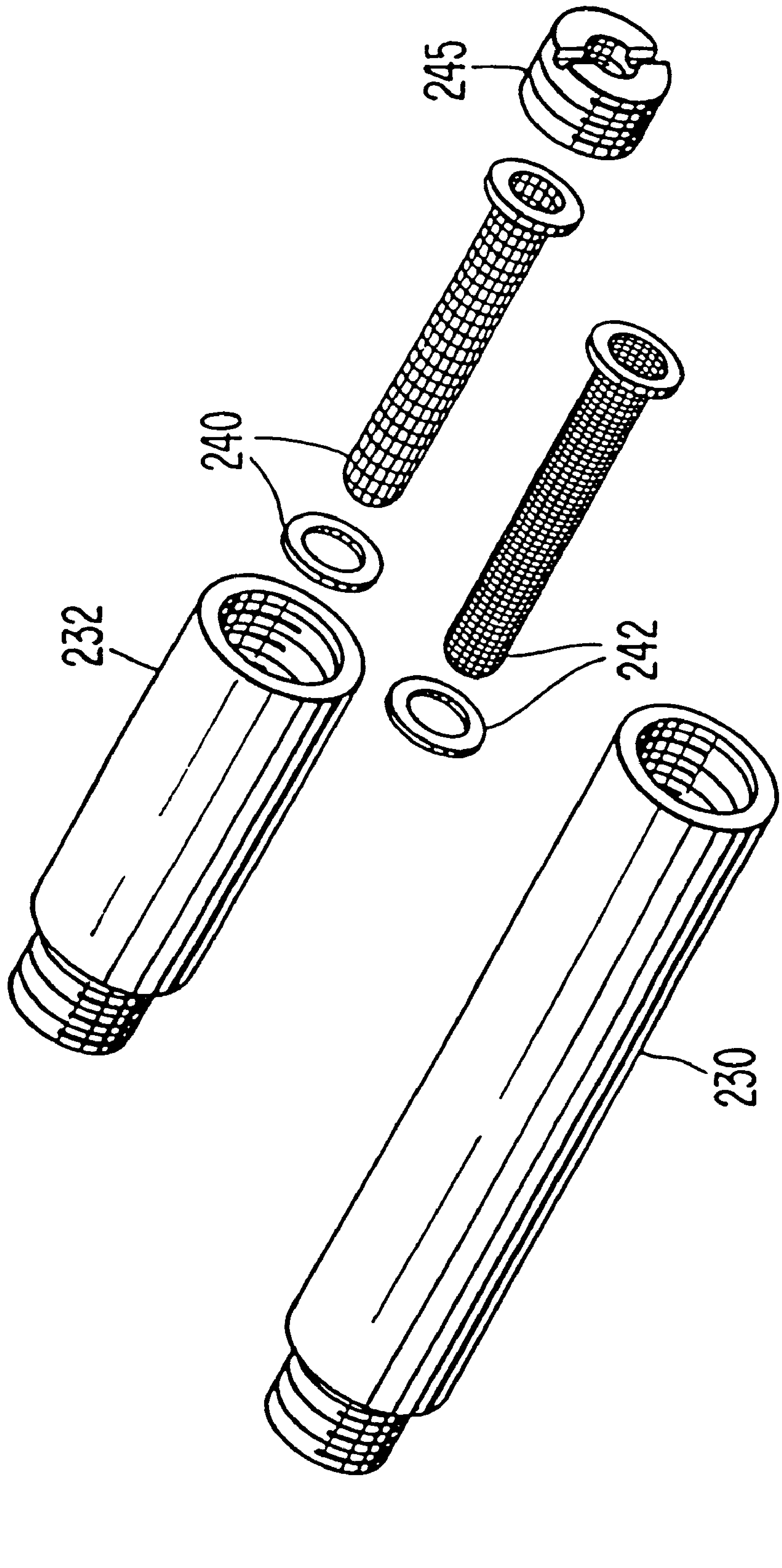


FIG. 15A

FIG. 15B

FIG. 15C



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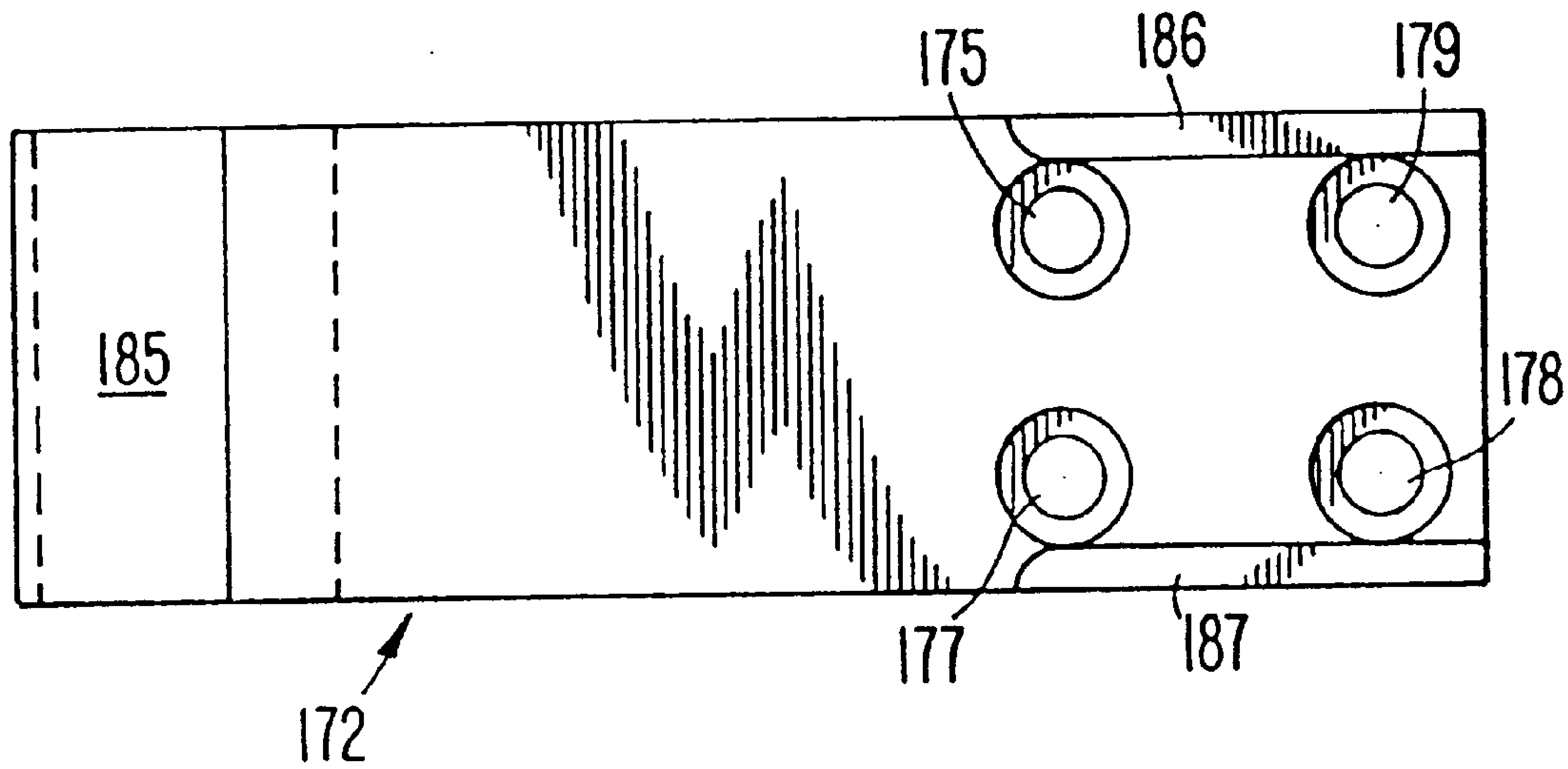

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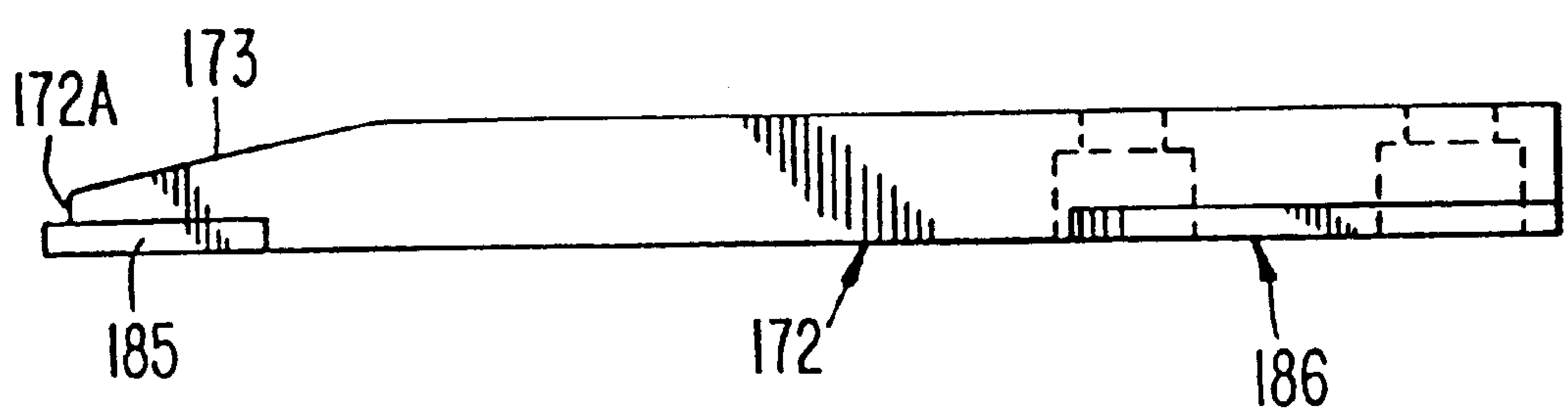

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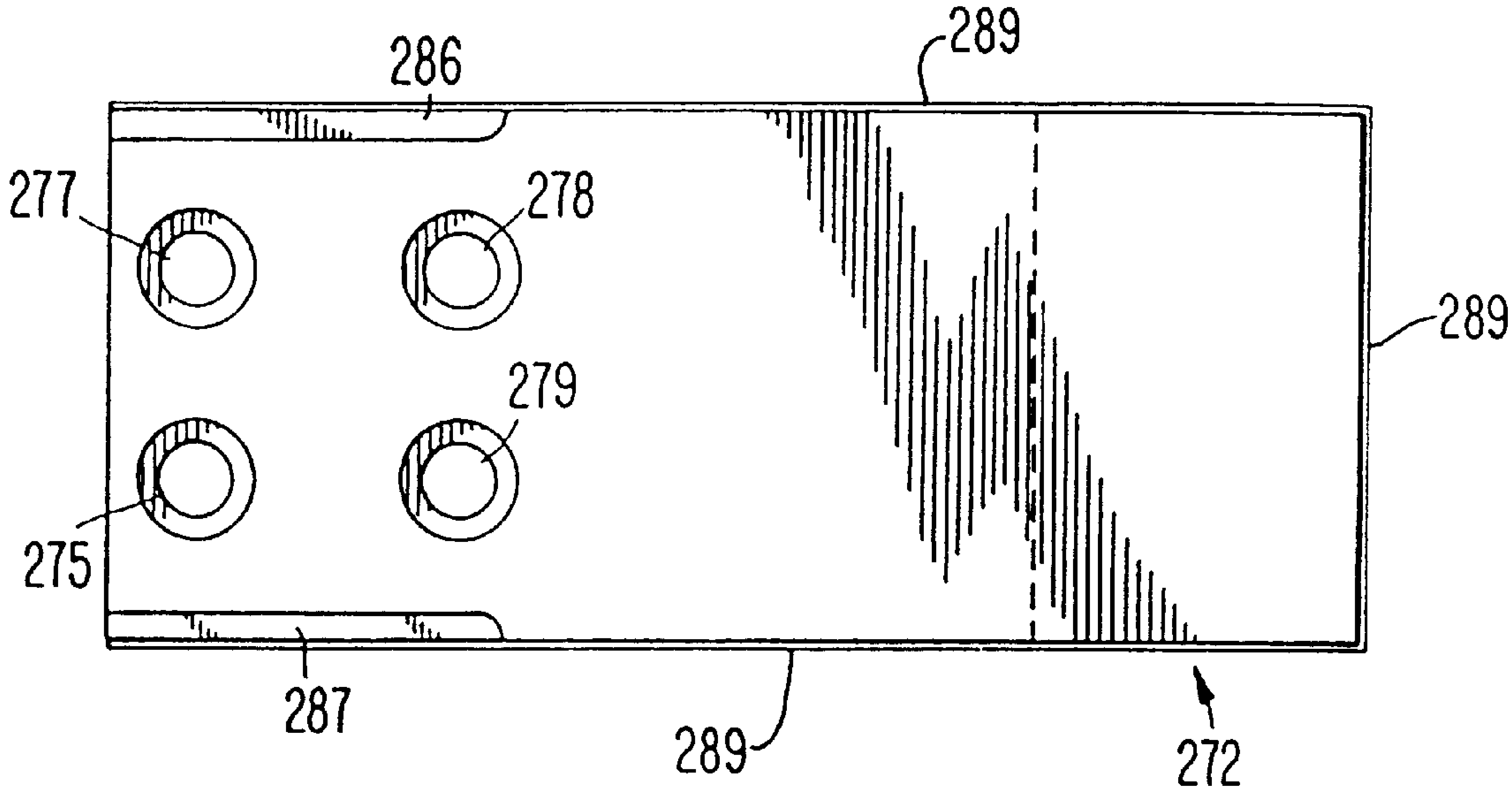

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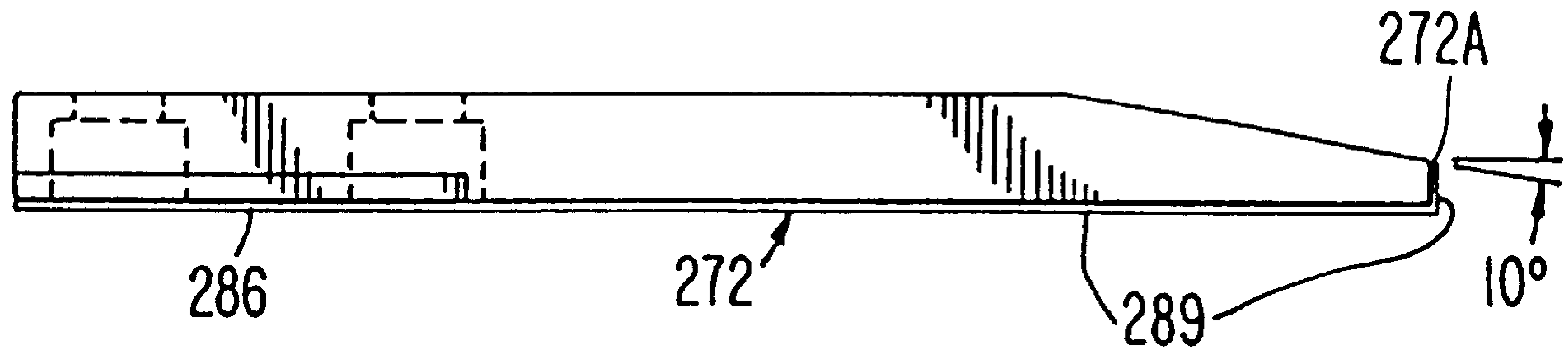

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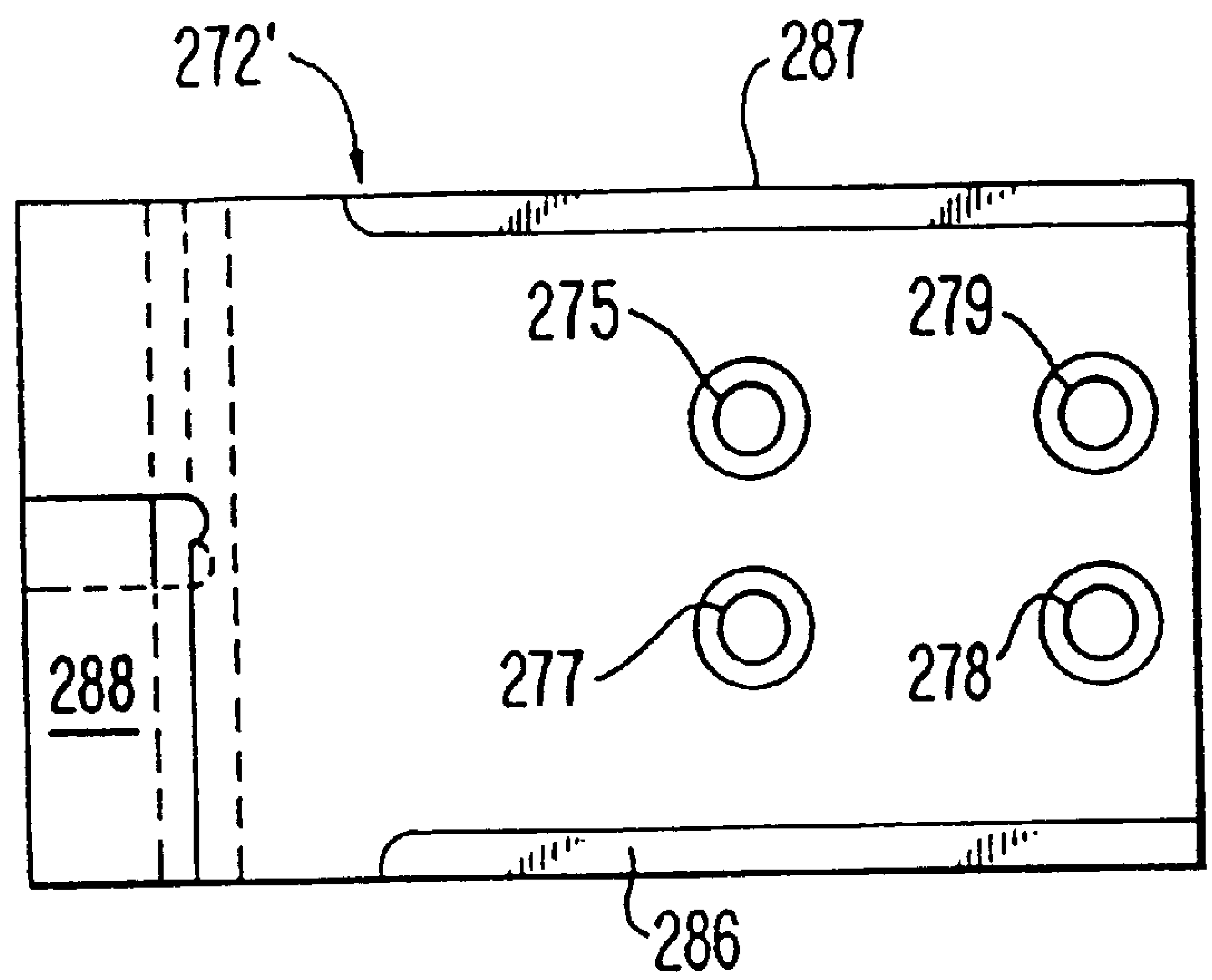


FIG. 22

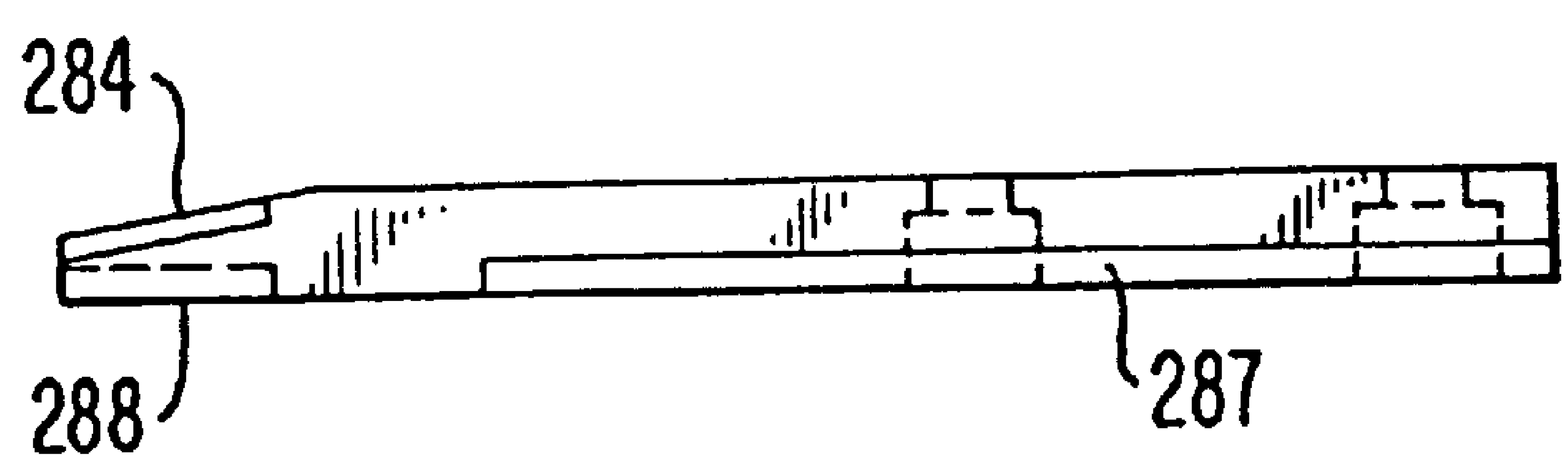
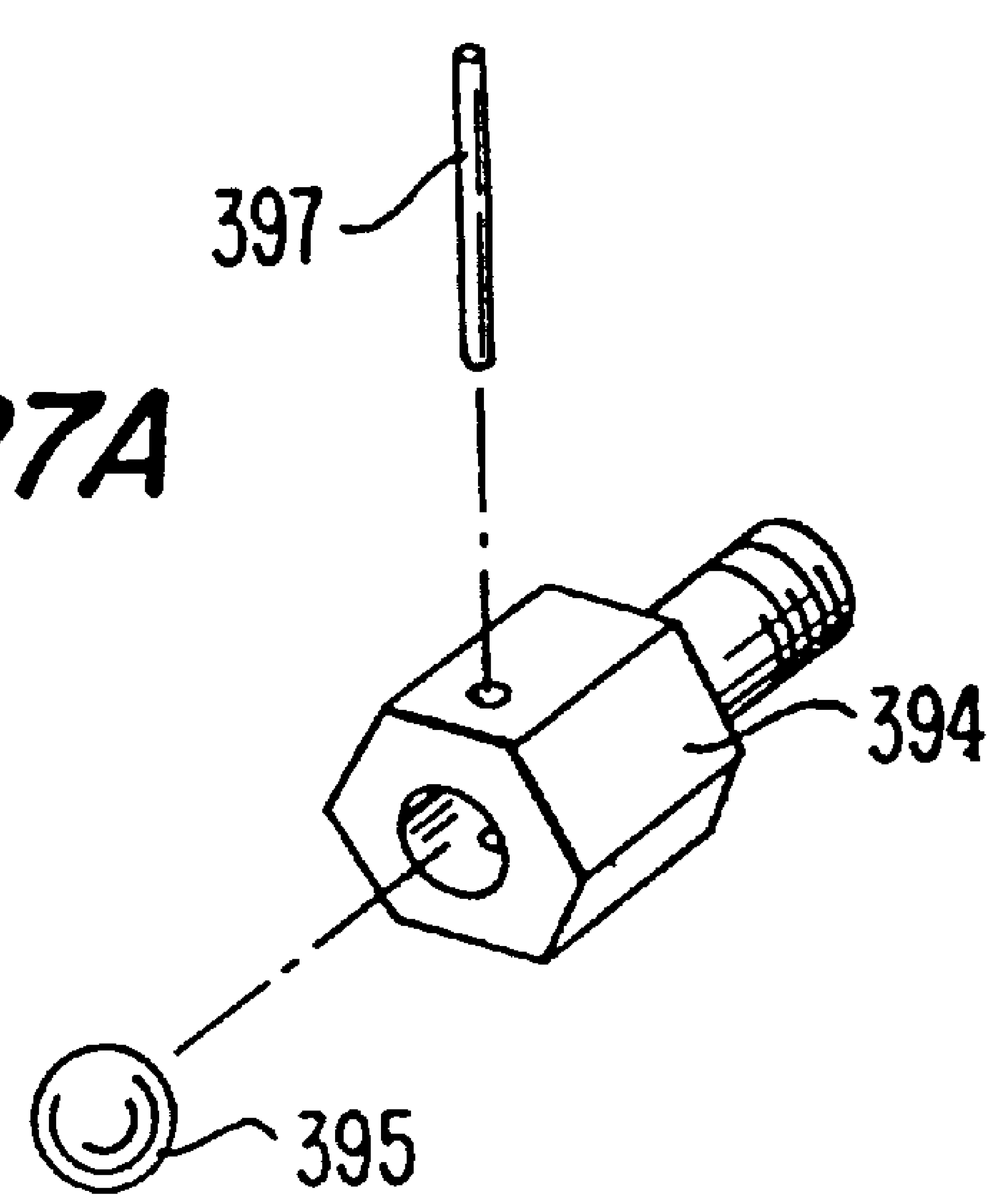
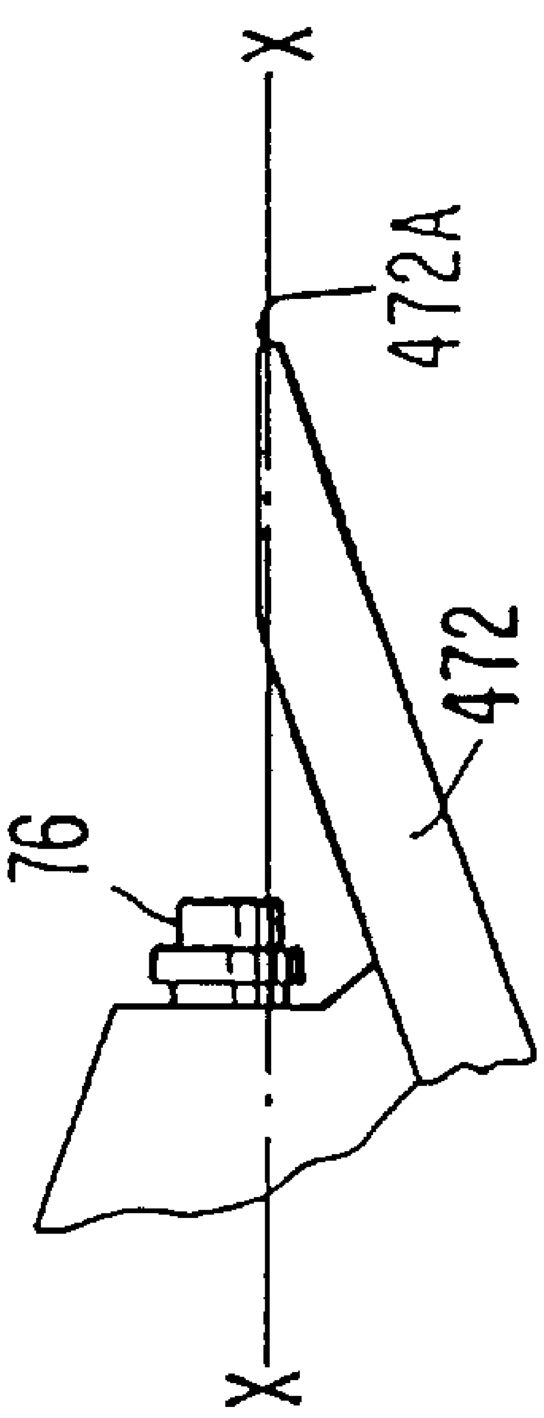


FIG. 27A





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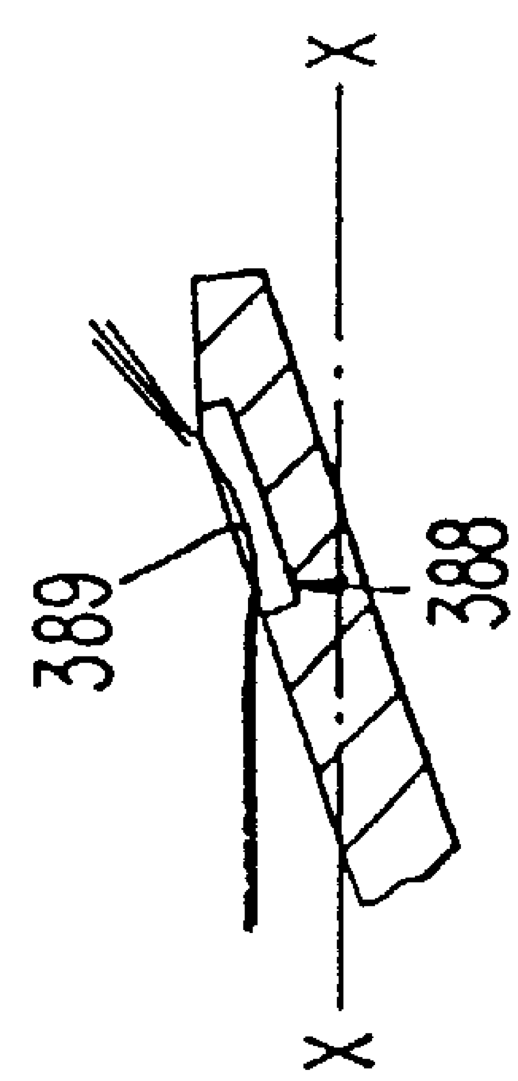
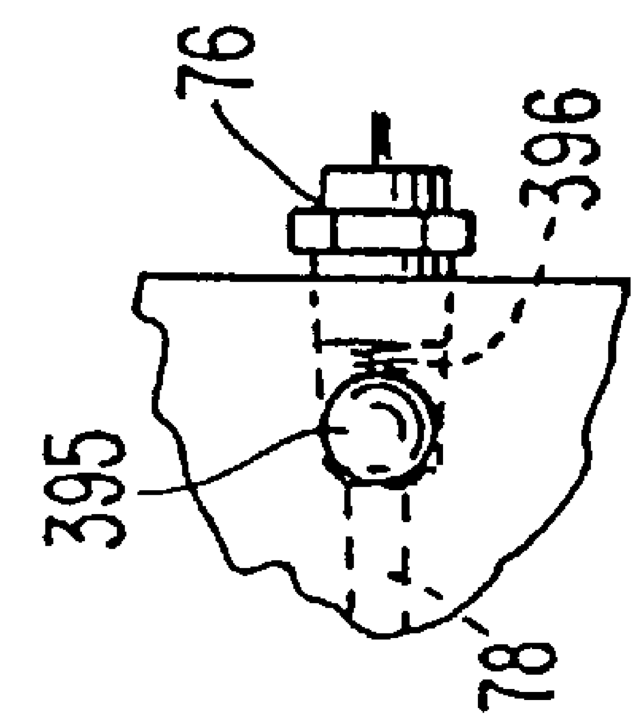


FIG. 26



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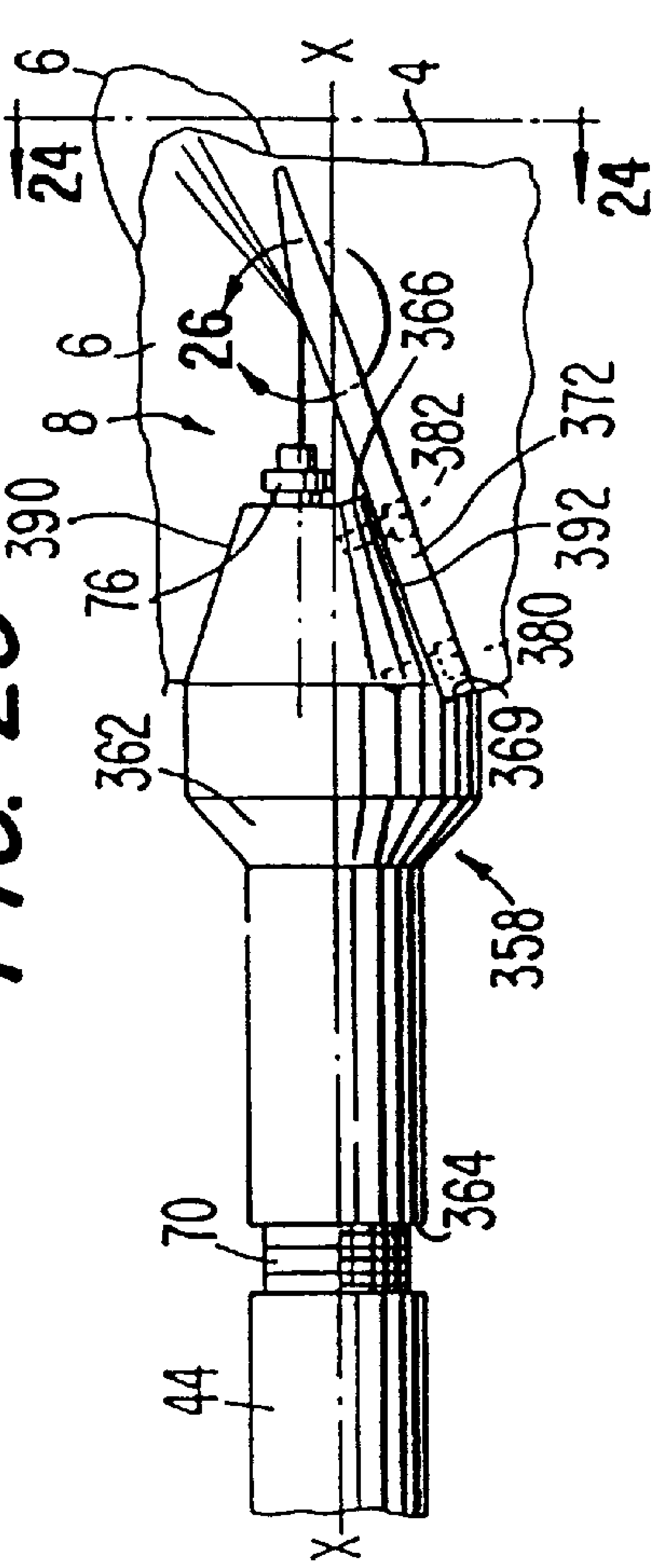

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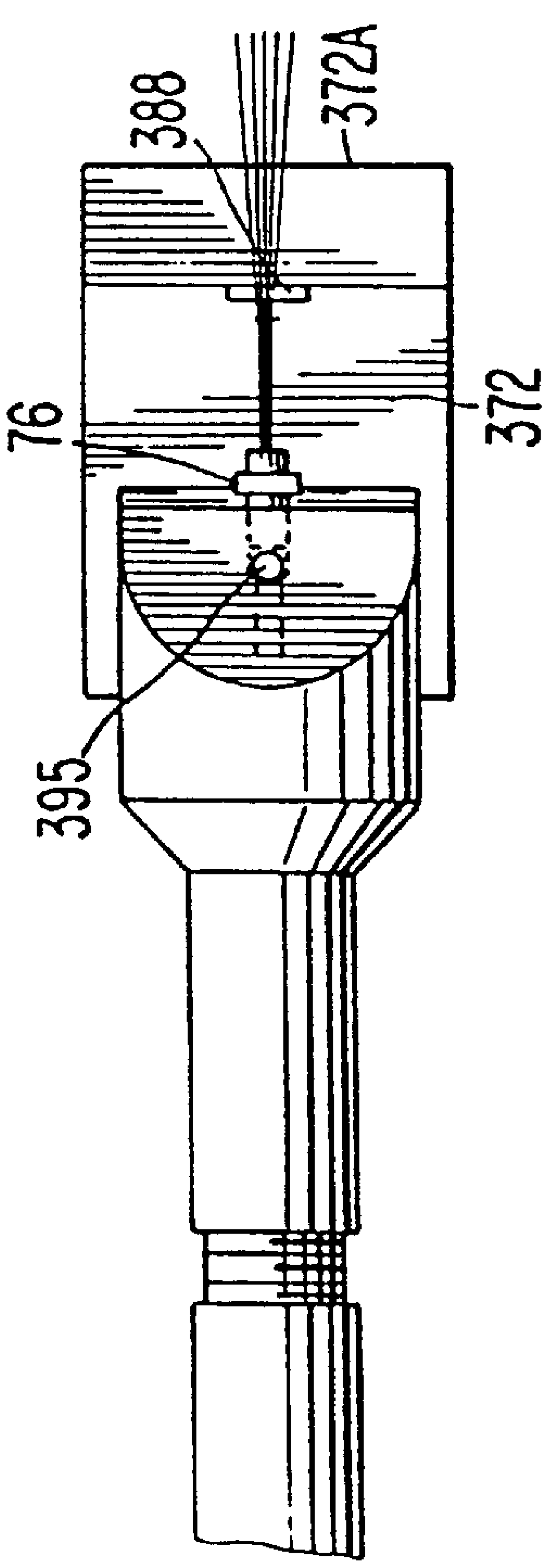

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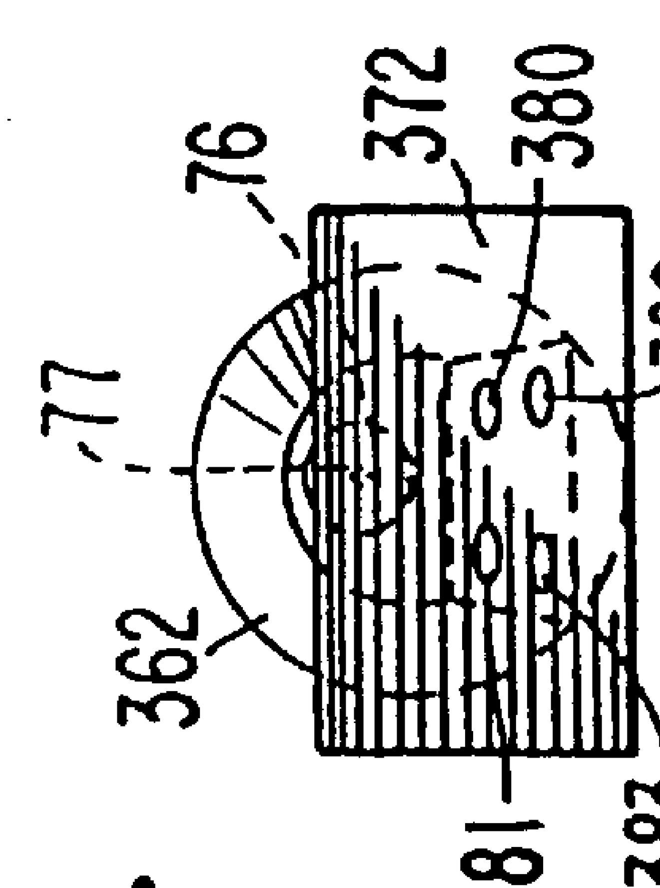
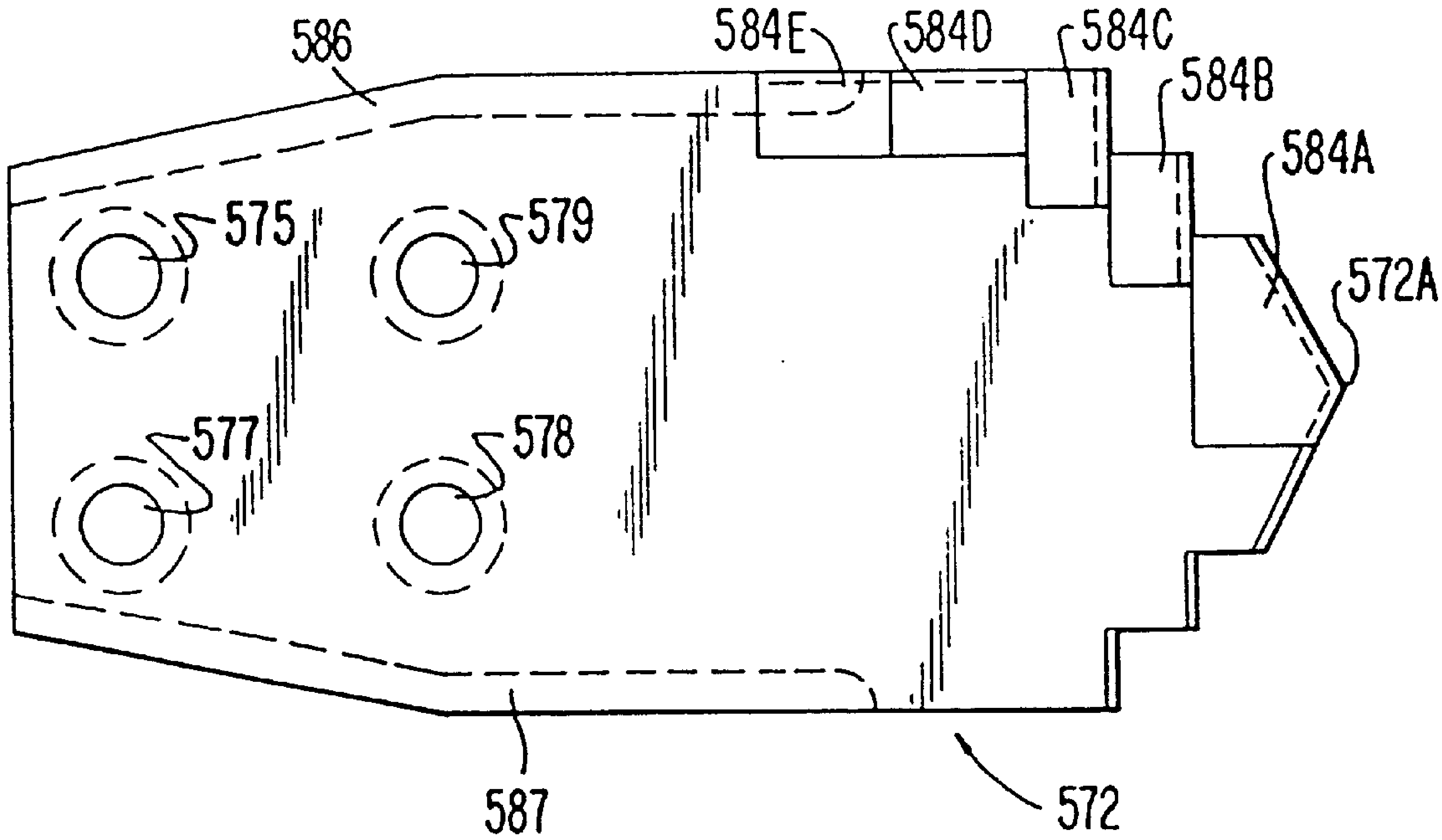


FIG. 25

FIG. 29



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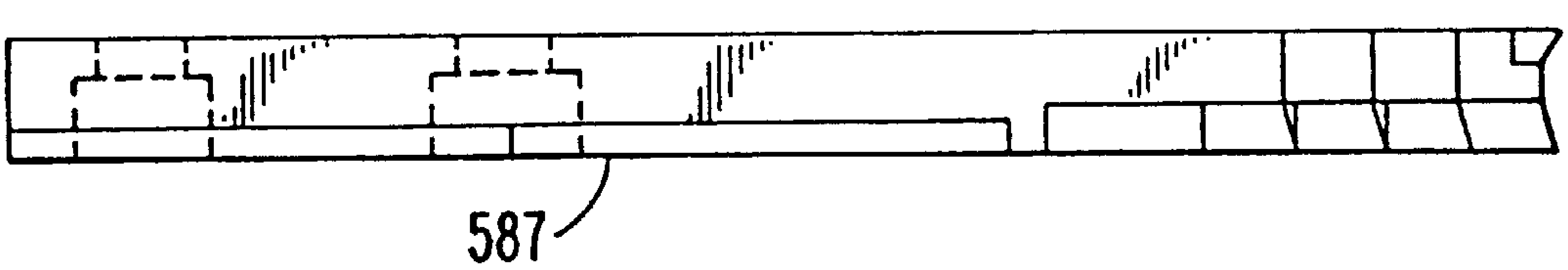

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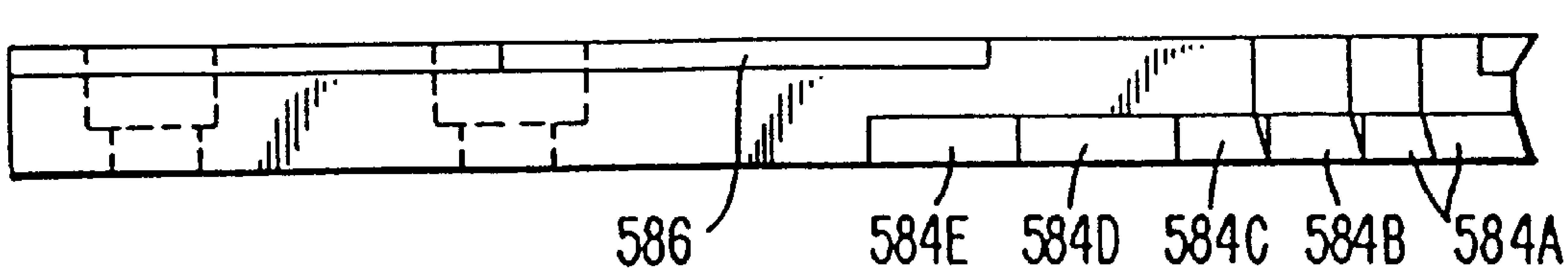

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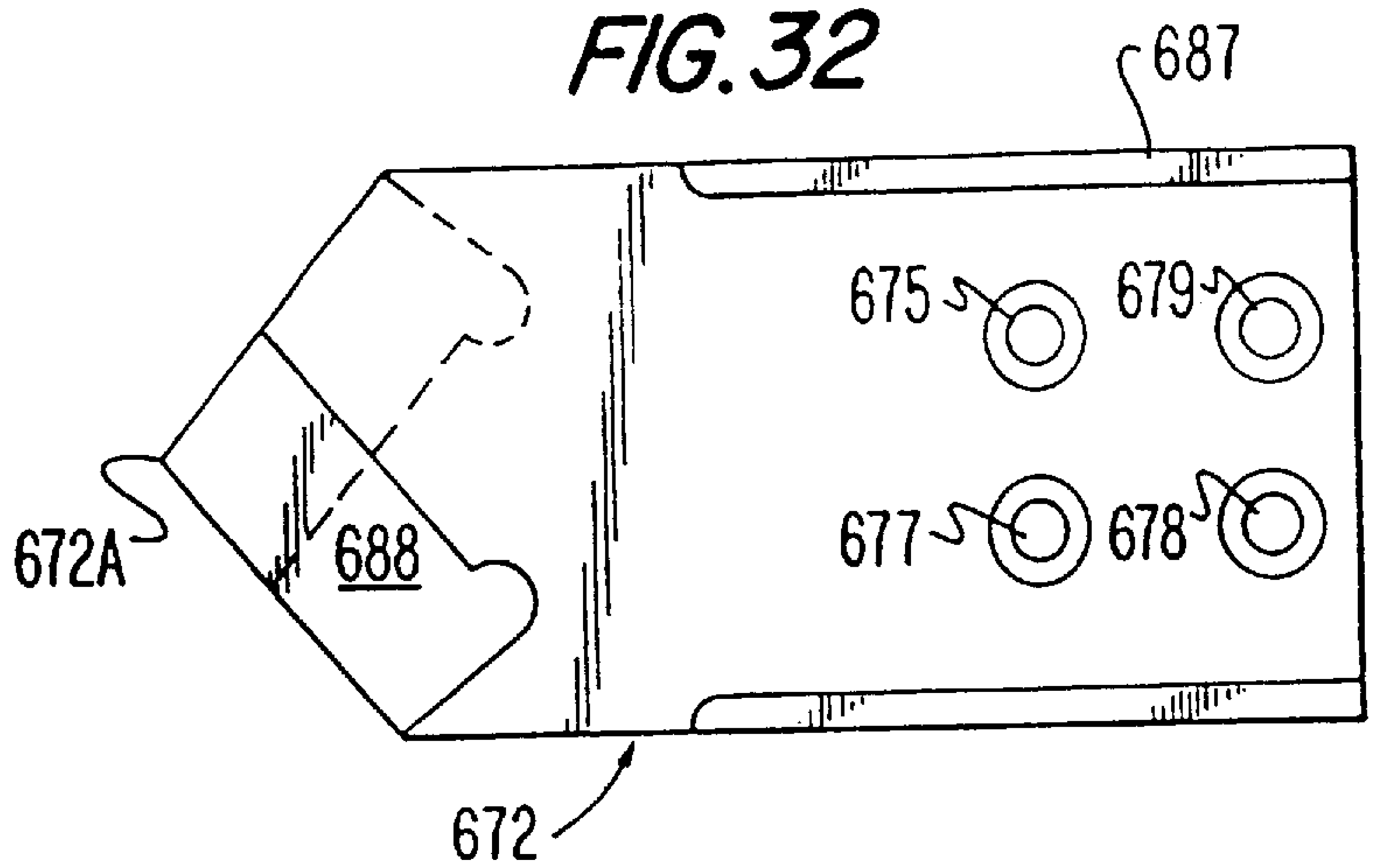

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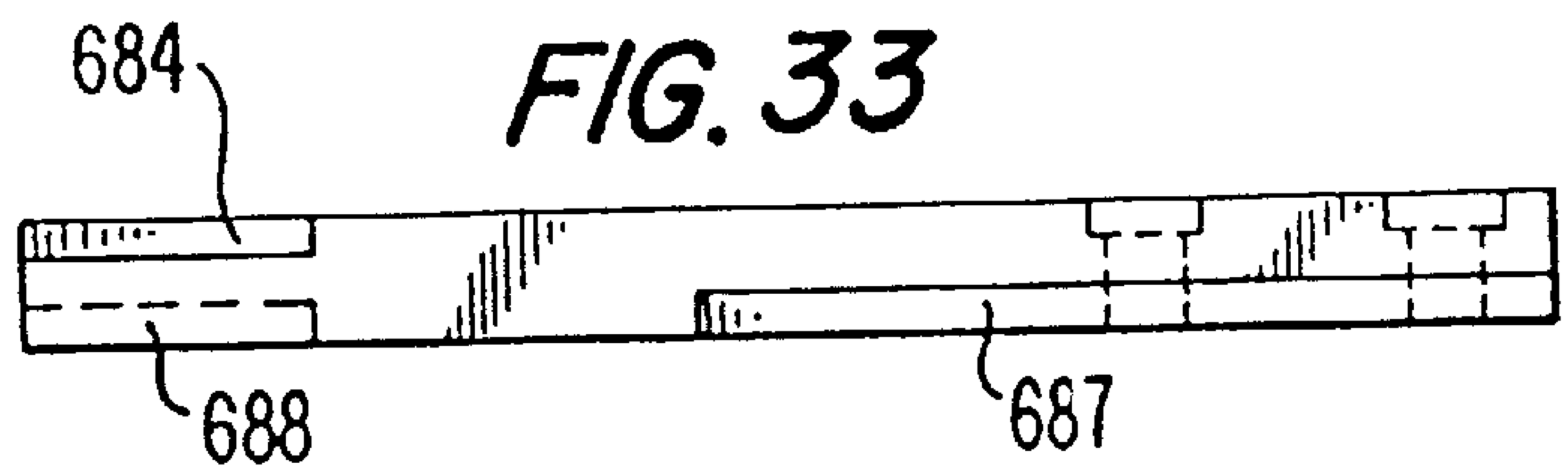

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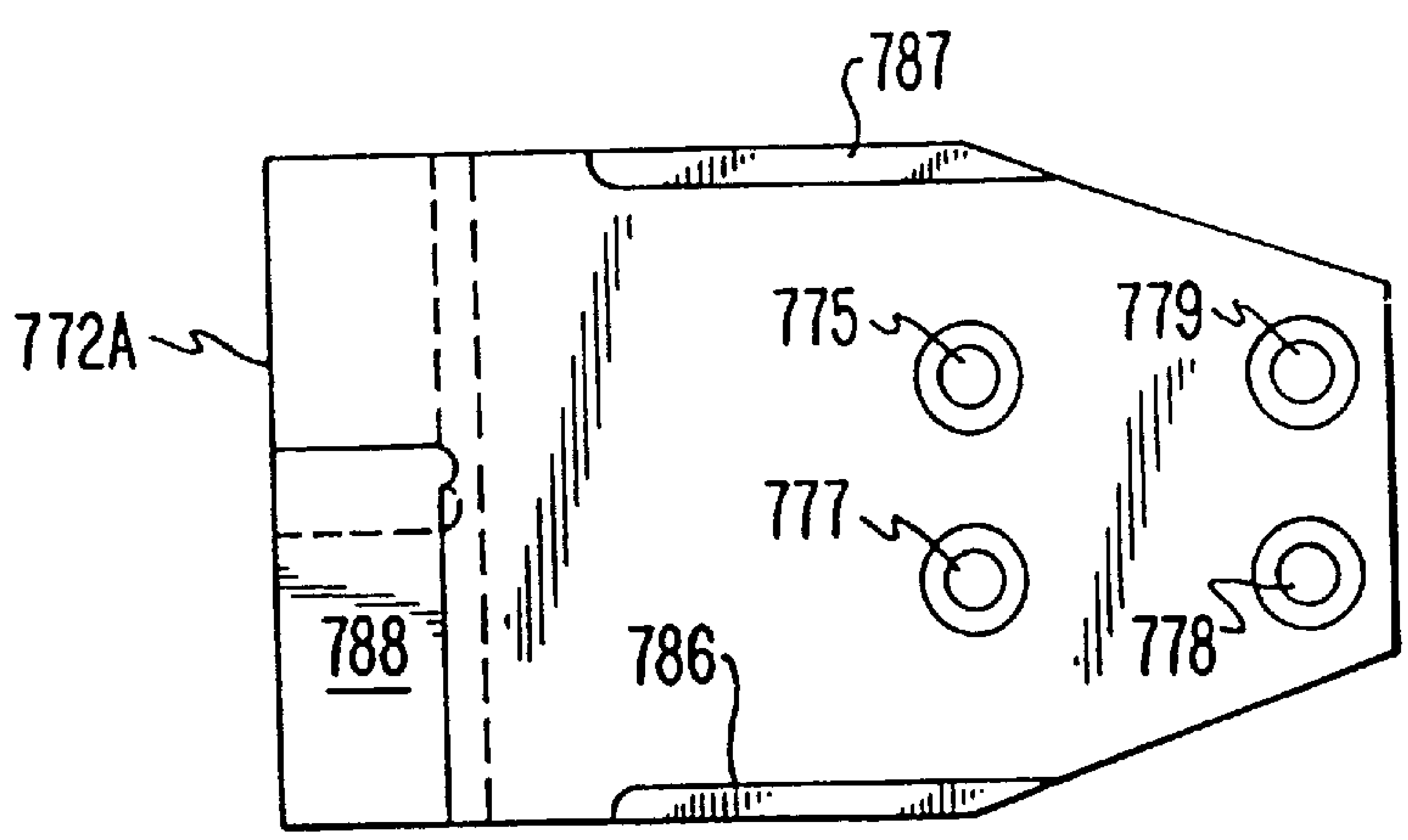

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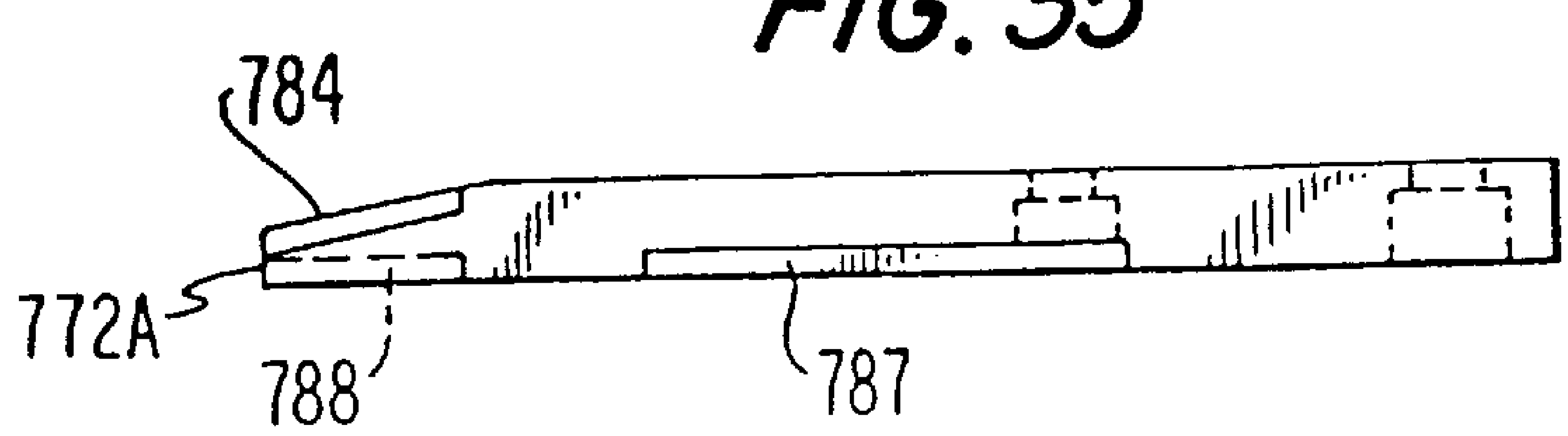

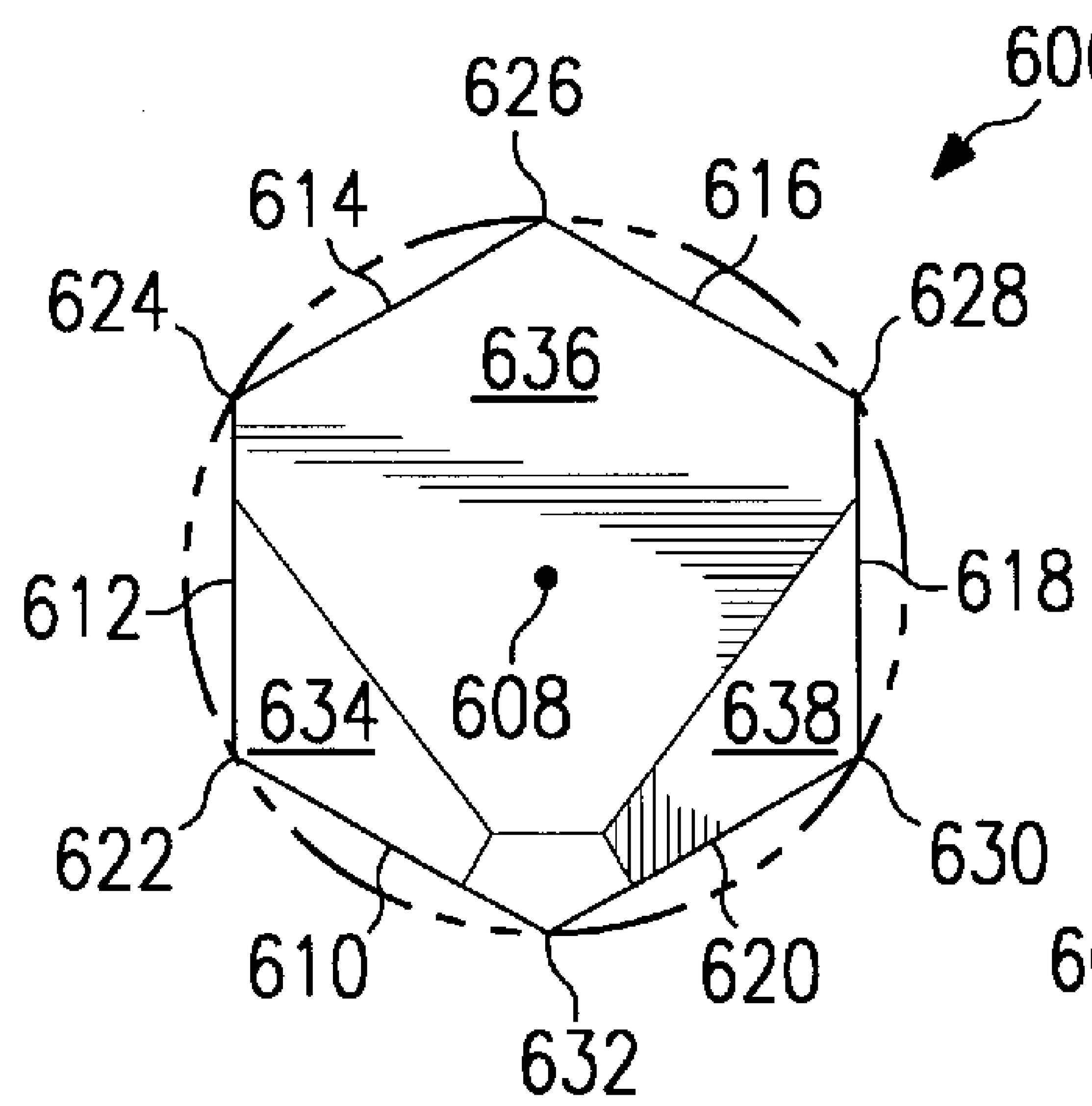

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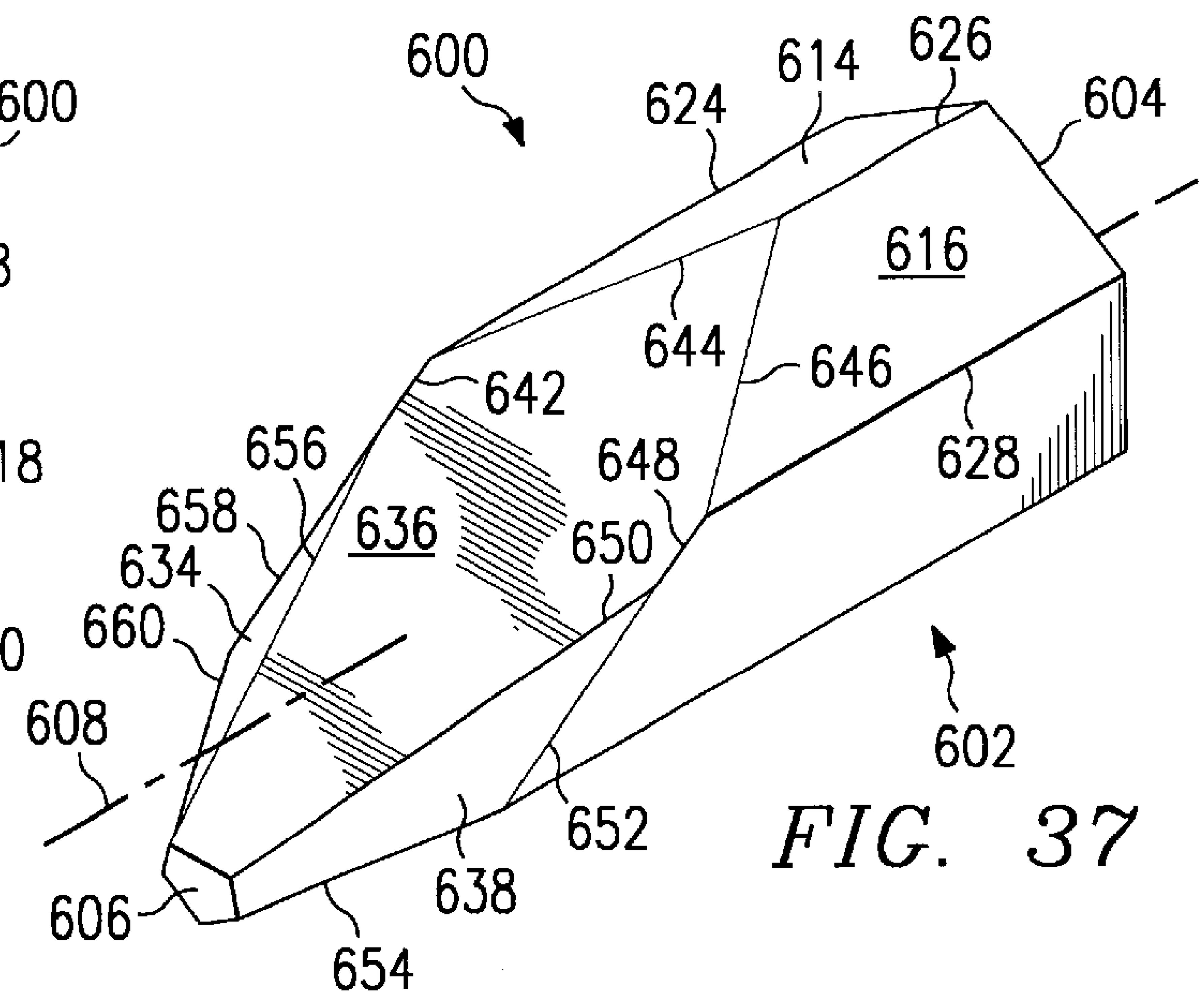

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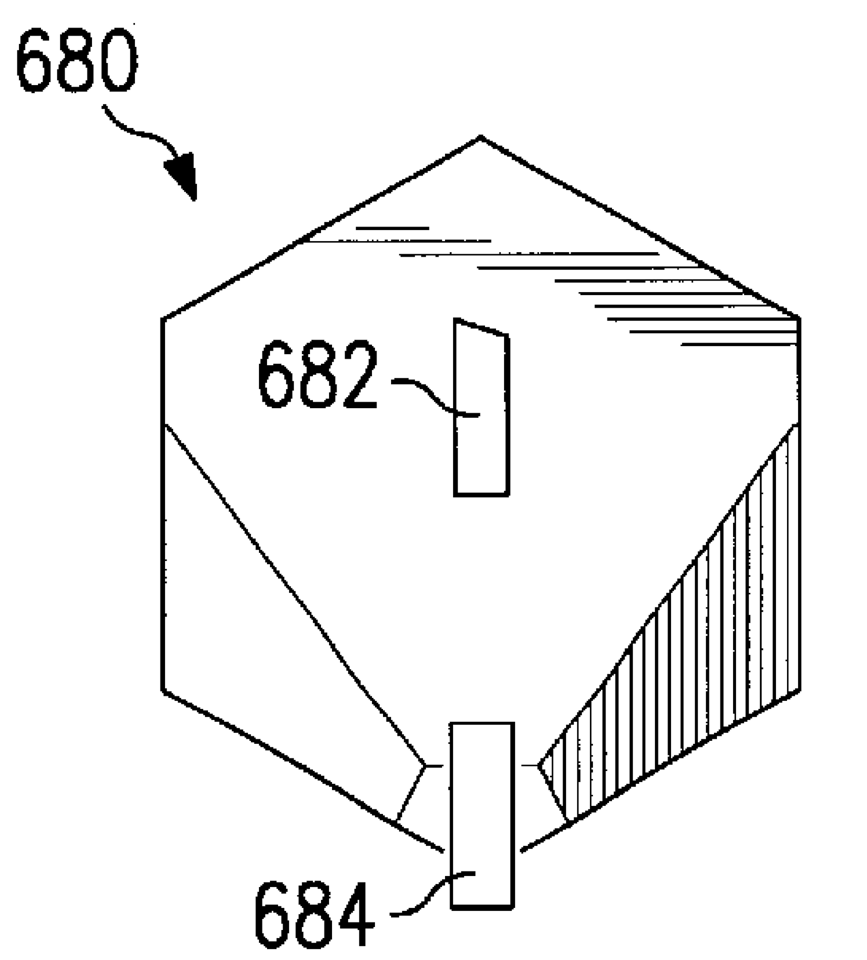

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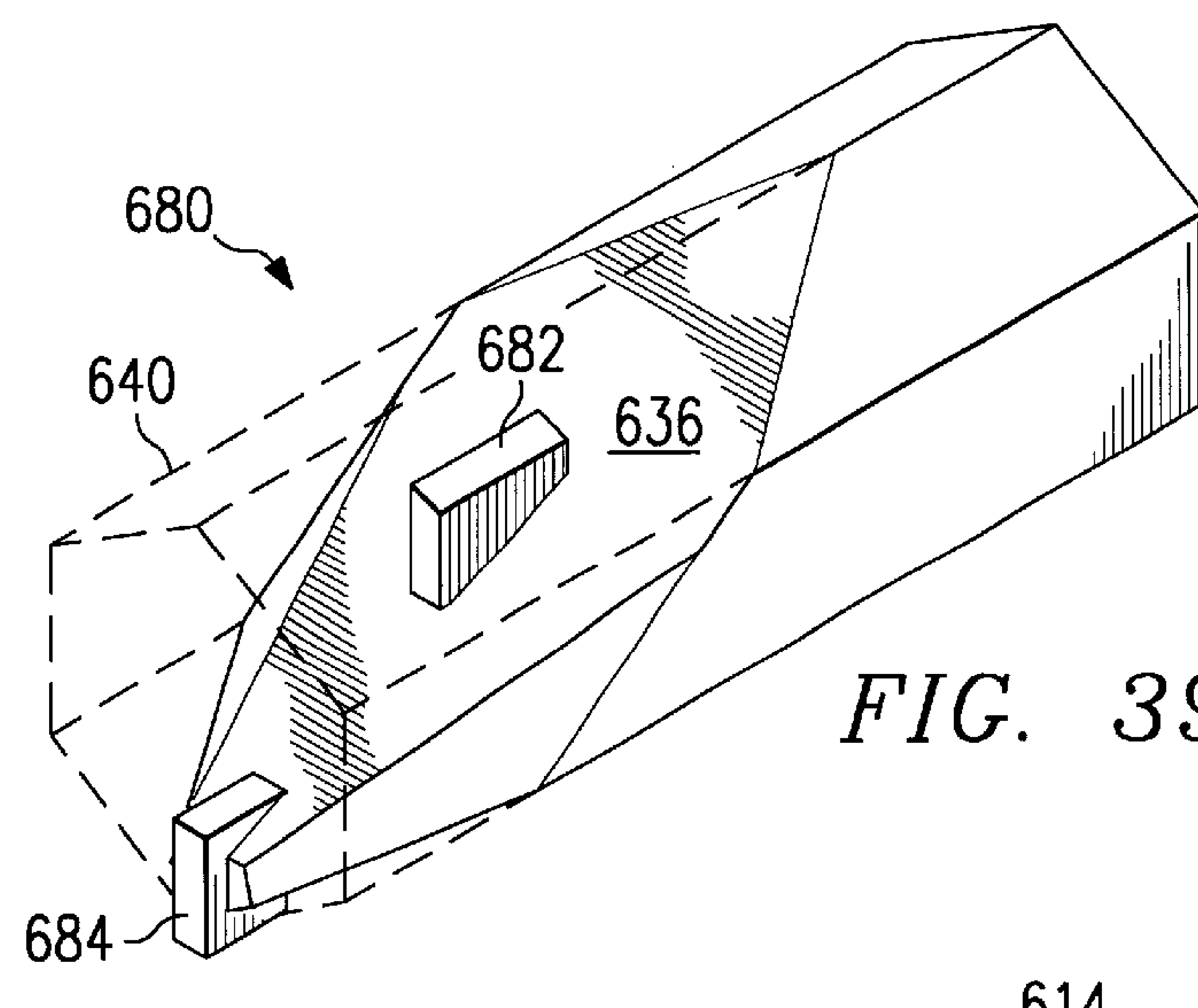

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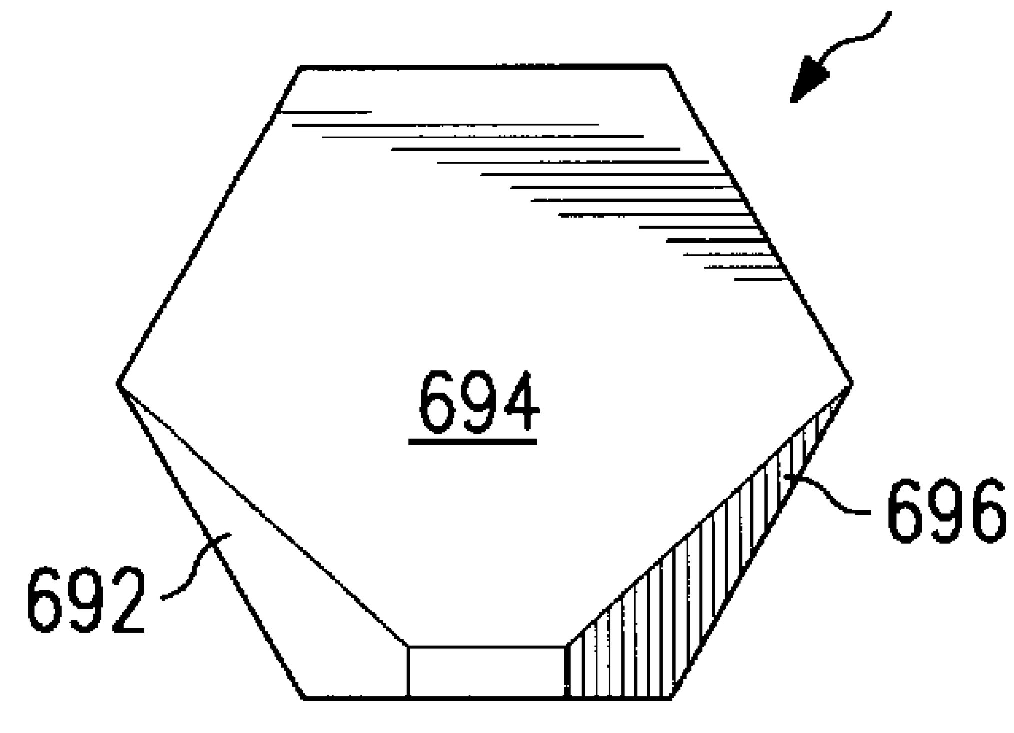

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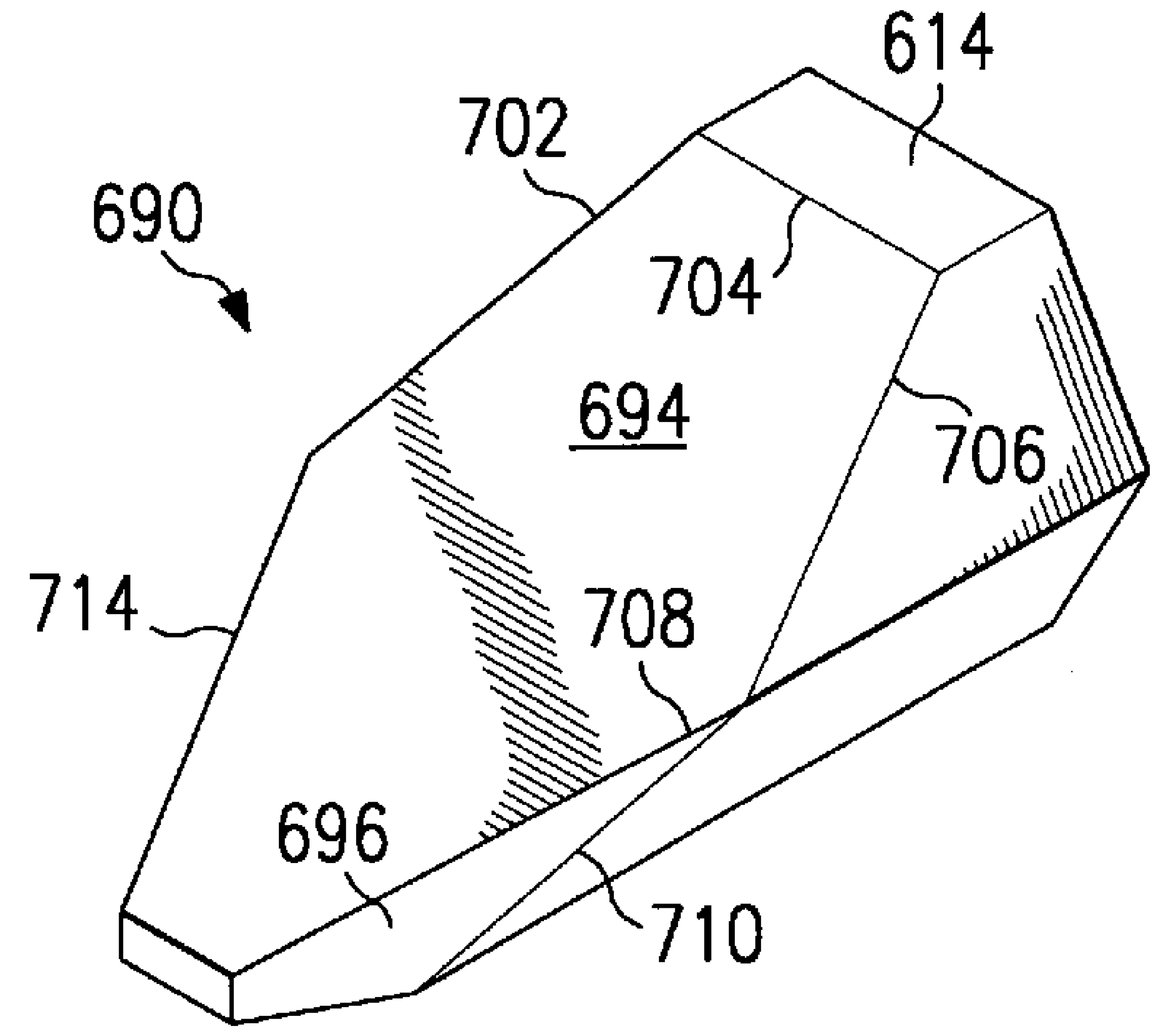

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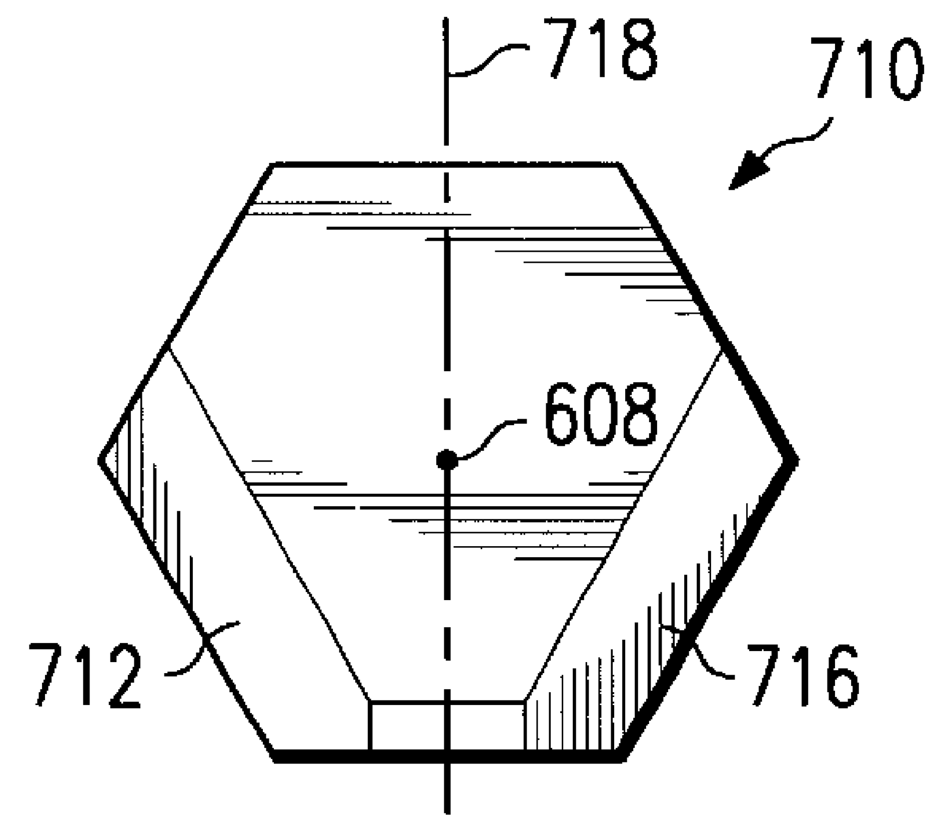

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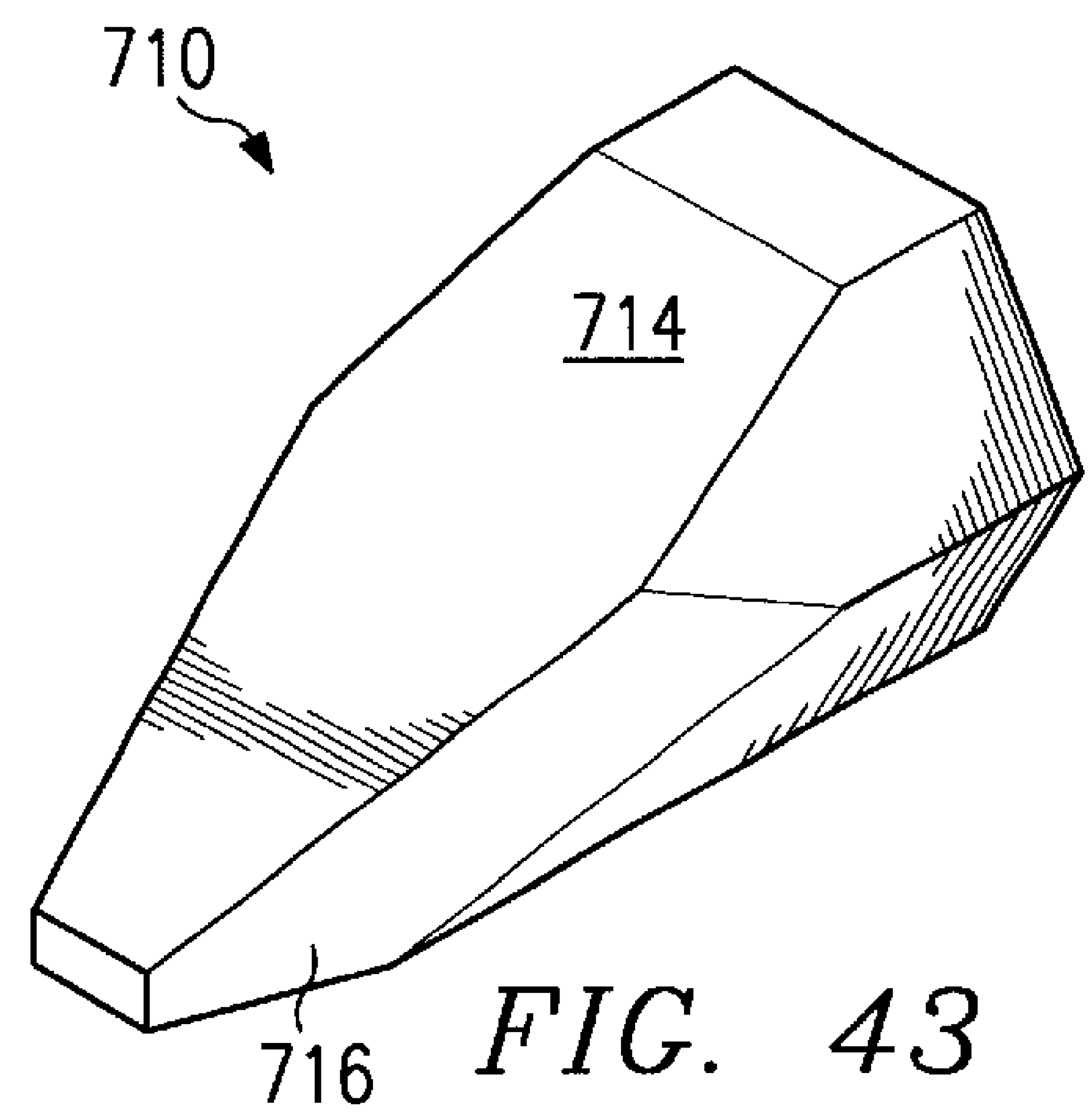

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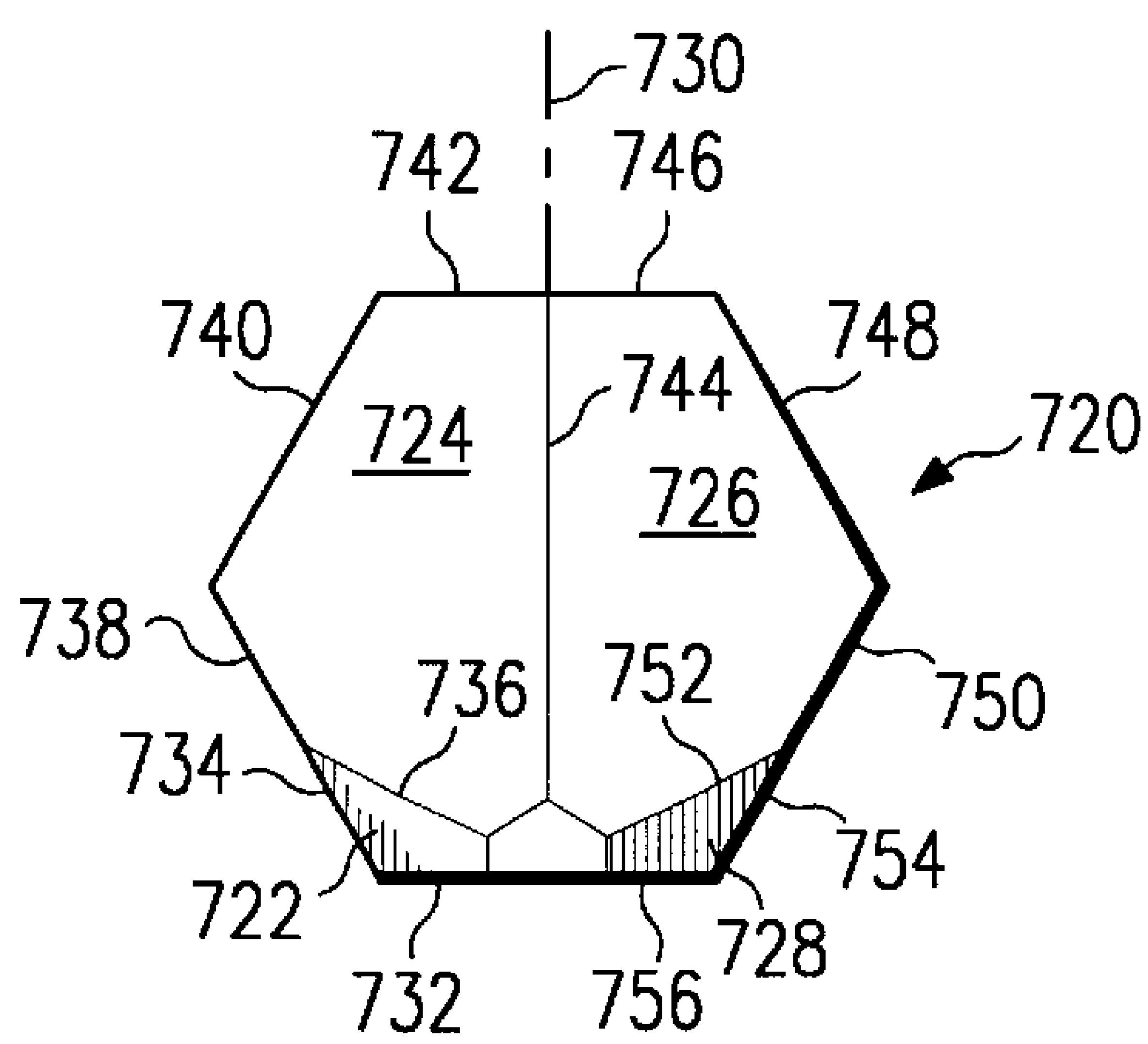
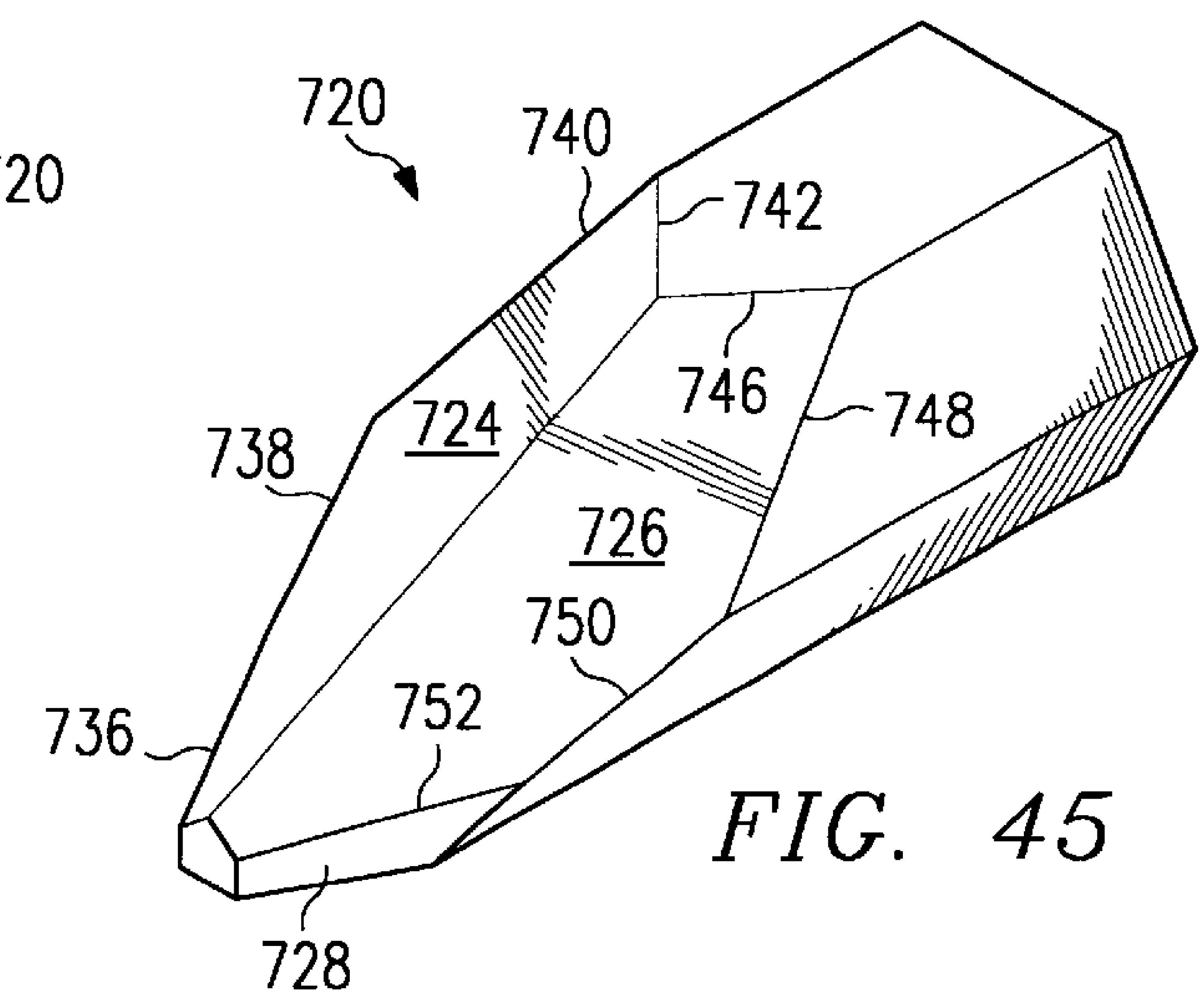


FIG. 44



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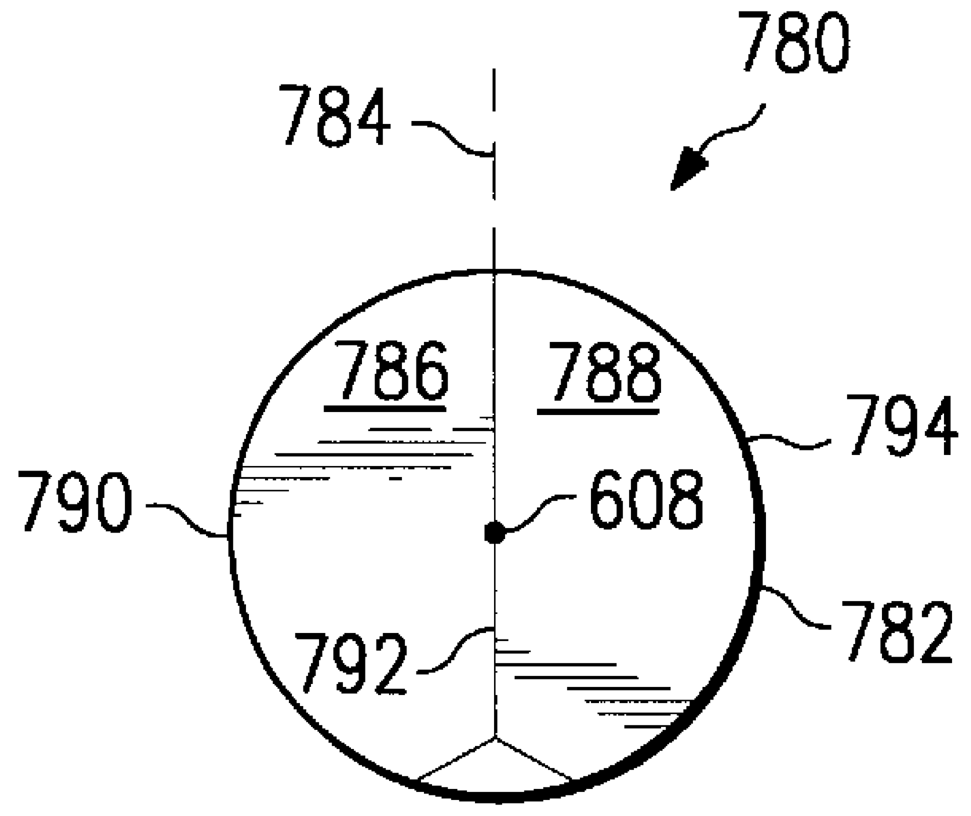

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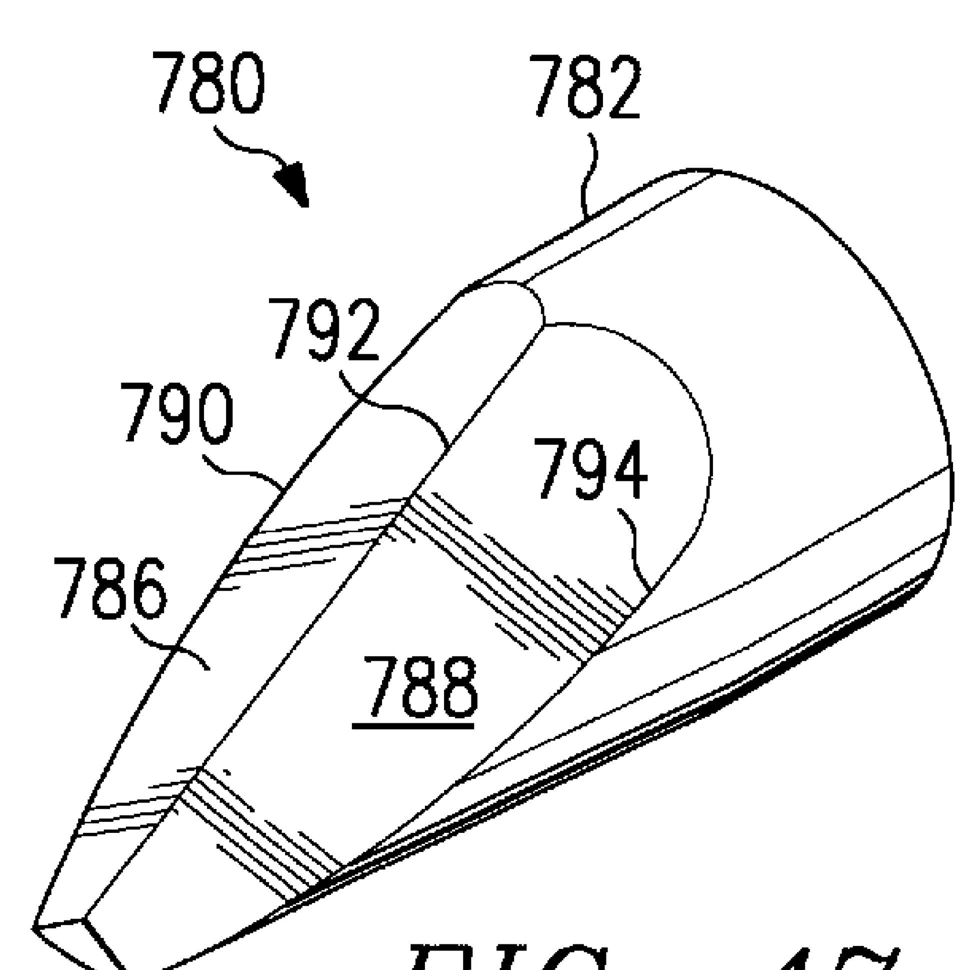

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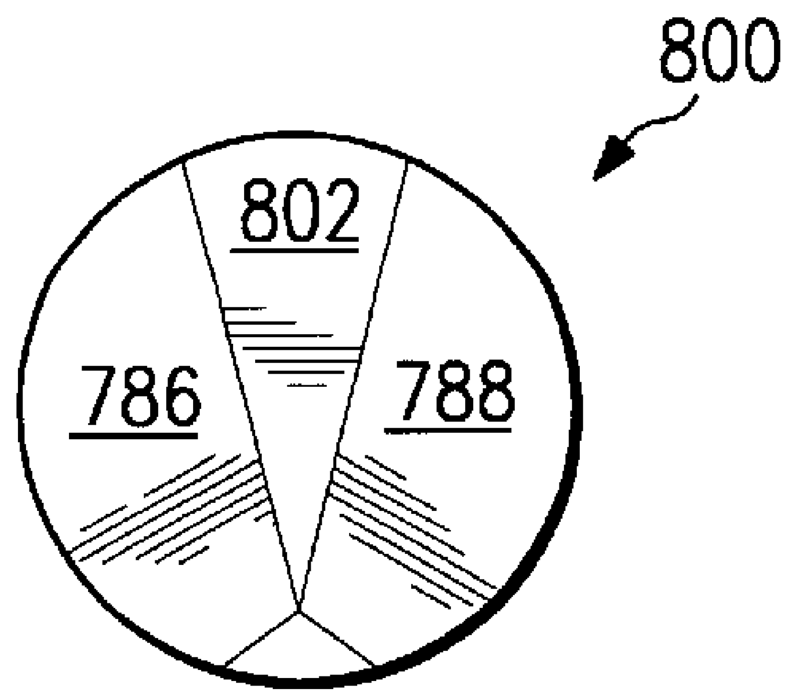

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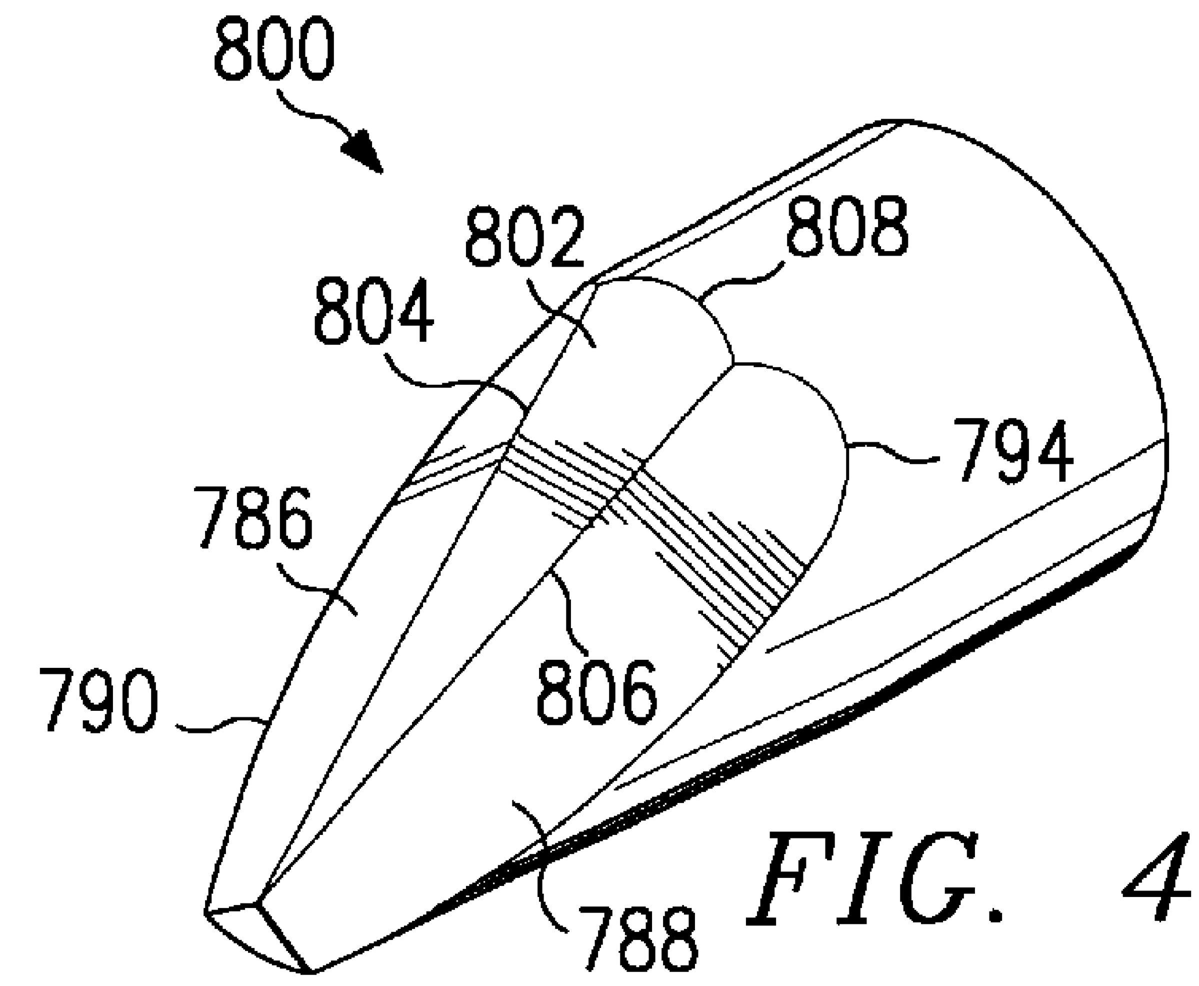

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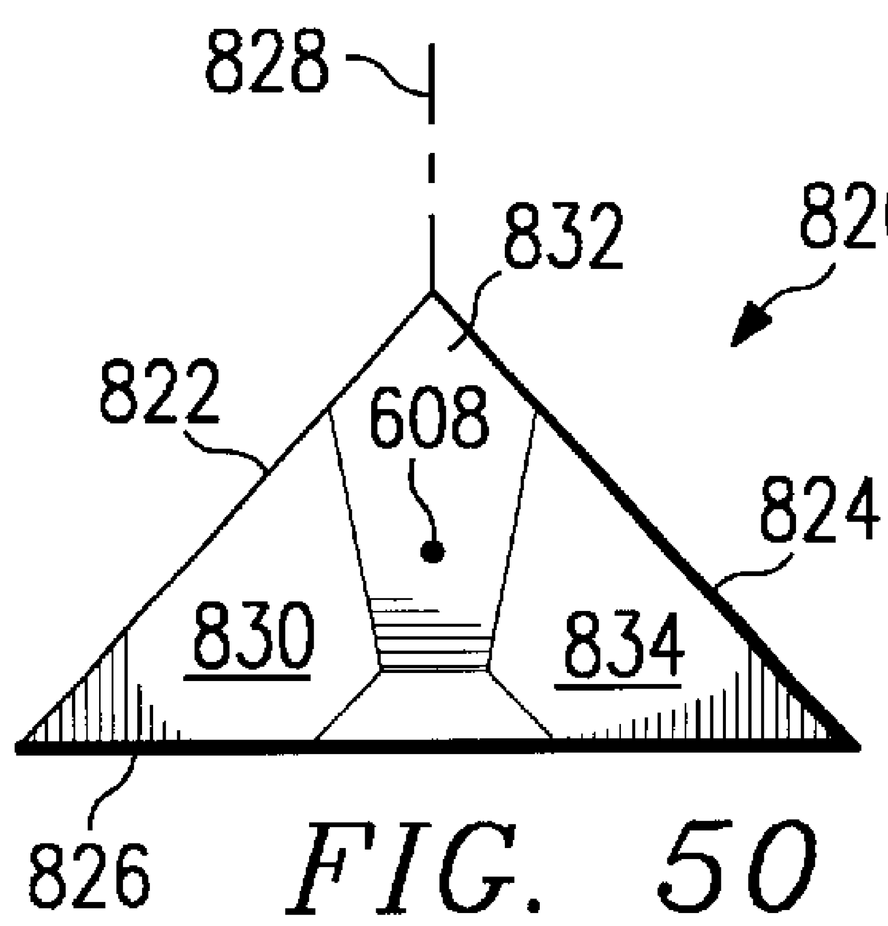


FIG. 50

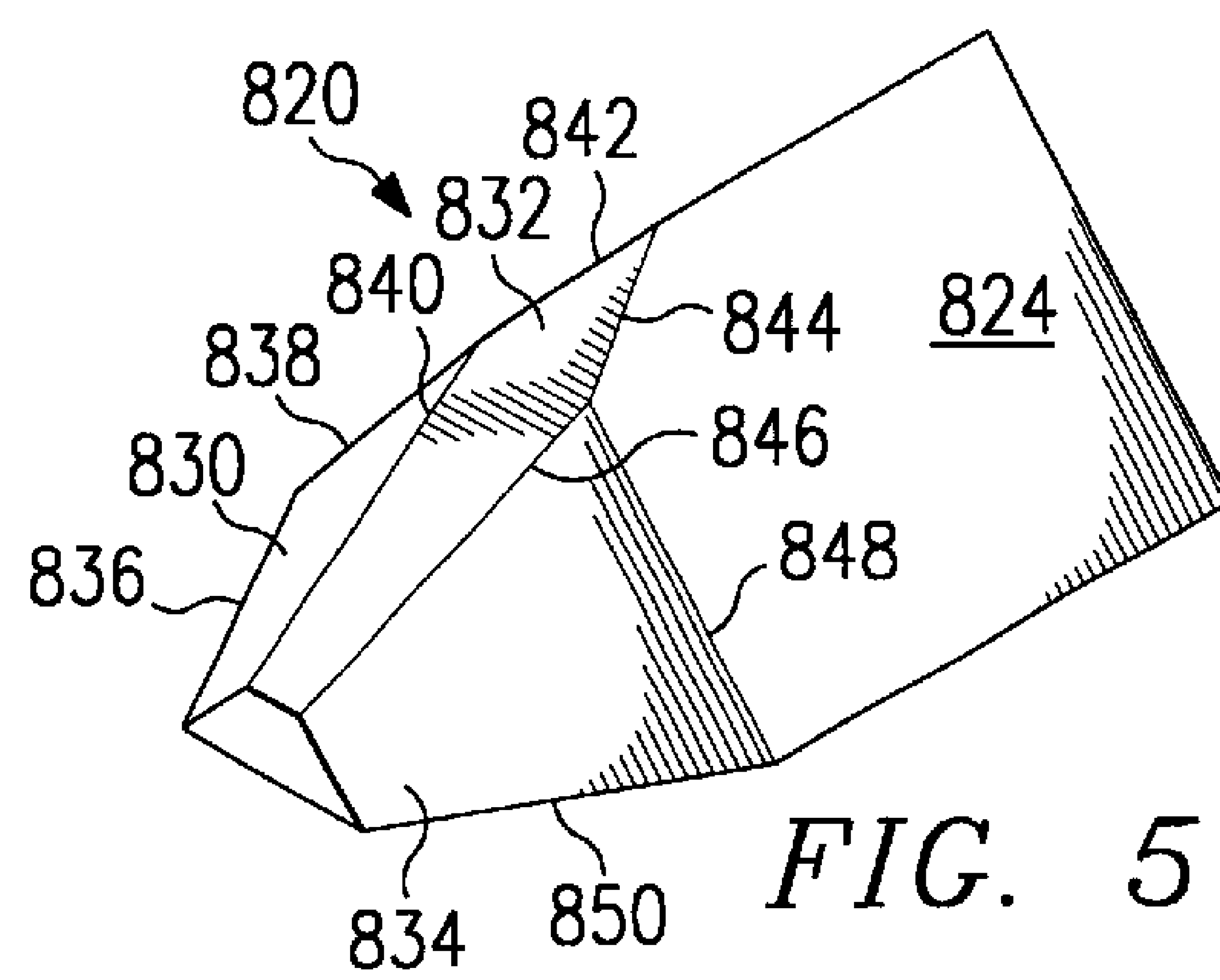


FIG. 51

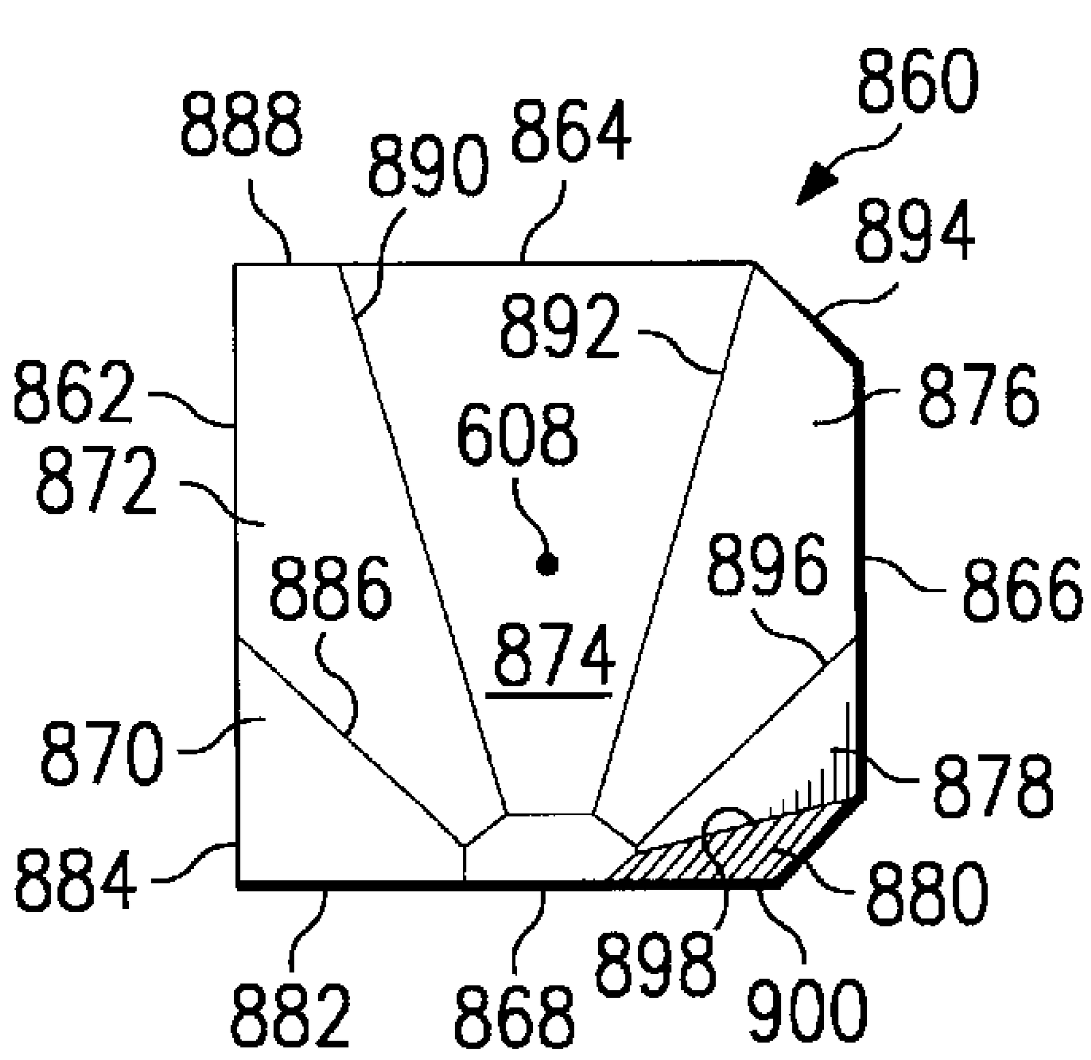


FIG. 52

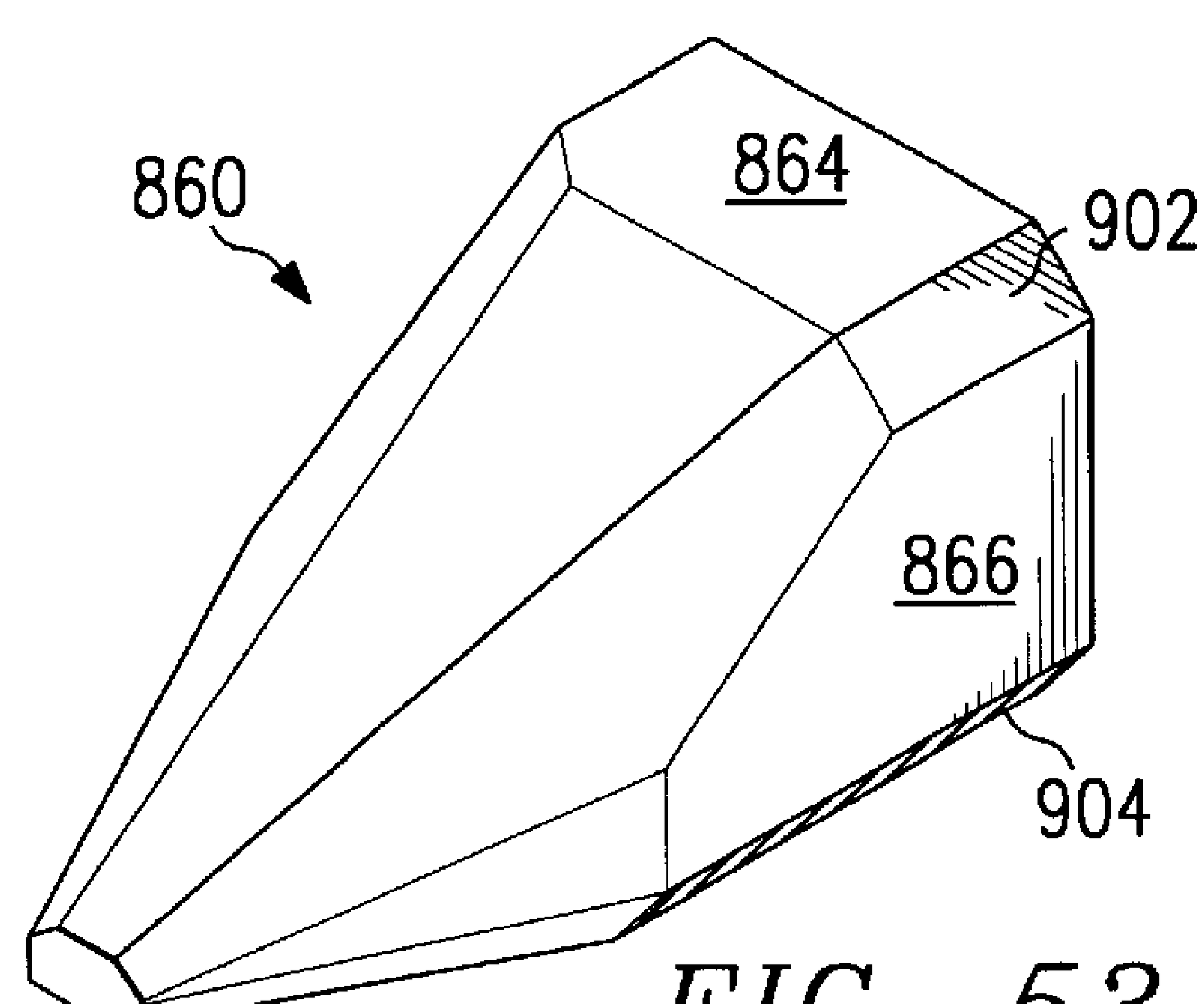


FIG. 53

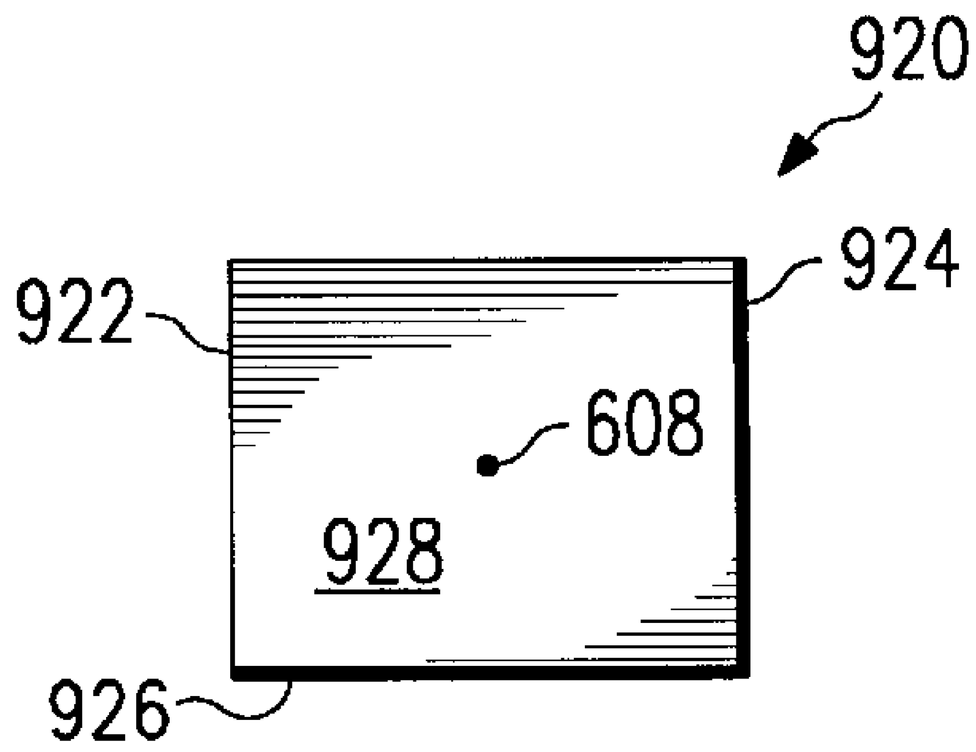


FIG. 54

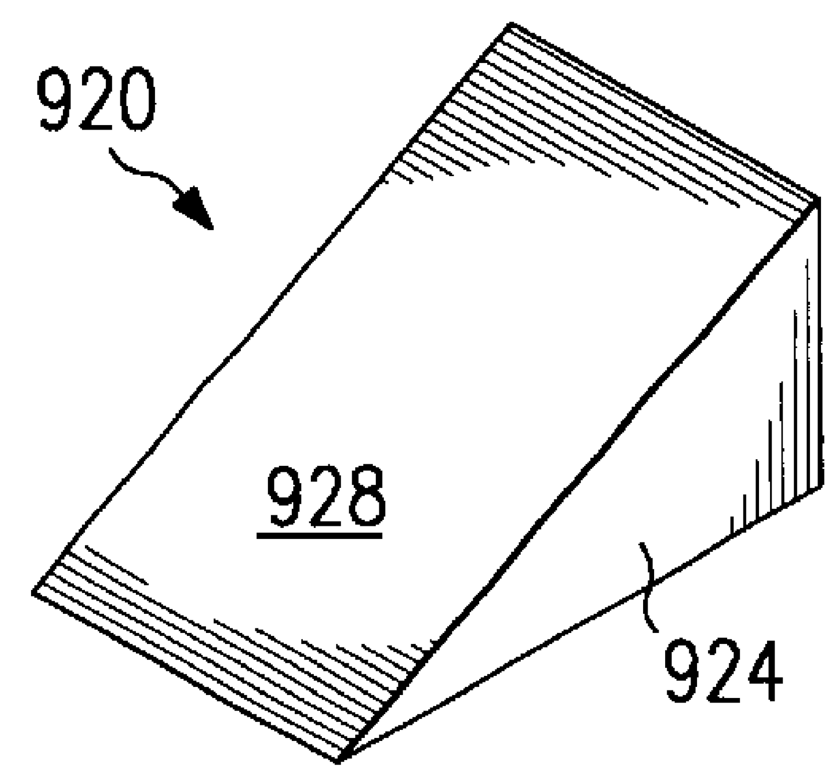


FIG. 55

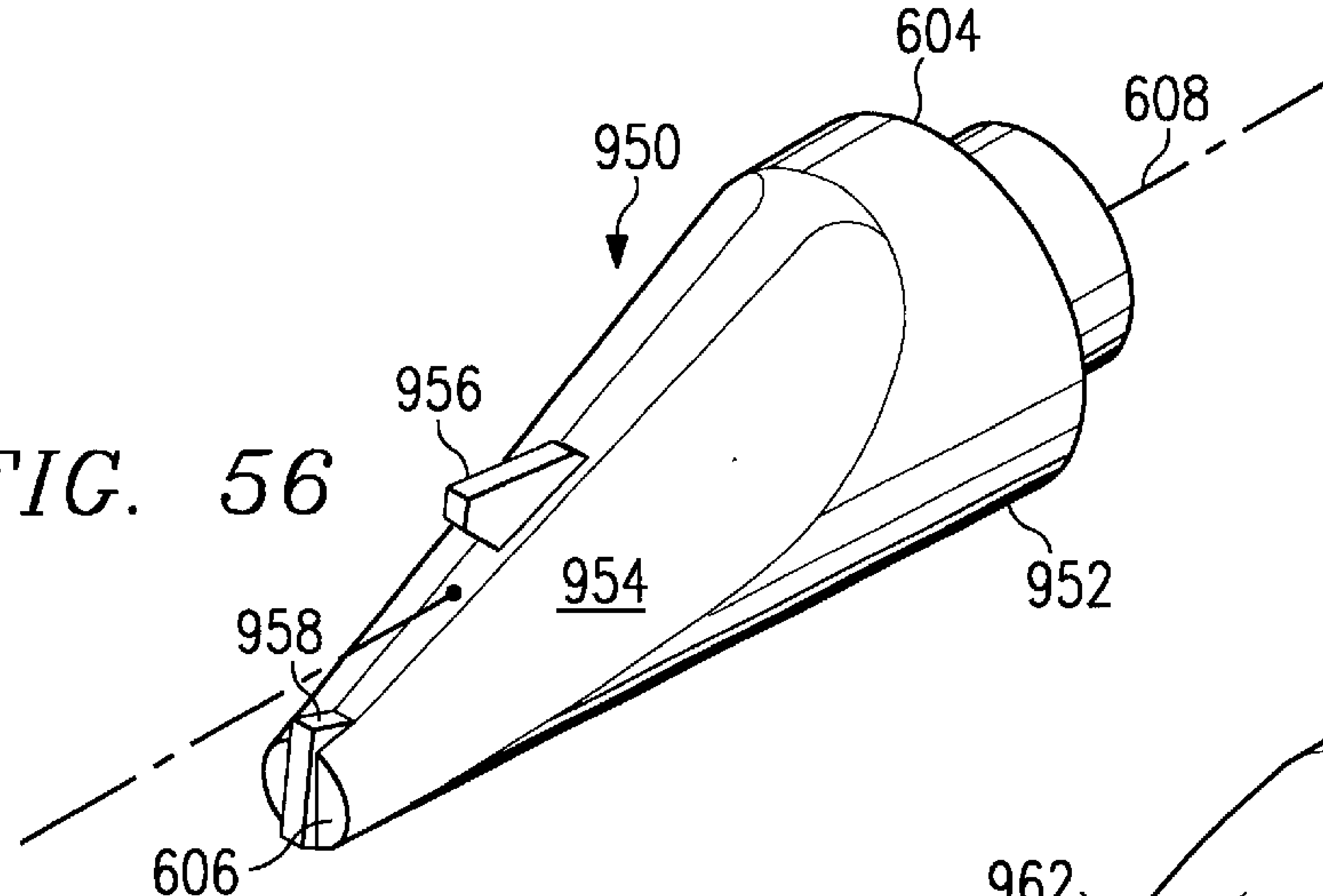


FIG. 56

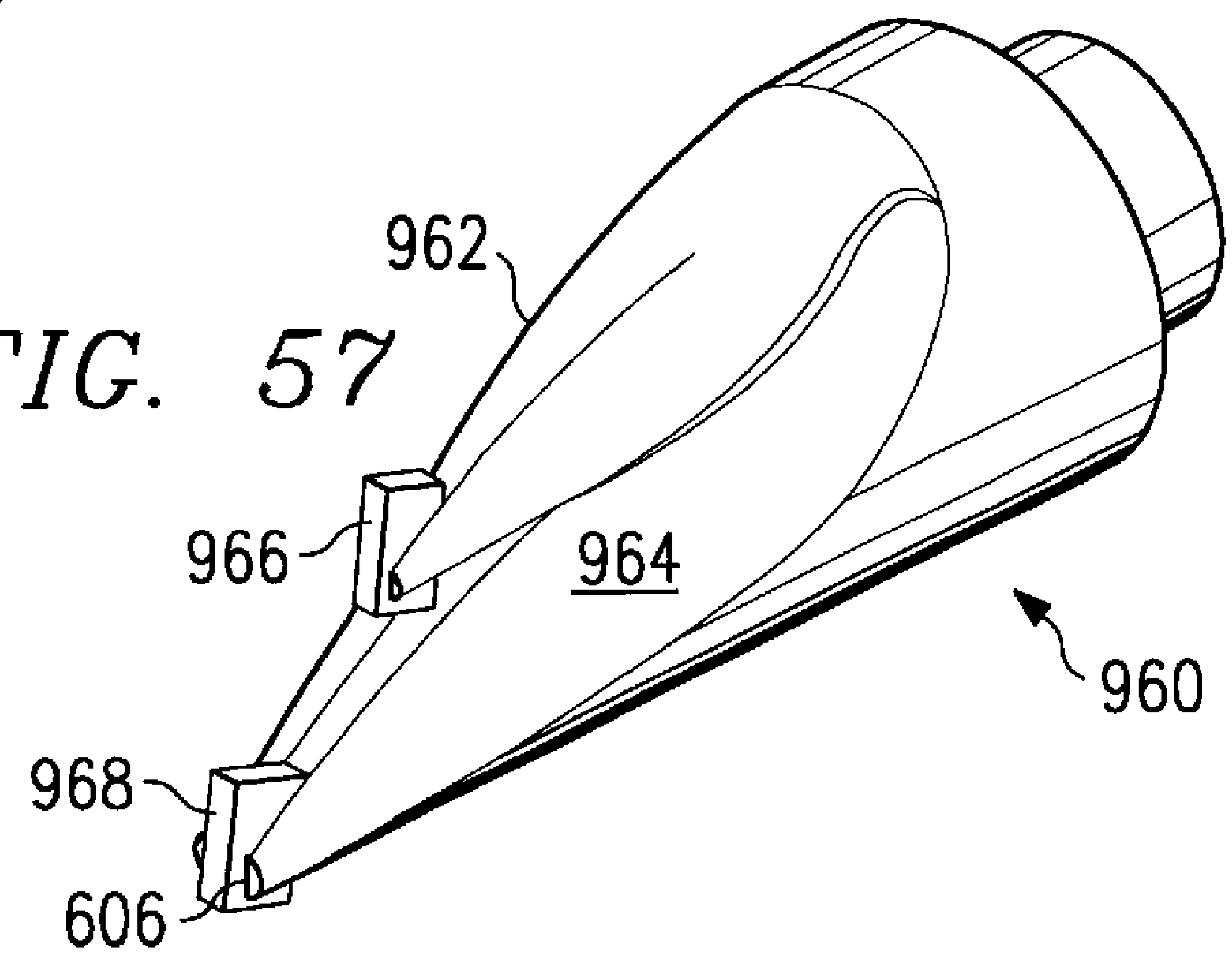
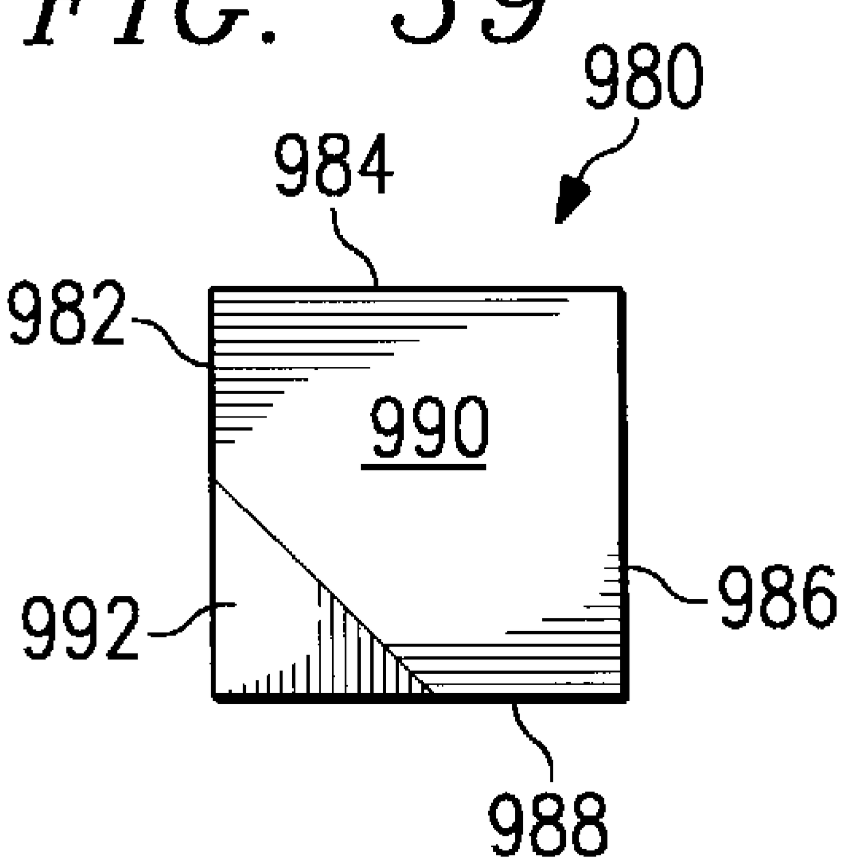


FIG. 57

FIG. 59



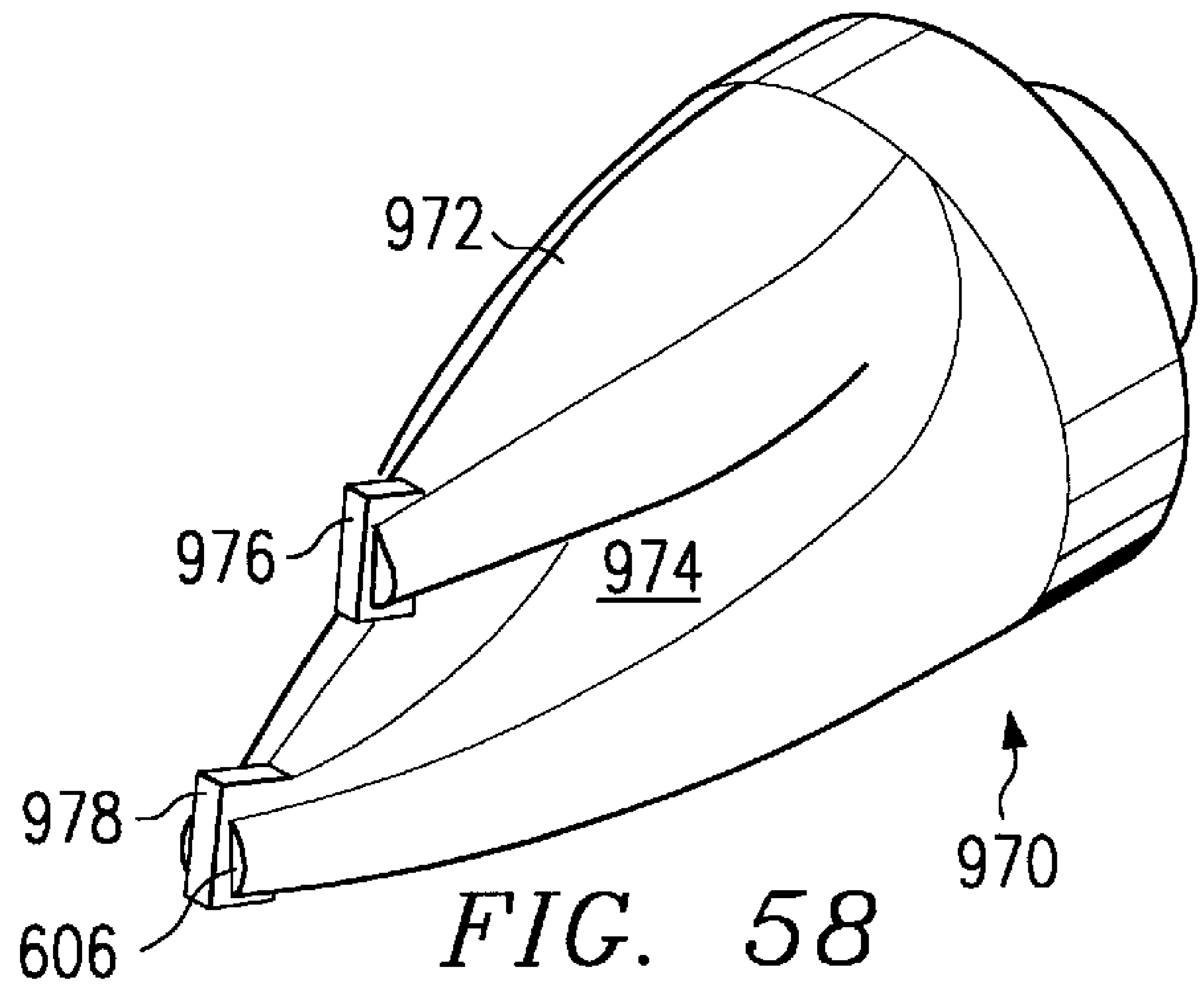


FIG. 58

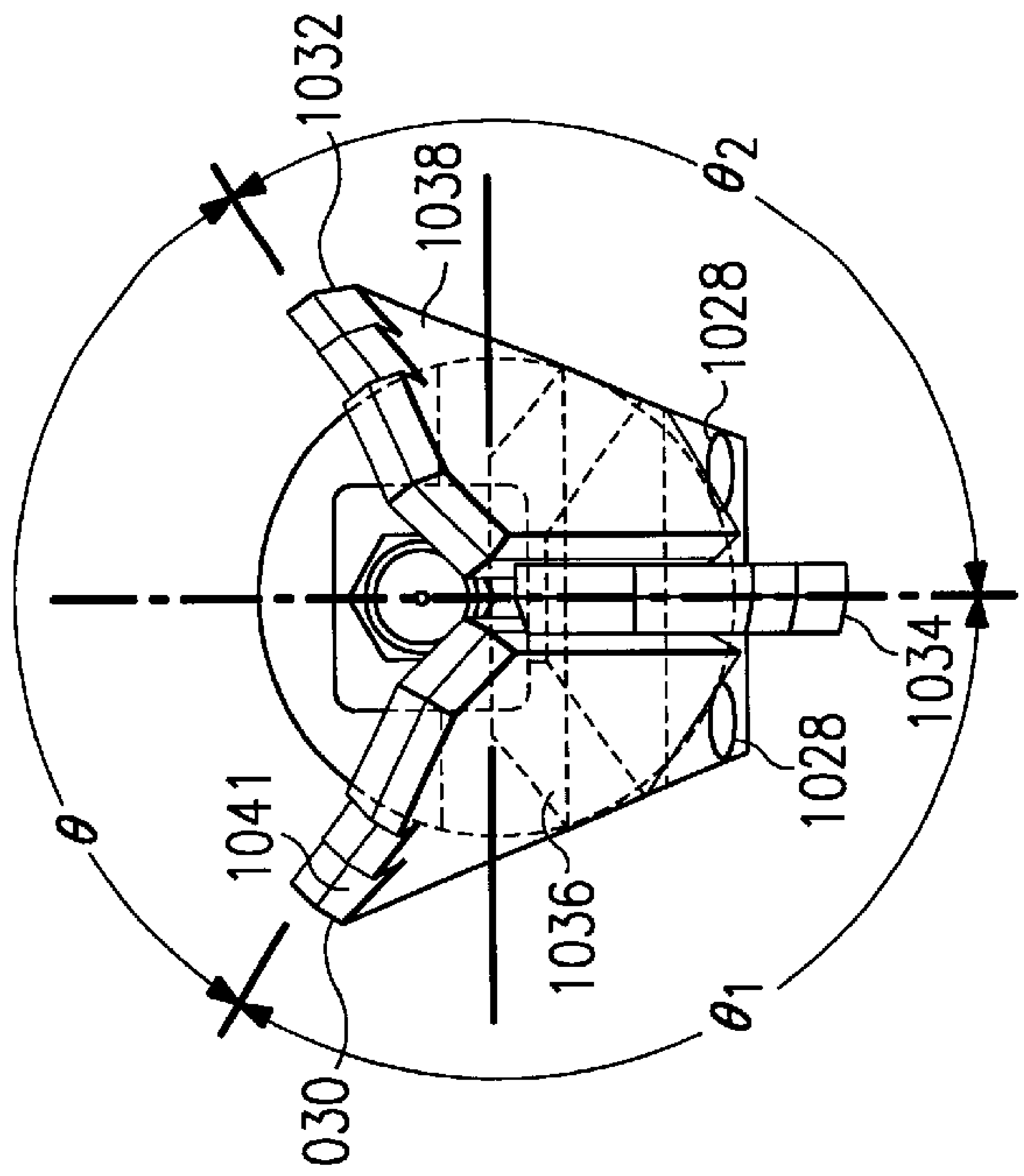


FIG. 61

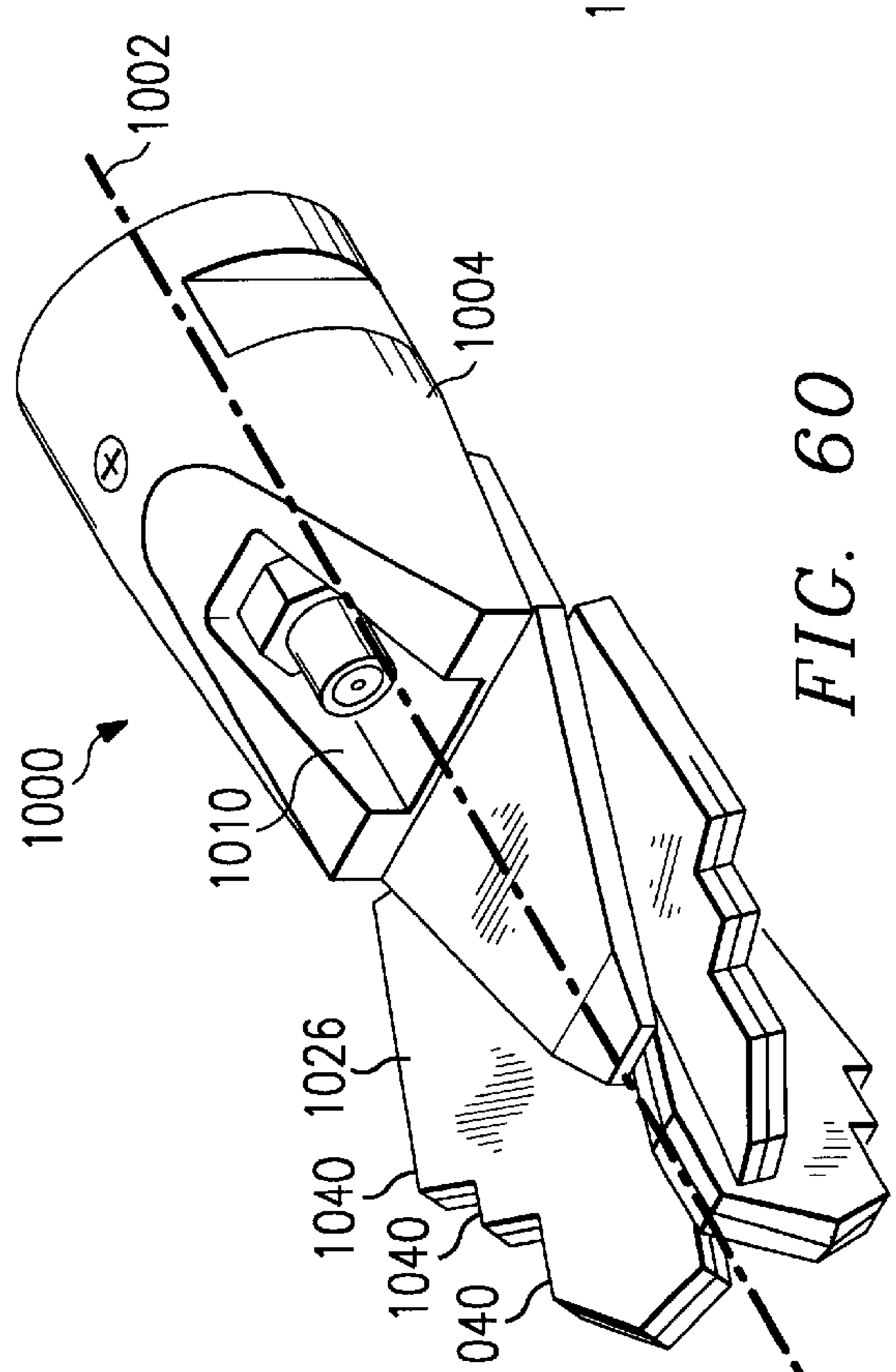


FIG. 60

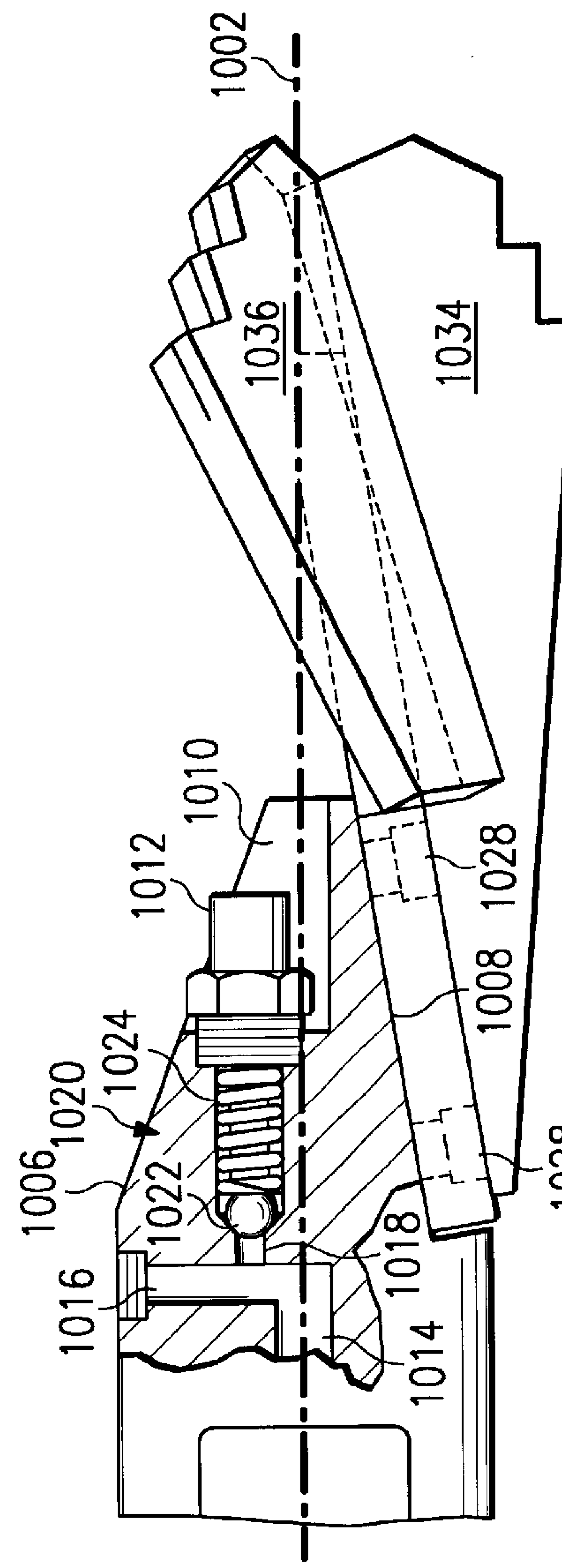


FIG. 62

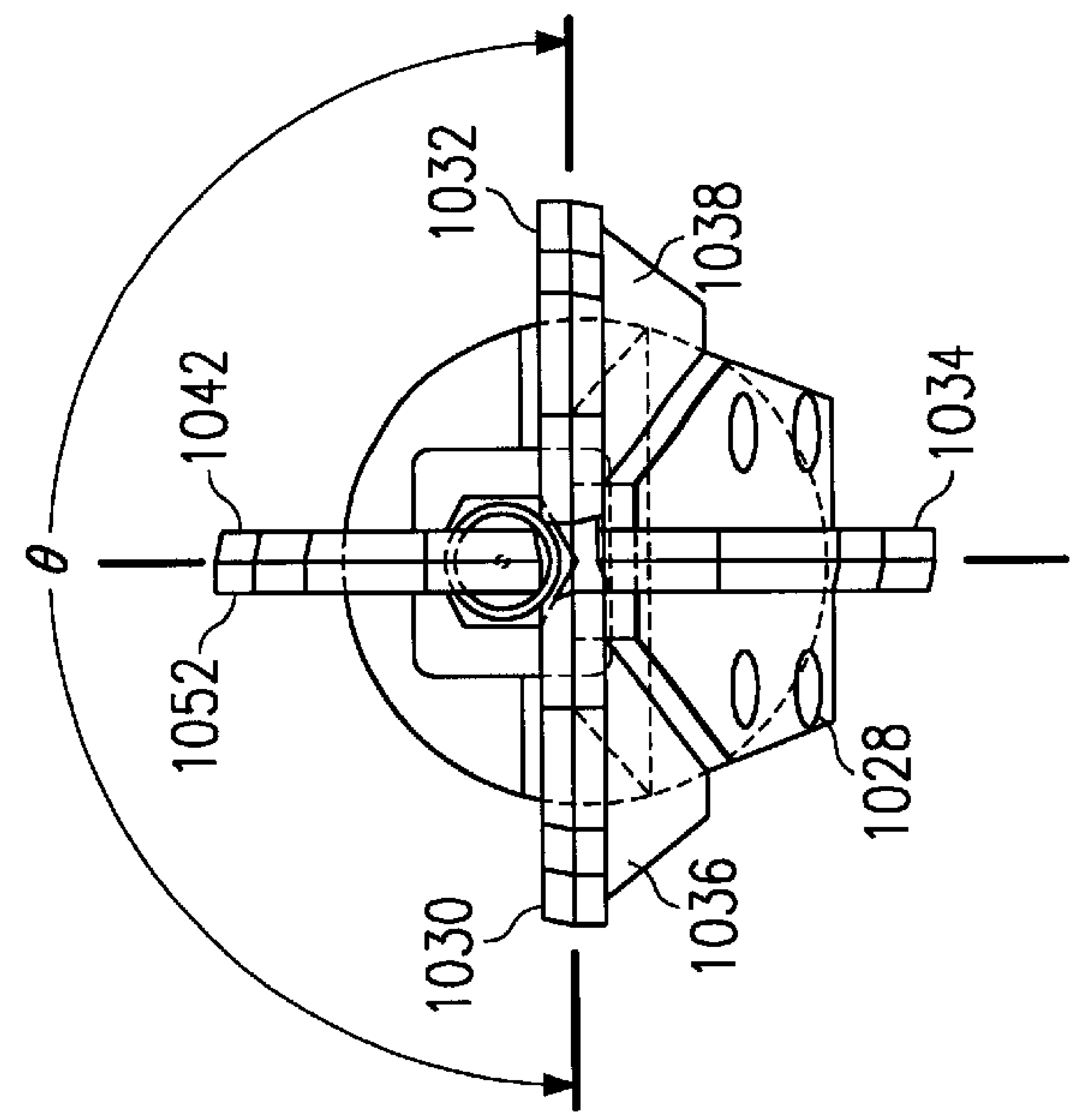


FIG. 64

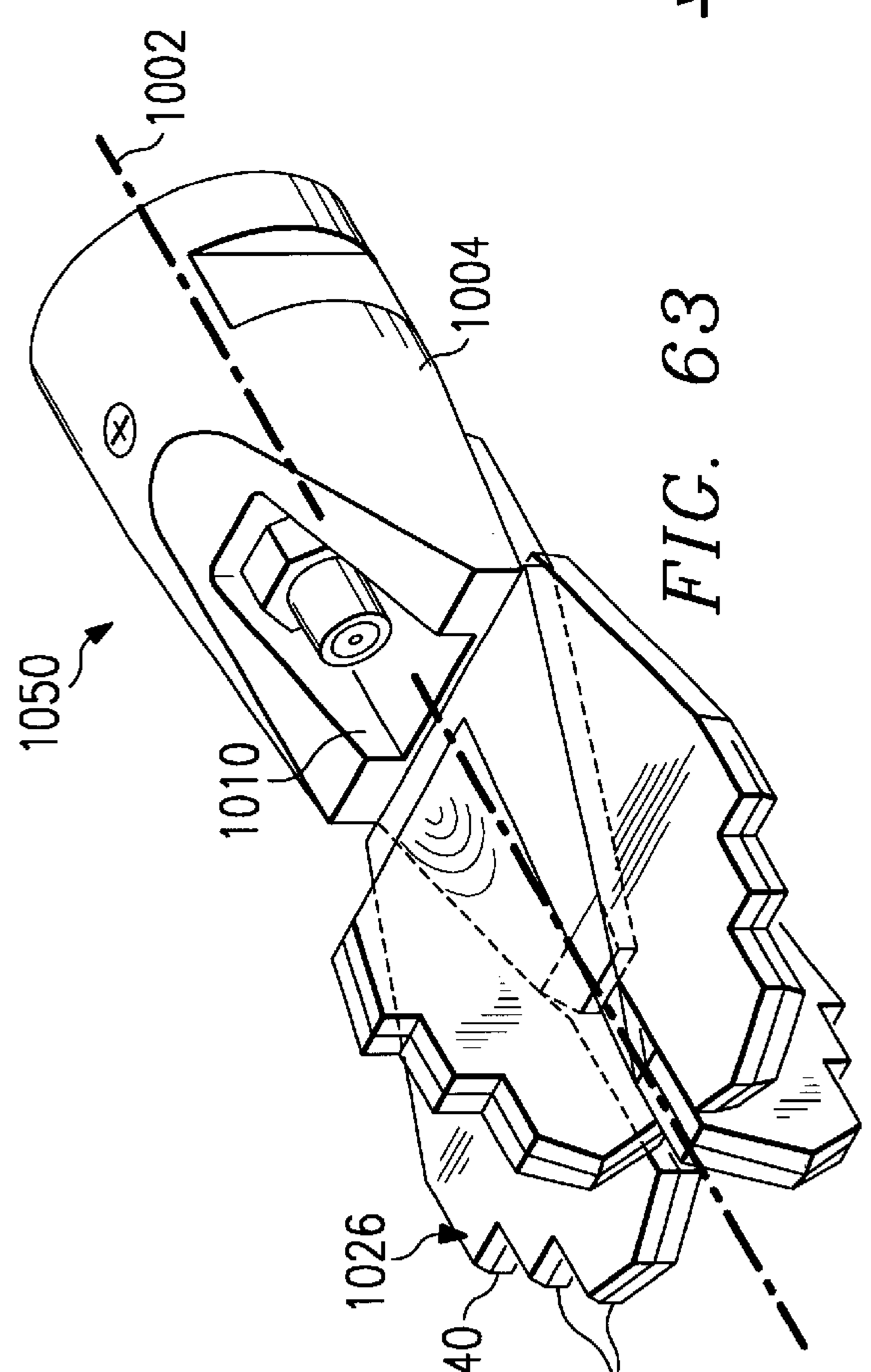


FIG. 63

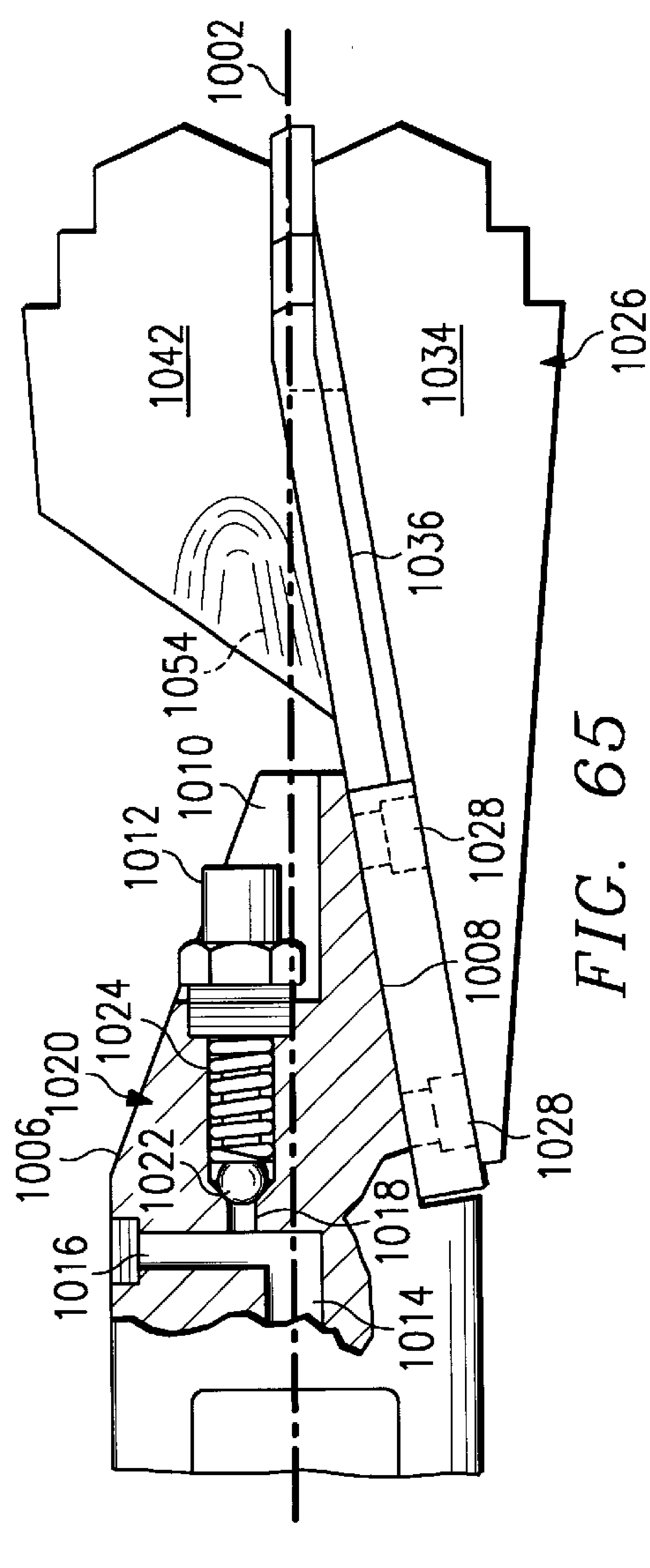


FIG. 65

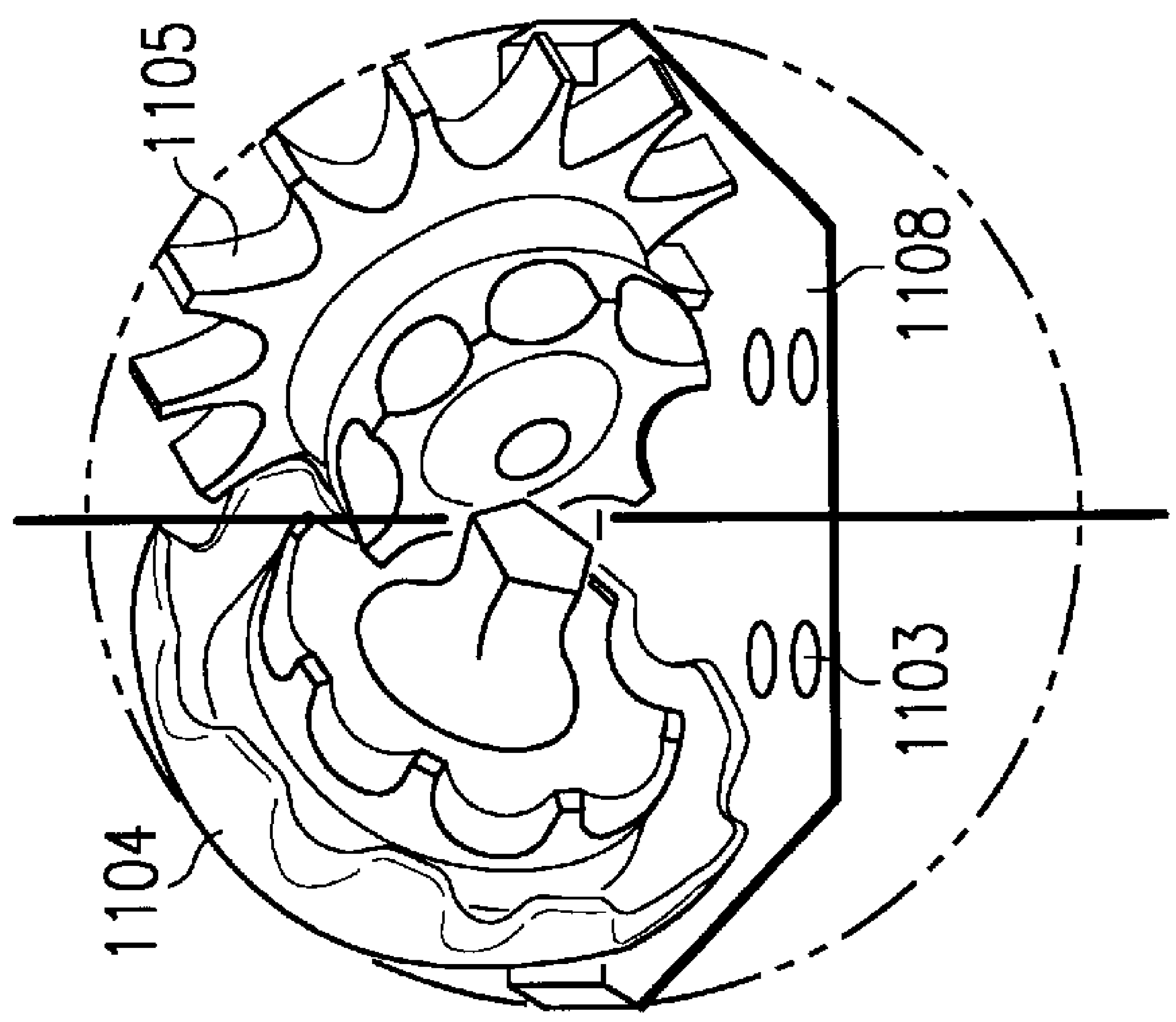


FIG. 67

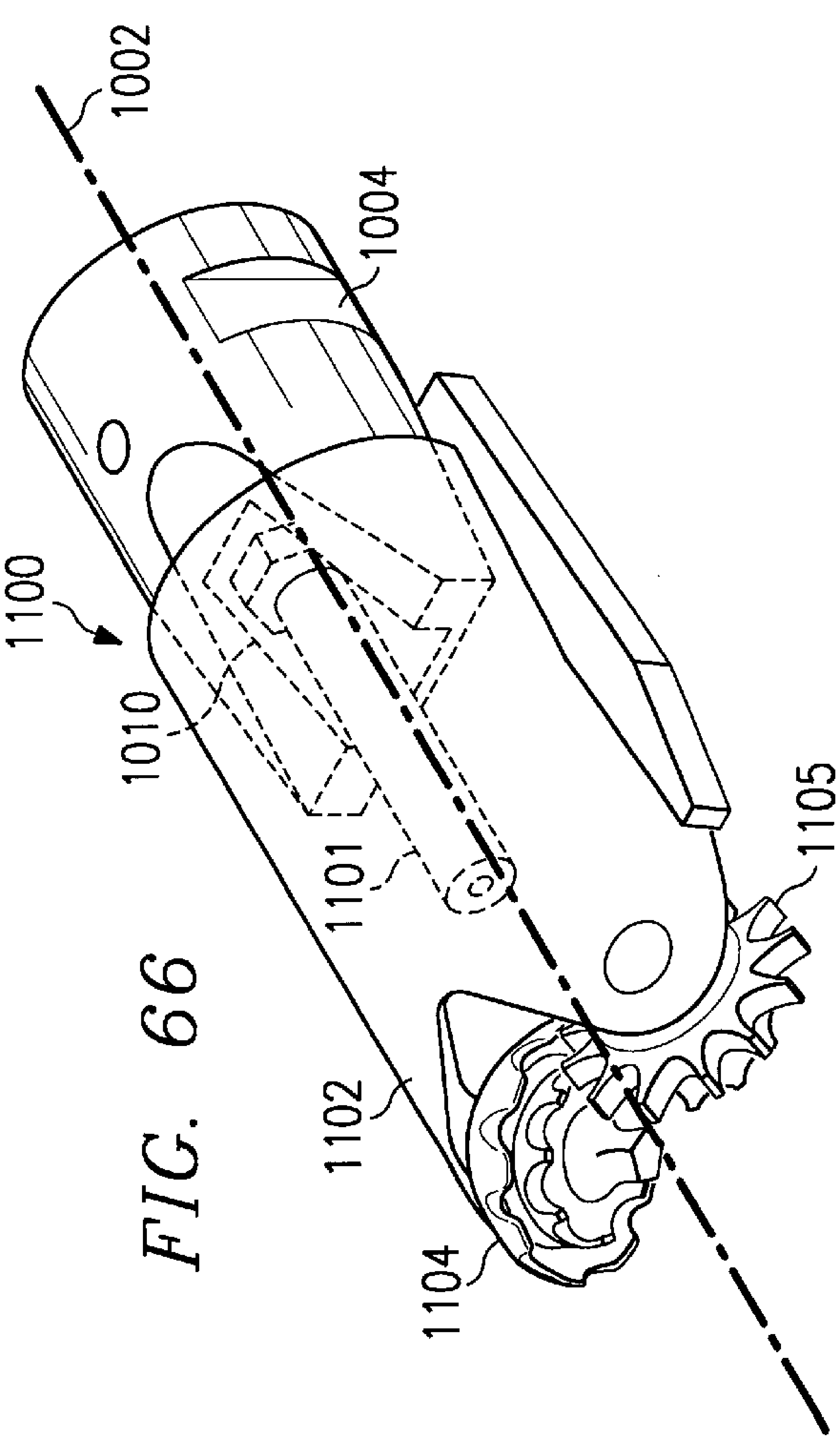


FIG. 66

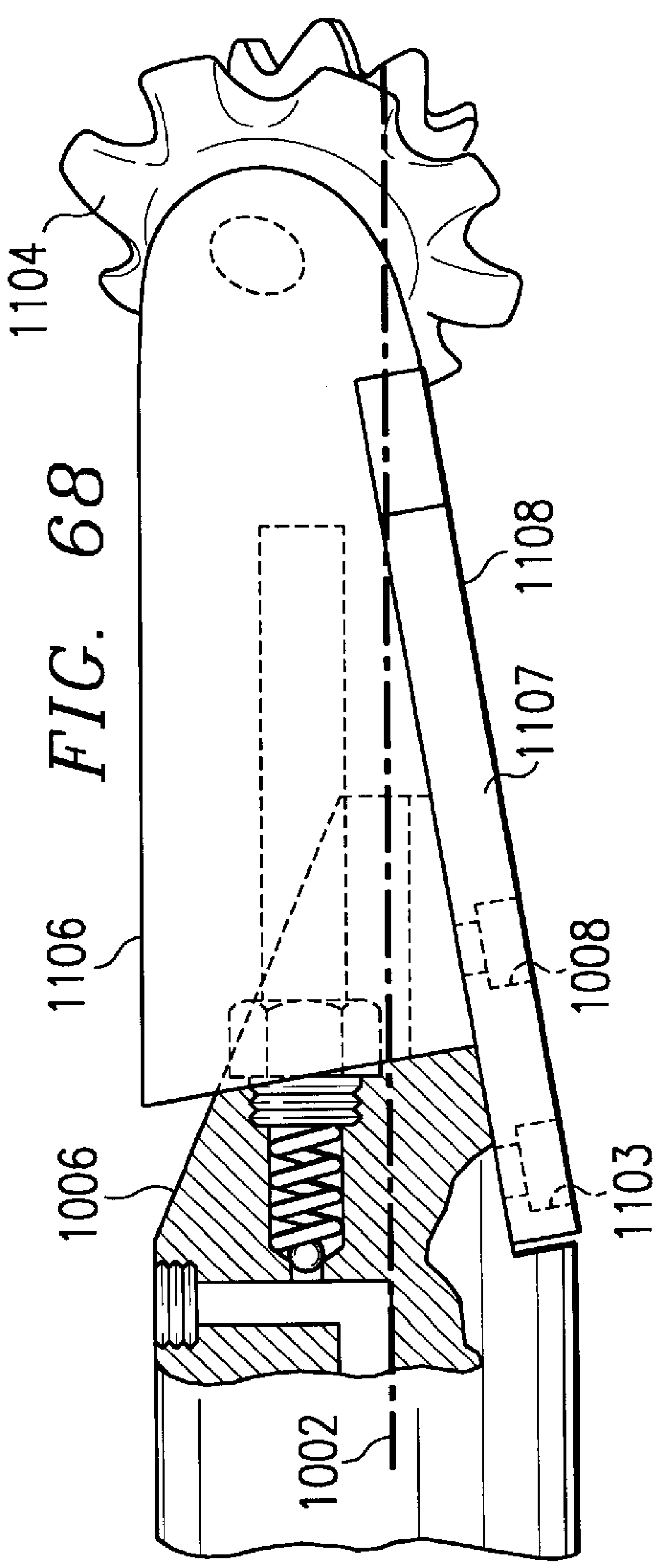


FIG. 68

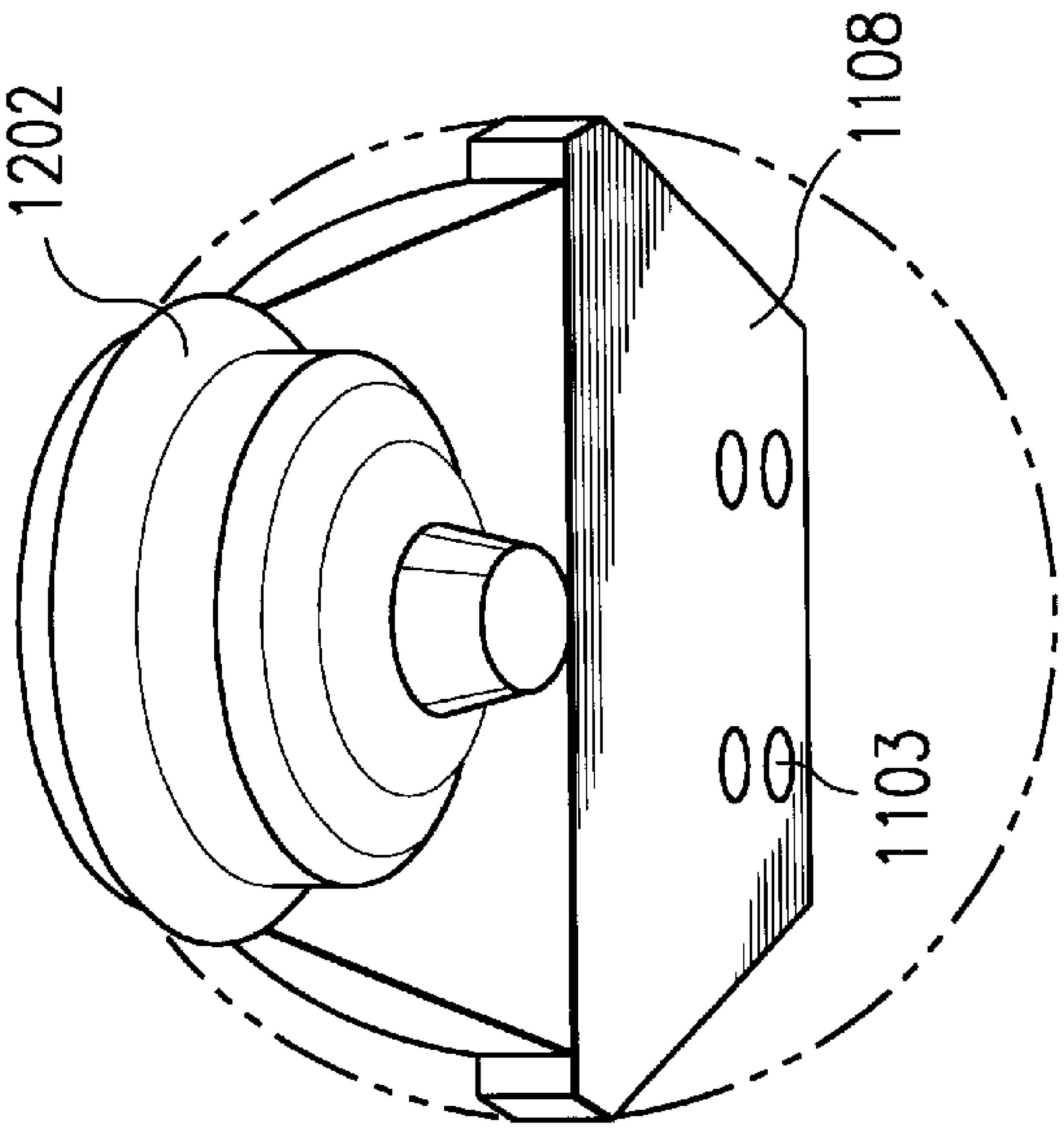


FIG. 70

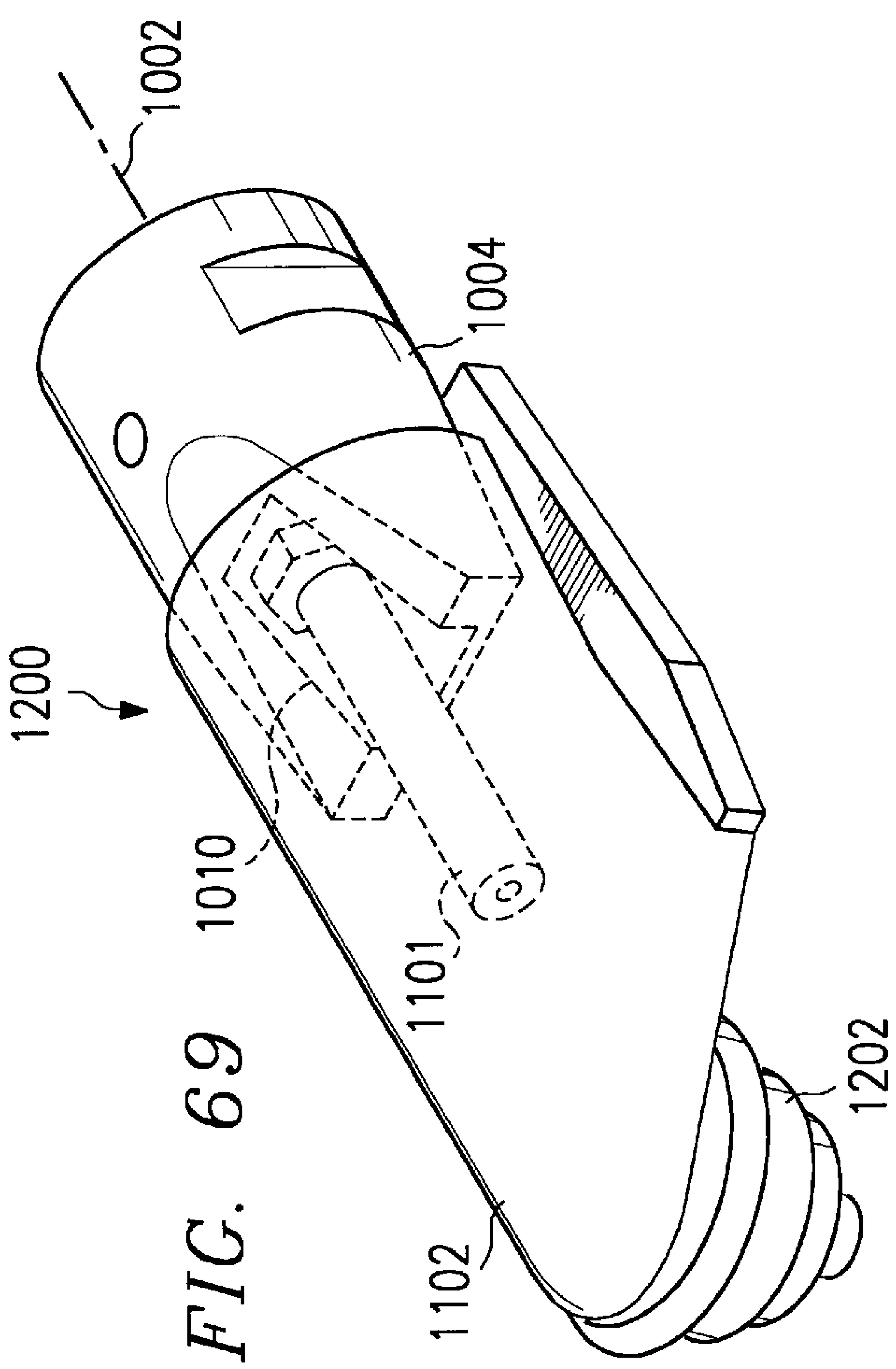


FIG. 69

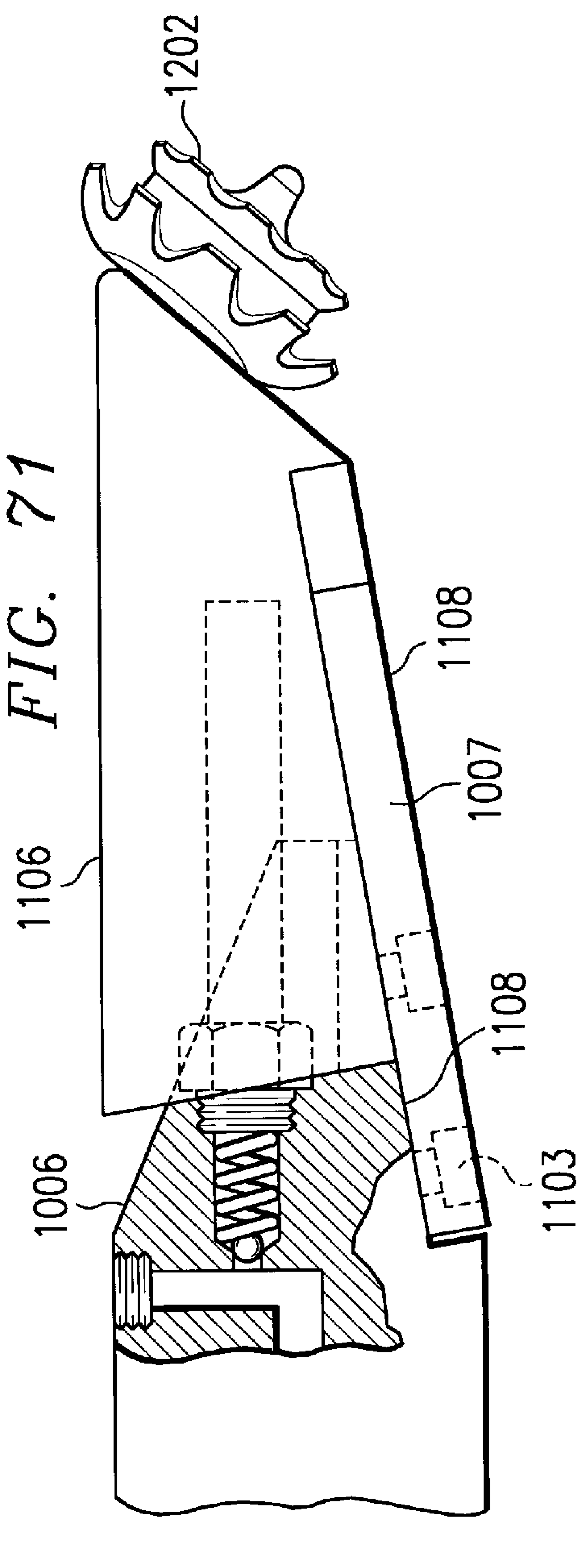


FIG. 71

DIRECTIONAL MULTI-BLADE BORING HEAD

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of application Ser. No. 08/067,298, [filed on May 25, 1993] *entitled DIRECTIONAL MULTI-BLADE BORING HEAD, filed on May 25, 1993, now U.S. Pat. No. 5,341,887, which was a continuation-in-part of application Ser. No. 857,167, entitled, METHOD OF AND APPARATUS FOR DRILLING A HORIZONTAL CONTROLLED BOREHOLE IN THE EARTH, filed Mar. 25, 1992, now U.S. Pat. No. 5,242,026, which was a continuation-in-part of application Ser. No. 575,568, entitled APPARATUS FOR DRILLING A HORIZONTAL CONTROLLED BOREHOLE IN THE EARTH, filed Aug. 31, 1990, now U.S. Pat. No. 5,148,880, which was a continuation-in-part of application Ser. No. 211,889, entitled METHOD OF AND APPARATUS FOR DRILLING A HORIZONTAL CONTROLLED BOREHOLE IN THE EARTH, filed Jun. 27, 1988, now U.S. Pat. No. 4,953,638.*

TECHNICAL FIELD OF THE INVENTION

This invention relates to a steerable fluid assisted mechanical boring head for drilling substantially horizontal boreholes under a roadway or other obstruction.

BACKGROUND OF THE INVENTION

Using boring machines with a steerable bit or head for drilling horizontal boreholes under a roadway or other obstruction is a well known practice. The process of providing such boreholes is generally referred to as "trenchless" digging, since an open trench is not required. A key to the operation of such a boring device is to have an effective steerable boring bit or head. If the bit is steerable, the operator can redirect the borehole along the proper path if it begins diverting from the desired path, and also allows the operator to steer around obstructions underground.

Many drill bits have been designed which have such a steering feature. However, there is a continuing need to develop boring bits which have better directional control, operate in a variety of soil conditions effectively and provide enhanced cutting action.

SUMMARY OF THE INVENTION

In accordance with one aspect of the present invention, a directional boring bit is illustrated which is capable of axially advancing while the drill string on which the boring bit is mounted is rotated and is capable of moving in a different direction as the drill string rotation is stopped and the drill string and boring bit are thrust forward. The directional boring bit has a body and a deflecting surface on the body at an oblique angle to the central axis rotation of the body. The directional boring bit also has at least one conically shaped rotary cutter or cone mounted thereon to assist in boring.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an elevational view of a boring machine as employed in practicing the method of the invention for drilling a borehole in the earth.

FIG. **2** is an elevational enlarged scale view of the boring machine of FIG. **1**.

FIG. **3** is a top plan view of the boring machine of FIGS. **1** and **2** taken along line of **3**—**3** of FIG. **2**.

FIG. **4** is an elevational, enlarged scale view of the boring machine of FIGS. **1** and **2** taken along line **4**—**4** of FIG. **2**.

FIG. **5** is an elevational, cross-sectional, enlarged scale view taken along line **5**—**5** of FIG. **2** showing how the drill string is supported and rotationally oriented.

FIG. **6** is an enlarged elevational view of the boring bit or downhole tool [or downhole tool **173** of FIG. **1** taken at **(6)** of FIG. **2**.

FIG. **7** is a top plan view of the bit of FIG. **6**.

FIG. **8** is an end view of the bit of FIG. **6** taken along line **8**—**8** of FIG. **6**.

FIG. **9** is a broken away perspective view of elements associated with a second alternative embodiment of a boring machine including a second alternative embodiment of a downhole tool body.

FIG. **10** is a broken away perspective view of elements associated with the second alternative downhole tool body of FIG. **9**.

FIG. **11** is a side sectional view of the downhole tool body of FIG. **10**.

FIG. **12** is a cut-away view of the bottom flat surface of the downhole tool body of FIGS. **10** and **11**.

FIG. **13** is a front view of the downhole tool body of FIGS. **10** and **11**.

FIG. **14** is a top view of the downhole tool body of FIGS. **10** and **11**.

FIG. **15**A is a broken away perspective view of elements associated with a frame of the second alternative embodiment of a boring machine.

FIG. **15**B is a broken away partial perspective view of a connector link between a chain and forward end of the frame of FIG. **15**A.

FIG. **15**C is a broken away partial perspective view of a connector link between a chain and a thread of the frame of FIG. **15**A.

FIG. **16** is a broken away perspective view of a saver sub and an adapter assembly for a drill string.

FIG. **17** is a bottom view of a dirt blade assembly of FIG. **10**.

FIG. **18** is a side view of the dirt blade assembly of FIG. **17**.

FIG. **19** is a bottom view of the sand blade assembly of FIG. **10**.

FIG. **20** is a side view of the sand blade assembly of FIG. **19**.

FIG. **21** is a bottom view of an alternative sand blade assembly.

FIG. **22** is a side view of the sand blade assembly of FIG. **21**.

FIG. **23** is an enlarged elevational view of a third alternative embodiment of a downhole tool and of a portion of a drill string.

FIG. **24** is a top view of the downhole tool of FIG. **23**.

FIG. **25** is a front view of the tool of FIG. **23** taken along line **25**—**25** of FIG. **23**.

FIG. **26** is an exploded view of the blade of the downhole tool of FIG. **23** illustrating the wear resistant material on the blade.

FIG. **27** is an exploded view of FIG. **24** showing a ball in a check valve assembly which is disposed inside the fluid passageway and adjacent the nozzle.

FIG. **27**A is a perspective view of the check valve assembly of FIGS. **24** and **27**.

FIG. **28** is a partial view of the downhole tool body of FIG. **23** including an alternative embodiment of a blade.

FIG. **29** is a top view of a hard soil/soft rock tapered blade assembly.

FIG. **30** is a side view of the hard soil/soft rock tapered blade assembly of FIG. **29**.

FIG. **31** is an opposite side view of the hard soil/soft rock tapered blade assembly of FIG. **29**.

FIG. **32** is a bottom view of a spade-like blade assembly.

FIG. **33** is a side view of the spade-like blade assembly of FIG. **32**.

FIG. **34** is a bottom view of a relatively wide blade assembly.

FIG. **35** is a side view of the relatively wide blade assembly of FIG. **34**;

FIGS. **36–59** illustrate various drill bits that can be used;

FIG. **60** is a perspective view of a directional multi-blade boring head;

FIG. **61** is a front view of the boring head;

FIG. **62** is a side view of the boring head;

FIG. **63** is a perspective view of a modified directional multi-blade boring head;

FIG. **64** is a front view of the boring head;

FIG. **65** is a side view of the boring head;

FIG. **66** is a perspective view of a directional boring head;

FIG. **67** is an end view of the boring head of FIG. **66**;

FIG. **68** is a side view of the boring head of FIG. **66**;

FIG. **69** is a perspective view of a directional boring head forming a second embodiment of the present invention;

FIG. **70** is an end view of the boring head of FIG. **69**; and

FIG. **71** is a side view of the boring head of FIG. **69**.

DETAILED DESCRIPTION

Referring to the drawings, and first to FIG. **1**, the environment in which the apparatus of this invention is used is illustrated. The boring machine is generally indicated by the numeral **10**. Machine **10** is shown resting on earth's surface **12** and in position for forming borehole **14** underneath an obstruction on the earth such as roadway **16**. As shown in FIG. **1**, by using extended range boring machine **10**, the direction of the borehole can be changed as the borehole passes under roadway **16**. This illustrates how machine **10** can be utilized to form borehole **14** under an obstruction without first digging a deep ditch in which to place a horizontal boring machine, and, also without having to dig a deep ditch on the opposite side of the obstruction where the borehole is to be received. While the method of drilling a borehole and the machine used therewith will be described as showing the borehole being drilled from the earth's surface **12**, it can be appreciated that machine **10** can be used in a shallow ditch if desired. It should be kept in mind, however, that the main emphasis of the method and machine of this invention is that of drilling a borehole in which the direction of the borehole can be changed during the drilling process. These methods could be applied on other types of drilling machines as well.

In conventional fashion, drill string **44** is simultaneously rotated and advanced by means of boring machine **10** to establish a borehole in the earth. The drilling operation, wherein pipe **42** of FIG. **2** is simultaneously rotated and axially advanced, is continued until a change in direction of the borehole is desired. This typically occurs when the borehole is near a desired depth and when the borehole is to be moved substantially horizontal for a distance. In order to change the direction of the borehole the-following sequence is employed:

1. The rotation of drill string **44** is stopped.
2. The rotational position of drill string **44** is oriented so that blade assembly **72, 172, 172', 272, 372, 472, 572, 672** or **772** of downhole tool **58, 158** or **358** is inclined at an acute angle relative to the longitudinal axis of the drill string and towards the new direction of the borehole desired.
3. The drill string is axially advanced without rotation to axially advance downhole tool **58, 158** or **358** a short distance such that the blade assembly moves the downhole tool in the earth towards the new desired direction.
4. Simultaneous rotation and axial advancement of the drill string is resumed for a short distance.
5. Sequentially repeat steps 1, 2, 3 and 4, until the direction of the borehole is in the new direction desired.

Thereafter, the downhole tool **58, 158** or **358** is axially advanced and simultaneously rotated until it is again desirable to change directions. This typically can occur when a borehole has reached a point adjacent the opposite side of the obstruction under which the borehole is being drilled. At this stage in the drilling of the borehole, it is desirable to have the direction of the borehole inclined upwardly so that the borehole will emerge at the surface of the earth on the opposite side of the obstruction.

To again change the direction of the borehole, the same sequence is repeated. That is, the rotation of drill string **44** is stopped, the orientation of the drill string is corrected so that the downhole tool blade assembly is inclined in the newly desired direction (that is, in this example, upwardly), the drill string is axially advanced without rotation a short distance, the drill string is then rotated and axially advanced a short distance, and the sequence is repeated until the new direction of drilling the borehole is attained. After the new direction is attained, the borehole is drilled by simultaneously rotating and advancing the drill string until the borehole is completed.

Referring to FIGS. **2** and **3**, more details of the boring machine are illustrated. In particular, machine **10**, which is utilized for practicing a method of this invention, includes frame **18** having a forward end **18**A and a rearward end **18**B and supportable on the earth's surface. Frame **18** of FIGS. **2** and **3** and frame **118** of FIGS. **15**A–**15**C are preferably operated from a surface launch position which eliminates the need to dig a pit. Also, frames **18** and **118** provide an elongated linear travel pathway. As best seen in FIGS. **4, 5** and **15**A the linear pathway is preferably provided by spaced apart parallel channels **20** and **22** or **120** and **122**.

Rotary machine **24** of FIGS. **2, 3** and **4** is supported on the frame and in the travel path. More specifically, rotary machine **24** is supported on wheels **26** of FIG. **4** which are received within channels **20** and **22**.

Drill string **44** includes a plurality of drill pipes **42** each having a male thread at one end and a female threaded opening at the other end. Each pipe is attachable at one end to rotary machine **24** and to each other in series to form drill string **44**. As seen in FIGS. **2** and **3**, the rearward end of drill string **44** can be attached to rotary machine **24**. Drill string **44** can also include adapter **230** and saver subs **232**, as in

FIGS. **9** and **16**. Thread caps **234** and **236** are used to protect a drill pipe and are removed prior to insertion into the drill string.

Rotary machine **24** is supplied by energy such as by hydraulic pressure through hoses **28** and **30** of FIGS. **2** and **4**. This hydraulic energy can be supplied by an engine drive trailer mounted hydraulic pump (not shown) which is preferably positioned on the earth's surface adjacent the drilling machine. The use of hydraulic energy is by example only. Alternatively, rotary machine or drive **24** could be operated by electrical energy, an engine or the like. The use of hydraulic energy supplied by a trailer mounted engine driven pump is preferred, however, because of the durability and dependability of hydraulically operated systems. Third hose **32** of FIGS. **2** and **4**, is used for supplying fluid for a purpose to be described subsequently.

By means of control levers **34** of FIG. **2**, hydraulic energy can be controlled to cause rotary machine **24** to be linearly moved in the pathway provided by channels **20** and **22** of FIGS. **4** and **5** or **120** and **122** of FIG. **15**A, and at the same time to cause a drill pipe to be axially rotated. The linear advancement or withdrawal of rotary machine **24** is accomplished by means of chain **36** of FIG. **2** or chain **136** of FIG. **15**A which is attached at one end to frame front end **18**A or **118**A and at the other end to frame rearward end **18**B or **118**B. Chain **36** passes over cog wheel **38**, the rotation of which is controlled by one of levers **34** to connect hydraulic power to a hydraulic motor (not shown) which rotates cog wheel **38** in the forward or in the rearward direction or which maintains it in a stationary position.

As seen in FIGS. **2** and **3**, extending from the forward end of rotary machine **24** is drive spindle or shaft **40** which has means to receive the male or female threaded end of drill pipe **42**. Upper or uphole end **60** of the drill string is attached to shaft **40** (FIG. **2**), that is, to the rotary machine **24**. Saver sub **232**, attached to shaft **40** with a thread retaining compound such as Loctite® RC/680 is a replaceable protector ("saver") of threads on shaft **40**.

A plurality of drill pipes **42** are employed and, when the drill pipes are assembled together, they form drill string **44** as seen in FIG. **1**. Drill pipes **42** are of lengths to fit a particular size drill frame **18** or **118**, such as 5 feet, 10 feet, 12 feet and/or 20 feet, and when sequentially joined can form a drill string of a length determined by the length of the hole to be bored. The preferred embodiments generally have a distance capability of over 400 feet in many soil conditions.

As seen in FIGS. **2** and **5**, adjacent forward end **18**A of the frame is drill pipe support **46**. Drill pipe support **46** maintains drill pipe **42** in a straight line parallel to the guide path formed by channels **20** and **22**. The drill pipe support can include sight **48**, the purpose of which will be described subsequently.

Positioned adjacent the forward and rearward ends of frames **18** or **118** are jacks **50** or **150** by which the elevation of the frame relative to the earth's surface **12** may be adjusted. In addition, at front end **18**A of the frame are opposed stakes **52** and **54** which are slidably received by the frame front end. Stakes **52** and **54** may be driven in the earth's surface so as to anchor the machine during drilling operation.

Also illustrated in FIG. **15**A are flange lock bolt **117** and flange lock nut **119** for attaching rearward end or rear cross-member **118**B of frame **118** to channels **120** and **122**. Also, as seen in FIG. **15**C, thread **113** (attached to rearward end **118**B by nuts **111**) adjustably engages chain **136** via connector link **137**. In addition, as seen in FIG. **15**B, the opposite end of chain **136** also engages forward end **118**A of frame **118** via second connector link **137**.

Affixed to downhole end **56** of drill string **44** is a bit or downhole tool generally indicated by the numeral **58**. The drill bit or downhole tool is best seen in FIGS. **6**, **7** and **8**.

The drill bit or downhole tool includes body portion **62** which has rearward end portion **64** and forward end portion **66**. Rearward end portion **64** of drill bit body **62** includes an internally threaded recess **68** which receives the external threads **70** of drill string forward end **56**.

Blades or blade assemblies **72**, **172**, **172'**, **272**, **272'**, **372**, **472**, **572**, **672** and **772** can be affixed to drill bit or downhole tool bodies **62**, **162** or **362**. The plane of blade assemblies **72**, **172**, **172'**, **272**, **272'**, **372**, **472**, **572**, **672** and **772** are inclined at an acute angle to axis X—X of the bit's internally threaded recess **68**. Axis X—X is also the longitudinal axis of drill string **44** or forward most drill pipe **42**. That is, axis X—X is the axis of the portion of the drill string immediately adjacent and rearwardly of the downhole tool.

The blade assemblies are preferably sharpened at their outer forward ends **72**A, **172**A, **272**A, **372**A, **472**A, **572**A, **672**A and **772**A. When rotated, the blade assemblies cut a circular pattern to form walls **6** or **6'** at end **4** of borehole **14** as illustrated in FIGS. **6** and **23**.

Bodies **62**, **162** and **362** have fluid passageway **78** therethrough connecting to jet or nozzle **76**. Fluid passageway **78** is in turn connected to the interior of tubular drill string **44**. As previously stated with reference to FIG. **2**, hose **32** provides means for conveying fluid under pressure to boring machine **24**. This fluid is connected to the interior of drill pipe **42** and thereby to the entire drill string **44**, and, thus, to the interior of bodies **62**, **162** and **362**. The fluid is ejected from tool bodies **62**, **162** and **362** through nozzle **76** to aid in the drilling action. That is, fluid is ejected from nozzle **76** to cool and lubricate blade assemblies **72**, **172**, **172'**, **272**, **272'**, **372**, **472**, **572**, **672** or **772** and flush away cuttings formed by the blade as it bores through the earth by forming a slurry of cuttings.

Nozzle **76** in this case refers to any of a plurality of fluid nozzles designed for different soil conditions. For example, one can use one nozzle for soft dirt or hard dirt and then interchange that with another nozzle for sand. Also, one can interchange nozzles to vary the flow rate.

As best seen in FIGS. **6** and **7**, blade assembly **72** includes an outer surface which is substantially flat. Also, blade assembly **72** is rectangular as illustrated.

The preferred downhole tool improves the ability to make rapid steering corrections. Downhole tool body **62**, **162** and **362** include a tapered portion, between the rearward end **64** and the forward end **66**, which tapers toward the forward end of the drill body. Also, this surface of the drill body defines an outer surface which is free of cutters, except for the blade.

Although not necessary, downhole tool body **62** has a substantially triangular cross-section defined by a converging flat top surface **90** and flat bottom surface **92**. Also, blade assembly **72** is fixed to the bottom flat surface of the drill bit body and extends axially beyond forward end **66** of body **62** at an acute angle. This angled extension, in conjunction with converging top surface **90** of the drill bit body, defines relief space **8** in which fluid nozzle **76** is positioned. In use, relief space **8** will form a cavity in the borehole which will facilitate rapid steering corrections. Thus, the structure in FIG. **6** illustrates this acute angle of the blade assembly and the tapered portion of the drill body having the uniquely advantageous function of defining a relief area or space **8** of reduced axial resistance near forward end **4** of borehole **14** to thereby allow for rapid deviation of the borehole from a straightline when downhole tool **58** is thrust forward without rotation.

Although the invention provides an improved rapid steering correction function in a downhole tool with both a blade assembly and a fluid jet or nozzle, it is not necessary, though, in certain circumstances to have a fluid jet to still achieve the desired advantageous functions. A preferred structure, however, is blade assembly **72** having an outer surface which is substantially flat and tool body tapered portion which defines an outer surface of the tool body from which only the blade assembly **72** and nozzle **76** project from.

When a change of direction of the drill pipe is desired, rotation is stopped and the drill pipe is advanced axially without rotation. However, in certain soils or ground conditions, it is very difficult to move the drill pipe forward without rotation. The relief area **8** shown in FIGS. **6** and **23** which is created by the structure of the drill bit allows for reduced axial resistance at least over the relief area when drill string **44** is advanced without rotation. This relief area **8** of reduced axial resistance may be all that is needed to provide for rapid or sudden steering corrections. In some soil or boring situations, however, it may be necessary to incrementally repeat the rotation and push cycle to get the proper steering correction to form walls **6** of borehole **14** along a curved path as in FIG. **1** or some other desired path. The present invention, thus, provides for improved rapid steering correction which is not available with known prior art devices.

An orientation directional indicator may be secured to the drill string adjacent the drill machine so that the angle of the plane of the drill bit body can at all times be known. Referring back to FIGS. **2** and **4**, a device which is utilized to indicate the rotational orientation of drill string **44**, and thereby the rotational orientation of drill bit or downhole tool **58**, is shown. Ring member **80** is slidably and rotatably received on drill pipe **42**. The ring has a threaded opening therein receiving set screw **82** having handle **84**. When the set screw **82** is loosened, ring **80** can be slid on drill pipe **42** and rotated relative to it.

Affixed to ring **80** is bracket **85** having pointer **86**. In addition to pointer **86**, bracket **85** carries a liquid bubble level **88**.

The function of ring **80** with its pointer and bubble level is to provide means of maintaining the known orientation of the drill string **44**. When a drilling operation is to start, the first length of drill pipe **42** is placed in the machine and bit or tool **58** is secured tightly to it. At this juncture, the tool is above ground and the operator can easily observe the orientation of blade assemblies **72, 172, 172', 272, 272', 372, 472, 572, 672** or **772**. The operator can then affix ring **80** so that it is in accurate orientation with the blade, that is, as an example, ring **80** is affixed so that pointer **86** points straight up with the blade aligned so that a plane drawn perpendicular to the plane of the blade would be vertical. With ring **80** so aligned, set screw **82** is tightened by handle **84**. Thereafter, as drill pipe **42** is rotated and advanced into the earth, ring **80** remains in the same axial rotation orientation, rotating with the drill string. As the drill string is advanced by the advancement of machine **24** towards forward end **18A** of the boring machine frame, ring **80** moves with it. It can be seen that when the boring machine has advanced so that shaft **40** is adjacent the frame forward end, drilling must be stopped and a new length of pipe **42** inserted. With drilling stopped, drill string **44** can be aligned with pointer **86** in

alignment with pointer **48** affixed to drill pipe support **46**. Ring or collar **80** may then be removed and inserted on a new length of drill pipe **42** threadably secured to the drill string and the procedure continually repeated, each time tightening set screw **88** so that the alignment of the blade is always known to the operator.

To form borehole **44** in the earth, the operator attaches the drill pipe and drill bit as shown in FIG. **2**, begins rotation of the drill pipe and at the same time, by means of control levers **34**, causes rotary machine **24** to linearly advance in the travel path of the frame towards the forward end **18A** or **118A** of frame **18** or **118**. Drill bit **58**, rotating and advancing, enters the earth and forms a borehole therein. As long as bit **58** is rotated as it is advanced, the borehole follows generally the axis of the drill pipe. That is, the borehole continues to go straight in the direction in which it is started.

In the most common application of the invention wherein the borehole is started at the earth's surface to go under an obstruction such as a highway, the borehole must first extend downwardly beneath the roadway. When the borehole has reached the necessary depth, the operator can then change the direction of drilling so as to drill horizontally. This can be accomplished in the following way: When it is time to change direction, the operator stops drilling and orients the drill string so that drill bit blade assembly **72, 172, 172', 272, 272', 372, 472, 572, 672** or **772** is oriented in the direction desired. In the illustrated case of FIG. **1**, the borehole is first changed in the direction so that instead of being inclined downwardly, it is horizontal. For this purpose the operator will stop drilling with drill string **44** having collar pointer **86** pointing straight up, that is, with bracket **84** in the vertical position. With rotation stopped and the drill string properly oriented, the operator causes rotary machine **24** to move forwardly without rotating the drill pipe. After forcing the bit a foot or two (or as far as possible, if less), the operator begins rotation of the drill bit and continues to advance the drill string for a short distance.

After a short distance of rotary boring, the procedure is repeated. That is, the drill string is reoriented so that the operator knows the inclination of blade assembly **72, 172, 172', 272, 272', 372, 472, 572, 672,** or **772** and then he advances the tool a short distance as above described without rotation and repeats the procedure. The procedure may be repeated sequentially for a number of times until the direction of drilling has changed to that which is desired. The opposite steering correction will have to be applied just prior to the bit reaching the desired path in order to prevent or minimize any overshooting of that path. After the borehole has been oriented in the desired direction, such as horizontal, the drilling can continue by simultaneous rotation and advancement of drill string **44**, adding new links of drill pipe **42** as necessary until it is again time to change the direction of drilling, such as to cause the borehole to be inclined upwardly towards the earth's surface after the borehole has reached the opposite of the extremity of the obstruction under which the borehole is being placed. This is achieved as previously indicated; that is, by orienting drill string **44** to thereby orient the blade assembly, advancing the downhole tool without rotation of drill string **44**, rotating and advancing the drill string for a short distance, reorienting the drill bit or tool and advancing without rotation and sequentially repeating the steps until the new direction of drilling is achieved.

The experienced operator soon learns the number of sequences which are normally required in order to achieve a desired direction of drilling.

Thus, it can be seen that a method of drilling provided by the present disclosure is completely different than that of the typical horizontal boring machine. The necessity of digging ditches to the opposite sides of an obstruction in which to place a horizontal boring machine is avoided.

The structure of FIGS. **9–35**, which disclose alternative embodiments for a boring system, will now be described in greater detail. Shown in FIGS. **9–22** is a second embodiment of a drill string assembly and a second embodiment of a downhole tool body. Downhole tool body **162** of FIGS. **10–14** at least differs from body **62** of the embodiment of FIGS. **1–8** in that the jet is no longer at an acute angle to the centerline of the longitudinal axis of the drill string **557** and the blade assembly is now removable. If a difference is not identified between embodiments, the elements described herein to operate boring machine **10** can be used in the latter discussed embodiments.

As seen from the combination of FIGS. **9–14** and **3–28**, downhole tool bodies **162** and **362** have fluid nozzle **6** fixed to the fluid passageway and positioned behind a forward end **72A**, **172A**, **272A**, **372A**, **472A**, **572A**, **672A** and **772A** of the blade assembly. Nozzle **76** can project from a nozzle receiving portion either on or adjacent top **190** and **390** of the outer surface of the bodies **162** and **362**. Nozzle **76** can also be recessed into the nozzle receiving portion of the tool body.

Top surface **190** of body **162** is preferably 20° to the longitudinal axis X—X of the drill pipe. It can be appreciated that other types of nozzles or jet orifices could be employed.

Nozzle **76** on bodies **162** and **362** has a centerline Y—Y substantially parallel to the longitudinal axis X—X of drill pipe **42**. Preferably, as most clearly seen in FIG. **28**, nozzle **76** is displaced laterally from the longitudinal axis X—X of drill pipe **42** so that a fluid stream is emittted above the blade. Also, nozzle opening or orifice **77** size is governed by factors such as pump capacity, fluid viscosity and flow rate desired downhole.

Blade assemblies **72**, **172**, **172'**, **272**, **272'**, **372**, **472**, **572**, **672** and **772** include an outer surface which is substantially flat. Blade assemblies **172**, **172'**, **272**, **272'**, **372**, **472** **572**, **672** and **772** are removably mounted on the tapered portion of the downhole tool body so that the blade assembly is at an acute angle to the longitudinal axis X—X of the drill pipe and the blade assembly is extending beyond the forward end **166** and **366** of the downhole tool bodies **162** and **362**. Having removable blade assemblies means that the blade can be replaceable without having to replace the body. This results in substantially, lower operating cost. Also one obtains versatility, because one can use a variety of cutter blade assemblies for trenchless installations in various soil types without having to invest in a plurality of downhole tools.

The means for mounting removable blade assemblies is especially important, because of the high stress which these blades undergo. A preferred mode for mounting a removable blade assembly includes having apertures on blade assembly receiving surfaces **192** and **392** of the outer surface of the tool body and having corresponding apertures on the blade assemblies. Also, the blade assemblies are preferably disposed directly adjacent and flush mounted with shouldered sections **169** and **369** of tool bodies **162** and **362**. Furthermore, shouldered sections **169** and **369** are preferably at an angle 10° to a line perpendicular to axis X—X.

Apertures on body **162** are identified as elements **180–183** in FIGS. **11–14** and apertures on body **362** are identified as elements **380–83** in FIGS. **23** and **25**. Apertures on blade assembly **172** are identified as elements **175** and **177–79** in FIG. **17**. Apertures on blade assembly **272** are identified as elements **275** and **277–279** in FIG. **19**. Also, apertures on blade assembly **572** are identified as elements **575** and **577–9** in FIG. **29**, apertures on blade assembly **672** are identified as elements **675** and **677–79** in FIG. **32**, and apertures on blade assembly **772** are identified as elements **775**, and **777–79** in FIG. **34**. As seen in FIG. **10**, each blade assembly is removably mounted on the downhole tool body by means of a plurality of bolts **194** mounted through the corresponding apertures and substantially flush with an outer surface of the blade. Preferably bolts **194** are coated with a thread retaining compound, such as Loctite® 242, and torqued to 40 ft.-lbs. by wrench **199**.

Different types of removable blade assemblies are preferred. One blade type, represented by preferred blade assemblies **172** and **172'** in FIGS. **10**, **17** and **18**, is for cohesive soils and soils that offer a reasonable amount of steering resistance. Thus, blade assemblies **172** and **172'** are primarily for dirt/clay conditions. Blade assembly **172** is preferably 2¼ inches wide, 7 inches long and ½ inch thick and preferred for dry/hard clay. Alternative blade assembly **172'** is slightly wider at 2½ inches. The wider blade assembly **172'** would be preferable for less resistant applications such as moist or soft dirt/clay conditions. The wider blade assembly is more advantageous in these softer dirt applications, because the wider the blade assembly the more steering force one obtains.

Even wider 3" blade assemblies **272** or **272'** of FIGS. **19–22** are preferred for sandy soils and other loose soils of little resistance. In these sandy soils, a big surface area blade assembly is desired. The additional width provides improved steering response.

Wear resistant material is added in selective areas of the blade assemblies for additional durability. As seen in FIGS. **17** and **18**, blade assembly **172** includes wear resistant material **185** such as a carbide strip on the underside of forward portion **173** of the blade. Blade assembly **172** also includes wear resistant material **186** and **187** adjacent the underside rear portion of the blade as seen in FIGS. **17** and **18**.

Alternatively, one can place a weld bead **289** (of harder surface material than the blade) on the forwardmost portion of the blade and down the edges of the blade as seen in FIGS. **19** and **20**. Basically, it is preferred that all blade assemblies have either the weld bead or hard facing strips such as carbide on three edges as shown. It is not desired, though, that the carbide strips and weld beads be mixed on a blade assembly. Note, however, if the soil has any rock content, use of carbide strips on the blades is preferred.

Seen in the alternative 3" blade assembly **272'** of FIGS. **21** and **22** is a more preferred location for hard surfacing on a forward portion of the blade. As seen in FIGS. **21** and **22**, the forward portion of the blade includes strips **284** and **288** of harder surface material (i.e., carbide) than the blade which are disposed in recesses on portions of the surfaces of the blade. In particular, strip **288** is disposed on a right-hand side portion of the bottom or outer side of the blade when facing endwall **4** of borehole **14** and strip **284** is on a left-hand side portion of the top or inner side of the blade when facing endwall **4** of borehole **14**. With clockwise rotating (when looking in the direction of boring) of the blade assembly, the preferred location of hard surfacing in FIGS. **21** and **22** is more effective in protecting both front corners of the blade assembly. Consequently, the strips are provided on the portions of the surfaces of the blade assembly which have the primary contact with the earth when the tool body is simultaneously rotated and axially advanced.

It is also preferred that the recesses and the strips of harder surface material in the recesses cross a centerline of the blade assembly as seen in FIG. **21**. This double reinforcement at the centerline of the blade assembly is particularly advantageous where the blade and carbide strips **684** and **688** define a spade-like profile in the forward portion of blade assembly **672** as seen in the blade of FIGS. **32** and **33**.

In addition, as seen in FIGS. **21** and **22**, blade assembly **272** includes hard surface material **286** and **287** in the rear portion of the blade assembly. This wear resistant material is preferably either brazed or welded onto the blade.

Downhole tool body **162** includes a forward end **166** and rearward end **164** having an aperture including threads for engaging a drill pipe. As seen in FIG. **11**, an intermediate portion of tool body **162** has cavity **165** for receiving a transmitter and first fluid passageway **163**A.

As can be appreciated from FIGS. **10** and **11**, transmitter **220** is disposed in cavity **165** of the intermediate portion of the body. Pulling tool or wrench **218** is preferably used to install transmitter **220** in cavity **165**. Transmitter **220** produces an electromagnetic signal which allows the position and depth of tool body **162** to be determined by use of an above-ground receiver.

The rotational orientation of blade assembly **172** et al., must also be known when advancing without rotation to make course direction changes. An angle or roll sensor, such as those known in the art, can be used in conjunction with the above transmitter/receiver system to determine blade rotational orientation or aid in positioning the blade assembly at a particular desired orientation. Although downhole roll sensing is preferred, tophole drill string indicating means, such as described in the parent U.S. application Ser. No. 07/211,889, may be employed to determine blade orientation.

Removable plug **214** of FIG. **10** is disposed on a rearward portion of cavity **165** of the intermediate portion of the body. Plug **214** is also installed with pulling tool or wrench **218**. The plug is waterproof and it is positioned in the body for diverting pressurized fluid from drill string **44** to first passageway **163**A of the intermediate portion of the tool body. In other words, as the fluid comes down the center of fluid pipe (i.e., drilling cap) **210** in FIGS. **9** and **10**, the fluid path is deviated as it hits plug **214**. The fluid path is diverted downward through first passageway **163**A of tool body **162** of FIG. **11**. An advantage of this arrangement is that plug **214** is removable. Thus, one can get into body **162** or **362** to replace battery **222** of transmitter **220**. Also, while performing a fluid deviating function, the plug protects the transmitter from fluid. Consequently, an additional advantage of this structure is that it allows the on-board transmitter to be disposed very close to the drill bit.

The downhole tool further comprises O-rings **212** and **216** adjacent each end of plug **214**. Also, adjacent the forward end of the tool body is second fluid passageway **163**B and third fluid passageway **163**C. Second passageway **163**B is in fluid communication with and substantially perpendicular to first passageway **163**A. Third passageway **163**C is in fluid communication with and substantially perpendicular to second passageway **163**B. It would be understood by one of ordinary skill in the art that the passageway adjacent the connection of first passageway **163**A with second passageway **163**B would be tightly sealed at shouldered section **169** and at outer end **170**. Also, as can be appreciated from FIGS. **9–11**, fluid nozzle **76** is fixed to the fluid passageway and associated with forward end **166** of body **162**.

FIGS. **9**, **10** and **16** illustrate elements for an arrangement wherein nozzle **76** or the like is actually moved up the drill string and inside saver sub **232** or inside adapter **230**. In particular, drill string **44** includes a channel for transferring fluid from the exterior of the borehole to the front of the drill string. In FIG. **10**, is fluid outlet **171** fixed to the fluid passageway and associated with downhole tool body **162**.

When boring in sandy situations, it is preferred to place the nozzle rearward of the tool body and install it in saver sub **232** or adapter **230**. As can be appreciated from FIG. **9**, disposed adjacent drive spindle **40** and the back end of drill string **44** is saver sub assembly **232**. As shown in FIG. **16**, within saver sub assembly **232** is filter seating plug **245** which is internally threaded to hold nozzle **76**. If inserted in saver sub **232**, inner nozzle **76** meters the amount of and controls the rate of fluid that the surface fluid pump discharges into borehole **16**. Once ejected from that inner nozzle, the fluid fills drill string **44** and exits out through outlet or building **171** in tool body **62**, **162** or **362**. The hole in outlet or bushing **171** is large enough so that the downhole debris entering drill string **44** when the flow stops will likely be flushed back out when the flow resumes. In the preferred embodiments, outlet **171** has a diameter approximately the same as the diameter of the fluid passageway. This arrangement is particularly beneficial when drilling in sand or sandy soils where sand particles flowing back into a small orifice nozzle located at end **166** of body **162**, could at least partially plug the opening when pressurized flow is resumed.

When installing the nozzle in saver sub **232**, the operator must be careful. When the fluid pump is turned on, the pressure gauge will begin to show pressure before fluid ever reaches the tool body. Even though the gauge shows pressure, the operator must wait until the fluid has reached the tool body. This waiting time varies depending upon whether there are just a few feet or a few hundred feet of drill pipe in the ground. If the operator happens to thrust the tool body forward before fluid reaches it, there is the possibility of plugging the tool body. If drilling is continued while the tool body is plugged, damage to the transmitter can occur.

To reduce the operator involvement in this process, one can alternatively install nozzle **76** in adaptor **230**. By installing nozzle **76** in adapter **230**, the operator knows that when the gauge pressures up, the fluid is at the tool body. This is true whether there are thirty feet or three hundred feet of pipe in the ground.

Saver sub **232** and adapter **230** both include filter and gasket combinations **240** and **242** as seen in FIG. **16**. Filter and gasket combination **240** includes 30 mesh coarse screen filter for use with drilling fluids (bentonite, polymers, etc.). Fluid filter and gasket combination **242** includes 100 mesh fine screen for use with water or a water and antifreeze combination. If one uses 100 mesh filter with drilling fluid, the filter may collapse and stop the flow of fluid. The purpose of the filters is to remove any particles from the fluid flow which could obstruct nozzle **76**.

FIGS. **23–27**A illustrate an alternative tool body embodiment **362**. As shown in FIGS. **23–26**, some embodiments function to deflect fluid from nozzle **76** to an acute angle relative to the longitudinal axis X—X of the drill pipe. In particular, by having spray from nozzle **76** impinge upon removable cutting blade **372**, the deflected jet stream should more easily allow redirecting of the body out of an existing borehole. This becomes important if an obstruction is encountered.

The deflecting portion of blade assembly **372** comprises wear-resistant material **388** disposed in the blade as seen in FIGS. **24** and **26**. Furthermore, the deflecting material **388** includes concave portion **389** for controlling the fluid spray pattern.

As soils become more difficult to drill, it is preferred to have the forward end of the blade assembly adjacent the longitudinal axis X—X of the drill pipe as in FIG. **28**. This relationship of the blade assembly forward end to axis X—X is preferred, because if one happens to drill into a hard soil or soft rock, the downhole tool and its drill sting will start rotating around the tip of the tool. If the blade assembly tip is not on or adjacent the centerline of the bore, this may cause the rear portion to wobble and rub against walls of the diameter of borehole **14** which are behind the bit. Thus, in these situations blade assembly **472** of FIG. **28** may be more advantageous. Therefore, in the embodiment of FIG. **28**, a forward end **472**A of blade assembly **472** is adjacent and in fact on the longitudinal axis X—X of the drill pipe. For example, when harder soils or soft rock formations are anticipated, a tapered (pointed) rather than straight leading edge on the blade assembly (as in the spade-like blade assembly of FIGS. **32** and **33** or the stepped-taper blade assembly of FIGS. **29**–**31**) can further aid in causing the blade assembly to "pilot" into the end of the borehole and will also rotate more smoothly than a straight-edged bit in such hard conditions.

In soft soils, however, it is preferred to have the forward end of the blade assembly extend beyond the longitudinal aids X—X of the drill pip as in FIGS. **23**–**26**. In soft soils, the tool will not tend to pilot on the face of the bore but instead will slip across it. In fact, for such soils it is advantageous for the blade assembly to be above (i.e., beyond) the centerline of the borehole in order to provide more steering force. It should be recognized that the above principle would apply whether or not deflecting of the spray is employed. By varying the lateral displacement of the jet relative to the X—X axis, a deflecting of the spray can be accomplished for the various types of blades discussed herein.

Shown in FIGS. **24**, **27** and **27**A is ball check valve **394** to prevent sand or the like from plugging the nozzle opening. When boring a hole in a tight formation, there tends to be a head pressure in borehole **16** at front portion **166** or **366** of downhole tool **162** or **362**. Therefore, when one shuts off fluid flow to drill string **44** in order to, for example, add another piece of drill pipe, external debris-laden fluid in the borehole can actually flow upstream and into the drill pipe. Cuttings such as grains of sand and the like which enter nozzle **76** may plug the relatively small nozzle orifice **77** and, after adding a new piece of drill pipe and beginning fluid pressure through the fluid passageway, restrict or prevent the start of flow again.

It is preferred, therefore, to have check valve **394**, disposed in the passageway, for opening the passageway when fluid pressure in the passageway towards nozzle **76** and on valve **394** is greater than pressure from borehole **16** on valve **384**, and for closing the passageway when pressure from borehole **16** on valve **394** is greater than fluid pressure in the passageway towards nozzle **76** and on valve **394**. The preferred valve includes ball **395** for preventing external downhole particles from entering a portion of the fluid passageway which is upstream of the ball. Also, included in valve **394** is roll pin **397**.

Even with an essentially horizontal drill string, there is a tendency for fluid to flow out of nozzle **76** during the addition to the drill string or other work stoppages. This tends to be wasteful of drilling fluid and also causes delays in re-initiating the drilling operation, because of the time required to refill the drill string and reach operating pressure. This factor can become significant when drilling longer boreholes. Thus, the check valve means also preferably includes spring **396** disposed in the passageway and on a front side of the ball. The spring provides little pressure. In fact, the spring only biases the check valve closed with sufficient force to hold fluid in the drill string when pump flow is stopped and another joint of pipe is added to the drill string. In particular, the light spring force only causes the ball to close the passageway when the pressure of fluid in the passageway towards nozzle **76** and on ball **395** is less than 10–20 PSI.

As discussed herein, as an alternative to using ball check valve **394** one can use nozzle **76** in saver sub assembly **232** in combination with outlet **171**. If the nozzle **76** is moved to adapter **230** instead of saver sub **232** for operation in sand, however, the ball check valve may preferably be used in combination with the nozzle to prevent plugging since nozzle **76** is only about a foot behind forward portion **166** (containing bushing/outlet **171**) of body **162**. In fact, a further reason for having the nozzle in adapter **230** at the downhole end of the drill string is to make use of the spring-biased check valve method of keeping the drill string full.

When drilling with nozzle **76** in saver sub **232** or adapter **230** and with check valve **394** installed in place of the nozzle on the tool body, one will reduce the change of mud and fluid being sucked back into the housing while breaking loose drill pipe to add another joint. This should also reduce the chance of plugging the tool body. In addition, it should reduce the possibilities of damaging the transmitter **220**. Note, however, it is strongly suggested that one should not run nozzles in both the tool body and adapter **230** at the same time.

Also, one can also utilize two or more jets instead of one. It is preferred that these jets also be displaced vertically from the centerline of the housing as in FIGS. **13** and **23** and side by side. In other words, the front of body **362** of FIG. **25** can be modified to include one or more nozzles **76** laterally displaced from longitudinal axis X—X of drill pipe **42**.

Shown in FIGS. **29**–**31** is removable blade assembly **572** for hard soil or soft rock cutting. In particular, blade assembly **572** is for drilling harder formations such as soft sedimentary rocks (i.e., sandstone or even soft limestone). Stepped-taper blade assembly **572** is advantageous because it has improved steering control. Blade assembly **572** includes a forward portion including end **572**A, which when mounted on the tool body, projects beyond a forward end of the drill body. The forward portion of blade assembly **572** preferably, when viewed from its top as in FIG. **29**, has a staggered profile which steps rearwardly from a forwardmost point **572**A at a center of the blade to an outside of the forward portion of the blade.

As discussed with respect to blade assembly **272** of FIGS. **21** and **22** and blade assembly **672** of FIGS. **32** and **33**, blade **572** also preferably includes a plurality of strips **584**A–E which are disposed on recessed portions of the top and bottom surfaces of the substantially flat blade assembly. These strips have the primary contact with the earth when the blade assembly is simultaneously rotated and axially advanced.

The forward portion of a top of blade assembly **572** is a mirror image of a forward position of a bottom of blade assembly **572**. Furthermore, as discussed it is preferred to have strips **584A** on the top and bottom surfaces extend across the centerline of blade assembly **572** and to have these same strips extend forward of the forwardmost point of the blade as illustrated in FIGS. **30** and **31**.

Forward portion of blade assembly **572** is wider than rear portions of the blade for smoother operation when rotated in hard soil or soft rock formations. Also, bottom edges **586** and **587** include wear resistant material such as carbide. Also, apertures **575** and **577–579** are for mounting the blade assembly on a tool body **162** or **362**.

Blade assembly **572** has been shown to penetrate hard formations at a fast drilling rate, as well as enabling some corrective steering action in those formations. In this hard formation application, as was mentioned herein, it is desirable to have the forwardmost point on strip **584A** on the longitudinal axis X—X of drill pipe **42** in order to prevent the tool body from being rotated eccentrically around the center of bit rotation. In order to steer in soft rock, it takes an operating technique of intermittent rotating and thrusting. With this technique, directional blade assembly **572** allows a selective chipping away of the face of the borehole in order to begin deviating in the desired direction.

Blade assembly **772** of FIGS. **34** and **35** is a 4" wide bit having hard facing carbide strips **784** and **788** at forward point or tip **772A** and carbide strips **786** and **787** all functioning and having advantages as discussed herein. The 4" wide blade assembly is preferred for making a larger pilot hole so that backreaming is not necessary for a 3" to 4" conduit installation.

There can also be an assembly associated with the drill frame **18** or **118** of a boring machine for preventing rotation of a drill pipe **42** having wrench receiving slots **43** as shown in FIG. **9**. The assembly includes wrench **238A** of FIG. **15A** having an open end for removably engaging wrench receiving slots **43** of a rearward portion of a lower or first drill pipe. Also, included is pin **237** received in apertures of both the wrench and the frame and disposed adjacent forward end **118A** of the frame for attaching wrench **238** to the frame. When the wrench engages the drill pipe, the lower or first drill pipe is substantially prevented from rotation.

With this preferred structure, a method of breaking a joint between drill pipe **42** and rotary drive **24** with saver sub **232** can include the steps of moving saver sub **232**, which is joined to drill pipe **42**, to a forward portion in drill frame **18** or **118**. This joint breaking method then includes placing lower joint wrench **238**, which is attached to the frame and adjacent a forward end **118A** of the frame, in wrench receiving slots **43** on drill pipe **42** to substantially prevent rotation of the drill pipe, and using rotary drive **24** to rotate saver sub **232** in a reverse direction to unscrew saver sub **232** from drill pipe **42**.

The method of adding a second drill pipe between saver sub **232** and a first drill pipe **42** includes breaking a joint between first drill pipe **42** and saver sub **232** as discussed in the prior paragraph. The method further includes the steps of moving saver sub **232** to a rearward portion in drill frame **18** or **118**, placing a second or intermediate drill pipe in the frame between saver sub **232** and the lower or first drill pipe, threading a male end of the second or intermediate drill pipe into the saver sub, aligning a female end of the second drill pipe with a male end of the first drill pipe, moving the second drill pipe forward until a female end of the second drill pipe fits around a male end of the first drill pipe and applying rotational torque to tighten the rotating second drill pipe with the stationary first drill pipe. This method can further include the steps of a slight reversing rotation to relieve pressure on joint wrench **238** and removing the joint wrench from wrench receiving slots **43** of the first drill pipe **42**.

Preferably an open end of wrench **238** is at a first end of the wrench and a pin receiving aperture **239** of the wrench is at an opposite second end of the wrench so that the wrench can be rotated into engagement with the wrench receiving slots of the drill pipe. In addition, it is preferable that the wrench can be slid on pin **237** in a direction parallel to a centerline of drill pipe **42** for easy alignment with drill pipe receiving slots **43**.

A second wrench **238'** is also preferred for removing a second drill pipe from between a first drill pipe and saver sub **232** as would be required when withdrawing the drill string from the borehole. The second wrench **238'** also has aperture **239'** for receiving pin **237'** which attaches the second wrench to frame **18** or **118**. The second wrench is closer to rearward end **18B** or **118B** of the frame than to forward end **18A** or **118A** of the frame. A preferred method for removing a second drill pipe from between a first drill pipe and saver sub **232** includes the steps of moving rotary drive **24** to a substantially rearward position in drill frame **18** or **118** so that wrench receiving slots on a rearward portion of the first drill pipe are adjacent a forward end of the frame and the second or intermediate drill pipe is disposed on the frame between the saver sub and the first or lower drill pipe. This method then includes placing a first joint wrench **238**, which is attached to the frame and adjacent forward end **18A** or **118A** of the frame, in wrench receiving slots **43** of the first drill pipe to substantially prevent rotation of the first drill pipe. The next preferred step includes securing the second drill pipe to saver sub **232** to ensure that the joint of the second drill pipe to the first drill pipe will loosen before the joint of the second drill pipe to the saver sub when rotational torque is applied to the second drill pipe. It is preferred that a lock be applied between the saver sub and the second drill pipe so that this joint does not break before the joint between the second drill pipe and the lower first drill pipe is broken. One can, however, use additional torque applied by a hand held pipe wrench on the second drill pipe to accomplish this same function, i.e., to insure that the lower joint is broken first.

The method then includes applying a rotational torque to the second drill pipe which is sufficient to loosen the second drill pipe from the first drill pipe. After applying this rotational torque, one can then unsecure the second drill pipe from the saver sub. The method then includes rotating the saver sub and the second drill pipe in a reverse direction to unscrew the second or intermediate drill pipe from the first or lower drill pipe. Further steps include placing second joint wrench **238'** which is attached to the frame, in wrench receiving slots on a rearward portion of the second drill pipe to substantially prevent rotation of the second uppermost drill pipe, and rotating the saver sub in a reverse direction to unscrew the saver sub from the second drill pipe.

Additional steps in removing a second drill pipe can include removing second joint wrench **238'** from the wrench receiving slots of the second drill pipe and removing the second drill pipe from the frame. Further steps can include moving rotary drive **24** forward in the frame, rotating the saver sub to join it with the first drill pipe and, removing the first joint wrench from the wrench receiving slots of the first drill pipe. To remove additional drill pipes, these above recited steps can be repeated.

Having a joint wrench attached to the frame provides advantages in safety, simplicity and economy. Safety is attained because attaching the wrench to the frame alleviates the prior worry about the wrench being accidentally loosened if, for example, the drill pipe accidentally rotates in an opposite direction than desired. Also, by using this fixed wrench assembly, one eliminates the complex hydraulic systems and the need for another valve section as would be required for a powered break-out wrench.

All patents and applications mentioned in this specification are hereby incorporated by reference in their entireties. In addition, the structures described in this specification and claimed are preferably used with structures disclosed in U.S. patent application Ser. Nos. 07/539,851; 07/539,699; 07/539,551; 07/539,847; 07/539,616; 07/513,186; and 07/513,588 which are also hereby incorporated by reference in their entireties.

With reference now to FIGS. **36–55**, a number of bits suitable for use with the boring machine will be described. These bits will be used for horizontal and near horizontal drilling as well as vertical drilling. FIGS. **36** and **37** illustrate a bit **600**. The bit has a body **602** which defines a rearward end **604** for attachment to the drill string and a forward end **606** facing the ground to be bored.

The portion of the body adjacent the rearward end **604** can be seen to have a hexagonal cross-section perpendicular to the axis of rotation **608** of the bit. The body defines six parallel surfaces **610–620** which each extend parallel the axis **608**. Outer edges **622–632** are defined at the intersection of the parallel surfaces as illustrated.

Three angled surfaces **634**, **636** and **638** are defined on the body and extend from intermediate the rearward and forward ends to the forward end **606**. Each of the surfaces **634**, **636** and **638** are at an angle relative to the axis **608**. The orientation of the angled surfaces can be defined relative to a hypothetical framework **640** (illustrated in FIG. **39**) which is defined as if the parallel surfaces **610–620** of the body extended all the way to the forward end **606**. The angled surfaces **634** and **638** can be seen each to intersect two of the hypothetical parallel surfaces, specifically parallel surfaces **610** and **612** in the case of angled surface **634** and parallel surfaces **618** and **620** in the case of angled surface **638**. It is also helpful to define a plane of symmetry **601** (not shown) which contains axis **608** and divides the drill bit **600** into two mirror image halves. Each angled surface **634** and **638** is a mirror image of the other relative the plane of symmetry **601**. Angled surface **636**, in turn, will intersect a total of four parallel surfaces, specifically surfaces **612–618**. Angled surface **636** also is bisected by the plane of symmetry **601**. The intersection of the angled surfaces and the actual parallel surfaces will define a series of edges **642–660** between the various intersecting surfaces, each one of those edges being at an angle relative to the axis **608**.

The bit **600** has numerous advantages in the drilling operation. Each of the edges **622–632** and **642–660** are potential cutting surfaces to cut the ground. The angled surfaces **634**, **636** and **638** define an area as the drill bit is thrust forward which causes the drill bit to be deflected in a new direction. The area is a compaction area during thrust and simultaneous rotation. Further, the inclined surfaces **634–638** define incline planes that, as the bit is rotated and thrust forward simultaneously, permit the surfaces **634–638** to work in conjunction with cutting edges **642–660** to cut the periphery of the borehole and simultaneously compact the material into the bore wall or pass the cuttings through the relief areas defined by the borehole and surfaces **610–620**. Further, the use of a hexagonal cross-section defined by the surfaces **610** through **620** will further define an additional relief area as the drill bit is rotated bounded by the surfaces and the cylindrical bore cut through the ground. This additional relief area will also assist steering of the bit. As the drill bit is rotated to form a borehole, the bit will define a cylindrical borehole of diameter determined by the radial dimension between the axis of rotation **608** and the edges **622–632**. When the bit rotation is halted to steer the bit into a new direction, voids exist between the inner surface of the borehole and the surfaces **610–620**, providing this additional area to more easily deflect the bit into the new direction of drilling. It also has a stabilizing effect to maintain a truer line (course) while making corrections to a new base path.

With reference now to FIGS. **38** and **39**, a bit **680** is illustrated which is in all respects identical to bit **600** with the exception of the addition of two carbide cutting tips **682** and **684**. The carbide tip **682** is positioned to extend outwardly from about the center of surface **636** and near axis **608**. The carbide tip **684** is at the forward end **606**. As the bit **680** rotates, the carbide tips will define cutting circles established by radial distance between the rotational axis **608** and the individual tip. Tip **682**, being closer to axis **608**, defines the inner cutting circle. Tip **684**, at the outer portion of the bit, defines the outer cutting circle. The tips **682** and **684** assist in boring, particularly in cutting through hard soil conditions.

FIGS. **40** and **41** illustrate a bit **690** which is a modification of bit **600**. In bit **690**, angled surfaces **692**, **694** and **696** are positioned on the bit with the surface **694** intersecting five of the six parallel surfaces. The plane of symmetry **698** bisects parallel surface **614** and the angled surface **694**. The surfaces define angled outer edges **702–714**. The distance between edges **702** and **714** and the edges **706** and **708** are greater in bit **690** than the corresponding distance in bit **600**, which makes the surface **694** wider and the bit more appropriate for boring in softer soils. It is expected that bit **690** will be easier to direct in soft soils because of the width of the surface **694** and the greater surface area of the angled surface **694**.

With reference to FIGS. **42** and **43**, a bit **710** is illustrated which is a slight modification of bit **690**. In bit **710**, the angled surfaces **712** and **716** are at a slighter greater angle relative to the plane of symmetry **718** than those of bit **690**. It would be expected that bit **710** would be more effective in medium soils than bit **690**.

With reference now to FIGS. **44** and **45**, a bit **720** is illustrated which is formed with angled surfaces **722–728**. Angled surfaces **722** and **724** are on a first side of the plane of symmetry **730**. Each of the surfaces **724** and **726** intersect three of the parallel surfaces, while angled surfaces **722** and **728** each intersect two of the parallel surfaces. The surfaces define angled outer edges **732–756**. Bit **720** would be intended primarily for clay and harder soils.

FIGS. **46** and **47** illustrate a bit **780**. Bit **780** has a body **782** with a circular cross-section perpendicular the axis **608**. A plane of symmetry **784** passes through the bit, intersecting axis **608**, to divide the bit into two equal mirror halves. Angled surfaces **786** and **788** are formed on the bit **780** on either side of the plane of symmetry. Because of the circular cross-section of the bit, the surfaces **786** and **788** will define curved edges **790** and **794**, and linear edge **792**. Bit **780** would also be intended primarily for clay and harder soils.

FIGS. **48** and **49** illustrate a bit **800** which is a modification of bit **780**. Bit **800** includes a third angled surface **802** which bisects the plane of symmetry to form linear edges **804** and **806** and a curved edge **808**.

FIGS. **50** and **51** illustrate a bit **820** which has a triangular cross-section perpendicular the axis of rotation **608**. The bit defines parallel surfaces **822**, **824** and **826**. A plane of symmetry **828** is defined through the bit **820** which divides the bit into mirror image halves. Angled surface **830** is formed on one side of the plane while an angled surface **834** is formed on the other side of the plane. An angled surface **832** bisects the plane of symmetry between the surfaces **830** and **834**. The surfaces define slanted outer edges **836–850**.

FIGS. **52** and **53** illustrate a bit **860** which has a generally square cross-section perpendicular the axis **608** defining parallel surfaces **862–868**. Angled surfaces **870–880** are formed to define angled edges **882–900**. It should be noted that bit **860** does not have a plane of symmetry, defining two parallel surfaces **902** and **904** on one side of the bit.

With reference to FIGS. **54** and **55**, a bit **920** is illustrated which has a tapered wedged shape. The bit includes parallel surfaces **922**, **924** and **926** and angled surface **928**.

With reference to FIG. **59**, a bit **980** is illustrated which has parallel surfaces **982**, **984**, **986** and **988** and an angled surface **990**. The front end of the bit **992** is perpendicular parallel surfaces **982–988** and is formed at the intersection of parallel surfaces **982** and **988** and angled surface **990**. The angled surface **990** preferably extends at an angle of about 20° from the rotational axis of the bit.

With reference now to FIG. **56**, a drill bit **950** is illustrated which has a body **952** with a circular cross-section perpendicular the axis **608**. A curved surface **954** is formed on the drill bit which extends from near the rear end **604** to the forward end **606**. Carbide cutting tips **956** and **958** are mounted along the drill bit to aid in cutting with the same cutting action as described in bit **680**.

With reference to FIG. **57**, a drill bit **960** is illustrated which has a prong **962** which extends outward from the curved surface **964**. A carbide cutting tip **966** is mounted at the end of the prong **962** and a carbide cutting tip **968** is mounted at the end **606** of the drill bit to provide the same cutting action as described in bit **680**.

With reference to FIG. **58**, a drill bit **970** is disclosed which has a prong **972** extending from surface **974**. A carbide cutting tip **976** is mounted at the end of prong **972**, a carbide cutting tip **978** is mounted at the end **606** of the drill bit to provide the same cutting action as described in bit **680**.

With reference now to FIGS. **60–62**, a directional multi-blade boring head **1000** will be described. The head **1000** is mounted at the end of a drill string which is capable of selectively rotating the head about its central axis of rotation **1002** and advancing the head along the axis **1002**. The head includes a body **1004** which is attached to the end of the drill string in a conventional manner. The body defines a first planar surface **1006** on a first side of the body and a second planar surface **1008** on the other side of the body. The planar surfaces are both angled in an oblique angle, preferably 13°, relative to the axis **1002**. A jet recess **1010** is cut from the first planar surface **1006** and mounts a jet **1012** to discharge a fluid to assist in the boring action.

As can best be seen in FIG. **62**, the body has internal passages **1014**, **1016** and **1018** which direct the fluid from the drill string to the jet **1012**. The fluid can be air, water, gas or any suitable drilling fluid. As can be seen, a check valve **1020** is provided within the passages which includes a check ball **1022** and a spring **1024** to urge the check ball into a closed position unless the fluid pressure in passage **1018** acting on the ball is sufficient to overcome the force of the spring **1024**.

A blade assembly **1026** is mounted to the body at the second planar surface **1008**. Preferably, the blade assembly **1026** is bolted to the body by bolts **1028** to permit the body assembly to be removed for repair or replaced by a new blade assembly when necessary.

The blade assembly **1026** is formed of at least three blades, including a first blade **1030**, a second blade **1032** and at least one intermediate blade **1034**.

The first blade **1030** defines a deflecting surface **1036** and the second blade defines a similar deflecting surface **1038**. The deflecting surfaces extend at an oblique angle relative to the axis **1002**, preferably 13°. These deflecting surfaces act to deflect the head when the drill string to which the head is attached is thrust forward without rotation. Thus, the head **1000** acts as a directional boring head in the manner of the bits and heads described previously.

The first and second blades **1030** and **1032** also define staggered cutting teeth **1040** to assist the boring action. The included angle θ between the first and second blades is preferably about 120°. The intermediate blade **1034** extends between the deflecting surfaces **1036** and **1038** at an angle θ_1 from the first blade and at an angle θ_2 from the second blade. With the single intermediate blade **1034**, the angles θ_1 and θ_2 are preferably each 120°.

Each of the teeth **1040** are staggered in the direction of rotation of the head for more effective cutting. Also, carbide cutting elements **1041** form the part of the teeth exposed to the greatest wear to lengthen the service life of the blade assembly **1026**.

With reference now to FIGS. **63–65**, a directional multi-blade boring head **1050**, forming a modification of the invention, is illustrated. A number of the elements of boring head **1050** are identical to those of multi-blade boring head **1000**. These elements have been identified by the same reference numerals and have similar functions to those described with reference to head **1000**.

However, the included angle θ between the blades **1030** and **1032** is 180°. A second intermediate blade **1042** extends between the blades **1030** and **1032** on the sides of the blades opposite the deflecting surfaces **1036** and **1038**. The second intermediate blade **1042** in effect forms a continuation of the intermediate blade **1034** and is also provided with serrated teeth **1040** and carbide cutting elements **1041**. It will be noted that the discharge of nozzle **1012** will strike a portion of the second intermediate blade **1042** and a recess **1054** has been formed in the blade **1042** to redirect the stream to assist in the cutting action. The four bladed bit **1050** will permit smoother, straighter bores in harder soil conditions while the inclined planes **1036** and **1038** provide the bit with directional capabilities.

Now with reference to FIGS. **66–68**, a directional dual-cone boring bit **1100** is illustrated. The dual cone boring bit has rotary cutters or cones **1104** and **1105** similar to those used on prior art Tri-cone drilling bits used in the oil field. The boring bit **1100** is used to directionally drill in hard or semi-hard materials. The head **1100** is mounted at the end of a drill string which is capable of selectively rotating the head about its central axis of rotation **1002** and advancing the head along the axis **1002**. The head includes a body **1004** which is attached to the end of the drill string in a conventional manner. The body defines a first planar surface **1006** on the first side of the body and a second planar surface **1008** on the other side of the body. The planar surfaces are both angled in an oblique angle, preferably 13 degrees, relative to the axis **1002**. A jet recess **1010** is cut from the first planar surface **1006** and mounts a jet **1101** to discharge a fluid such as a liquid or a gas to assist in the boring. The jet **1101** is extended in length as compared to jet **1012** of the previous multi-blade bits to ensure fluid is directed at the dual cones to provide lubrication, cooling and assist in boring. All other aspects of the fluid delivery system are the same as boring heads **1000** and **1050**.

The bit assembly **1102** is mounted to the body at the second planar surface **1008**. Preferably, the bit assembly **1102** is bolted to the body by bolts **1103** to permit the body assembly to be removed for repair or install a new bit assembly when necessary.

The bit is formed of two roller cones and attachment body consisting of the center cut cone **1104** and adjacent cone **1105** from a standard tri-cone oil field bit. The rotational axis of each of the cones preferably intersects the axis **1002**. The cones and bodies are welded to components **1106** and **1107** to form bit assembly **1102**. A part of the bit assembly defines a deflecting surface **1108** extending at an oblique angle similar to and causing the bit to act as a directional boring head in the manner of the bits and heads described previously.

With reference now to FIGS. **69**–**[72]***71*, a directional single cone boring bit **1200** is illustrated. The single cone boring bit has a single rotary cutter or cone **1202** similar to those used on prior art tri-cone drilling bits used in the oil field. The jet **1101** discharges against the side of the cutter **1202** to clean debris therefrom. In other aspects, the boring bit **1200** is identical to boring bit **1100** discussed previously and identical elements on the figures are identified by the same reference numerals.

The roller cones described in this invention provide the same cutting action as in the oil field application of the tri-cone bits previously described. These tri-cone bits have one center cut cone and two adjacent cones. However, the addition of the deflecting surface and the removal of one of the adjacent roller cones permits the bit **1100** when thrust forward without rotation to be deflected from the axis of the bore thus permitting the direction of the bore to be altered. The addition of the deflecting surface and the removal of two of the adjacent roller cones permits the bit **1200** when thrust forward without rotation to be deflected from the axis of the bore thus permitting the direction of the bore to be altered. The continuous rotation of the drill bit and application of thrust permits the bore to be in a straight line relative to the drill string axis **1002**. The hardness of the material being cut will dictate the amount of steering capable of being accomplished. Some semi-hard materials will permit the oscillating of the bit and the drill string about the central axis of rotation **1002** while applying thrust to change the direction of the bore axis.

The heads **1000**, **1050**, **1100** and **1200** described have a number of significant advantages over previous known boring heads. The heads **1000**, **1050**, **1100** and **1200** bore a rounder, straighter hole than a one-sided slanted head which tends to drill more of a helical borehole. The heads **1000**, **1050**, **1100** and **1200** have proven particularly effective in boring productivity and direction accuracy through sand and rock. With previous one-sided slanted heads, the head could impact and catch on a hard object, causing the boring rods in the drill string to wind up in torsion until the head breaks free of the object with a sudden release. The heads **1000**, **1050**, **1100** and **1200** appear to alleviate this problem.

The additional advantages of heads **1000**, **1050**, **1100** and **1200** include an improvement in the directional accuracy of the head through rock and other hard boring conditions. The boring head also uses less water to cool the bit which has significant advantages as EPA regulations for disposal of drilling fluids are becoming more difficult to comply with. The presence of the blades also reduces a tendency for the head to roll when pushed forward without rotation to make a directional change. Finally, the head provides an improved ease of surface launch.

While the invention has been described with a certain degree of particularity it is manifest that many changes may be made in the details of construction and arrangement of components without departing from the spirit and scope of this disclosure. It is understood that the invention is not limited to the embodiments set forth herein for purposes of exemplification, but is to be limited only by the scope of the attached claim or claims, including the full range of equivalency to which each element thereof is entitled.

We claim:

1. A directional boring head for a boring machine, the boring machine capable of axially advancing and rotating a drill string about an axis of rotation underground, the drill string ending in the directional boring head, said directional boring head comprising:

a body having a central axis of rotation;

a deflection structure mounted on the body defining a deflecting surface at an oblique angle to the central axis of rotation of the body;

[at least one**]** *a single* roller cone mounted to said body; and

the deflecting surface deflecting the boring head as the boring machine advances the drill string without rotation and the directional boring head drilling a relatively straight borehole as the boring machine advances the drill string with rotation.

[2. The direction boring head of claim **1** having two roller cones mounted on the body.**]**

3. The directional boring head of claim **1** wherein a fluid jet is mounted on the body, the body having a passage for flow of fluid for discharge from the jet to assist in the drilling.

4. The directional boring head of claim **3** wherein the jet is oriented to discharge a fluid at the roller cone.

5. The directional boring head of claim **1** wherein the deflection structure and roller cone are mounted on a bit assembly removably attached to the body.

6. The directional boring head of claim **1** wherein the rotational axis of the roller cone intersects the central axis of rotation of the body.

[7. The directional boring head of claim **1** having one roller cone mounted on the body.**]**

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