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(54) **EXTRUSION PRESS DIE ASSEMBLY**

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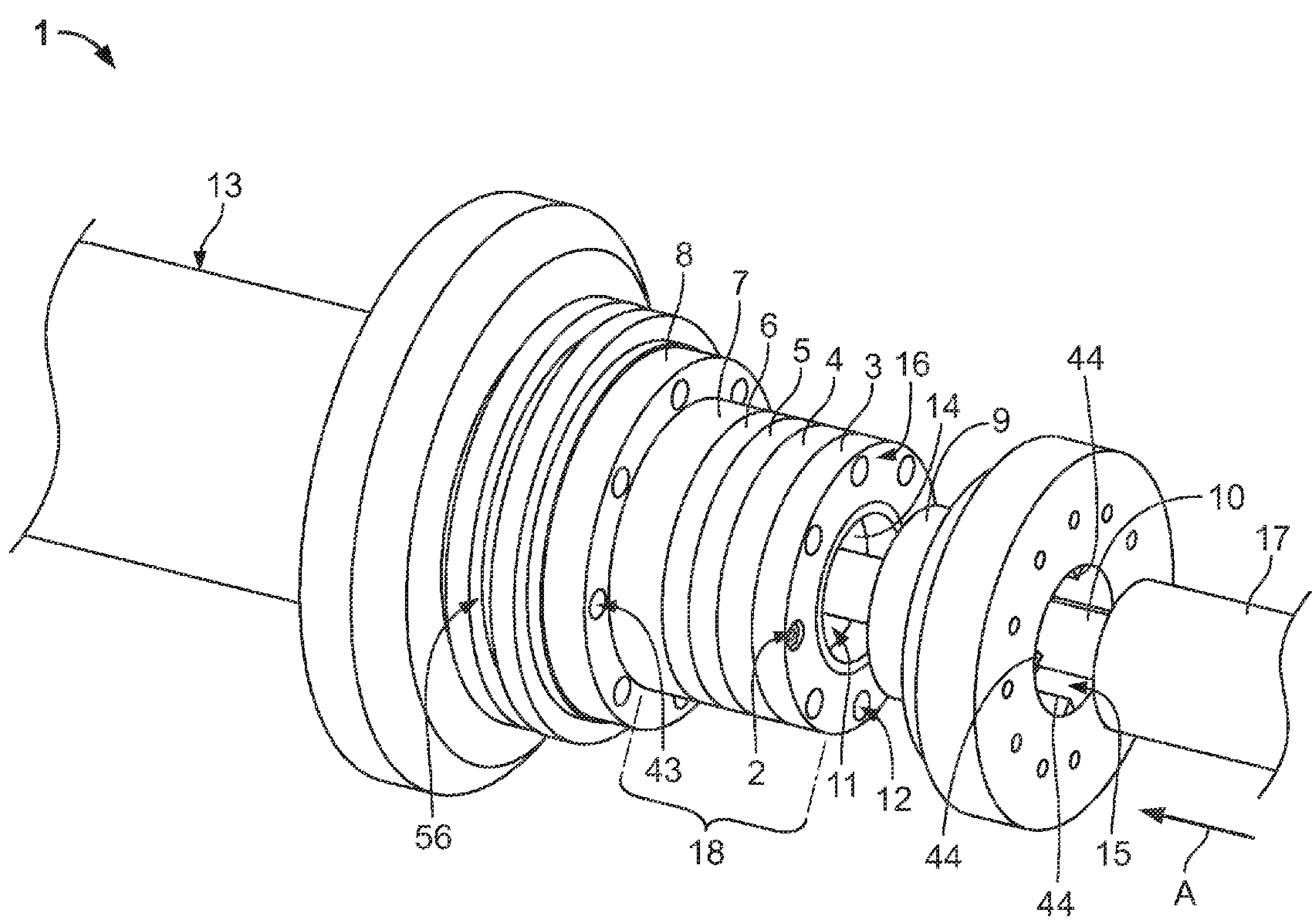
(57) **ABSTRACT**

Systems, devices, and methods for continuous extrusion of material billets are provided. A die assembly for press extrusion of a material includes a plurality of die plates forming a die body. The die body has an entrance and an exit having a diameter smaller than the entrance, with a tapered surface between the entrance and the exit. Each die plate has a center bore with a tapered interior surface, and the interior surfaces form the tapered surface that extends from the entrance to the exit. A base is coupled to the die body, and rotation of the base causes rotation of the die body. A billet pressed into the die body is heated by friction between the interior surface and an outer surface of the billet. The billet is heated to a deformable temperature and is extruded into a tube product as the billet is pressed from the entrance to the exit of the die body.



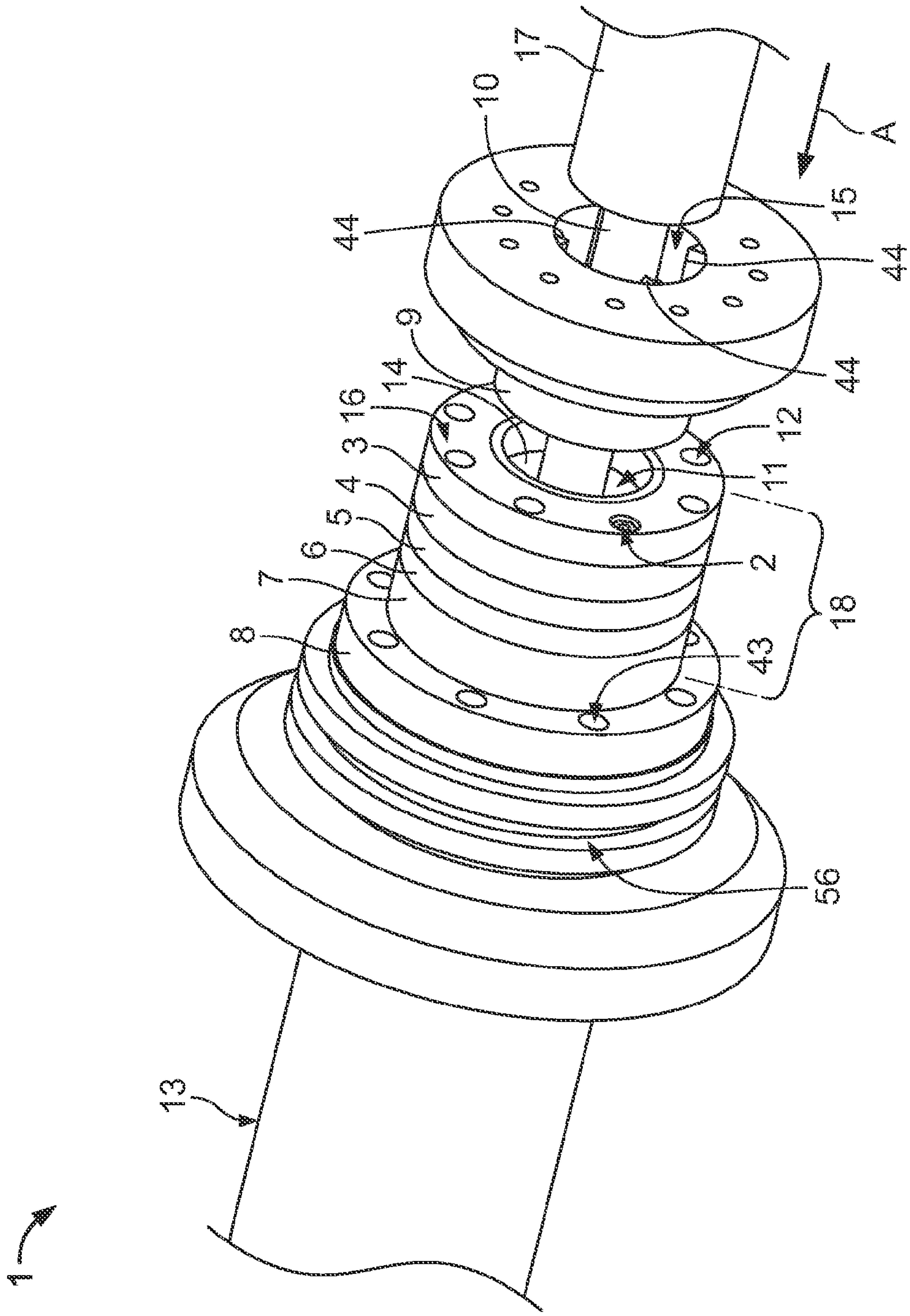


FIG. 1

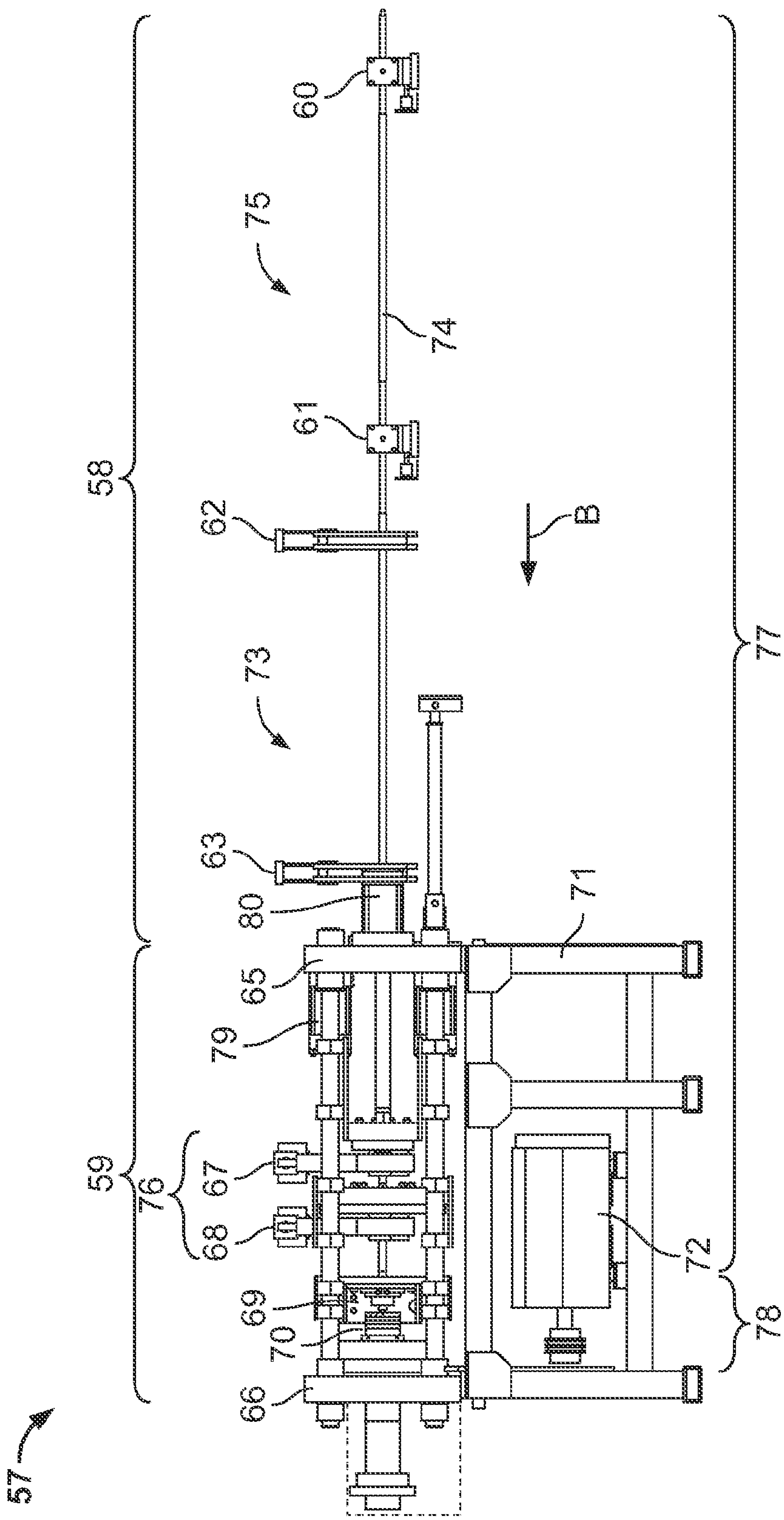


FIG. 2

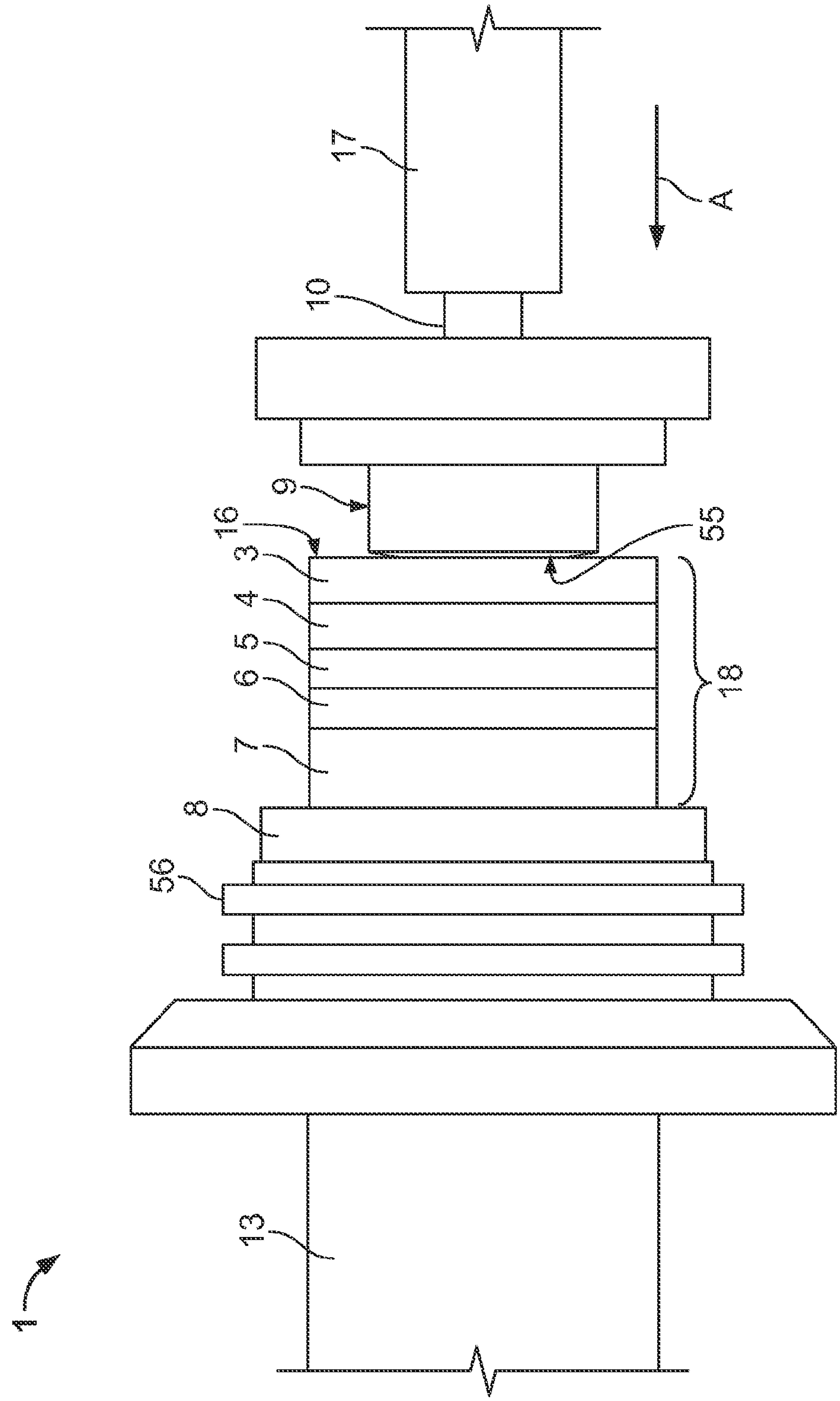


FIG. 3

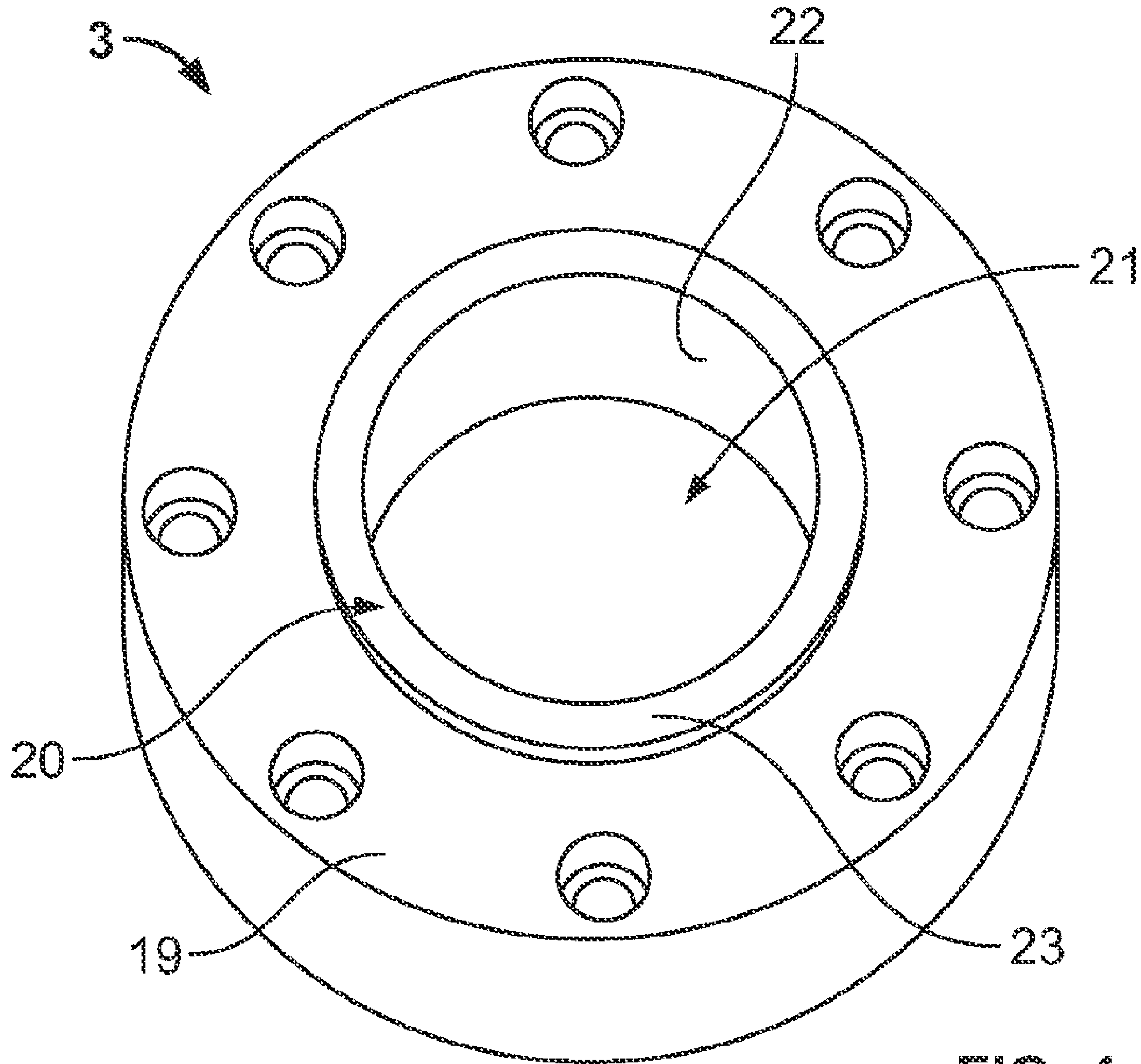


FIG. 4

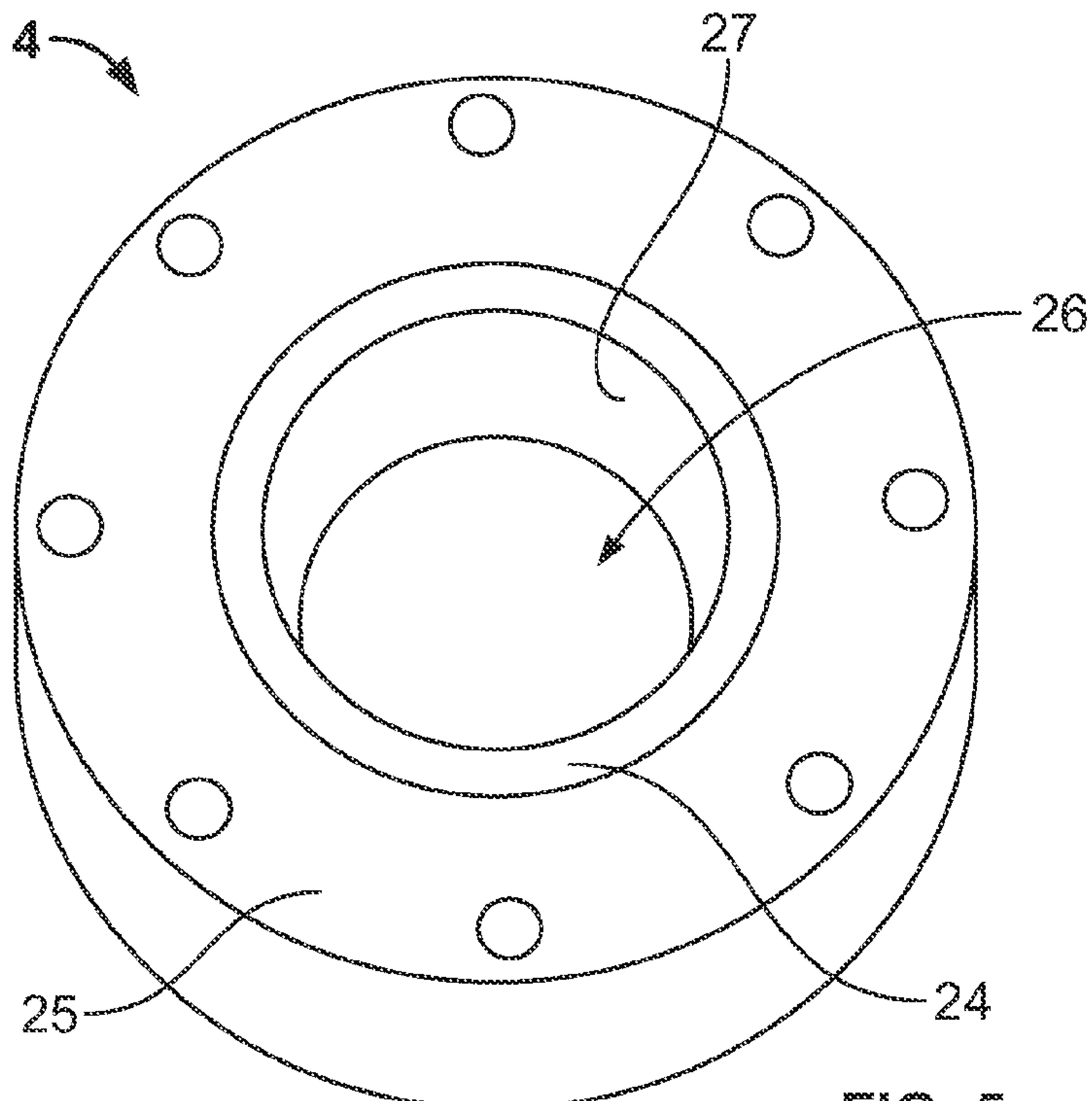


FIG. 5

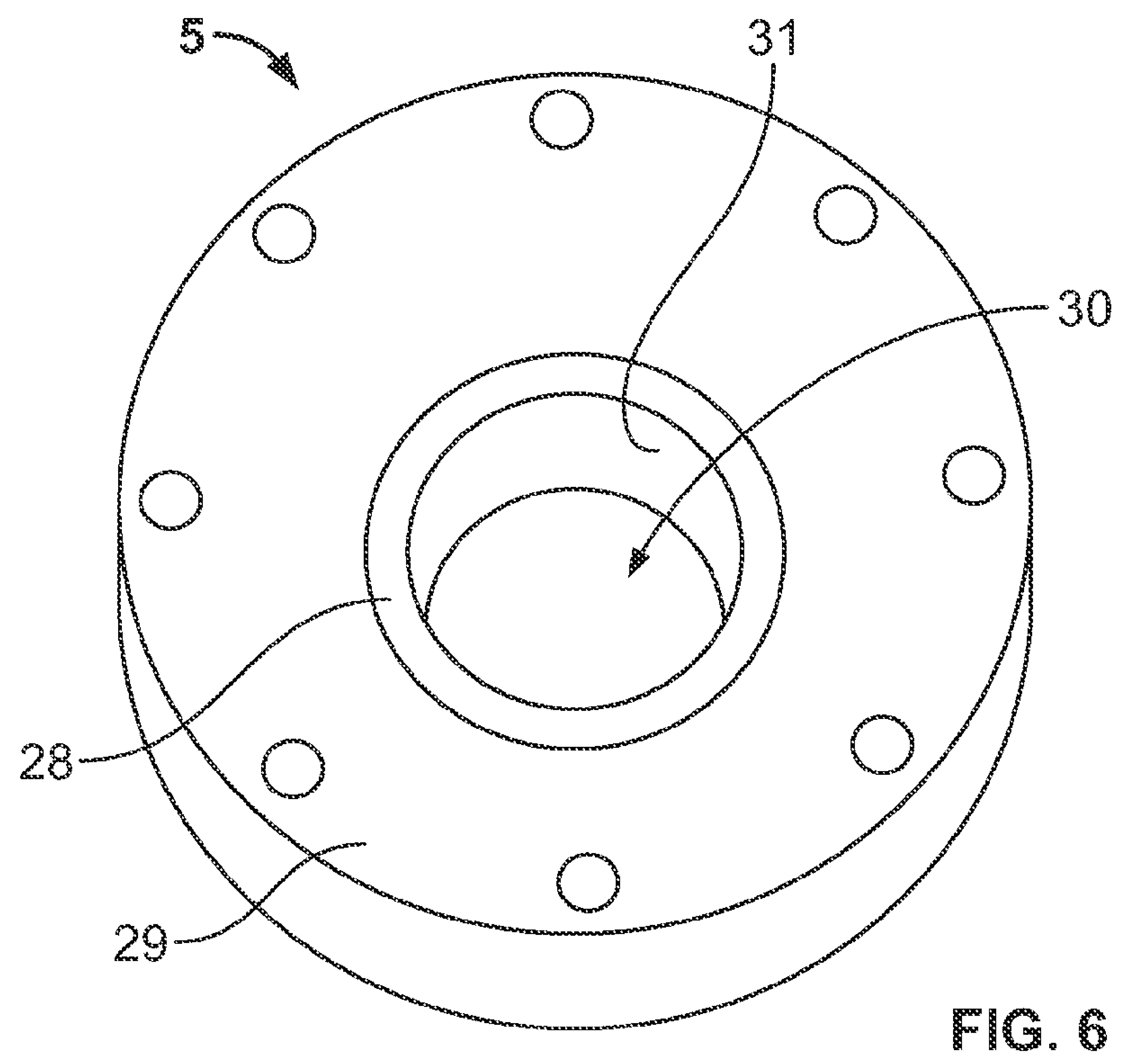


FIG. 6

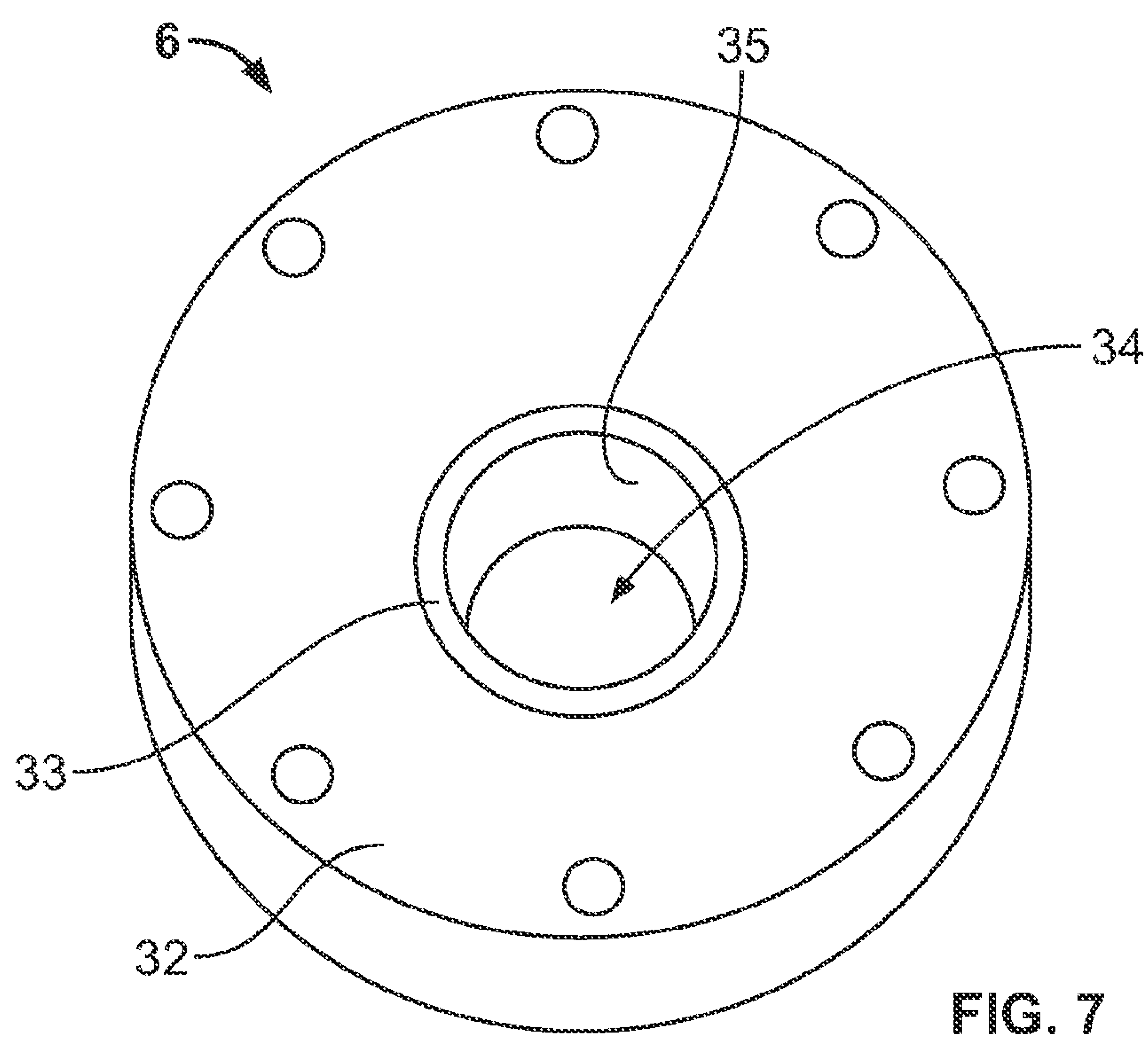


FIG. 7

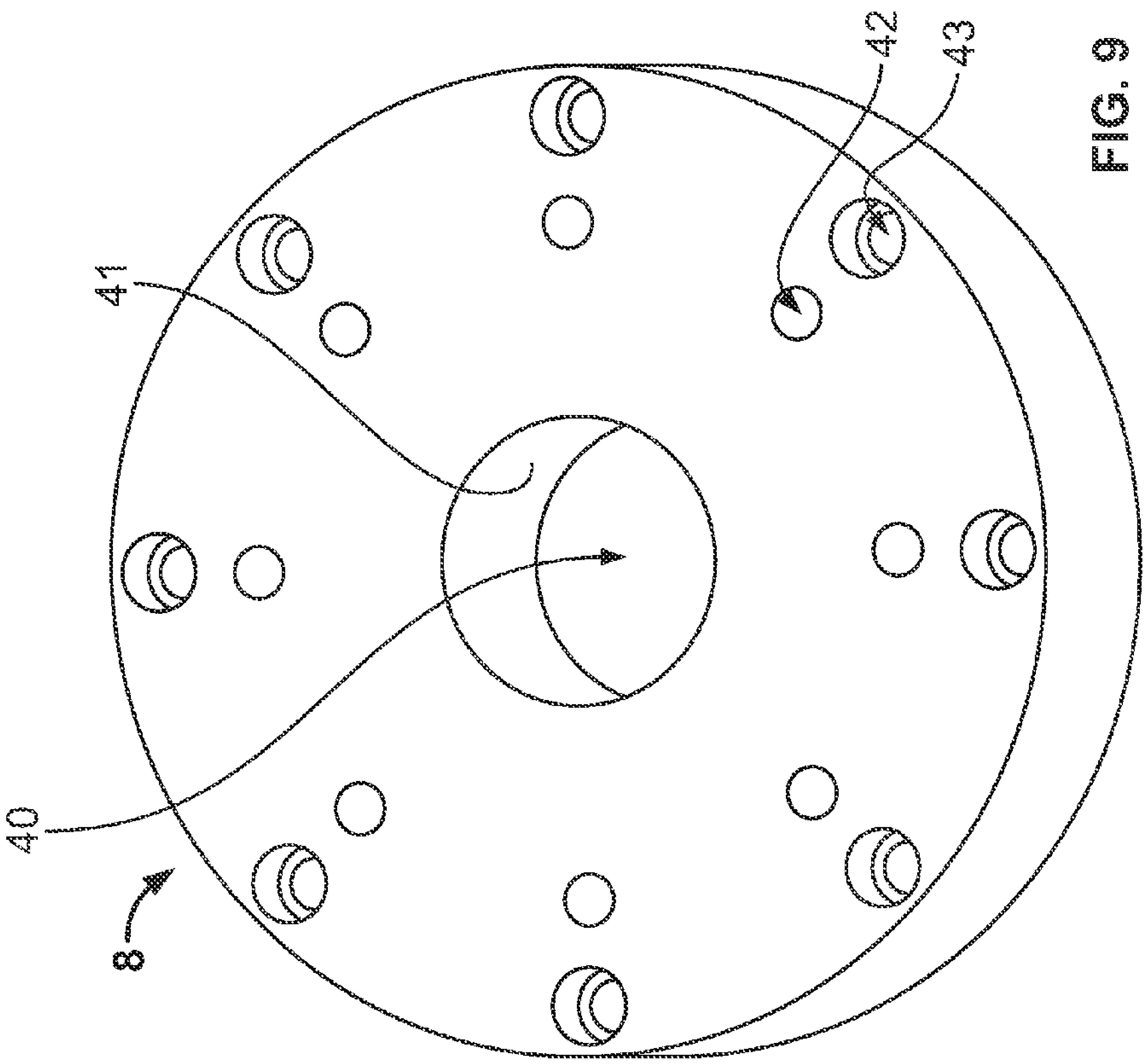


FIG. 9

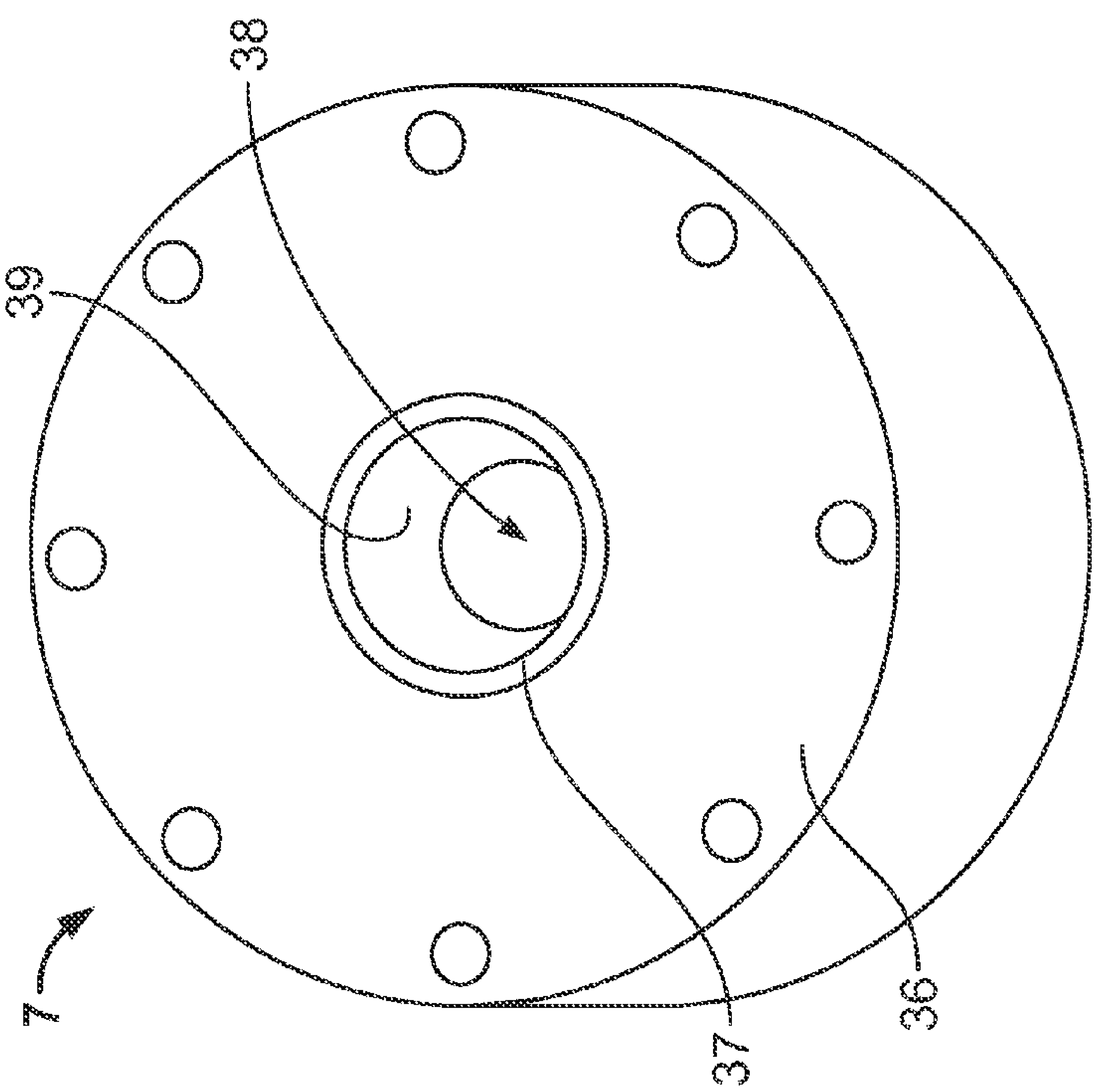


FIG. 8

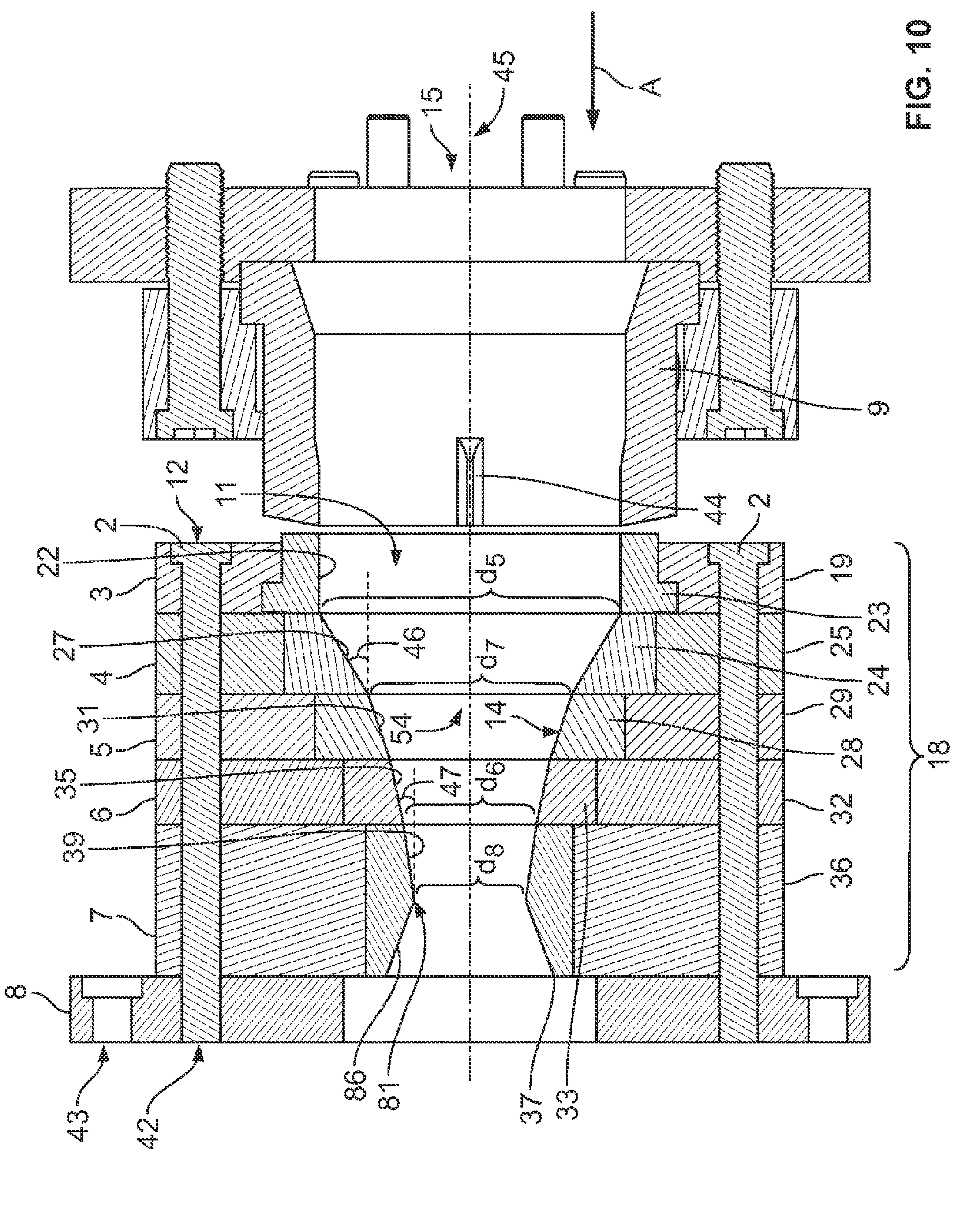

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FIG. 10

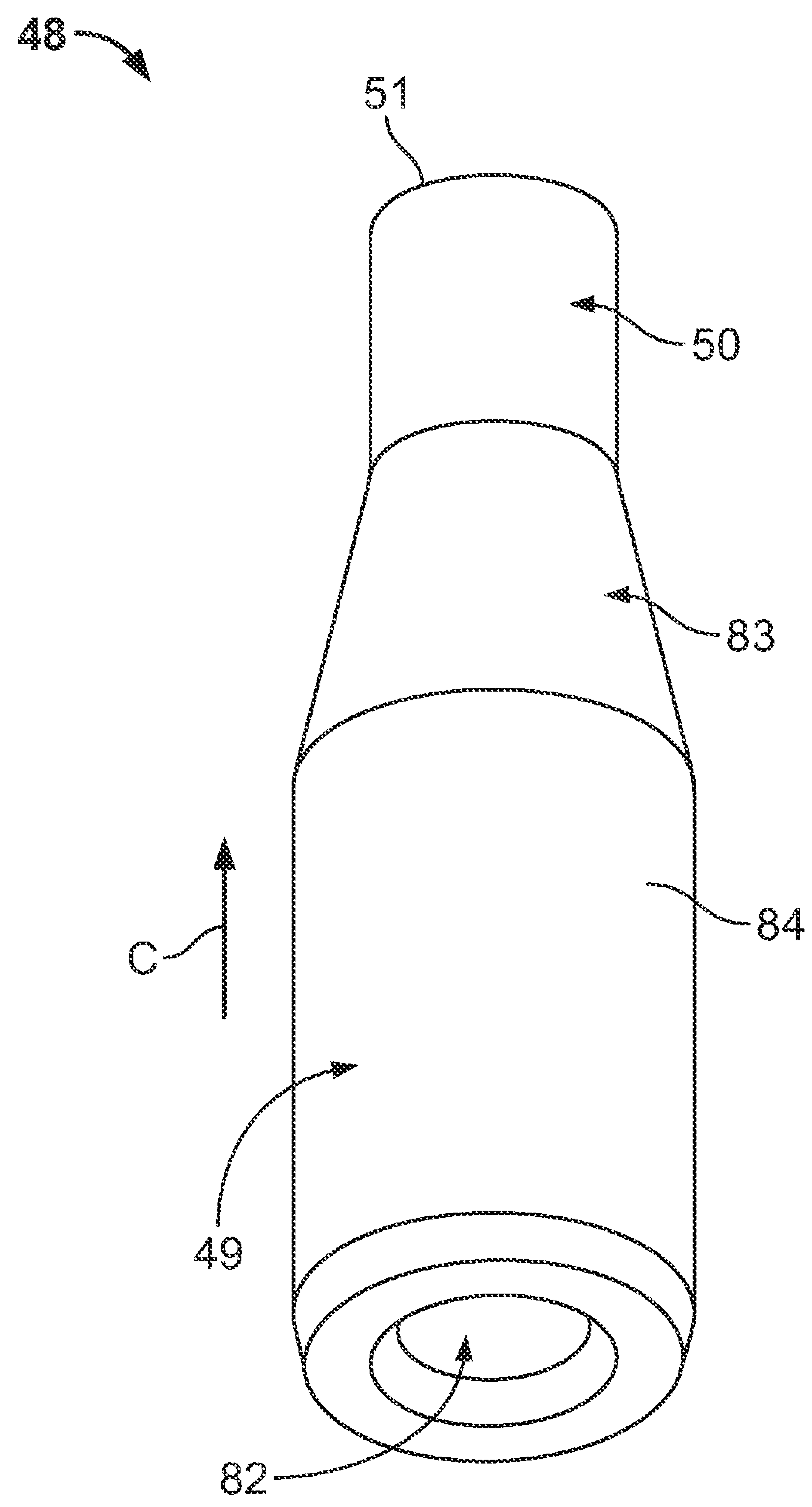

FIG. 11

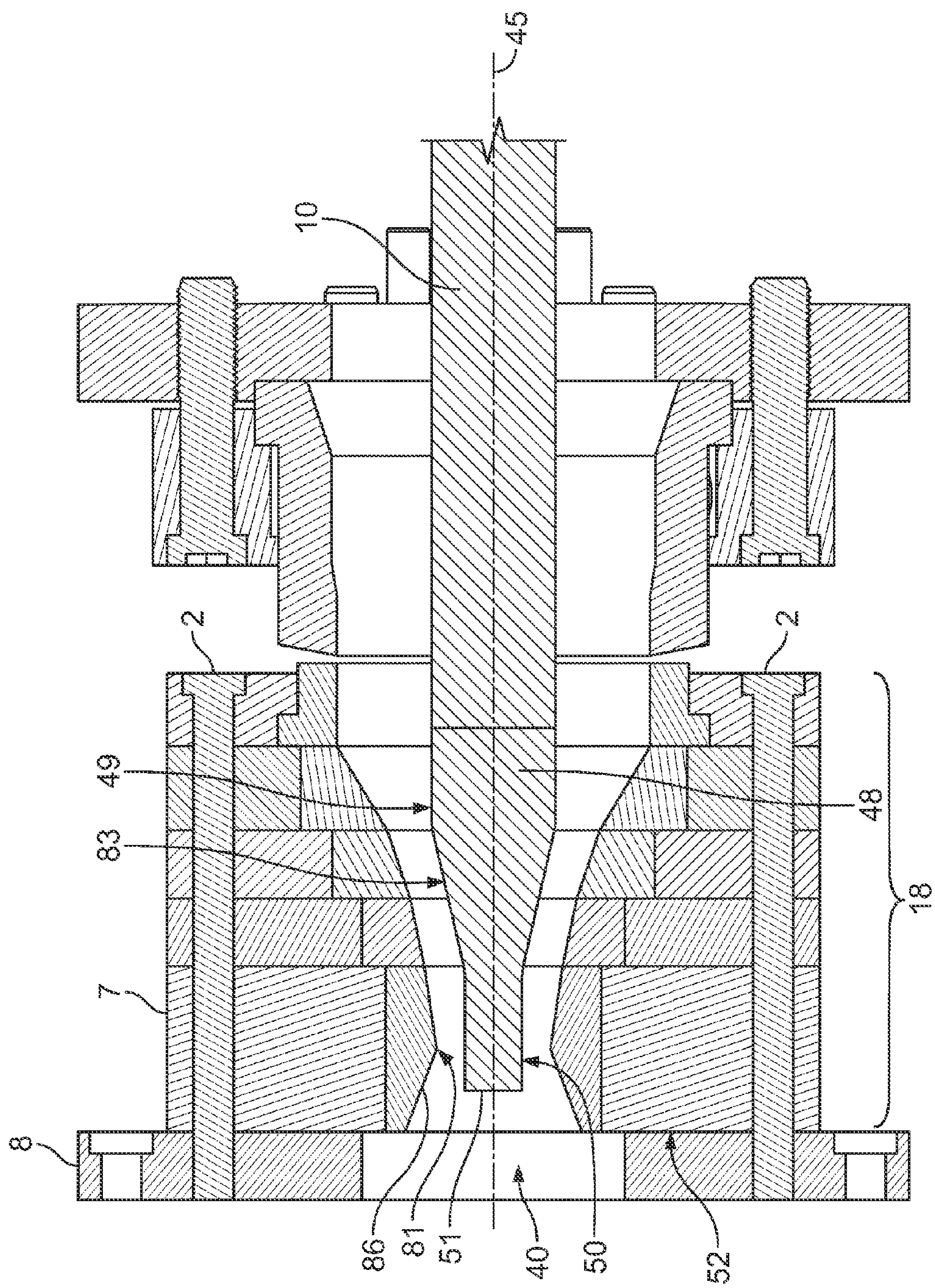

FIG. 12

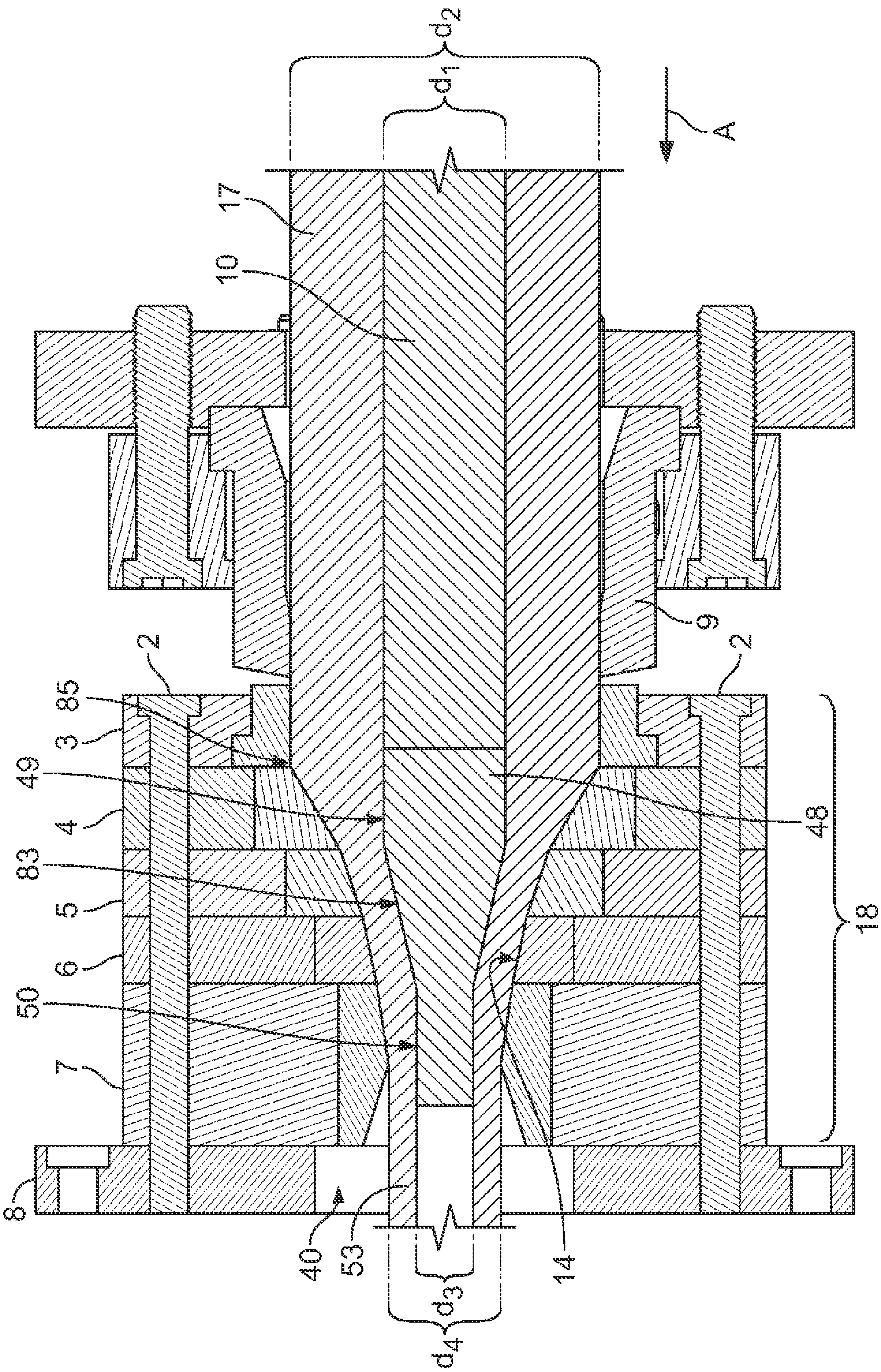

FIG. 13

EXTRUSION PRESS DIE ASSEMBLY

BACKGROUND

[0001] Tubing material, such as metal piping formed from copper, aluminum, metal alloy, or other metals, is often manufactured by extrusion processes. In an extrusion process, a large block of metal, referred to as a billet, is worked through a die structure having a circular or other configuration with an opening smaller than the size of the billet used to form the tubing material. The billet may be pre-heated to a high temperature before a piercing rod is forced through the center of the billet to form a channel therethrough. A large pressure, typically on the order of 1,000 to 100,000 pounds-per-square-inch, is then applied to the billet to force the pre-heated material over the piercing rod and through the die opening. The pressure forces the material to deform and extrude, exiting the back of the die as a tube having a diameter similar to the diameter of the opening of the die.

[0002] In order to produce large quantities of metal tubing by extrusion, large billets and manufacturing machinery are required, and billets used in extrusion processes to create metal tubing often reach or exceed 1,000 pounds in weight. The size of the machines and billets requires large manufacturing facilities to produce the tubing, and the size requirements of the extrusion process lead to large start-up and maintenance costs for the manufacturing operation. Furthermore, limitations of the processes, such as extruding only one billet at a time, lead to inefficiencies from billet sizes.

SUMMARY

[0003] Disclosed herein are systems, devices and methods for extruding materials using a rotating extrusion press die assembly. In certain embodiments, the systems, devices and methods allow for continuous extrusion of a plurality of material billets. Such continuous extrusion allows for relatively smaller billets to be efficiently used to produce a desired quantity of extruded material, and therefore the scale and size requirements of such continuous extrusion press systems can be smaller than conventional extrusions processes.

[0004] In one aspect, a die assembly for extruding a material includes a plurality of die plates coupled together to form a die body. The die body has a passage defining an entrance and an exit, and the diameter of the exit is smaller than the diameter of the entrance. A tapered surface is located between the entrance and the exit. Each of the die plates has a center bore with a tapered interior surface around the center bore, and an interior surface of a center bore in a first die plate is tapered at a smaller angle relative to an axis of the passage than an interior surface of a center bore in a second die plate positioned adjacent to a front face of the first die plate. A base is coupled to the die body, and rotation of the base causes the die body to rotate.

[0005] In certain implementations, the second die plate is positioned nearer to the entrance of the die body than the first die plate. The die assembly may include a third die plate having a center bore with an interior surface that is tapered at a larger angle relative to the axis than an interior surface of a center bore in a die plate positioned adjacent to a front face of the third die plate. The die plate positioned adjacent to the front face of the third die plate may be the first die plate, and the third die plate may be positioned nearer to the exit of the die body than the first die plate.

[0006] In certain implementations, the die assembly includes a third plate that forms a portion of the die body, and the third plate has a central bore with an interior surface around the center bore that is not tapered at an angle relative to the axis of the passage. The center bore of the third plate defines the entrance of the die body. In certain implementations, the base includes a center bore, and the center bore of the base has a diameter that is greater than a diameter of the die body exit.

[0007] In certain implementations, the die body is configured to receive a billet of material for extrusion, and the billet is not pre-heated before entering the die body. Rotation of the die body creates friction between the tapered interior surface and a billet advanced through the entrance and into the interior passage of the die body. The friction heats the billet to a temperature that is sufficient to cause deformation of the billet material, and the heated billet is deformable under a deformation force that does not exceed mechanical property limits of the billet material. Friction between the billet and a mandrel over which the billet is advanced heats the billet and the mandrel. A cooling system provides cooling fluid to an interior portion of the mandrel.

[0008] In certain implementations, at least one of the die plates is formed from two different materials, with a first material forming a perimeter of a bore in the die plate and a second material forming an outer portion of the die plate. At least one of the first and second materials is a ceramic material, a steel, or a consumable material. In certain implementations, a front face of the die body near the entrance is configured to mate with a centering insert having a diameter substantially equal to the diameter of the entrance. The centering insert and a perimeter of the entrance are formed from the same material.

[0009] In certain implementations, the die body is configured to receive a mandrel tip through the entrance such that the mandrel tip is positionable within the interior passage of the die body. The interior surface of the die body includes a complementary portion having an angle that corresponds to an angle of an outer surface of the mandrel tip. The die body is configured to receive a billet pressed through the interior passage of the die body to form an extruded product, the extruded product having an outer diameter corresponding to the diameter of the exit of the die body and an inner diameter corresponding to a diameter of the mandrel tip.

[0010] In one aspect, a die assembly includes a means for extruding a material that includes a plurality of plate means. The means for extruding has a passage means defining an entrance and an exit of the means for extruding, and the diameter of the exit is smaller than the diameter of the entrance. The means for extruding also has a tapered surface means between the entrance and the exit. Each of the plate means has a center bore with a tapered surface around the center bore, and an interior surface of a center bore in a first plate means is tapered at a smaller angle relative to an axis of the passage means than an interior surface of a center bore in a second plate means positioned adjacent to a front face of the first plate means. The die assembly also includes a means for coupling the means for extruding to a rotation means, and rotation of the means for coupling causes the means for extruding to rotate.

[0011] In certain implementations, the second plate means is positioned nearer to the entrance of the means for extruding than the first plate means. The means for extruding may include a third plate means having a center bore with an interior surface that is tapered at a larger angle relative to the axis than an interior surface of a center bore in a plate means positioned adjacent to a front face of the third plate means. The plate means positioned adjacent to the front face of the third plate means may be the first plate means, and the third plate means may be positioned nearer to the exit of the means for extruding than the first plate means.

[0012] In certain implementations, the die assembly includes a third plate means that forms a portion of the means for extruding, the third plate means having a central bore with an interior surface around the center bore that is not tapered at an angle relative to the axis. The center bore of the third plate means defines the entrance of the means for extruding. In certain implementations, the means for coupling includes a center bore. The center bore of the means for coupling has a diameter that is greater than a diameter of the exit of the means for extruding.

[0013] In certain implementations, the means for extruding is configured to receive a billet of material for extrusion, and the billet is not pre-heated before entering the means for extruding. Rotation of the means for extruding creates friction between the tapered surface means and a billet advanced through the entrance and into the passage means of the means for extruding. The friction heats the billet to a temperature that is sufficient to cause deformation of the billet material. The heated billet is deformable under a deformation force that does not exceed mechanical property limits of the billet material. Friction between the billet and a rod means over which the billet is advanced heats the billet and the rod means, and a means for cooling provides cooling fluid to an interior portion of the rod means.

[0014] In certain implementations, at least one of the plate means is formed from two different materials, with a first material forming a perimeter of a bore in the plate means and a second material forming an outer portion of the plate means. At least one of the first and second materials is a ceramic material, a steel, or a consumable material. In certain implementations, a front face of the means for extruding near the entrance is configured to mate with a means for centering a billet, the means for centering having a diameter substantially equal to the diameter of the entrance. The means for centering and a perimeter of the entrance are formed from the same material.

[0015] In certain implementations, the means for extruding is configured to receive a rod tip means through the entrance such that the rod tip means is positionable within the interior passage of the means for extruding. The tapered surface means of the means for extruding comprises a complementary portion having an angle that corresponds to an angle of an outer surface of the rod tip means. The means for extruding is configured to receive a billet pressed through the passage means of the means for extruding to form an extruded product, the extruded product having an outer diameter corresponding to the diameter of the exit of the means for extruding and an inner diameter corresponding to a diameter of the rod tip means.

[0016] Variations and modifications of the embodiments discussed herein will occur to those of skill in the art after reviewing this disclosure. The foregoing features and aspects may be implemented in any combination and sub-combination, including multiple dependent combinations, and sub-combinations with one or more other features described herein. The various features described or illustrated herein, including any components thereof, may be combined or integrated in other systems. Moreover, certain features may be omitted or not implemented.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The foregoing and other objects and advantages will be apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings in which like-referenced characters refer to like parts throughout.

[0018] FIG. **1** shows a perspective view of an illustrative extrusion press die assembly.

[0019] FIG. **2** shows a side elevation view of an illustrative extrusion press system.

[0020] FIG. **3** shows a side elevation view of the extrusion press die assembly of FIG. **1**.

[0021] FIG. **4** shows an illustrative steel end holder of the extrusion press die assembly of FIG. **1**.

[0022] FIG. **5** shows an illustrative entry plate of the extrusion press die assembly of FIG. **1**.

[0023] FIG. **6** shows an illustrative first intermediate plate of the extrusion press die assembly of FIG. **1**.

[0024] FIG. **7** shows an illustrative second intermediate plate of the extrusion press die assembly of FIG. **1**.

[0025] FIG. **8** shows an illustrative exit plate of the extrusion press die assembly of FIG. **1**.

[0026] FIG. **9** shows an illustrative base plate of the extrusion press die assembly of FIG. **1**.

[0027] FIG. **10** shows an illustrative cross-section view of the extrusion press die assembly of FIG. **1**.

[0028] FIG. **11** shows an illustrative mandrel bar tip.

[0029] FIG. **12** shows an illustrative cross-section of the extrusion press die assembly of FIG. **1** with the mandrel bar tip of FIG. **11** advanced into the die assembly.

[0030] FIG. **13** shows a cross-sectional view of the die assembly and mandrel bar tip of FIG. **12** during extrusion of a material.

DETAILED DESCRIPTION

[0031] To provide an overall understanding of the systems, methods, and devices described herein, certain illustrative embodiments will be described. Although the embodiments and features described herein are discussed for use in connection with extrusion press systems, it will be understood that the components, connection mechanisms, manufacturing methods, and other features outlined below may be combined with one another in any suitable manner and may be adapted and applied to systems to be used in other manufacturing processes. Furthermore, although the embodiments described herein relate to extruding metal tubing from hollow billets, it will be understood that the systems, devices, and methods described herein may be adapted and applied to systems for extruding any suitable type of material.

[0032] FIG. **1** shows a die assembly **1** for forming extruded tubing, which may include seamless extruded tubing, in a press extrusion system. The die assembly **1** may provide for continuous extrusion of a plurality of billets to produce a seamless extruded tubing product according to various seamless tubing standards including, for example, the ASTM-B88 Standard Specification for Seamless Copper Water Tube. The seamless extruded tubing may also comply with the standards under NSF/ANSI-61 for Drinking Water System Components. The die assembly **1** includes a mandrel bar **10** over which material billets, such as billet **17**, are passed in the direction of arrow A and through the die assembly to form an extruded tubing product. The billet **17** may be formed from any suitable material for use in extrusion press systems including, but not limited to, various metals including copper and copper alloys, or any other suitable non-ferrous metals such as aluminum, nickel, titanium, and alloys thereof, ferrous metals including steel and other iron alloys, polymers such as plastics, or any other suitable material or combinations thereof. The billets passing over the mandrel bar **10** are advanced through a centering insert **9** and a die body **18**, which is composed of a stack of die plates **3**-**7** and a base plate **8**, and through a cooling system **13** to form the tube product. While die assembly **1** includes five plates coupled to a base plate, a die assembly may include more plates or fewer plates, and a die body may be longer or shorter than the die body **18** in certain applications.

[0033] During extrusion, the die body **18** rotates while billet **17** is pressed through the die body. The billet **17** is held by grippers **44** of the centering insert **9**, which does not rotate, and thus the billet **17** does not rotate as it enters the rotating die body **18** at the entrance **11** to the center passage through the die body. The rotation of the die body **18** creates friction with the outer surface of the non-rotating billet **17** as it is pressed through the die, and the friction heats the billet **17** to a temperature sufficient for the billet material to deform. For example, a metal billet may be heated by the friction to a temperature greater than 1000° F. for deformation. The temperature requirements of different materials and different metals may vary, and billet temperatures less than 1000° F. may be suitable in some applications. In contrast to other extrusion systems, the die assembly **1** does not require preheating of billets before extrusion, as the rotation of the die body **18** and the friction created by contact with the non-rotating billet **17** provide energy that heats the billet to a deformable temperature.

[0034] The die assembly **1** may be used for forming an extruded material in any suitable extrusion system, including, for example, the extrusion press system described in copending, commonly-assigned U.S. patent application Ser. No. ______ (Attorney Docket No. 109965-0004-101), filed concurrently herewith, and entitled "EXTRUSION PRESS SYSTEMS AND METHODS," the disclosure of which is hereby incorporated by reference herein in its entirety. For example, the die assembly **1** may be implemented in the extrusion press system **57** shown in FIG. **2** for continuous material extrusion. The extrusion press system **57** includes a mandrel carriage section **58** and a platen structure section **59**. The mandrel carriage section **58** includes a mandrel bar **74**, water clamps or cooling elements **60** and **61**, mandrel grips or gripping elements **62** and **63**, and a billet delivery system. The mandrel carriage section **58** is supported by a physical carriage structure, which is not shown in FIG. **2** to avoid overcomplicating the drawing, but which carriage structure serves as a mount for the components of the mandrel carriage **58**. The platen structure section **59** includes an entry platen **65** and a rear die platen **66**, press-ram platens **67** and **68**, a centering platen **69**, and a rotating die **70** that presses against the rear die platen **66**. The platen structure section **59** is supported by a frame **71** that also serves as a mount for the motor **72** and related gearbox components (not shown). The direction along which billet loading, transport, and extrusion occurs according to the extrusion press system **57** is denoted by arrow B. The extrusion press system **57** may be operated, at least in part, by a PLC system that controls aspects of the billet delivery subsystem **77**, extrusion subsystem **78**, and a cooling subsystem of the extrusion press system **57**

[0035] The mandrel grips **62**, **63** comprise a mandrel bar gripping system **73** designed to hold the mandrel bar in place while allowing a plurality of billets to be continuously fed along and about the mandrel bar **74** to provide for continuous extrusion. The mandrel grips **62**, **63** may be controlled by the PLC system to securely hold in place and prevent the mandrel bar **74** from rotating such that at any given time during the extrusion process, at least one of the mandrel grips **62**, **63** is gripping the mandrel bar **74**. The mandrel grips **62**, **63** set the position of the mandrel bar **74** and prevent the mandrel bar **74** from rotating. When the mandrel grips **62**, **63** are in a gripping position, thereby gripping the mandrel bar **74**, the mandrel grips **62**, **63** prevent billets from being transported along the mandrel bar **74** through the grips.

[0036] The mandrel grips **62**, **63** operate by alternately gripping the mandrel bar **74** to allow one or more billets to pass through a respective mandrel grip at a given time. For example, the upstream mandrel grip **62** may release the mandrel bar **74** while the downstream mandrel grip **63** is gripping the mandrel bar **74**. At any given time, at least one of the mandrel grips **62**, **63** is preferably gripping or otherwise engaged with the mandrel bar **74**. One or more billets queued or indexed near the upstream mandrel grip **62**, or being transported along the mandrel bar **74**, may pass through the open upstream mandrel grip **62**. After a specified number of billets have passed through the open upstream mandrel grip **62**, the mandrel gripper **62** may close and thereby return to gripping the mandrel bar **74**, and the billets may be advanced to the downstream gripping element **63**. The downstream gripping element **63** may remain closed, thereby gripping the mandrel bar **74**, or the downstream mandrel grip **63** may open after the upstream mandrel grip **62** re-grips the mandrel bar **74**. Although two mandrel grips **62**, **63** are shown in the extrusion press system **57**, it will be understood that any suitable number of mandrel grips may be provided.

[0037] The water clamps **60**, **61** comprise a mandrel bar water delivery system **75** designed to supply cooling water along the interior of the mandrel bar **74** to the mandrel bar tip during the extrusion process. The water clamps **60**, **61** may be controlled by the PLC system to continuously supply process cooling water to the mandrel bar during the extrusion process while allowing a plurality of billets to be continuously feed along and about the mandrel bar **74**. The water clamps **60**, **61** operate such that there is no or substantially no interruption to the supply of process cooling water to the mandrel bar tip during the extrusion process. Similar to the operation of the mandrel grips **62**, **63** discussed above, when the water clamps **60**, **61** are clamped to or engaged with the mandrel bar **74**, the water clamps **60**, **61** prevent billets from being transported along the mandrel bar **74** through the water clamps.

[0038] The water clamps **60**, **61** operate such that at any given time during the extrusion at least one of the water clamps is clamped to or engaged with the mandrel bar **74** and thereby delivers cooling water into the mandrel bar **74** for delivery to the tip of the mandrel bar. When a billet passes through one of the water clamps **60**, **61**, the respective water clamp discontinues delivering cooling water and releases or disengages the mandrel bar **74** to allow the billet to pass therethrough before re-clamping the mandrel bar **74** and continuing to deliver cooling water. While one of the water clamps **60**, **61** is unclamped or disengaged from the mandrel bar **74**, the other water clamp continues to deliver cooling water to the mandrel bar.

[0039] For example, the upstream water clamp **60** may release the mandrel bar **74** while the downstream water clamp **61** is clamped to the mandrel bar **74**. At any given time, at least one of the water clamps **60**, **61** is preferably clamped to the mandrel bar **74** to continuously deliver cooling water. One or more billets queued or indexed near the upstream water clamp **60**, or being transported along the mandrel bar **74**, may pass through the open upstream water clamp **60**. After a specified number of billets has passed through the open upstream water clamp **60**, the water clamp **60** may close and thereby return to clamping the mandrel bar **74** and delivering cooling water, and the billets may be advanced to the downstream water clamp **61**. The downstream water clamp **61** may remain closed, thereby clamping the mandrel bar **74**, or the downstream water clamp **61** may open after the upstream water clamp **60** re-clamps to the mandrel bar **74**. Although two water clamps **60**, **61** are shown in the extrusion press system **57**, it will be understood that any suitable number of water clamps may be provided.

[0040] The mandrel bar **74** extends along substantially the length of the extrusion press system **57** and is positioned to place the mandrel bar tip through the rotating die **70**. The rotating die **70** may incorporate the die body **18** shown in FIG. **1**. The adjustment to properly position the mandrel bar tip through the die **70** is accomplished by moving the mandrel carriage section **58**, thus moving the mandrel bar **74**. The adjustments to the mandrel bar **74** and the mandrel carriage section **58** may be towards or away from the die **70**. The mandrel bar **74** and the mandrel carriage section **58** preferably cannot be adjusted while the extrusion press system **57** is in operation, although it will be understood that in certain embodiments the mandrel bar **74** and/or mandrel carriage section **58** may be adjusted during operation.

[0041] As discussed above, the extrusion press system **57** includes a platen structure section **59** having an entry platen **65** and a rear die platen **66**, press-ram platens **67** and **68**, a centering platen **69**, and a rotating die **70** presses against the rear die platen **66**. Near the entry platen **65** is the press-ram platen assembly **76** that includes a first press-ram platen **67**, or A-Ram, and a second press-ram platen **68**, or B-Ram. The first and second press-ram platens **67**, **68** feed billets into the centering platen **69**, which grips the billets and prevents the billets from rotating prior to entering the rotating die **70**, which presses against the rear die platen **66**.

[0042] The press-ram platens **67**, **68** operate by gripping the billets and providing a substantially constant pushing force in the direction of the extrusion die stack **70**. At any given time at least one of the press-ram platens **67**, **68** grips a billet and advances the billet along the mandrel bar **74** to provide the constant pushing force. The press-ram platens **67**, **68** form the final part of the billet delivery subsystem **77** before the billet enters the centering insert **69** and the rotating die **70** of the extrusion subsystem **78**. Similar to the billet feed track section before the entry platen **65**, the section prior to the press-ram platens **67**, **68** preferably continuously indexes the billets to minimize any gaps between a billet that is gripped by the press-ram platens **67**, **68** and the next billet.

[0043] As discussed above, the press-rams **67**, **68** continuously push billets into the rotating die **70**. The press-rams **67**, **68** alternate gripping and advancing billets towards and into the rotating die **70** and then ungripping the advanced billets and retracting for the next gripping/advancing cycle. There is preferably an overlap between the time when one press-ram stops pushing and the other press-ram is about to start pushing so that there is always uniform pressure on the rotating die **70**. The press-rams **67**, **68** advance and retract via press-ram cylinders coupled to the respective press-ram. As shown there are two press-ram cylinders **79**, **80** per press-ram. A first set of press-ram cylinders **80** is located on the left and right of the entry platen **65** (although the right-side press-ram cylinder is hidden from view behind the left-side press-ram cylinder). The first set of press-ram cylinders **80** couples with the first press-ram platen **67** and is configured to move the first press-ram **67** as the first press-ram **67** advances billets and retracts to grab a following billet. A second set of press-ram cylinders **79** is located to the top and bottom of the entry platen **65**. The second set of press-ram cylinders **79** couples with the second press-ram platen **68** and is configured to move the second press-ram **68** as the second press-ram **68** advances billets and retracts to grab a following billet. Although two press-ram cylinders are shown for each of the first and second press-ram platens **67**, **68**, it will be understood that any suitable number of press-ram cylinders may be provided, and in certain embodiments press-ram cylinders may be coupled to both the first and second press-rams **67**, **68**.

[0044] The centering platen **69** receives billets advanced by the press-rams **67**, **68** and functions to hold the billets during the extrusion process prior to entry of the billets into the rotating die **70**. When the centering platen **69** is positioned in place for the extrusion process, the centering platen **69** substantially becomes part of the extrusion die **70**. That is, a centering insert of the centering platen **69** substantially abuts the rotating die **70**. The centering platen **69** itself, however, and the components therein including the centering insert, do not rotate with the rotating die **70**. The centering platen **69** prevents the billets that are no longer held by the second press-ram from rotating while the die **70** rotates by gripping the billets and thereby preventing the billets from rotating prior to entry of the billets into the rotating die **70**.

[0045] Referring back to the die assembly **1** of FIG. **1**, when the assembly is used in an extrusion process, for example in the extrusion system of FIG. **2**, the centering insert **9** is advanced to the front edge of the die body **18**, such that a front surface **55** of the centering insert **9** contacts a front surface **16** of the die body **18**. This orientation of the die body **18** and the centering insert **9** during extrusion is shown in FIG. **3**. In this orientation, the contact between the faces **55** and **16** of the centering insert **9** and die body **18**, respectively, prevents material from escaping the die body **18** during the extrusion process. To begin the extrusion, a billet **17** is advanced over the mandrel bar **10** in the direction of arrow A and through the die assembly **1** to press the billet **17** into an extruded tube product. Before entering the die assembly **1**, the billet **17** is advanced into the opening **15** of the centering insert **9**, where grippers **44** engage the outer surface of the billet **17**. As the billet **17** is advanced through the opening **15**, these grippers **44** prevent rotation of the billet **17** when the billet **17** is contacted by the rotating interior surface **14** of the die body **18**.

[0046] While the billet **17** and centering insert **9** do not rotate during the extrusion process, the die body **18** and base plate **8** to which the die body is connected are rotated by the motor-driven spindle **56**. As the billet **17** is advanced through the centering insert **9**, it passes through the entrance **11** of the die body **18** and contacts the interior surface **14** of the die body **18**. A torsional force is applied to the outer surface of the billet **17** due to the interference contact between the rotating die **18** and the billet **17**. The grippers **44** of the centering insert **9** resist this torsional force and prevent the billet **17** from rotating before it enters the die body **18**, creating friction and producing the energy that heats the billet **17**.

[0047] The profile of the tapered interior surface **14** of the die body **18** is defined by the shape and orientation of central bores that pass through the plates in the die body **18**. The die body **18** is formed of a stack of die plates, including a steel end holder **3**, an entry plate **4**, a first intermediate plate **5**, a second intermediate plate **6**, and an exit plate **7**. This series of plates that makes up the die body **18** are stacked together, secured to one another by a fastener, such as the bolt **2** in FIG. **1**, and connected to the base plate **8**. The bolt **2** is placed into each of the through-holes **12**, which pass through each of the plates **3-8**. The base plate **8** is then coupled to motor-driven spindle **56**, which rotates the plate **8**, as well as the plates **3-7** of the die body **18**. In certain implementations, a die body may be employed that includes more or fewer than the five plates **3-7** shown in die body **18**.

[0048] The interior surface **14** created by the central bores of the plates of the die body **18** exhibits a tapered profile that narrows the interior passage through the die body **18** from the entrance **11** to an exit of the passage at the exit plate **7**. Thus, when force is applied to the billet **17** to press the billet through the die body **18**, the material of the billet **17** is extruded as the outer diameter of the material is forced to decrease to pass through each of the plates **3-7**. The dimensions of the plates **3-7**, and the interaction between the interior surface **14** and the billet **17**, is described in more detail below with respect to FIGS. **4-13**.

[0049] FIGS. **4-9** show each of the plates **3-7** in the die body **18**, and the base plate **8** to which the die body **18** is connected. FIG. **4** shows the steel end holder **3** of the die body **18** that forms the front face **16** of the die body and the entrance **11** to the interior passage of the die body. The steel end holder **3** includes a central circular bore **21** that defines the diameter of the opening entrance **11** when stacked in the die body **18**. As shown in FIG. **4**, the steel end holder **3** is formed from two materials, with the outer perimeter **19** of the plate formed from one material and the perimeter **20** of the bore **21** formed from a different material. The two materials that make up the steel end holder **3** may be chosen to form complementary interfaces between the steel end holder **3** and both the centering insert **9** and the entry plate **4**. For example, the outer perimeter **19** may be formed of a steel, such as H13 steel, that is the same as or similar to the material that forms an outer perimeter of the entry plate **4**, while the bore perimeter **20** may be formed of a different material, such as an inconel steel, that is the same as or similar to the material used to form the centering insert **9**. By matching the material of the bore perimeter **20** and the centering insert **9**, the front face **23** of the bore perimeter **20** that contacts the front face **55** of the centering insert **9** provides a complementary interface that reduces wear when the die assembly **1** is in use. Because the die body **18** rotates and the centering insert **9** remains stationary, friction may be created between the face **23** and the face **55**. By forming the bore perimeter **20** and the centering insert **9** from the same material or similar materials, along with adjusting the pressure of surface **55** against surface **16**, the wearing effect of this friction can be minimized, particularly during start up and shut down of the extrusion process when rotation of the die body **18** starts or stops.

[0050] The second plate in the die body **18** is the entry plate **4**, shown in FIG. **5**. As with the steel end holder **3**, the entry plate **4** is formed from two different materials. One material forms the outer perimeter **25** of the plate while a second material forms the bore perimeter **24** around the central bore **26** through the center of the plate. The outer perimeter **25** may be made of the same material or a similar material as the outer perimeter of the steel end holder **3**, for example H13 steel material. The perimeter **24** of the bore **26** is formed from a wear-resistant material, for example a ceramic material, that resists degradation when a billet, such as billet **17**, is pressed through the bore **26** and contacts the interior surface **27**.

[0051] The entry plate **4** begins the taper of the interior surface **14** of the die body **18** from the entrance **11** to the exit of the die body. The interior surface **27** of the perimeter **24** is angled such that the diameter across the diameter of the center bore **26** is greater at the front face of the plate **4** that abuts the back face of the steel end holder **3** and smaller at the back face of the entry plate **4** that abuts the first intermediate plate **5**. When billet **17**, having a diameter that is equal to the diameter of the bore **26** at the front face, is pressed through the entry plate **4**, the tapering of the surface **27** creates friction between the rotating plate **4** and the billet **17**. This friction generates energy that heats the billet **17** as it is advanced into the rotating die body **18**, beginning the deformation of the billet through the tapered interior surface **14**. In contrast to extrusion processes in which contact between a pre-heated billet and a non-rotating die creates heat energy as a by-product, the friction heating of the non-pre-heated billet **17** is necessary for extrusion as it is needed to heat the billet to a temperature adequate for deformation.

[0052] FIG. **6** shows the first intermediate plate **5** that is located behind the entry plate **4** in the stack of plates that make up the die body **18**. The first intermediate plate **5** includes an outer perimeter **29**, formed from a first material, and a bore perimeter **28**, formed from a second material. The outer perimeter **29** may be formed of the same materials or similar materials as the outer perimeters of the other plates in the stack, for example an H13 steel. Perimeter **28** of the center bore **30** through the plate is formed from a wear-resistant material, for example a ceramic material, as discussed with respect to bore perimeter **24** of the entry plate **4**. The inner surface **31** of the bore perimeter **28** is tapered from the front face of the first intermediate plate **5** that abuts the entry plate **4** in the stack to the back face of the first intermediate plate **5** that abuts the second intermediate plate **6** in the plate stack. The angling of the inner surface **31** tapers the center bore **30** from the front face to the rear face and further tapers the interior passage and surface **14** of the die body **18**, as discussed above with respect to the center bore **26** of the entry plate **4**.

[0053] The degree at which the inner surface **31** tapers with respect to a center axis of the central bore **30** in the first intermediate plate **5** relative to the taper angle of the inner surface **27** of the entry plate **4** is dependent on the material being extruded and the total overall number of die plates. In certain implementations for a particular material, the degree at which the inner surface **31** tapers may be less than the taper angle of the inner surface **27** of the entry plate **4**. This change in the angle of the inner surface and the smaller diameter of the center bore **30** relative to the center bore **26** may spread the frictional interface with the billet **17** and the work required to deform the billet **17** more evenly over the entry plate **4** and the first intermediate plate **5**, reducing material wear and extending the lifetime of the die plates as well as improving concentricity and uniformity of an extruded product. This spreading of work and frictional force and the correlation between materials and the degree of surface tapering is discussed more fully below with respect to the cross sections shown in FIGS. **10**, **12** and **13**.

[0054] The second intermediate plate **6**, which follows the first intermediate plate **5** in the die stack, is shown in FIG. **7**. Similar to plates **3-5**, the second intermediate plate **6** has an outer perimeter **32**, formed of a first material, and a perimeter **33** around a center bore **34**, formed of the second material. The first material that forms outer perimeter **32** may be the same as or similar to the other plates in the stack, for example an H13 steel, and the material that forms the bore perimeter **33** may be a wear-resistant material, such as a ceramic. The interior surface **35** of the perimeter **33** around the central bore **34** is angled from a front face of the plate **6** that abuts the first intermediate plate **5** to a back face of the plate **6** that abuts the exit plate **7**.

[0055] The final plate in the plate stack that makes up the die body **18** is the exit plate **7**, which is shown in FIG. **8**. The exit plate **7**, similar to plates **3-6**, has an outer perimeter **36** formed from a first material, such as an H13 steel, and a perimeter **37** around a central bore **38** formed from a second material, for example a wear-resistant ceramic. The diameter of exit plate **7** is substantially smaller than the diameter of the opening **11** at the steel end holder **3** shown in FIG. **4** as a result of the tapering of the interior surface **14** from the steel end holder **3** to the exit plate **7**. The interior surface **39** that surrounds the central bore **38** of exit plate **7** is angled with respect to a central axis of the center bore **38**. The narrowest section of the center bore **38** defines the narrowest portion of the passage through the die body **18**, and thus sets the outer diameter of an extruded tube that is produced when a billet **17** is pressed through the die body **18**. This diameter and the dimensions of the extruded product created using the die assembly **1** are discussed in more detail below with respect to FIG. **13**.

[0056] FIG. **9** shows the base plate **8**, which couples the stacked plates that form the die body **18** to a rotational power source. For example, as shown in FIGS. **1** and **3**, the base plate **8** in the die assembly **1** couples the die body **18** to a spindle **56**. The spindle **56** is driven to rotate by a motor that powers the rotation of the spindle **56** at a set rotational speed. The spindle **56** is connected to the base plate **8** by bolts which pass through outer through-holes **43** around the perimeter of the base plate **8** and transfer the rotational force of the spindle **56** to the base plate **8**.

[0057] The base plate **8** is also rotationally coupled to the plates in the die body **18** by bolts, such as bolt **2** shown in FIG. **1**, that pass through the through-holes **12** of the die body **18** and into the holes **42** in the base plate **8**.

[0058] The base plate **8** includes a central bore **40** having an interior surface **41**. The bore **40** and the interior surface **41** define an opening in the base plate **8** that may have a wider diameter than the diameter of the bore in the exit plate **7**. The wider diameter of the base plate bore **40** allows the extruded material to exit the die body **18** without directly contacting the interior surface **41** and may allow for a cooling component, such as a fluid source, to partially enter the base plate **8** and apply a cooling fluid to extruded material exiting the exit plate **7** near the exit of the die body **18**. The exit plate **7** may also include a relief angle near the back face of the plate that further facilitates the application of cooling fluid, as discussed below with respect to FIG. **13**.

[0059] The die assembly **1** is assembled prior to extrusion by stacking plates **3-7** and connecting the die body **18** formed by the plates to the base plate **8** with bolts placed into the through-holes **12** of the die body plates and into the holes **42** of the base plate. The stacking of these plates to form the die body **18** forms the interior profile of the die body **18** that causes extrusion of billets pressed through the die assembly **1**. This inner profile and the orientation of the stacked plates are shown in the cross-sectional view of the die assembly **1** in FIG. **10**.

[0060] The cross section in FIG. **10** shows the die body **18** and the centering insert **9** positioned for extrusion. The die plates **3-7** are coupled together and fastened to the base plate **8** by bolts **2** inserted into the series of through-holes **12** in the outer perimeters **19**, **25**, **29**, **32**, and **36** of the plates. In this orientation, the opening **11** of the interior passage **54** in the die body **18** is aligned with the centering insert **9** to receive a billet pressed through the opening **15** of the centering insert **9** and into the die body **18** along the center axis **45** of the interior passage **54**.

[0061] Each of the bore perimeters **23**, **24**, **28**, **33**, and **37** of the die plates **3-7** abuts bore perimeters in adjacent plates to form the tapered interior surface **14** that outlines the interior passage **54** through the die body **18**. The inner surface **14** narrows the interior passage **54** from the largest diameter of the passage at the opening **11** to the smallest diameter at the exit **81**, and the narrowing of the passage **54** causes the narrowing deformation and extrusion of a billet pressed into the rotating die body **18** during operation. The extrusion requires friction energy to be produced at the interface of the inner surface **14** to heat the billet, and the energy can create wear on the bore perimeters of the die plates **3-7**. To reduce the effect of the friction wear and produce uniform stresses across the interior surface **14** during extrusion, the inner surfaces **27**, **31**, **35**, and **39** are designed to spread the friction interface and reduce the concentration of energy and friction on any one plate. The design of the inner surfaces and the profile of the interior surface **14** may differ for different applications, and in particular for the extrusion of different materials. Depending on the material properties of billets used for extrusion, for example heat transfer properties that may affect the heating of the billets during extrusion, the inner profile of die plates in a die body may be varied to spread work and wear over the die plates. In addition, the die rotation speed may be varied to increase the efficiency of the die and avoid exceeding material properties of the billets. For example, a die rotation speed between about 200 rpm and about 1000 rpm may be used. In certain implementations, a slower rotation speed, for example about 300 rpm, may be desired to avoid applying a high level of torsional sheer to a billet while still heating the billet to a sufficient temperature for deformation. A faster speed, for example about 800 rpm, may be used for a material that is not adversely affected by a higher torsional sheer or that requires more energy, and thus greater friction, to heat to a deformation temperature. In other implementations, die rotation speeds in excess of 100 rpm may be desired for extrusion.

[0062] As shown in FIG. **10**, the inner surfaces **27**, **31**, **35**, and **39** do not taper at uniform angles with respect to the central axis **45**. Each surface in the depicted die is tapered at an angle that decreases from the entry plate **4** near the opening **11** to exit plate **7** at the exit **81**. This decreasing angle design may be desired for a particular extrusion material or application of the die assembly **1**. In certain embodiments, however, the taper angle of the interior surface **27** with respect to the central axis **45** may be equal to or less than the taper angle of the adjacent surface **31**. In the embodiment shown in FIG. **10**, the angle **46** at which the interior surface **27** of the entry plate **4** is tapered is greater than the angle **47** at which the interior surface **39** of the exit plate **7** is tapered. The differences in taper angles between the plates spreads the frictional energy and stress over the plates as a result of the differences in diameters of the center bores from the opening **11** to the exit **81**.

[0063] Each plate has an entrance diameter, for example diameter d**5** of plate **4**, and an exit diameter, for example diameter d**7** of plate **4**. When a billet is pressed into the plate, a threshold amount of energy must be generated to heat and deform the billet from the diameter d**5** to the diameter d**7**. This amount of energy is affected by the percent reduction in diameter, in particular the resulting percent reduction in cross-sectional area of a billet as it passes through the plate **4**. If the central bores in plates **3**-**7** were each tapered at a single uniform angle, the diameter change from the entrance to the exit of each plate would be equal, and thus the percent reduction in billet cross-sectional area would increase for each successive plate. For example, if the absolute difference between diameters d**5** and d**7** of plate **4** were equal to the absolute difference between diameters d**6** and d**8** of plate **7**, the percent reduction in the diameter of the central bore would be higher in plate **7** than plate **4**, and a greater amount of stress and energy could cause plate **7** to wear faster than plate **4**.

[0064] In addition to the percent area reduction of a billet over a plate, mechanical and thermal properties of the billet materials may dictate the number and design of plates in a die stack. For example, a billet material having high thermal conductivity may heat up to a deformable temperature more quickly than a material having a low thermal conductivity, and thus a shorter die with fewer plates may be used for the high conductivity material. In addition, the tapering angles of the inner surface of a die may be greater for the high conductivity material as a result of the quicker heating of the billet. In other implementations, dies of equal size having the same number of plates may be used, and the tapering angles of the dies may differ to accommodate the different thermal properties and heat the billets to a deformable temperature while spreading work and wear as evenly as possible over the die surface and the surface of a mandrel tip within the die.

[0065] A billet pressed through the die body **18** produces an extruded tube product through exit **81** of the die body **18** having an outer diameter that is similar to the diameter d**8**, the diameter at the narrowest portion of exit plate **7**. The inner diameter of the extruded product is selected by advancing the mandrel bar **10** into the die body **18** with a mandrel tip having an end dimension, selected to create the inner diameter of the tube product, at the end of the mandrel bar **10**. FIG. **11** shows a mandrel tip **48** that may be coupled to the end of the mandrel bar **10** to create a desired inner diameter for extruded tubing. The mandrel tip **48** has an open end **82** that is configured to couple to the end of the mandrel bar **10**. The friction energy and heat generated during extrusion may heat the mandrel tip **48**, and the open end **82** may receive cooling fluid, such as water or gas, from a cooling system that runs through the mandrel bar **10** to cool the mandrel tip **48**.

[0066] Opposite the open end **82** of the mandrel tip **48** is a closed end **51**. The diameter of the closed end **51** is the dimension that sets the inner diameter of a tube extruded over the tip **48**, and the tip **48** can be selected from a series of tips having different diameters to achieve extrusions with different inner diameter dimensions. Between the open end **82** and the closed end **51** are three portions **49**, **83**, and **50** of the tip outer surface **84**. During extrusion, a billet is pressed over the mandrel bar **10** and the tip **48** in the direction of arrow C such that the billet passes over a deformation region including tip portions **49** and **83**, and an end portion **50**. When the tip **48** is positioned for extrusion, the tip is advanced into a die until the closed end **51** extends beyond the rear exit of the die at which the die diameter is narrowest. A billet having a hollow core diameter substantially equal to the outer diameter of the tip portion **49** is then passed over the mandrel bar **10** and the tip **48**. At the tip portion **49**, the diameter of the surrounding die narrows, and friction between the die and the billet creates energy that heats the billet as the outer diameter of the billet is compressed. The heated billet then passes over the tip portion **83**, and the inner diameter of the hollow core of the billet decreases to the outer diameter of end portion **50** as the material extrudes. This extrusion over the mandrel tip **48** is discussed in more detail below with respect to FIGS. **12** and **13**.

[0067] FIG. **12** shows the die assembly **1** with the mandrel **10** and mandrel tip **48** advanced through the centering insert **9** and into the center passage **54** of the die body **18**. The mandrel **10** is positioned such that the mandrel tip **48** extends through the exit **81** in the exit plate **7**. As discussed above with respect to FIG. **2**, gripping elements in an extrusion press system may be used to hold the mandrel bar **10** and in the orientation shown in FIG. **12** and to resist rotation while the die body **18** is rotated and a billet passes over the mandrel bar **10**.

[0068] FIG. **13** shows the die assembly and mandrel tip configuration of FIG. **12** as the billet **17** is passed through the die body **18** and extruded to form tubing **53**. During extrusion, the die body **18** is rotated while the mandrel bar **10** and centering insert **9** are held stationary. The billet **17** is pressed into the die body **18** in the direction of arrow A and contacts the interior surface **14** of the die body **18** at a first contact point **85**. The interference contact between the interior surface **14** and the billet **17** begins at the contact point **85** and generates the energy that heats the billet **17** to a plastic deformable temperature.

[0069] As the billet **17** is advanced over the first portion **49** of the mandrel tip **48**, the taper of the interior surface **14** applies a compression force to the outer surface of the billet **17** that presses the billet **17** inwards towards the mandrel tip **48**. Because the billet **17** is in a plastic deformation state, the material in the billet extrudes in the direction of portion **83** of mandrel tip **48** as the die body **18** decreases the outer diameter of the billet **17** from the original diameter d**2**. When the billet **17** reaches the tip portion **83**, the taper of the tip portion **83** towards the end portion **50** causes the inner diameter of the billet **17** to extrude and decrease from the original diameter d**1** as the billet advances further over the mandrel tip **48**. The tapered surface of the mandrel tip **48** at the tip portion **83** may substantially correspond to the angle of the interior surface **14** in the area surrounding the tip portion **83** to create substantially uniform extrusion in that portion. For example, the outer and inner diameters of the billet **17** may decrease by substantially the same amount or by substantially the same percentage from the end of tip portion **83** proximate first tip portion **49** to the end of tip portion **83** proximate end portion **50**.

[0070] When the extruding billet **17** reaches the end portion **50**, the inner diameter of the billet is reduced from the original diameter d**1** to the final diameter d**3** of the end tubing product. As the billet **17** passes over the end portion **50**, the outer diameter of the billet **17** continues to decrease to the final outer diameter d**4** when the extruded tubing product **53** exits the exit plate **7**. At the point of exit, the formation of the extruded product **53** is complete. Due to the friction and heating within the die body **18**, the product **53** is at a heightened temperature upon exit from the die body **18**, and a cooling element may be applied to prevent further deformation or increase operational safety of the extrusion press, eliminate the escape of extruded material, or maintain desired material characteristics. The bore **40** in the base plate **8** is shown in FIG. **13** with a diameter larger than the exit diameter of the exit plate **7**. This configuration may be preferable in order to allow cooling elements and cooling fluid to reach into the base plate **8** and contact the extruded product **53** as soon as it exits the final bearing in the exit plate **7** for earlier cooling. The exit plate **7** includes an angled relief surface **86** to further facilitate the introduction of a fluid material as near as possible to the exit **81** of the die body **18**. After the product **53** exits the base plate **8** and passing through a cooling system, the extrusion process is complete, and the product **53** may be gathered for post-processing.

[0071] It is to be understood that the foregoing description is merely illustrative and is not to be limited to the details given here in. While several embodiments have been provided in the present disclosure, it should be understood that the disclosed systems, devices and methods and their components may be embodied in many other specific forms without departing from the scope of this disclosure.

[0072] Various modifications will occur to those with skill in the art after reviewing this disclosure. The disclosed features may be implemented in any combination and sub-combinations, including multiple-dependent combinations and sub-combinations with one or more features described herein. The various features described or illustrated above, including any components thereof, may be combined or integrated into other systems, Moreover, certain features may be omitted or not implemented. Examples of changes, substitutions and alterations are ascertainable by one skilled in the art and can be made without departing from the scope of the information disclosed herein. All references cited herein are incorporated by reference in their entirety and made part of this application.

1. A die assembly for extruding a material, comprising:

a plurality of die plates coupled together to form a die body having:

a passage defining an entrance and an exit, wherein the diameter of the exit is smaller than the diameter of the entrance; and

a tapered interior surface between the entrance and the exit;

wherein each of the die plates has a center bore with an interior surface around the center bore, an interior surface of a center bore in a first die plate being tapered at a smaller angle relative to an axis of the passage than an interior surface of a center bore in a second die plate positioned adjacent to a front face of the first die plate; and

a base coupled to the die body, wherein rotation of the base causes the die body to rotate.

2. The die assembly of claim **1**, wherein the second die plate is positioned nearer to the entrance of the die body than the first die plate.

3. The die assembly of claim **1**, further comprising a third die plate having a center bore with an interior surface that is tapered at a larger angle relative to the axis than an interior surface of a center bore in a die plate positioned adjacent to a front face of the third die plate.

4. The die assembly of claim **3**, wherein the die plate positioned adjacent to the front face of the third die plate is the first die plate.

5. The die assembly of claim **3**, wherein the third die plate is positioned nearer to the exit of the die body than the first die plate.

6. The die assembly of claim **1**, further comprising a third plate that forms a portion of the die body, the first plate having a central bore with an interior surface around the center bore that is not tapered at an angle relative to the axis.

7. The die assembly of claim **6**, wherein the center bore of the third plate defines the entrance of the die body.

8. The die assembly of claim **1**, wherein the base comprises a center bore.

9. The die assembly of claim **8**, wherein the center bore of the base has a diameter that is greater than a diameter of the die body exit.

10. The die assembly of claim **1**, wherein the die body is configured to receive a billet of material for extrusion, and the billet is not pre-heated before entering the die body.

11. The die assembly of claim **10**, wherein rotation of the die body creates friction between the tapered interior surface and a billet advanced through the entrance and into the interior passage of the die body.

12. The die assembly of claim **11**, wherein the friction heats the billet to a temperature that is sufficient to cause deformation of the billet material.

13. The die assembly of claim **12**, wherein the heated billet is deformable under a deformation force that does not exceed mechanical property limits of the billet material.

14. The die assembly of claim **13**, wherein friction between the billet and a mandrel over which the billet is advanced heats the billet and the mandrel.

15. The die assembly of claim **14**, wherein a cooling system provides cooling fluid to an interior portion of the mandrel.

16. The die assembly of claim **1**, wherein at least one of the die plates is formed from two different materials, with a first material forming a perimeter of a bore in the die plate and a second material forming an outer portion of the die plate.

17. The die assembly of claim **16**, wherein at least one of the first and second materials is a ceramic material, a steel, or a consumable material.

18. The die assembly of claim **1**, wherein a front face of the die body near the entrance is configured to mate with a centering insert having a diameter substantially equal to the diameter of the entrance.

19. The die assembly of claim **18**, wherein the centering insert and a perimeter of the entrance are formed from the same material.

20. The die assembly of claim **1**, wherein the die body is configured to receive a mandrel tip through the entrance such that the mandrel tip is positionable within the interior passage of the die body.

21. The die assembly of claim **20**, wherein the interior surface of the die body comprises a complementary portion having an angle that corresponds to an angle of an outer surface of the mandrel tip.

22. The die assembly of claim **20**, wherein the die body is configured to receive a billet pressed through the interior passage of the die body to form an extruded product, the extruded product having an outer diameter corresponding to the diameter of the exit of the die body and an inner diameter corresponding to a diameter of the mandrel tip.

23-44. (canceled)

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