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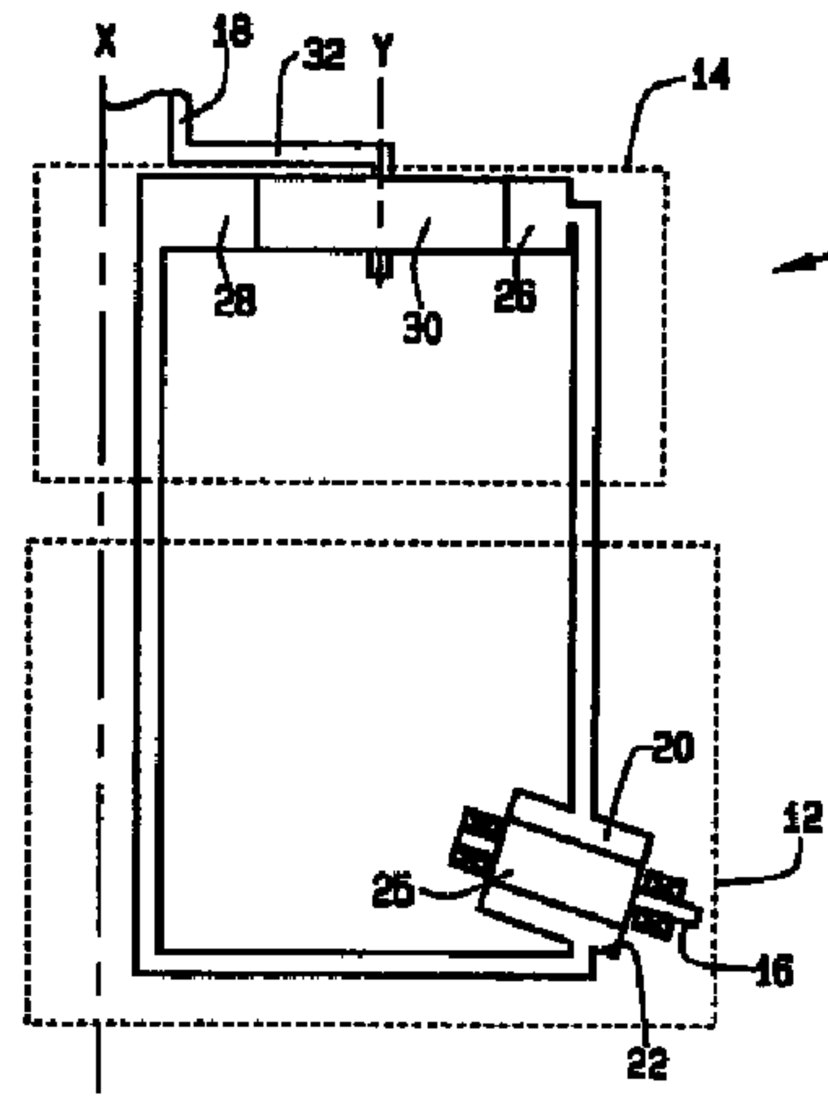

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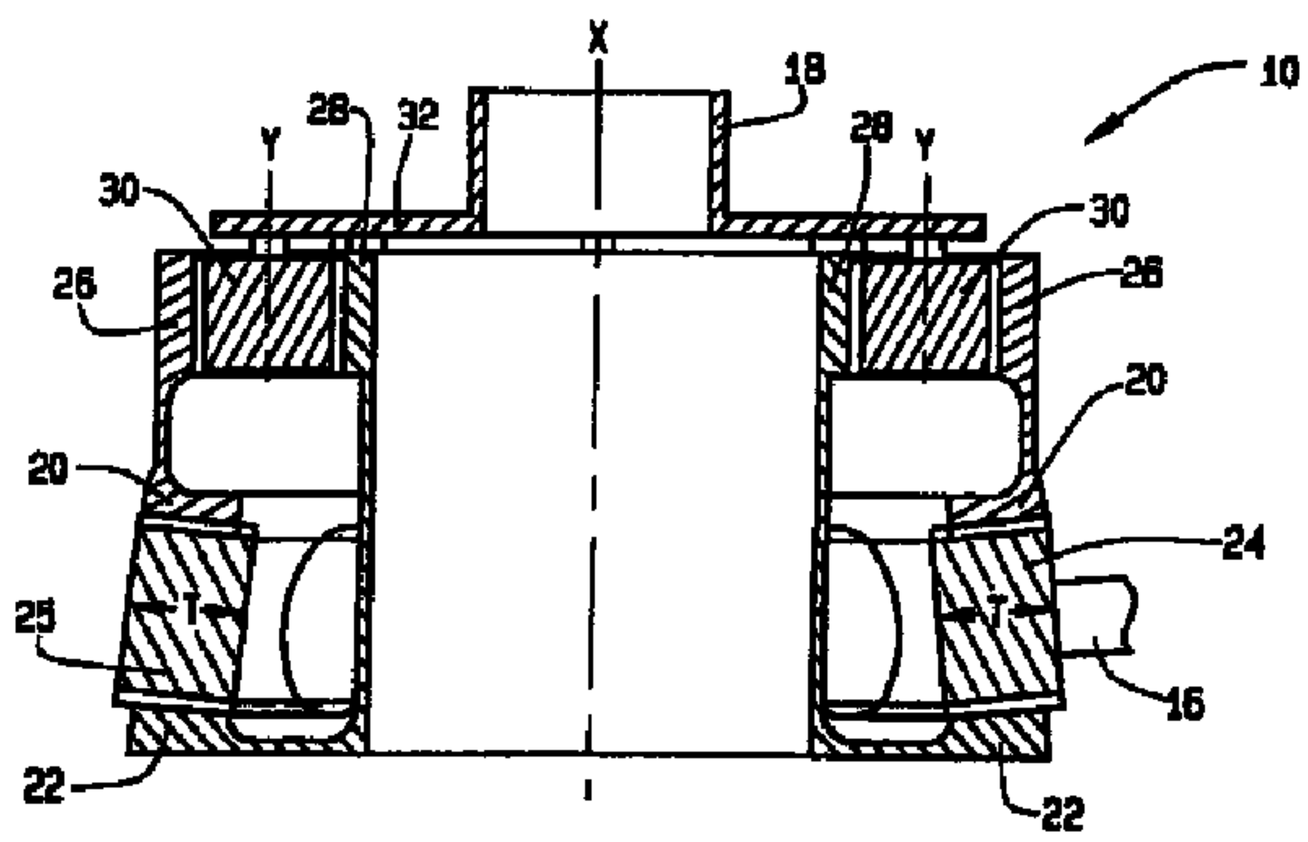

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(57) Abrégé/Abstract:
A high power, high speed gearbox including a compound face gear planetary gear assembly (FGPGA) is provided. The FGPGA includes a first planetary gear set (PGS1) and a second planetary gear set (PGS2). The PGS1 includes a spur gear connected to

(57) Abrégé(suite)/Abstract(continued):
an input shaft, a plurality of intermediate pinion gears, a first face gear and a second face gear oriented in a planetary arrangement. The PGS2 includes a plurality of gears oriented in a planetary arrangement and operate to turn an output shaft. The PGS1 first and second face gears are configured to engage the spur gear such that the input shaft can have angle of other than 90° with respect to the output shaft. By implementing the PGS1 face gears in a planetary arrangement with the spur gear and the intermediate pinion gears, the rotational direction of the output shaft can be altered by changing a tooth differential between the PGS1 first and second face gears without employing an idler gear in the PGS1.

FACE GEAR PLANETARY ASSEMBLY

ABSTRACT OF THE DISCLOSURE

A high power, high speed gearbox including a compound face gear planetary gear assembly (FGPGA) is provided. The FGPGA includes a first planetary gear set (PGS1) and a second planetary gear set (PGS2). The PGS1 includes a spur gear connected to an input shaft, a plurality of intermediate pinion gears, a first face gear and a second face gear oriented in a planetary arrangement. The PGS2 includes a plurality of gears oriented in a planetary arrangement and operate to turn an output shaft. The PGS1 first and second face gears are configured to engage the spur gear such that the input shaft can have angle of other than 90° with respect to the output shaft. By implementing the PGS1 face gears in a planetary arrangement with the spur gear and the intermediate pinion gears, the rotational direction of the output shaft can be altered by changing a tooth differential between the PGS1 first and second face gears without employing an idler gear in the PGS1.

FACE GEAR PLANETARY ASSEMBLY

FIELD OF THE INVENTION

[0001] The present invention relates to gear arrangements, and more particularly, to a face gear planetary assembly arrangement.

BACKGROUND OF THE INVENTION

[0002] In known high power, high speed gearbox applications, such as transmission gearboxes for helicopters, typically planetary gear sets are utilized. Generally, planetary gear sets utilized in these applications have straight, in-line input and output axes. Therefore, to have an output that is not in-line with the input different gear sets must be employed to alter the direction of the output with respect to the input direction. Additionally, to achieve low speed outputs from high speed inputs, significant gear reduction ratios are needed that require various stages of gears to be incorporated within the gearbox. Furthermore, to alter the direction of output of gearboxes utilizing planetary gear sets, additional idler gears need to be added. These additional gears and/or gear sets significantly increase the complexity, weight and manufacturing and repair costs for such high speed planetary gear set gearboxes.

[0003] Face gears are currently used for many applications throughout industry. However, face gears are typically implemented in low power, low speed applications. For example, face gears are commonly utilized in cement mixer trucks that use higher strength course tooth face gears to turn the large barrels; satellite applications that incorporate large diameter fine tooth face gears for precise indexing of equipment; and large ship propeller drives. Inexpensive nylon face gears are also being used in commercial items such as fertilizer spreaders. Recently, attempts have been made to utilize face gears in high power, high speed power transmission applications. However, typically the use of face gears in such high power, high speed applications has been limited by such things as the complexity of employing off-line input/output axes angles other than 90° and the general necessity to incorporate additional idler gears to change the rotational direction of the output.

[0004] Therefore, it is desirable to provide a gearbox incorporating a high power, high speed gear set that will allow for off-axes input/output implementations, provide high input/output gear ratios and provide the capability to change the rotational direction of the output while minimizing the number of parts and, thereby, significantly reducing the cost of manufacturing and repair of such gearboxes.

SUMMARY OF THE INVENTION

[0005] Generally, gearboxes, e.g. transmissions, that incorporate planetary gear sets, include a sun gear, a planet gear and a ring gear. The power transmission method and gearbox of the present invention incorporate a planetary gear set that includes a first face gear, a second face gear and a plurality of pinion gears.

[0006] In a preferred embodiment of the present invention, a high power, high speed gearbox is provided. The gearbox includes a compound face gear planetary gear assembly that includes a first planetary gear set (PGS1) and a second planetary gear set (PGS2). The PGS1 includes a spur gear connected to an input shaft, a plurality of intermediate pinion gears, a first face gear and a second face gear oriented in a planetary arrangement. The PGS2 includes a ring gear, a sun gear and a plurality of planet pinion gears oriented in a planetary arrangement. The planet gears are rotationally connected to a carrier that is coupled to an output shaft. The PGS1 first and second face gears are configured to engage the spur gear such that the input shaft can have angle of other than 90° with respect to the output shaft. By implementing the PGS1 face gears in a planetary arrangement with the spur gear and the intermediate pinion gears, the rotational direction of the output shaft can be altered by changing a tooth differential between the PGS1 first and second face gears without employing an idler gear in the PGS1.

[0007] In another preferred embodiment, the ring gear is a PGS2 first face gear and the sun gear is a PGS2 second face gear oriented in a planetary arrangement with the planet pinion gears. The rotational direction of the output shaft can therefore also be altered by changing a tooth differential between the PGS2 first and second face gears without employing an idler gear in the PGS2. Therefore, the rotational direction of the output shaft can be changed from clockwise to counter-clockwise, and vice-versa, by changing the tooth differential between the PGS1 first and second face gears, or by changing the tooth differential between the PGS2 first and second face gears, or changing the tooth differentials in both the PGS1 and PGS2, without employing an idler gear in the face gear planetary gear assembly.

[0008] The features, functions, and advantages can be achieved independently in various embodiments of the present inventions or may be combined in yet other embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0010] Figure **1** is an illustration of one-half of a cross-section of a face gear planetary gear assembly constructed in accordance with a preferred embodiment of the present invention;

[0011] Figure **1**B is a cross-sectional view of the face gear planetary gear assembly illustrated in Figure **1**A;

[0012] Figure **2**A is an illustration of one-half of a cross-section of a face gear planetary gear assembly constructed in accordance with an alternated preferred embodiment of the present invention;

[0013] Figure **2**B is a cross-sectional view of the face gear planetary gear assembly illustrated in Figure **2**A;

[0014] Figure **3**A is an illustration of one-half of a cross-section of a face planetary gear assembly constructed in accordance with another alternated preferred embodiment of the present invention;

[0015] Figure **3**B is a cross-sectional view of the face gear planetary gear assembly illustrated in Figure **3**A;

[0016] Figure **4**A is an illustration of one-half of a cross-section of a face gear planetary gear assembly constructed in accordance with yet another alternated preferred embodiment of the present invention; and

[0017] Figure **4**B is a cross-sectional view of the face gear planetary gear assembly illustrated in Figure **4**A.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0018] The following description of the preferred embodiment(s) is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses.

[0019] With reference to Figures **1**A and **1**B, a face gear planetary gear assembly **10** is illustrated in accordance with a preferred embodiment of the present invention. The face gear planetary gear assembly (FGPGA) **10** includes a first planetary gear set **12** connected to a second planetary gear set (SPGS) **14**, shown in Figure **1**A. The first planetary gear set **12** and the second planetary gear set **14** are respectively referred to herein as PGS**1** **12** and PGS**2** **14**. Thus, the (FGPGA) **10** can be referred to as a compound face gear planetary gear assembly. An input shaft **16** is associated with the PGS**1** **12** and an output shaft **18** is associated with the PGS**2** **14**. Rotation of the input shaft **16** from power provided by a motor or other such device (not shown) is transferred to the PGS**1** **12**, which in turn causes the PGS**2** set **14** to rotate, thereby causing the output shaft **18** to rotate. As described in detail below, physical characteristics of face gears included in the PGS**1** **12** and the PGS**2** **14**, e.g. the number of teeth in each gear, affect an input/output gear ratio and a rotational direction of the output shaft **18**. Particularly, the rotational direction of the output shaft **18** can be altered by merely changing the number of teeth of the face gears without employing additional gears, e.g. an idler gear. Additionally, as described in detail below, the face gears included in PGS**1** **12**, allow the input shaft **16** to have an angular orientation with respect to the output shaft **18** of approximately **0**° to **180**°.

[0020] In accordance with a preferred implementation of the present invention, the PGS**1** **12** includes a first face gear **20** (referred to herein as PGS**1** first face gear **20**), a second face gear **22** (referred to herein as PGS**1** second face gear **22**), a spur gear **24** and a plurality of intermediate pinion gears **25**, shown in Figure **1**B. The number of intermediate pinion gears **25** can be determined based on a desired amount of torque distribution via tooth sharing. That is, the greater the number of intermediate pinion gears **25** included in the PGS1, the greater the distribution of torque between the teeth of the intermediate pinion gears **25** and the PGS1 first and second face gears **20** and **22**. The PGS1 first face gear **20** and the PGS1 second face gear **22** are cooperative through the spur gear **24**. Thus, the spur gear **24** and the PGS1 first and second face gears **20** and **22** are configured in a planetary arrangement. The input shaft **16** is coupled to the spur gear **24**. The intermediate pinions gears include bearings (not shown) and are rotationally connected to a housing (not shown) of the (FGPGA) **10**. The intermediate pinion gears **25** are positioned between, and mate with, the PGS1 first and second face gears **20** and **22** around a circumference of the PGS1 first and second face gears **20** and **22**.

[0021] The PGS2 **14** includes a ring gear **26**, a sun gear **28**, and a plurality of planet pinion gears **30**. The ring gear **26** and the sun gear **28** operate to drive the planet pinion gears **30**. The planet pinion gears **30** are rotationally coupled to a carrier **32** that is connected to the output shaft **18**. The PGS1 first face gear **20** is connected with the ring gear **26** and the PGS1 second face gear **22** is connected with the sun gear **28**. The PGS1 first and second face gears **20** and **22** can be connected to the ring and sun gears **26** and **28** in any suitable manner, based on the various preferred embodiments described herein. For example, the PGS1 first and second face gears **20** and **22** can be splined with the ring and sun gears **26** and **28**, or the PGS1 first and second face gears **20** and **22** can be connected with the ring and sun gears **26** and **28** using nut and bolt connectors. Alternatively, the PGS1 first face gear **20** and the ring gear **26** can be fabricated as a single component and/or the PGS1 second face gear **22** and the sun gear **28** can be fabricated as a single component. As further described below, the rotation of the ring and sun gears **26** and **28** in opposite directions around an axis X of the (FGPGA) **10** causes the planet pinion gears **30** and the shaft **18** to rotate around the axis X in either a clockwise or counter-clockwise direction, based on a tooth differential between the PGS1 first and second face gears **20** and **22**.

[0022] Rotation of input shaft **16** rotates the spur gear **24**, which in turn rotates the PGS1 first face gear **20** in a first direction and rotates the PGS1 second face gear **22** in a second direction that is opposite the first direction. The ring gear **26** is connected to the PGS1 first face gear **20** and therefore, also rotates in the first direction. Similarly, the sun gear **28** is connected to the PGS1 second face gear **22** and therefore, also rotates in the second direction. Accordingly, rotation of the ring gear **26** and the sun gear **28** in opposite directions rotates the output shaft **18**. In order to obtain a high gear reduction ratio between the input **16** and the output **18**, any or all of the PGS1 first face gear **20**, the PGS1 second face gear **22**, the spur gear **24**, the ring gear **26**, the sun gear **28** and/or the planet gears **30** can be designed/manufactured to have a specific number of teeth such that the FGPGA **10** produces a desired gear ratio. Preferably, the number of teeth in the sun gear **28** is similar, but not the same as the number of teeth in the ring gear **26**. This allows the PGS2 **14** to include a greater number of planet gears **30** between the ring and sun gears **26** and **28**. Moreover, the strength of the sun gear **28** is increased in this configuration because the force on each tooth is less due to a bigger moment arm generated by a bigger radius for a given torque.

[0023] Since the PGS1 **12** includes the PGS1 first and second face gears **20** and **22** configured in a planetary gear set arrangement, the input shaft **16** can be offset from the output shaft **18** at an angle other than **90°**, as shown in Figure 1B. More specifically, the input shaft **16** can have an angle with respect to the output shaft **18**, between approximately **0°** and **180°**. For example, as illustrated in Figure 1B, the input shaft **16** can be angled at an angle of approximately **80°** with respect to the output shaft **18**, although any angle may be employed. In this configuration, the input shaft **16** enters the side of the (FGPGA) **10**.

[0024] In this embodiment, the rotational direction of the output shaft **18** can be changed by altering the tooth differential between the PGS1 first face gear **20** and the PGS1 second face gear **22**. Particularly, the rotational direction of the output shaft **18** can be altered by merely changing the number of teeth of the PGS1 first and second face gears **20** and **22**

without employing additional gears, e.g. an idler gear. For example, if the PGS**1** first face gear **20** has a greater number of teeth than the PGS**1** second face gear **22**, rotation of the input shaft will cause the spur gear to drive the PGS**1** first face gear **20** at a second rate of speed around the axis X than the PGS**1** second face gear **22**. Accordingly, via the connection between the PGS**1** first face gear **20** and the ring gear **26** and the connection between the PGS**1** second face gear **22** and the sun gear **28**, the ring gear **26** will likewise rotate around the axis X at a second rate than the sun gear **28**. This will cause the teeth of the planet gears **30** that engage the ring gear **26** to be driven around an axis Y of the planet gears **30** at a second rate than the teeth of the planet gears **30** that engage the sun gear **28**. Therefore, the planet gears **30** will travel around the axis X in the same direction that the sun gear **28** is rotating around the axis X, which will thereby cause the output shaft **18** to rotate in the same direction as the sun gear **28**.

[0025] Conversely, if the PGS**1** first face gear **20** included fewer teeth than the second PGS**1** face gear **22**, the ring gear **26** would rotate around the axis X at a faster rate of speed than the sun gear **28**. This would cause the teeth of planet gears **30** that engage the ring gear **26** to rotate around the axis Y at a faster rate of speed than the teeth of the planet gears **30** that engage the sun gear **28**. Therefore, the planet gears **30** travel around the axis X in the same direction as the ring gear **26** rotates around the axis X. Thus, the output shaft will have the same rotational direction around the axis X as the ring gear **26**.

[0026] By utilizing face gears in the PGS**1** **14**, i.e. PGS**1** first and second face gears **20** and **22**, altering the number of teeth included in each of the PGS**1** first and second face gears **20** and **22** merely changes a radius of the respective gear. As illustrated in Figure **1**B, the PGS**1** first face gear **20** has larger radius than the PGS**1** second face gear **22**; therefore, the PGS**1** first face gear **20** has a greater number of teeth and accordingly, the output shaft **18** will rotate in the same rotational direction as the sun gear **28**. To accommodate radial differences between the PGS**1** first and second face gears **20** and **22**, a thickness T of the spur gear **24** and intermediate pinion gears **25** will need to have a dimension adequate to fully engage the teeth of both the PGS**1** first and second gears **20** and **22**. Providing the capability for the input shaft **16** to enter the FGPGA **10** at angles other than **90°**, with respect to the output shaft **18**, allows the thickness T of the spur gear **24** and the intermediate pinion gears **25** to be smaller and still accommodate the radial difference between the PGS**1** first and second face gears **20** and **22**. This will greatly reduce the part cost and weight of the FGPGA **10**.

[0027] Figures **2**A and **2**B illustrate the FGPGA **10** in accordance with an alternate preferred embodiment of the present invention. Components illustrated in Figure **2**A and **2**B that are the same as parts illustrated in Figures **1**A and **1**B are identified in Figures **2**A and **2**B with like referenced numerals. In this embodiment, the PGS**2** **14** includes a first face gear **126** (referred to herein as PGS**2** first face gear **126**), a second face gear **128** (referred to herein as PGS**2** second face gear **128**), and a plurality of pinion gears **130**. The number of pinion gears **130** can be determined based on a desired amount of torque distribution via tooth sharing. That is, the greater the number of pinion gears **130** included in the PGS**2**, the greater the distribution of torque between the teeth of the pinion gears **130** and the PGS**2** first and second face gears **126** and **128**. Thus, the PGS**2** **14** includes the PGS**2** first and second face gears **126** and **128** configured in a planetary arrangement with the pinion gears **130**. The output shaft **18** is coupled to the pinion gears **130** via the carrier **32**. The PGS**1** first face gear **20** is connected to the PGS**2** first face gear **126** and the PGS**1** second face gear **22** is connected to the PGS**2** second face gear **128**.

[0028] The PGS**1** first and second face gears **20** and **22** can be connected to the PGS**2** first and second face gears **126** and **128** in any suitable manner based on the various preferred embodiments described herein. For example, the PGS**1** first and second face gears **20** and **22** can be splined with the PGS**2** first and second face gears **126** and **128**, or the PGS**1** first and second face gears **20** and **22** can be connected with the PGS**2** first and second face gears **126** and **128** using nut and bolt connectors. Alternatively, the PGS**1** first face gear **20** and the PGS**2** first face gear **216** can be fabricated as a single component and/or the PGS**1** second face gear **22** and the PGS**2** second face gear **128** can be fabricated as a single component. As set forth above, rotation of the input shaft **16** from power provided by a motor or other such device (not shown) is transferred to the PGS1 **12**, which in turn causes the PGS**2** set **14** to rotate, thereby causing the output shaft **18** rotate. Particularly, the rotation of the PGS**2** first and second face gears **126** and **128** in opposite directions around an axis X of the (FGPGA) **10** causes the pinion gears **130** to rotate around an axis Z and simultaneously to travel around the axis X. The movement of the pinion gears **130** around the axis X causes the shaft **18** to rotate around the axis X in either a clockwise or counter-clockwise direction. As described below, the direction of rotation is based on the tooth differential between the PGS**1** first and second face gears **20** and **22** and/or the tooth differential between the PGS**2** first and second face gears **126** and **128**.

[0029] More particularly, rotation of input shaft **16** rotates the spur gear **24**, which in turn rotates the PGS**1** first face gear **20** in a first direction and rotates the PGS**1** second face gear **22** in a second direction that is opposite the first direction. The PGS**2** first face gear **126** is connected to the PGS**1** first face gear **20** and therefore, also rotates in the first direction. Similarly, the PGS**2** second face gear **128** is connected to the PGS**1** second face gear **22** and therefore, also rotates in the second direction. Accordingly, rotation of the PGS**2** first and second face gears **126** and **128** in opposite directions rotates the output shaft **18**. In order to obtain a high gear reduction ratio between the input **16** and the output **18**, the tooth count of any or all of the PGS**1** first face gear **20**, the PGS**1** second face gear **22**, the PGS**2** first face gear **126**, the PGS**2** second face gear **128**, the pinion gears **130** and/or the spur gear **24** can be specified such that the FGPGA **10** produces a desired gear ratio.

[0030] As set forth above with reference to Figures 1A and 1B, utilizing the PGS1 first and second face gears **20** and **22** configured in a planetary gear set arrangement, the input shaft **16** can be offset from the output shaft **18** at an angle other than **90°**. More specifically, the input shaft **16** can have an angle with respect to the output shaft **18**, between approximately **0°** and **180°**.

[0031] In this embodiment, the rotational direction of the output shaft **18** can be changed by altering the tooth differential between the PGS**1** first face gears **20** and **22** and/or by altering the tooth differential between the PGS**2** first and second face gears **126** and **128**. Particularly, the rotational direction of the output shaft **18** can be altered by merely changing the number of teeth of the PGS**1** first and second face gears **20** and **22** and/or the number of teeth of the PGS**2** first and second face gears **126** and **128**, without employing additional gears, e.g. an idler gear. For example, if the PGS**1** first face gear **20** has a greater number of teeth than the PGS**1** second face gear **22**, rotation of the input shaft will cause the spur gear to drive the PGS**1** first face gear **20** at a second rate of speed around the axis X than the PGS**1** second face gear **22**. Therefore, via the connection between the PGS**1** first face gear **20** and the PGS**2** first face gear **126**, the PGS**2** first face gear **126** will rotate around the axis X in the same direction as the PGS**1** first face gear **20**. Likewise, via the connection between the PGS**1** second face gear **22** and the PGS**2** second face gear **128**, the PGS**2** second face gear **128** will rotate around the axis X in the same direction as the PGS**1** second face gear **22**. Accordingly, the PGS**2** first face gear **126** will rotate around the axis X at a second rate than the PGS**2** second face gear **128**.

[0032] This will cause the teeth of the pinion gears **130** that engage the PGS**2** first face gear **126** to be driven around an axis Z at a second rate than the teeth of the pinion gears **130** that engage the PGS**2** second face gear **128**. Therefore, the pinion gears **130** will travel around the axis X in the same direction that the PGS**2** second face gear **128** and the PGS**1** second face gear **22** are rotating around the axis X. This, in turn, will cause the output shaft **18** to also rotate in the same direction as the PGS**2** second face gear **128** and the PGS**1** second face gear **22**. Conversely, if the PGS**1** first face gear **20** included fewer teeth than the second PGS**1** second face gear **22**, the PGS**2** first face gear **126** would rotate around the axis X at a faster rate of speed than the PGS**2** second face gear **128**. Therefore, the pinion gears **130** would travel around the axis X, and the output shaft **18** would rotate in the same direction as the PGS**2** first face gear **126** and the PGS**1** first face gear **20**.

[0033] Alternatively, if the PGS**1** first and second face gears **20** and **22** included the same number of teeth, but the PGS**2** first face gear **126** had fewer teeth than the PGS**2** second face gear **128**, the output shaft **18** would rotate in the same direction as PGS**2** first face gear **126** and PGS**1** first face gear **20**. Specifically, the teeth of the pinion gears **130** that engage the PGS**2** first face gear **126** would be driven around the axis Z at a faster rate than the teeth of the pinion gears **130** that engage the PGS**2** second face gear **128**. This would cause the pinion gears **130** to travel around the axis X, and the output shaft **18** to rotate, in the same direction as the PGS**2** first face gear **126** and the PGS**1** first face gear **20** rotate around the axis X.

[0034] Further yet, the FGPGA **10** could be constructed such that there was a tooth differential between the PGS**1** first and second face gears **20** and **22** and a tooth differential between the PGS**2** first and second face gears **126** and **128**. Thus, the output gear ratio and the rotational direction and speed of the output shaft **18** can be controlled or set to desirable values by selecting the proper tooth differentials between the face gears implemented in one or both of the PGS**1** **12** and the PGS**2** **14**.

[0035] As described above, altering the number of teeth included in each of the PGS**1** first and second face gears **20** and **22** and/or the PGS**2** first and second face gears **126** and **128** merely changes a radius of the respective gear. To accommodate the radial differenced between the PGS**2** first and second face gears **126** and **128**, a thickness M of the pinion gears **130** will preferably have a dimension adequate to fully engage the teeth of both the PGS**2** first and second face gears **126** and **128**. Likewise, to accommodate the radial differences between the PGS**1** first and second face gears **20** and **22**, a thickness T of the spur gear **24** and intermediate pinion gears **25** will need to have a dimension adequate to fully engage the teeth of both the PGS**1** first and second gears **20** and **22**. Additionally, as described above, utilizing face gears in the PGS**1** **12**, i.e. PGS**1** first and second face gears **20** and **22**, allows the input shaft **16** to have an angular orientation with respect to the output shaft **18** of approximately **0°** to **180°**. Providing the capability for the input shaft **16** to enter the FGPGA **10** at angles other than **90°**, with respect to the output shaft **18**, allows the thickness T of the spur gear **24** and the intermediate pinion gears **25** to be smaller and still fully engage the teeth of the PGS**1** first and second face gears **20** and **22**.

[0036] Figures **3**A and B illustrate the FGPGA **10** in accordance with another alternate preferred embodiment of the present invention. Components illustrated in Figure **3**A and **3**B that are the same as parts illustrated in Figures **2**A and **2**B are identified in Figures **3**A and **3**B with like referenced numerals. In this embodiment, the PGS**1** first face gear **20** is connected to the PGS**2** second face gear **128** and the PGS**1** second face gear **22** is connected to the PGS**2** first face gear **126**. Having the PGS**1** first face gear **20** connected to the PGS**2** second face gear **128** allows separation forces of the PGS**1** first face gear **20** to substantially balance with the separation forces of the PGS**2** second face gear **128**. Particularly, as the teeth of the PGS**1** first face gear **20** engage the teeth of the spur gear **24** and intermediate pinion gears **25** there is a force generated that pushes the PGS**1** first face gear **20** away from the spur gear **24** and the intermediate pinion gears **25**. Similarly, there is a separation force generated between the PGS**2** second face gear **128** and the pinion gears **130**. Having the PGS**1** first face gear **20** connected with the PGS**2** second face gear **128** allows these separation forces to substantially balance each other. Likewise, having the PGS**1** second face gear **22** connected with the PGS**2** first face gear **126** allows the associated separation force to substantially balance each other. This allows the FGPGA **10** to not require additional components (not shown) to counter these separation forces and keep the teeth of the gears engaged.

[0037] Generally, the operation of the embodiment of the FGPGA **10** illustrated in Figures **3**A and **3**B is the same as that described above in reference to the embodiment of the FGPGA **10** illustrated in Figures **2**A and **2**B. Particularly, the PGS**1** first face gear **20** rotates in a first direction and the PGS**1** second face gear **22** rotates in a second direction that is opposite the first direction. However, in this embodiment, the PGS**2** second face gear **128** is connected to the PGS**1** first face gear **126** and the PGS**2** first face gear **126** is connected to the PGS **1** second face gear **126**. Therefore, the PGS**2** second face gear **128** rotates in the first direction and the PGS**2** first face gear **126** rotates in the second direction.

[0038] As with the embodiment described above with reference to Figures **2**A and **2**B, the rotational direction of the output shaft **18** can be changed by altering the tooth differential between the PGS**1** first and second face gears **20** and **22** and/or by altering the tooth differential between the PGS**2** first and second face gears **126** and **128**. Particularly, the rotational direction of the output shaft **18** can be altered by merely changing the number of teeth of the PGS**1** first and second face gears **20** and **22** and/or the number of teeth of the PGS**2** first and second face gears **126** and **128**, without employing additional gears, e.g. an idler gear. However, the rotational direction of the output shaft **18** with respect to the embodiment illustrated in Figures **3**A and **3**B will be opposite of the rotational direction of the output shaft **18** described above, in reference to Figures **2**A and **2**B. For example, as described above, if the PGS**1** first face gear **20** has a greater number of teeth than the PGS**1** second face gear **22**, then the PGS**1** first face gear **20** will rotate around the axis X at a second speed than the PGS**1** second face gear **22**. However, because the PGS**1** first face gear **20** is connected to the PGS**2** second face gear **128**, the PGS**2** second face gear will rotate around the axis X in the same direction as the PGS**1** first face gear **20**. Likewise, because the PGS**1** second face gear **22** is connected to the PGS**2** first face gear **126**, the PGS**2** first face gear **126** will rotate around the axis X in the same direction as the PGS**1** second face gear **22**. Accordingly, the PGS**2** second face gear **128** will rotate around the axis X at a second rate than the PGS**2** first face gear **126**.

[0039] This will cause the teeth of the pinion gears **130** that engage the PGS**2** second face gear **128** to be driven around the axis Z at a second rate than the teeth of the pinion gears **130** that engage the PGS**2** first face gear **126**. Therefore, the pinion gears **130** will travel around the axis X in the same direction as the PGS**2** first face gear **126**, but in the opposite direction of the PGS**1** first face gear **20**. This, in turn, will cause the output shaft **18** to also rotate in the same direction as the PGS**2** first face gear **126**, but in the opposite direction of the PGS**1** first face gear **20**. Conversely, if the PGS**1** first face gear **20** included fewer teeth than the second PGS**1** second face gear **22**, the PGS**2** second face gear **128** would rotate around the axis X at a faster rate of speed than the PGS2 first face gear **126**. Therefore, the pinion gears **130** would travel around the axis X, and the output shaft **18** would rotate in the same direction as the PGS2 second face gear **128**, but in the opposite direction of the PGS1 second face gear **22**.

[0040] Alternatively, if the PGS1 first and second face gears **20** and **22** included the same number of teeth, but the PGS2 first face gear **126** had fewer teeth than the PGS2 second face gear **128**, the output shaft **18** would rotate in the same direction as PGS2 first face gear **126**, but in the opposite direction of the PGS1 first face gear **20**.

[0041] As described above, altering the number of teeth included in each of the PGS1 first and second face gears **20** and **22** and/or the PGS2 first and second face gears **126** and **128** merely changes a radius of the respective gear. To accommodate the radial difference between the PGS2 first and second face gears **126** and **128**, a thickness M of the pinion gears **130** will preferably have a dimension adequate to fully engage the teeth of both the PGS2 first and second face gears **126** and **128**. Likewise, to accommodate the radial differences between the PGS1 first and second face gears **20** and **22**, a thickness T of the spur gear **24** and intermediate pinion gears **25** will need to have a dimension adequate to fully engage the teeth of both the PGS1 first and second gears **20** and **22**. Additionally, as described above, utilizing face gears in the PGS1 **12**, i.e. PGS1 first and second face gears **20** and **22**, allows the input shaft **16** to have an angular orientation with respect to the output shaft **18** of approximately **0°** to **180°**. This allows the thickness T of the spur gear **24** and the intermediate pinion gears **25** to be smaller and still fully engage the teeth of the PGS1 first and second face gears **20** and **22**. Similarly, as illustrated in Figure **3**B, utilizing face gears in the PGS2 **14**, i.e. PGS2 first and second face gears **126** and **128**, allows the pinion gears **130** to have an angular orientation with respect to the output shaft **18** other than **90°**. This allows the thickness M of the pinion gears **130** to be smaller and still fully engage the teeth of the PGS2 first and second face gears **126** and **128**.

[0042] Referring to Figures **4**A and **4**B, another preferred embodiment is illustrated. This embodiment is substantially the same as the embodiment described above with reference to Figures **3**A and **3**B in form and function. However, Figures **3**A and **3**B illustrate the pinion gears **130** having an angular orientation with respect to the output shaft **18** that is different than that of the spur gear **24** and the intermediate pinion gears **25**. The embodiment shown in Figures **4**A and **4**B illustrates a preferred embodiment of the present invention wherein the angular orientation of the pinion gears **130** with respect to the output shaft **18** is parallel to that of the spur gear **24** and the intermediate pinion gears **25**.

[0043] The FGPGA **10** implements face gears, i.e. the PGS**1** and PGS**2** face gears **20**, **22**, **126** and **128**, in a planetary arrangement. Thus, the FGPGA **10** provides a gearbox that incorporates at least two high power, high speed gear sets, i.e. the PGS**1** **12** and the PGS**2** **14**. Additionally, the implementation of high speed face gear in a planetary arrangement allows for off-axes input/output implementations and high input/output gear ratios. Furthermore, utilizing the PGS**1** and PGS**2** face gears **20**, **22**, **126** and **128** in a planetary arrangement provides the capability to change the rotational direction of the output and minimizes the number of parts, thereby, significantly reducing the cost of manufacturing and repair of such gearboxes.

[0044] While various preferred embodiments have been described, those skilled in the art will recognize modifications or variations which might be made without departing from the inventive concept. The examples illustrate the invention and are not intended to limit it. Therefore, the description and claims should be interpreted liberally with only such limitation as is necessary in view of the pertinent prior art.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A compound face gear planetary gear assembly comprising:

   a first planetary gear set (PGS**1**) including a plurality of pinion gears, a first face gear and a second face gear oriented in a planetary arrangement; and

   a second planetary gear set (PGS**2**) having an output shaft associated therewith.

2. The assembly of Claim **1**, wherein one of the PGS**1** pinion gears comprises a spur gear connected to an input shaft.

3. The assembly of Claim **2**, wherein the PGS**1** first face gear and the PGS**1** second face gear are adapted to allow the input shaft to have an angular orientation, with respect to an output shaft associated with the PGS**2**, that is greater than **90**°.

4. The assembly of Claim **2**, wherein the PGS**1** first face gear and the PGS**1** second face gear are adapted to allow the input shaft to have an angular orientation, with respect to an output shaft associated with the PGS**2**, that is less than **90**°.

5. The assembly of Claim **1**, wherein the PGS**1** first face gear includes a different number of teeth than the PGS**1** second face gear such that the output shaft rotates in a clockwise direction.

6. The assembly of Claim **1**, wherein the PGS**1** first face gear includes a different number of teeth than the PGS**1** second face gear such that the output shaft rotates in a counter-clockwise direction.

7. The assembly of Claim **1**, wherein the PGS**1** is adapted such that a rotational direction of the output shaft can be altered by changing a tooth differential between the PGS**1** first and second face gears absent the use of an idler gear.

8. The assembly of Claim **1**, wherein the PGS**2** includes a plurality of pinion gears, a first face gear and a second face gear oriented in a planetary arrangement.

9. The assembly of Claim **8**, wherein the PGS**2** first face gear includes a different number of teeth than the PGS**2** second face gear such that the output shaft rotates in a clockwise direction.

10. The assembly of Claim **8**, wherein the PGS**2** first face gear includes a different number of teeth than the PGS**2** second face gear such that the output shaft rotates in a counter-clockwise direction.

11. The assembly of Claim **8**, wherein the PGS**2** is adapted such that a rotational direction of the output shaft can be altered by changing a tooth differential between the PGS**2** first and second face gears absent the use of an idler gear.

12. A method for rotating an output shaft of a gearbox, said method comprising:

orienting a first face gear, a second face gear and a plurality of pinion gears in a planetary arrangement to thereby provide a first planetary gear set (PGS**1**) within the gearbox;

orienting a ring gear, a sun gear and a plurality of planet gears in a planetary arrangement to thereby provide a second planetary gear set (PGS**2**) within the gearbox;

connecting to the PGS**1** first face gear with the PGS**2** ring gear, the PGS**1** second face gear with the PGS**2** sun gear and the plurality of planet gears to an output carrier connected to the output shaft, and

connecting an input shaft to one of the PGS**1** pinion gears such that the input shaft has an angular relationship with the output shaft of between approximately **0**° and **180**°.

13. The method of Claim **12**, wherein connecting the input shaft comprises providing the PGS**1** first face gear and the PGS**1** second face gear to have teeth configured to engage teeth of the pinion gear connected to the input shaft such that the input shaft has an angular orientation of between approximately **90**° and **180**° with respect to the output shaft.

14. The method of Claim **12**, wherein connecting the input shaft comprises providing the PGS**1** first face gear and the PGS**1** second face gear to have teeth configured to engage teeth of the pinion gear connected to the input shaft such that the input shaft has an angular orientation of between approximately **0**° and **90**° with respect to the output shaft.

15. The method of Claim **12,** wherein orienting PGS**1** first and second face gears in a planetary arrangement comprises providing the PGS**1** first face gear with a different number of teeth than the PGS**1** second face gear such that the output shaft rotates in a clockwise direction.

16. The method of Claim **12**, wherein orienting PGS**1** first and second face gears in a planetary arrangement comprises providing the PGS**1** first face gear with a different number of teeth than the PGS**1** second face gear such that the output shaft rotates in a counter-clockwise direction.

17. The method of Claim **12**, wherein orienting PGS**1** first and second face gears in a planetary arrangement comprises providing the PGS**1** first and second face gears with different tooth counts such that a rotational direction of the output shaft can be altered by changing the tooth differential between the PGS**1** first and second face gears absent the use of an idler gear.

18. The method of Claim **12**, wherein the ring gear comprises a PGS**2** first face gear and the sun gear comprises a PGS**2** second face gear.

19. The method of Claim **18**, wherein orienting the ring and sun gears in a planetary arrangement comprises providing the PGS**2** first face gear with a different number of teeth than the PGS**2** second face gear such that the output shaft rotates in a clockwise direction.

20. The method of Claim **18**, wherein orienting the ring and sun gears in a planetary arrangement comprises providing the PGS**2** first face gear with a different number of teeth than the PGS**2** second face gear such that the output shaft rotates in a counter-clockwise direction.

21. The method of Claim **18**, wherein orienting the ring and sun gears in a planetary arrangement comprises providing the PGS**2** first and second face gears with different tooth counts such that a rotational direction of the output shaft can be altered by changing the tooth differential between the PGS**2** first and second face gears absent the use of an idler gear.

22. A gearbox comprising:

a high power, high speed compound face gear planetary gear assembly comprising:

a first planetary gear set (PGS**1**) including a spur gear connected to an input shaft, a plurality of intermediate pinion gears, a first face gear and a second face gear oriented in a planetary arrangement; and

a second planetary gear set (PGS**2**) including a ring gear, a sun gear and a plurality of planet gears oriented in a planetary arrangement, the planet gears rotationally connected to a carrier coupled to an output shaft;

wherein, the PGS**1** first and second face gears are engaged with the spur gear such that the input shaft has an angular relationship with the output shaft of other than **90**°, and a rotational direction of the output shaft can be altered by changing a tooth differential between the PGS**1** first and second face gears absent the use of an idler gear.

23. The assembly of Claim **22**, wherein the PGS**1** first face gear and the PGS**1** second face gear are engaged with the spur gear such that the input shaft has an angular orientation of between approximately **0**° and **90**° with respect to the output shaft.

24. The assembly of Claim **22**, wherein the PGS**1** first face gear and the PGS**1** second face gear are engaged with the spur gear such that the input shaft has an angular orientation of between approximately **90**° and **180**° with respect to the output shaft.

25. The assembly of Claim **22**, wherein the ring gear comprises a PGS**2** first face gear and the sun gear comprises a PGS**2** second face gear.

26. The assembly of Claim **25**, wherein the PGS**2** is adapted such that a rotational direction of the output shaft can be altered by changing a tooth differential between the PGS**2** first and second face gears absent the use of an idler gear.

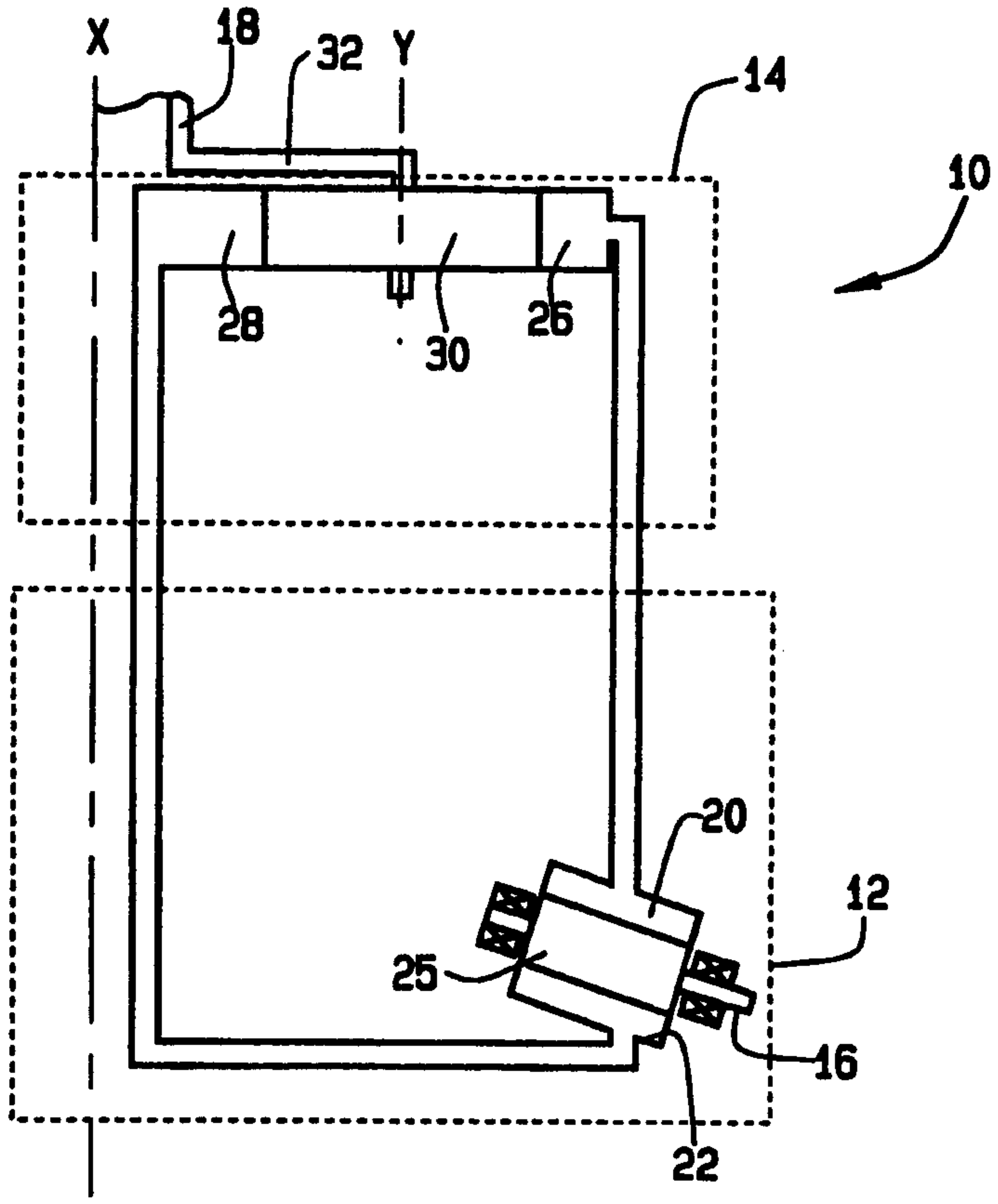
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FIG.1A

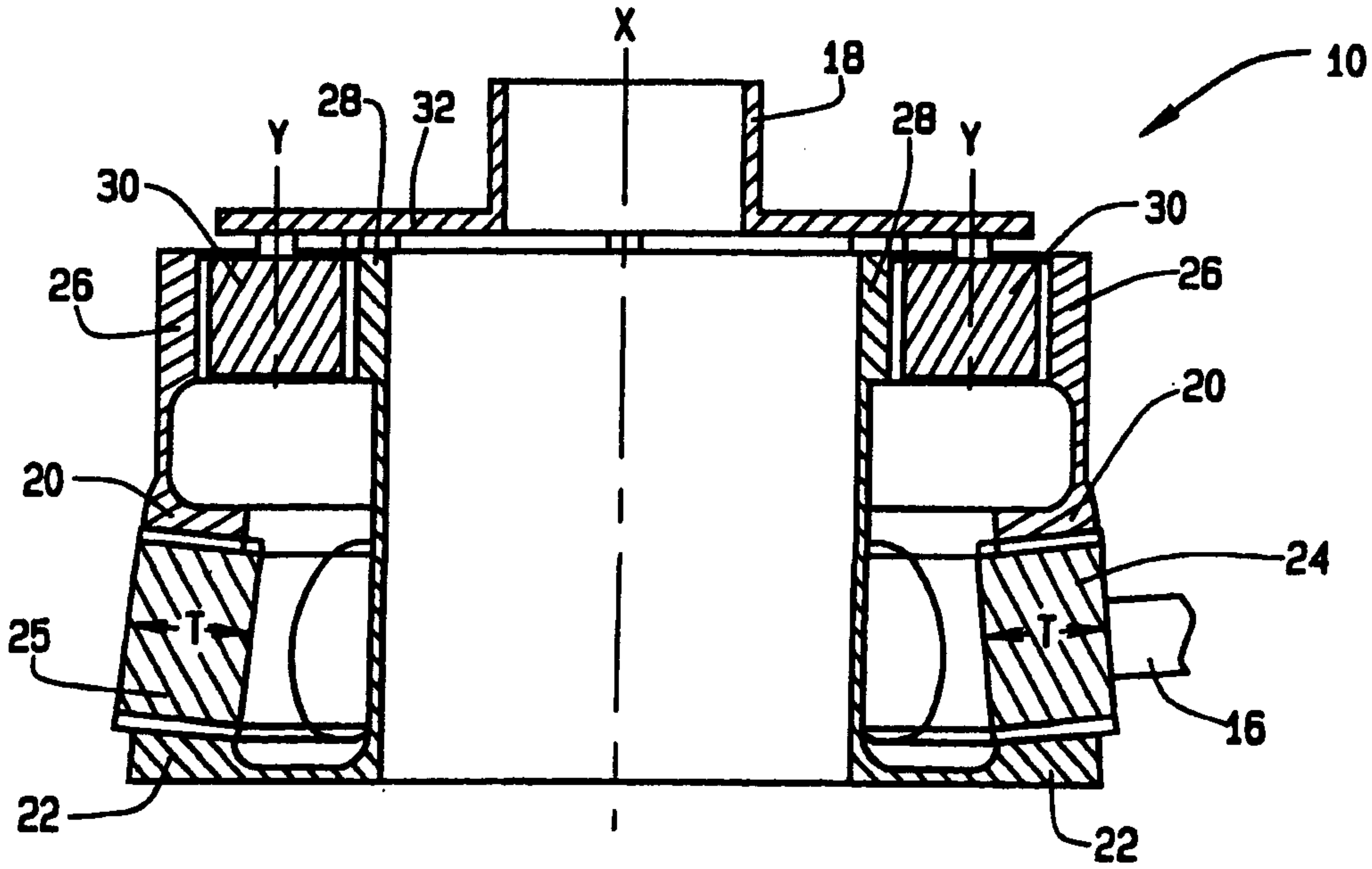
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FIG.1B

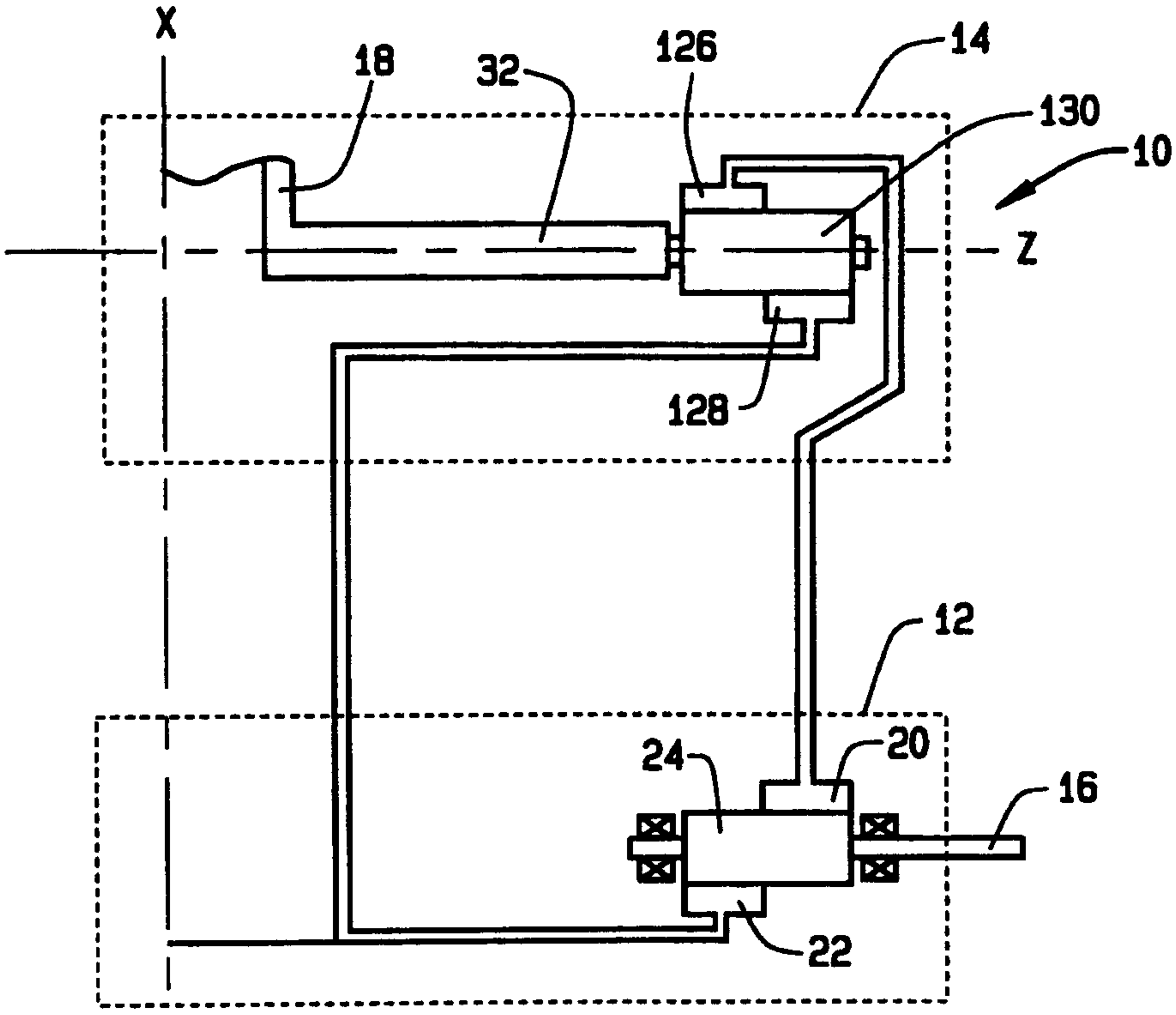
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FIG. 2A

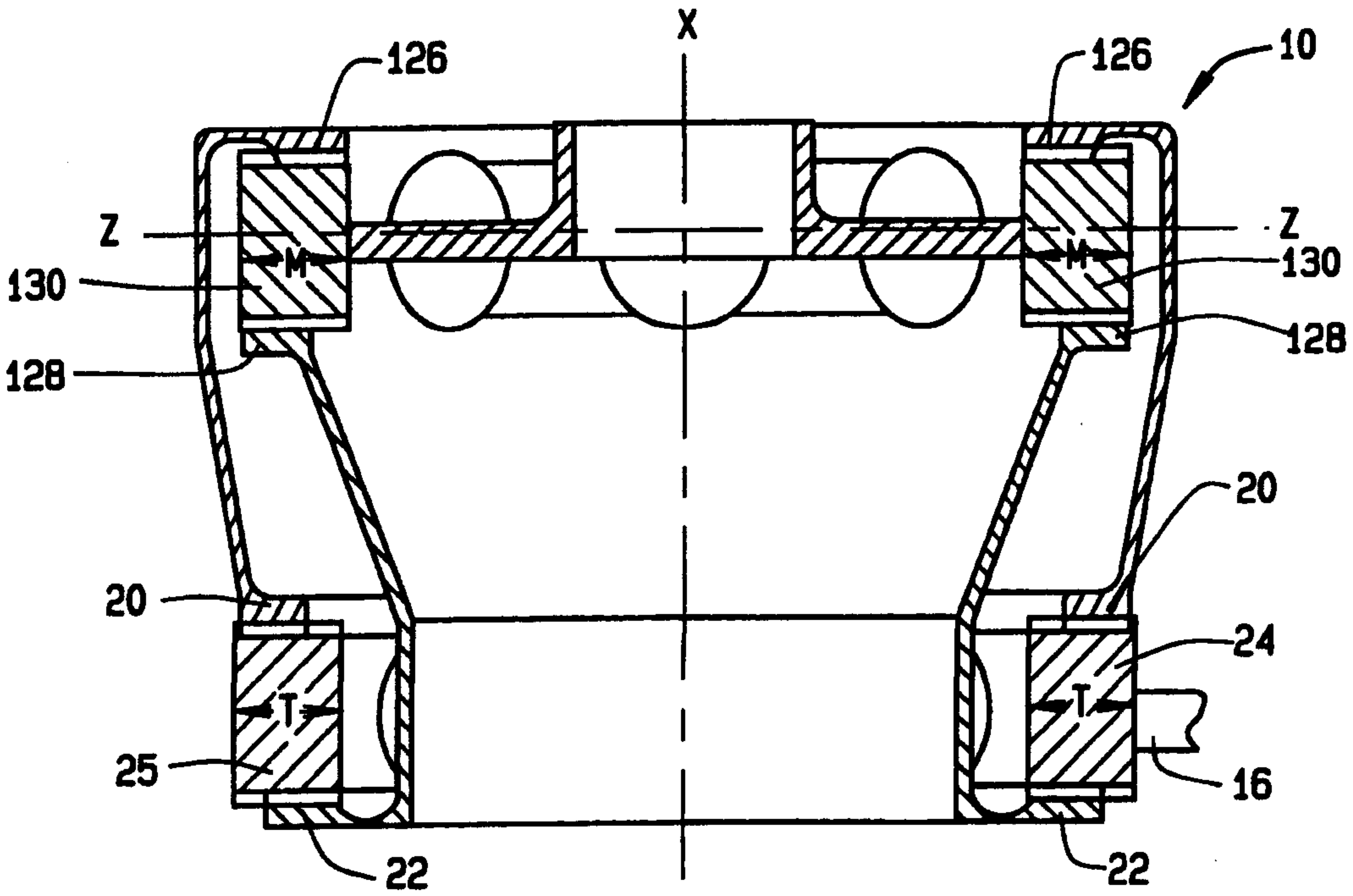
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FIG. 2B

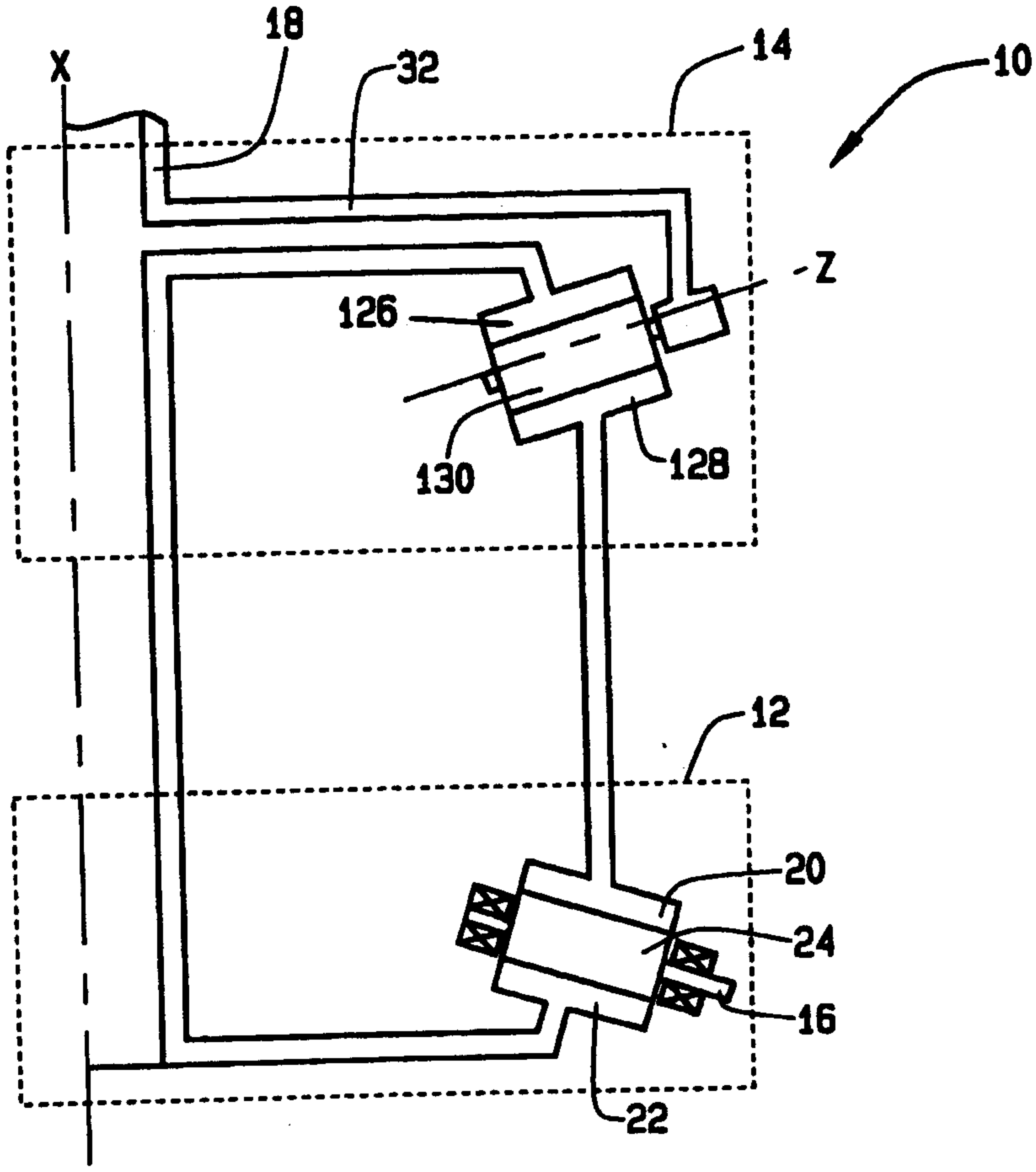
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FIG. 3A

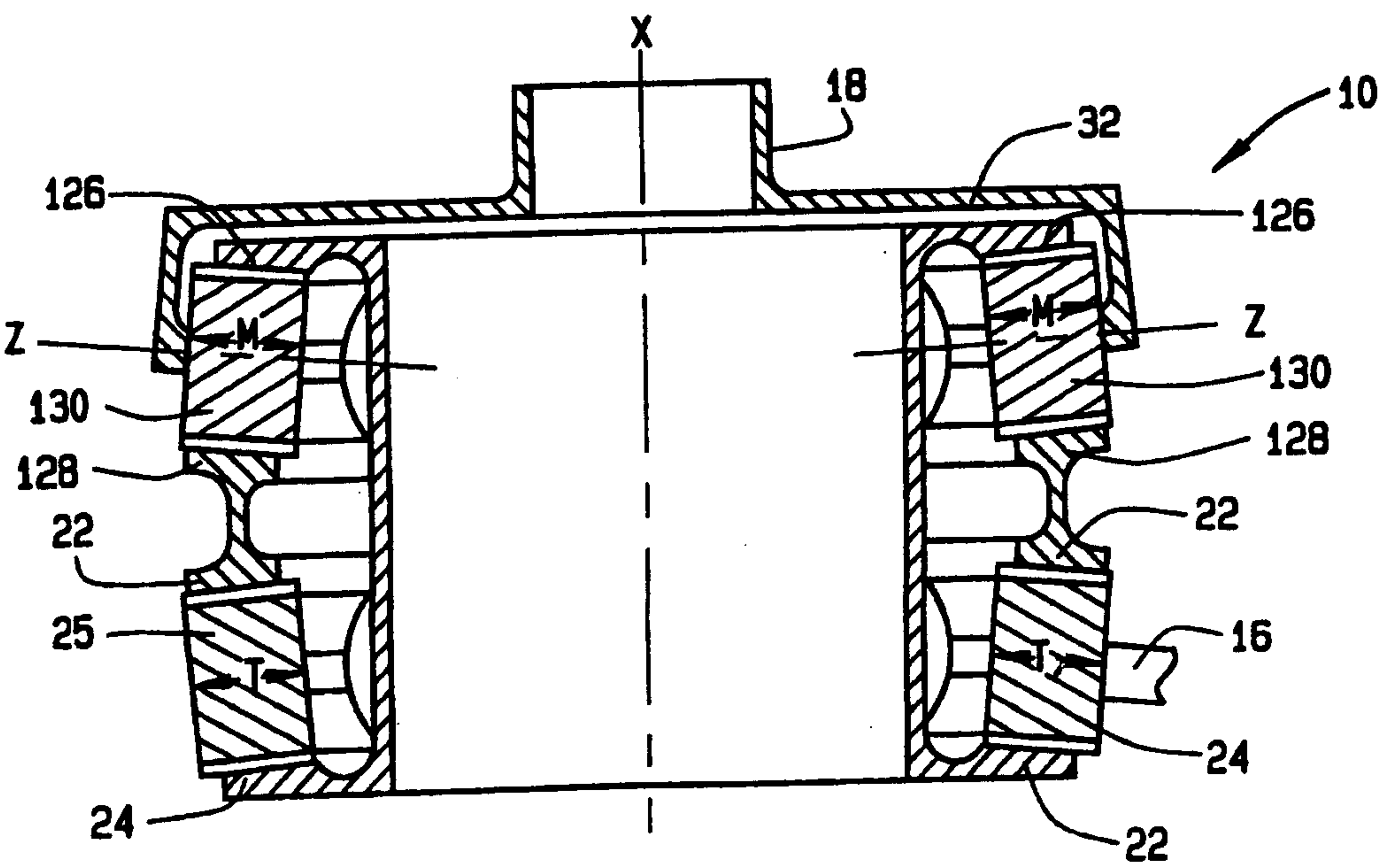
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FIG. 3B

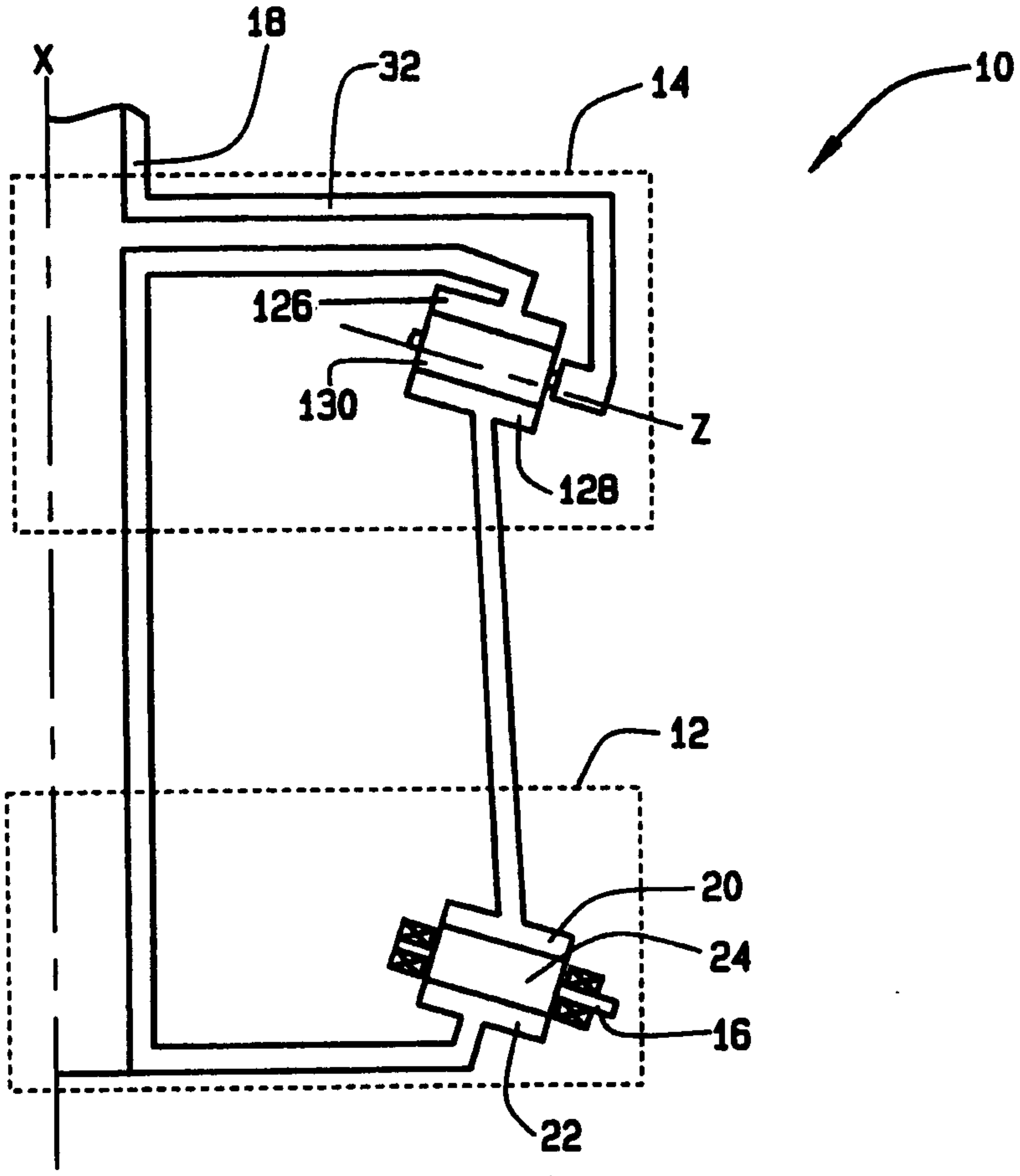
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FIG. 4A

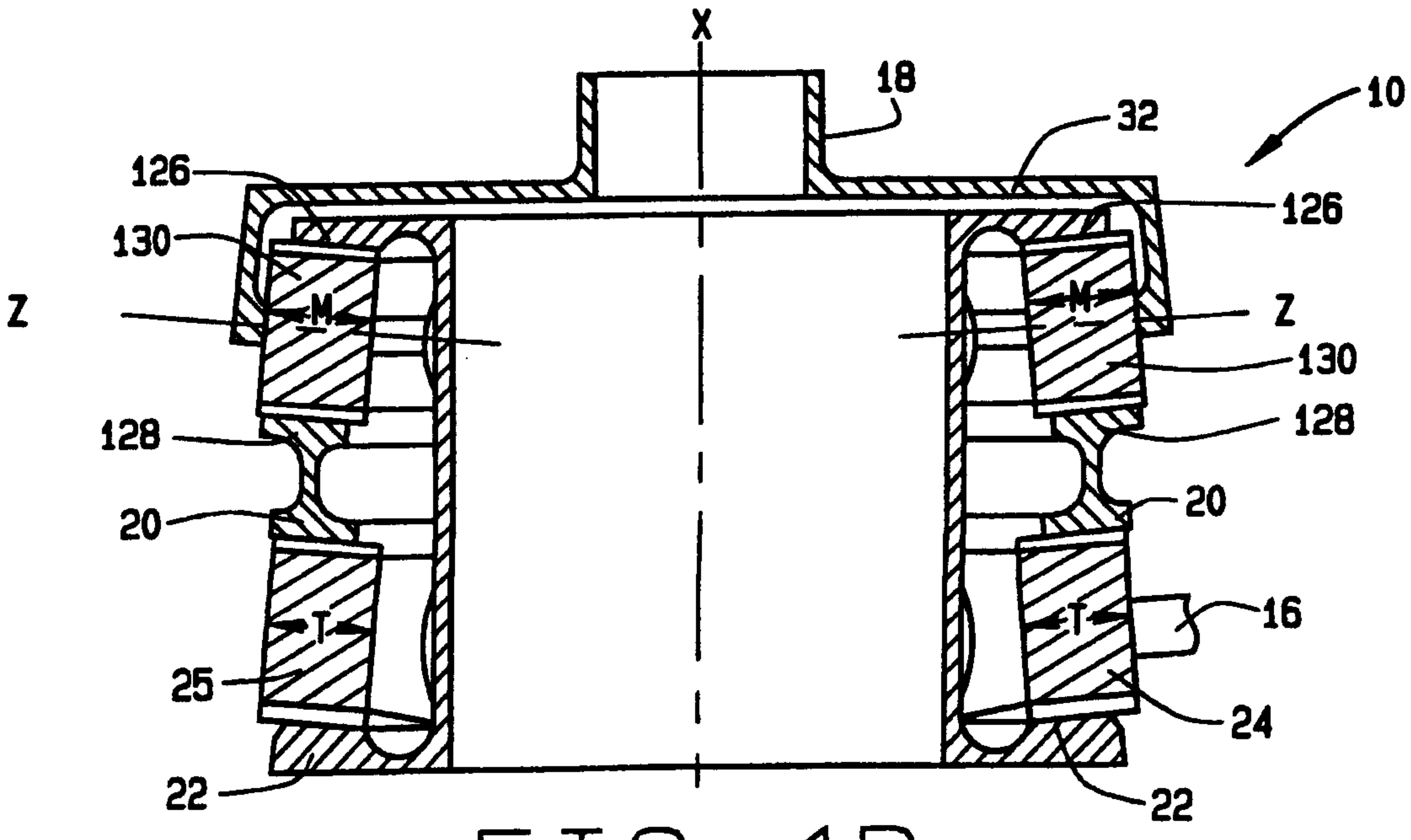
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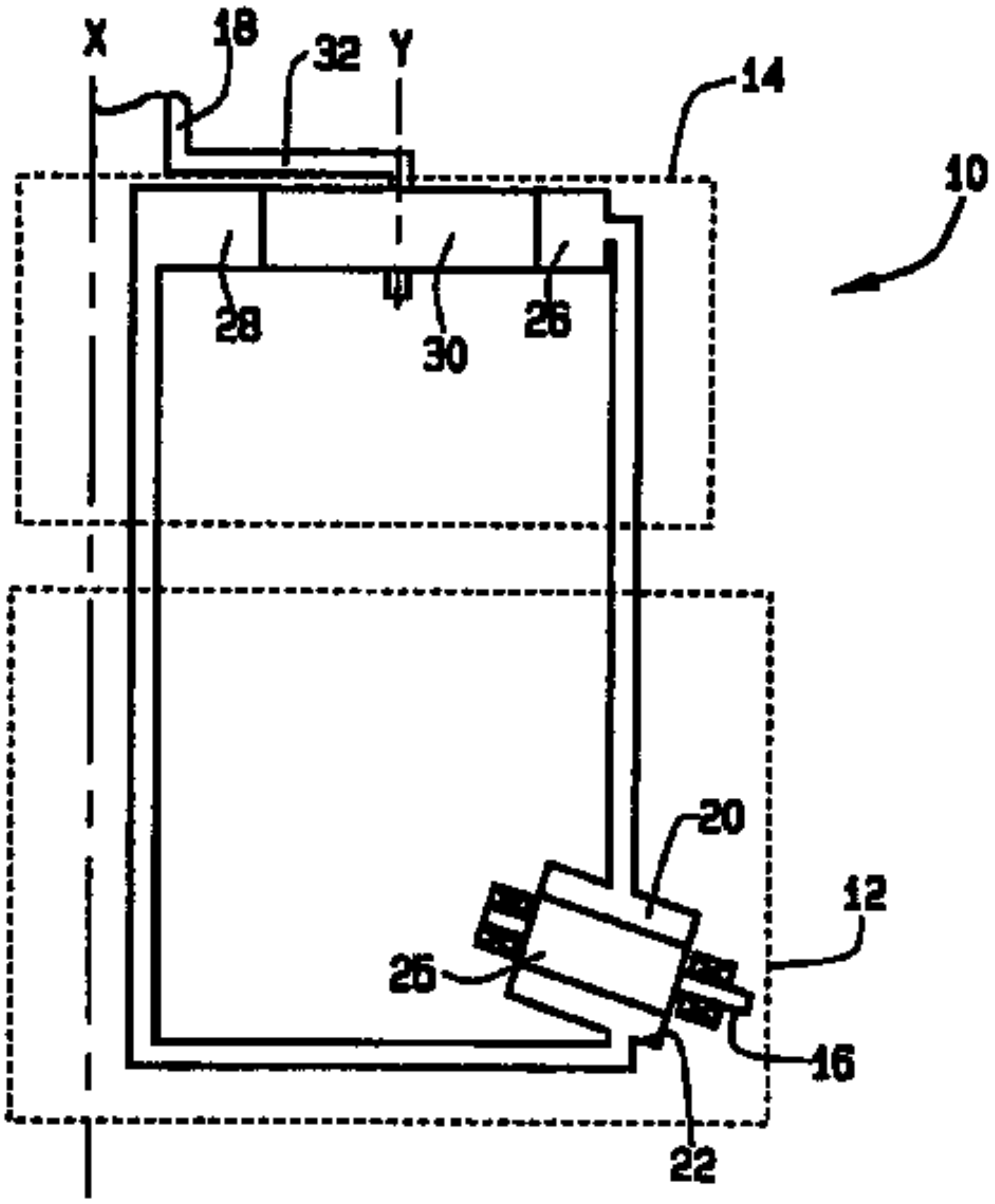
FIG. 4B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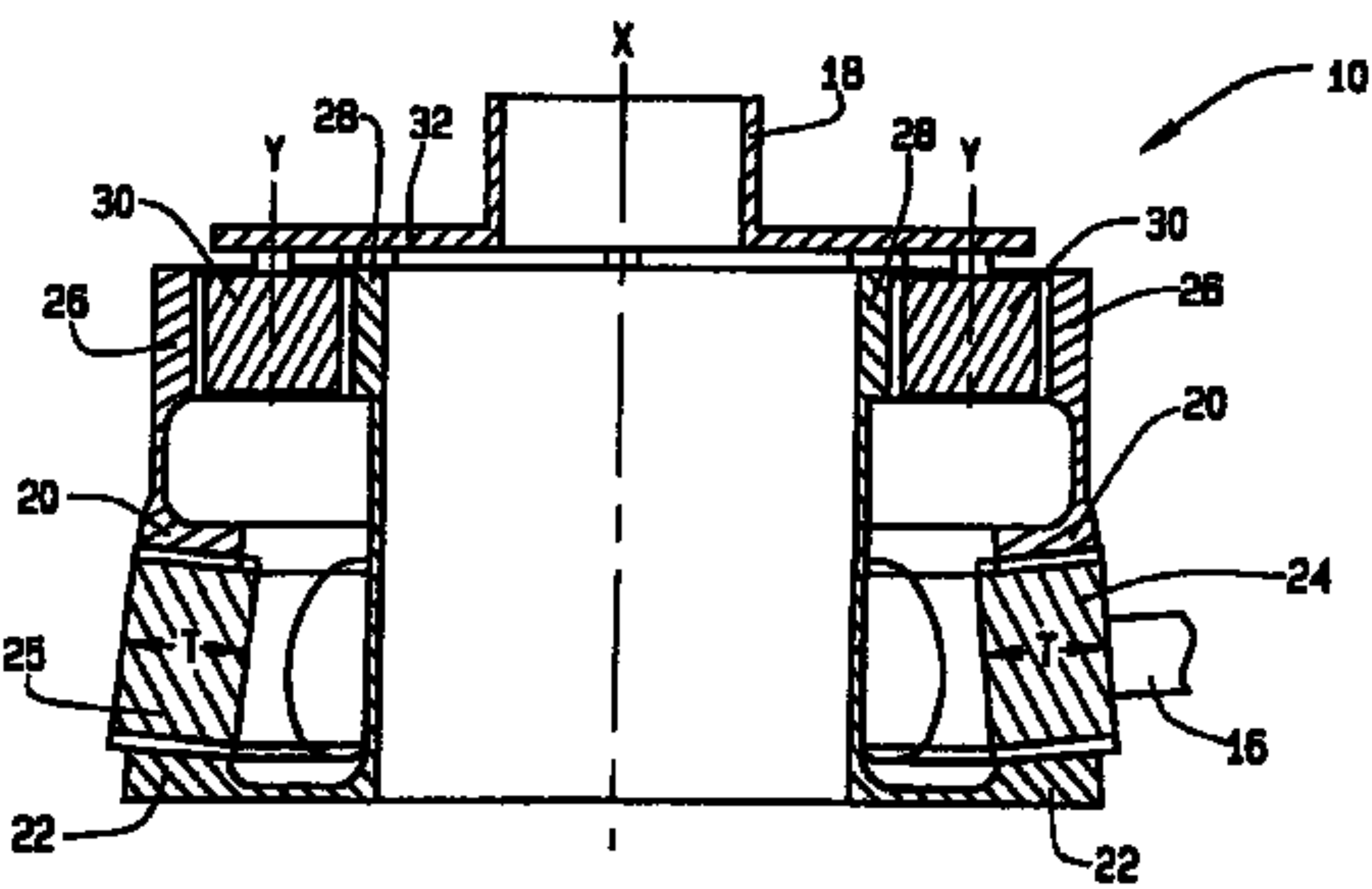
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