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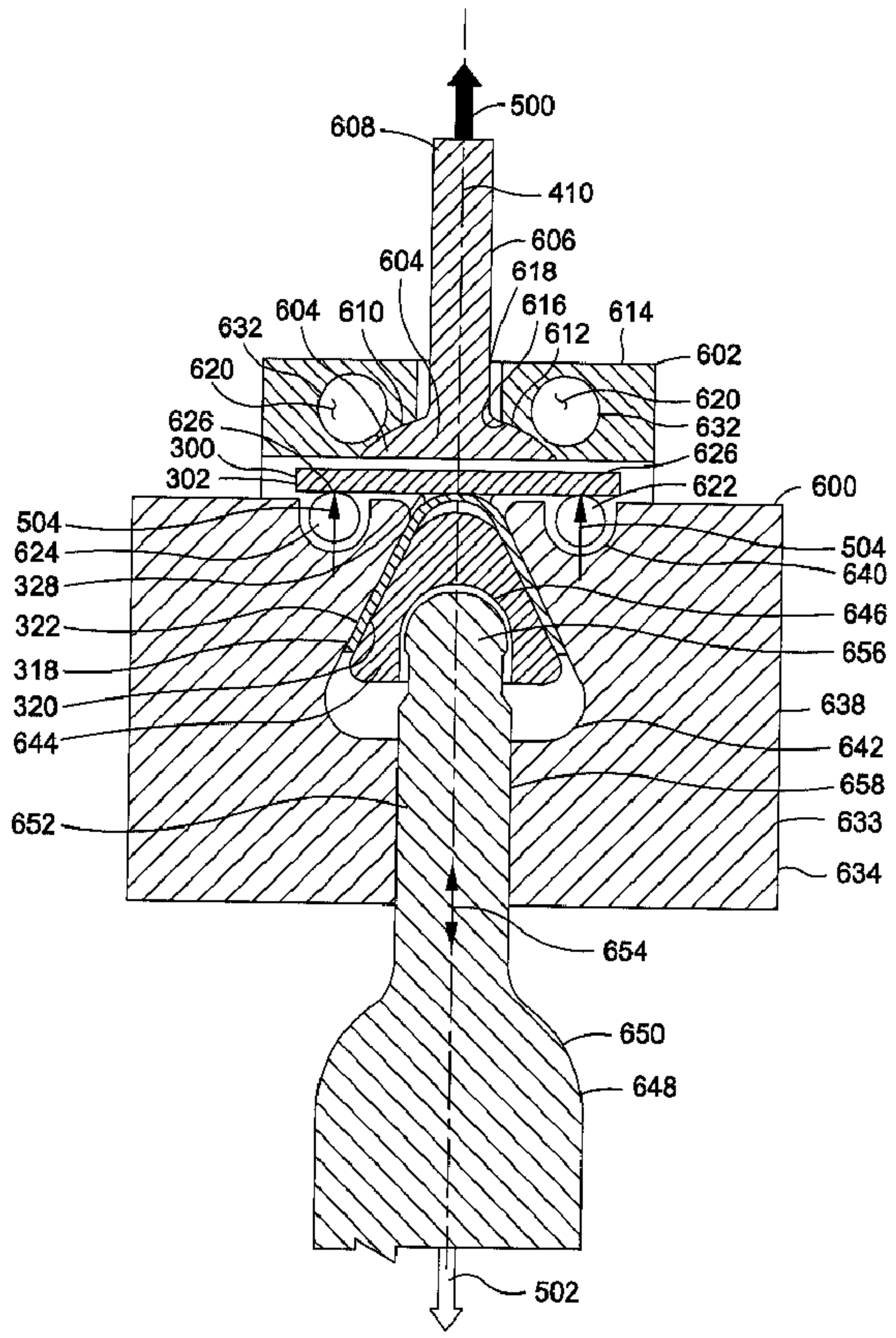

(57) **Abrégé/Abstract:**
A testing apparatus (600) for characterizing a tension strength of a fillet bond (128) of a test specimen (300) may include a lower fixture (634) and an upper fixture (602). The test specimen (300) may include a skin component (302) bonded to a stiffener

(57) **Abrégé(suite)/Abstract(continued):**
component (308). The lower fixture (634) may maintain the stiffener component (308) in a fixed position. The upper fixture (602) may engage the skin component (308) at a pair of discrete engagement locations (626) on opposite sides of the fillet bond (128). The upper fixture (602) may be mechanically coupled to a gimbal joint (604) and may substantially isolate the filet bond (128) from asymmetric bending during application of a tension test load (500) to the fillet bond (128).

ABSTRACT

A testing apparatus (**600**) for characterizing a tension strength of a fillet bond (**128**) of a test specimen (**300**) may include a lower fixture (**634**) and an upper fixture (**602**). The test specimen (**300**) may include a skin component (**302**) bonded to a stiffener component (**308**). The lower fixture (**634**) may maintain the stiffener component (**308**) in a fixed position. The upper fixture (**602**) may engage the skin component (**308**) at a pair of discrete engagement locations (**626**) on opposite sides of the fillet bond (**128**). The upper fixture (**602**) may be mechanically coupled to a gimbal joint (**604**) and may substantially isolate the filet bond (**128**) from asymmetric bending during application of a tension test load (**500**) to the fillet bond (**128**).

SYSTEM AND METHOD FOR TESTING A FILLET BOND

FIELD

[0001] The present disclosure relates generally to structural testing and, more particularly, to testing systems for characterizing the tension test load-carrying capability of fillet bonds between two structural components.

BACKGROUND

[0002] Adhesive bonding of structural components provides several advantages over mechanical fastening. For example, adhesive bonding results in a more uniform stress distribution across a bonded joint relative to the stress distribution across a mechanically-fastened joint. In addition, adhesive forms a barrier between structural components which may avoid undesirable effects that may be associated with mechanical joints wherein dissimilar materials are in direct contact with one another. Adhesive bonding of structural components may also reduce assembly costs and provide increased fatigue life relative to the assembly costs and fatigue life associated with mechanically-fastened joints.

[0003] A fillet bond is a type of adhesive bond between a curved surface of one component and a generally flat surface of another component. In a fillet bond, adhesive material forms fillets between the joined components. The thickness of a fillet bond may vary across a bondline between the two components. Advantageously, fillet bonds may provide improved stress distribution in a joint by spreading load in the joint over a relatively large surface area.

[0004] For certain assemblies having bonded joints, it may be necessary to qualify the strength-carrying capability of the bonded joints prior to placing the assembly into service. For example, prior to certifying an aircraft, it may be necessary to qualify bonded joints in primary load-carrying structure of the aircraft. Qualifying the bonded joints may include verifying that the margins of safety of the bonded joints are within design limits. The margins of safety may be determined by applying loads to test specimens of the bonded joint wherein the loads simulate actual loads to which the bonded joint may be subjected during the service life of the joint.

[0005] Certain structures may be subjected to in-service loads that place a fillet bond in tension pulloff (e.g., out-of-plane) loads. One such structure that may be subjected to tension pulloff loads is a skin panel having a plurality of stiffeners positioned in spaced relation to one another on one side of the skin panel. Each one of the stiffeners may be bonded to the skin panel with a fillet bond extending along a length of the stiffener. During service, the tension pulloff load may be distributed generally uniformly across the skin panel and may cause the fillet bonds to be loaded in tension.

[0006] Conventional testing apparatuses for testing the load-carrying capability of bonded joints are generally directed toward flat-bond geometry between two generally planar components. Adhesive material in such flat-bond geometry may have a generally uniform thickness across the bonded joint. Conventional testing apparatuses may include a generally flat backing plate that may be mounted to an outer surface of a test specimen having a flat-bond geometry. The testing apparatus may be mounted within a testing machine. The test specimen may be instrumented with strain gauges so that strain measurements may be recorded during application of a test load. The strain levels may be converted to stress. The test specimen may be tested to failure and the stress levels at failure may be correlated to strength values of the bonded joint.

[0007] Unfortunately,, conventional testing apparatuses using backing plates may not provide an accurate duplication of the forces induced in a fillet bond. For example, for the above-mentioned structural assembly having stiffeners bonded to a skin panel, tension pulloff loads on the skin panel may induce bending loads in the test specimen at the fillet bonds. Although conventional testing apparatuses may be adequate for applying a tension test load to a fillet bond in a test specimen, the stiffness of the backing plate prevents the generation of bending loads in the test specimen.

[0008] A further drawback associated with conventional testing apparatuses is that eccentric or asymmetric loading may be produced in a test specimen. Such asymmetric loading may be caused by manufacturing tolerances of the test specimen, by misalignment of the test specimen with the testing machine, or due to other factors. The occurrence of asymmetric loading may minimize the repeatability of testing conditions across a plurality of test specimens and may compromise the accuracy of test results.

[0009] As can be seen, there exists a need in the art for a testing apparatus and method that may substantially duplicate the loading conditions in a fillet bond during application of a tension to the fillet bond. In this regard, there exists a need in the art for a testing apparatus and method capable of accurately inducing symmetric bending in a fillet bond during application of a tension test load. Ideally, the testing apparatus may avoid the need for measuring strain in a test specimen and then correlating the strain to stress for determining the strength capability of the fillet bond.

SUMMARY

[0010] The above-noted needs associated with structural testing of fillet bonds are specifically addressed and alleviated by the present disclosure which provides a testing apparatus for characterizing a tension strength of a fillet bond joining a stiffener component to a skin component of a test specimen. The testing apparatus may include a lower fixture configured to maintain the stiffener component in a fixed position, and an upper fixture configured to engage the skin component at a pair of engagement locations on opposite sides of the fillet bond. The testing apparatus may additionally include a gimbal joint mechanically coupled to the upper fixture and configured to substantially isolate the fillet bond from asymmetric bending during application of a tension test load to the fillet bond.

[0011] In a further embodiment, disclosed is a testing apparatus for characterizing a tension strength of a fillet bond. The testing apparatus may include a lower fixture and an upper fixture. The lower may maintain the stiffener component in a fixed position. The upper fixture may have a pair of load pins oriented generally parallel to one another and configured to engage an inner surface (304) of the skin component at a pair of discrete engagement locations on opposite sides of the fillet bond. The testing apparatus may include a gimbal joint mechanically coupled to the upper fixture and configured to substantially isolate the fillet bond from asymmetric bending during application of a tension test load to the fillet bond. The engagement locations may be positioned such that fillet

edges of the fillet bond are subjected to a moment-shear ratio that is substantially equivalent to the moment-shear ratio at the fillet edges of a structural assembly subjected to a uniformly distributed tension pulloff load

[0012] Also disclosed is a method of characterizing a tension strength of a fillet bond joining a stiffener component to a skin component of a test specimen. The method may include the steps of placing the test specimen in a testing apparatus, and fixedly positioning a stiffener component of the test specimen. The method may further include engaging the skin component at a pair of engagement locations on opposite sides of the fillet bond, and applying a tension test load to the fillet bond at the engagement locations. The method may additionally include substantially isolating the fillet bond from asymmetric bending when applying the tension test load.

[0012a] In one embodiment there is provided a testing apparatus for characterizing a tension strength of a fillet bond joining a stiffener component to a skin component of a test specimen, the fillet bond having a fillet face on each one of opposing sides of the fillet bond. The apparatus includes a lower fixture configured to maintain the stiffener component in a fixed position, an upper fixture having a pair of engagement devices positionable on opposite sides of the fillet bond and configured to engage the skin component at substantially equal distances from the fillet faces such that substantially equivalent tension forces are applied to the skin component on each side of the fillet bond during application of a tension test load on the test specimen and a gimbal joint mechanically coupled to the upper fixture and configured to substantially isolate the fillet bond from asymmetric bending during application of the tension test load to the fillet bond.

[0012b] The engagement devices may be mechanically coupled to the gimbal joint.

[0012c] The engagement devices may include cylindrical load pins engageable to an inner surface of the skin component on opposite sides of the fillet bond and the load pins may be oriented substantially parallel to a length of the fillet bond.

[0012d] The stiffener component may include a base portion and at least two legs extending outwardly from the base portion and the lower fixture may be configured to fixedly clamp the legs in the fixed position in a manner preventing vertical and lateral movement of the legs.

[0012e] The lower fixture may include an outer clamping block and an inner clamping block configured to clamp a pair of legs therebetween.

[0012f] The lower fixture may include an adjustment mechanism for adjusting a position of the inner clamping block relative to the outer clamping block such that the inner and outer clamping block are movable into clamping engagement with respective ones of inner and outer surfaces of the legs.

[0012g] The fillet bond of the test specimen may be configured substantially similar to a fillet bond of a structural assembly having a plurality of panel stiffeners adhesively bonded to a skin panel subjected to a substantially uniformly-distributed tension pulloff load acting on the skin panel, the fillet bond of the structural assembly having fillet edges on opposite sides of the fillet bond. The fillet bond may have a fillet edge on opposite sides of the fillet bond and each one of the engagement devices may be substantially equidistantly positioned at a distance from the fillet bond such that the fillet edges are subjected to a moment-shear ratio that is substantially equivalent to the moment-shear ratio at the fillet edges of the structural assembly.

[0012h] At least one adjacently-disposed pair of the panel stiffeners of the structural assembly may be spaced apart from one another at a stiffener pitch and the engagement devices of the test specimen may be spaced apart from one another at an engagement location spacing that is less than the stiffener pitch.

[0012i] The skin component may have a generally planar configuration.

[0012j] In another embodiment there is provided a testing apparatus for characterizing a tension strength of a fillet bond joining a stiffener component and a skin component of a test specimen, the fillet bond having a fillet face on each one of opposing sides of the fillet bond. The apparatus includes a lower fixture configured to maintain the stiffener component in a fixed position and an upper fixture having a pair of load pins being oriented generally parallel to one another and configured to engage an inner surface of a skin component at substantially equal distances from the fillet faces such that substantially equivalent tension forces are applied to the skin component on each side of the fillet bond during application of a tension test load on the test specimen. The apparatus also includes a gimbal joint mechanically coupled to the upper fixture and being configured to substantially isolate the fillet bond from asymmetric bending during application of the tension test load to the fillet bond and the load pins being positioned such that fillet edges of the fillet bond are subjected to a moment-shear ratio that is substantially equivalent to the moment-shear ratio at the fillet edges of a structural assembly subjected to a uniformly distributed tension pulloff load.

[0012k] In another embodiment there is provided a method of characterizing a tension strength of a fillet bond joining a stiffener component to a skin component of a test specimen, the fillet bond having a fillet face on each one of opposing sides of the fillet bond. The method involves placing the test specimen in a testing apparatus, fixedly positioning a stiffener component in a lower fixture of the test specimen and engaging the skin component using a pair of engagement devices of an upper fixture of the testing apparatus, the engagement devices being positioned on opposite sides of the fillet bond at substantially equal distances from the fillet faces. The method also involves applying a tension test load to the fillet bond using the pair of engagement devices, applying, using the engagement devices, substantially equivalent tension forces to the skin component on each side of the fillet bond during application of the tension test load and substantially isolating the fillet bond from asymmetric bending when applying the tension test load.

[0012l] Engaging the skin component using the pair of engagement devices may involve engaging an inner surface of the skin component using the pair of engagement devices.

[0012m] Engaging the skin component may involve engaging the skin component with two substantially parallel load pins in contact with an inner surface of the skin component on opposite sides of the fillet bond in an orientation substantially parallel to a length of the fillet bond and mechanically coupling the load pins to a gimbal joint.

[0012n] The method further involves preventing lateral and vertical movement of a pair of legs of the stiffener component.

[0012o] Preventing lateral and vertical movement of each one of a pair of legs may involve clamping the legs between an outer clamping block and an inner clamping block.

[0012p] The method may further involve adjusting, using an adjustment mechanism, a position of the inner clamping block relative to the outer clamping block such that the inner and outer clamping blocks are movable into clamping engagement with inner and outer surfaces of the legs.

[0012q] The method may further involves determining a static tension test load-carrying capability of the fillet bond by dividing a bond length by a magnitude of the tension test load recorded at failure of the fillet bond.

[0012r] Each one of the sides of the fillet bond may include a fillet edge at an adhesive-skin interface, and engaging the skin component may involve selecting a moment-shear ratio for the fillet edge comprising a ratio of a bending moment to a shear force at the fillet edge, the moment-shear ratio being substantially equivalent to a moment-shear ratio at a fillet edge of a structural assembly under a substantially uniformly-distributed tension pulloff load acting on a skin panel stiffened by panel stiffeners and positioning the engagement devices on each side of the fillet bond such that the tension test load on each side of the fillet bond causing the fillet edge to be subjected to the moment-shear ratio when applying the tension test load.

[0012s] Each side of the fillet bond may include a fillet edge at an adhesive-skin interface, and engaging the skin component may involve locating each one of the engagement devices at a distance from the fillet edge such that the fillet bond at each one of the fillet edges is subjected to the moment-shear ratio.

[0012t] The step of engaging the skin component may involve positioning the engagement devices at an engagement location spacing that is less than a stiffener pitch between at least one adjacently-disposed pair of panel stiffeners of a structural assembly under a substantially uniformly-distributed tension pulloff load acting on the skin panel.

[0013] The features, functions and advantages that have been discussed can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments, further details of which can be seen with reference to the following description and drawings below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] These and other features of the present disclosure will become more apparent upon reference to the drawings wherein like numbers refer to like parts throughout and wherein:

[0015] Figure **1** is a perspective view of a structural assembly having a skin panel in a plurality of stiffeners bonded thereto;

[0016] Figure **2** is a perspective view of a fillet bond bonding one of the stiffeners to the skin panel;

[0017] Figure **3** is a side view of the structural assembly of Figure **1** illustrating the stiffeners spaced apart from one another at a Stiffener pitch;

[0018] Figure **4** is a side view of the structural assembly in a loaded condition wherein a tension pulloff load is applied to the skin panel;

[0019] Figure **5** is a side view of the fillet bond between one of the stiffeners and the skin panel;

[0020] Figure **6** is a perspective view of a test specimen having a stiffener component bonded to a skin component using a fillet bond wherein the test specimen may represent the fillet bond between a panel stiffener and the skin panel of the structural assembly;

[0021] If Figure **7** is a side view of the test specimen of Figure **6** wherein the test specimen is inverted and illustrating opposing sides of the fillet bond having fillet faces each having a concave configuration;

[0022] Figure **8** is a side view of a fillet bond having fillet faces having a flat or planar configuration and oriented at a non-perpendicular angle relative to the skin component;

[0023] Figure **9** is a side view of a fillet bond having fillet faces having a planar configuration and oriented at a perpendicular angle relative to the skin component;

[0024] Figure **10** is a side view of a universal testing machine having an embodiment of a testing apparatus mounted to the universal testing machine;

[0025] Figure **11** is a side view of the testing apparatus having a fillet bond test specimen mounted therewithin ;

[0026] Figure **12** is a perspective view of a testing apparatus;

[0027] Figure **13** is a section view of the testing apparatus including an upper fixture and a lower fixture for fixedly positioning the test specimen therewithin;

[0028] Figure **14** is an enlarged view of the upper and lower fixture in illustrating a gimbal joint coupled to the upper fixture;

[0029] Figure **15** is a side view of the fillet bond between the stiffener component and the skin component;

[0030] Figure **16** is a side view of the testing apparatus and illustrating side plates mounted on opposite sides of the upper fixture;

[0031] Figure **17** is a bottom end view of the testing apparatus;

[0032] Figure **18** is a flowchart illustrating one or more operations that may be included in a method for characterizing a tension strength of a fillet bond;

[0033] Figure **19** is a side view of a test specimen having a skin component oriented at an angular offset relative to a nominal orientation of the skin component;

[0034] Figure **20** is a side view of a test specimen mounted within a testing apparatus having a gimbal joint for isolating the test specimen from asymmetric bending and asymmetric shear;

[0035] Figure **21** is a side view of the test specimen subjected to a tension test load and illustrating the reorientation of the upper fixture such that the load pins applying a substantially equivalent tension force to each side of the fillet bond;

[0036] Figure **22** is a loading diagram of the test specimen and illustrating symmetric bending and symmetric shear in the test specimen as a result of the reorientation of the upper fixture through the gimbal joint;

[0037] Figure **23** is a side view of the test specimen of Figure **19** mounted within a testing apparatus lacking a gimbal joint;

[0038] Figure **24** is a side view of the test specimen subjected to a tension test load and illustrating increased bending on one side of the fillet bond relative to the bending on an opposite side of the fillet bond due to the angular offset of the skin component relative to a nominal orientation of the skin component; and

[0039] Figure **25** is a loading diagram of the test specimen of Figure **24** and illustrating asymmetric bending and asymmetric shear in the test specimen.

DETAILED DESCRIPTION

[0040] Referring now to the drawings wherein the showings are for purposes of illustrating various embodiments of the present disclosure, shown in Figure **1** is perspective illustration of a structural assembly **100** having a plurality of panel stiffeners **108** adhesively bonded to a skin panel **102** with fillet bonds **128**. In Figure **1**, the skin panel **102** includes an inner surface **104** and an outer surface **106**. The panel stiffeners **108** may be bonded to the inner and/or outer surfaces **104, 106** of the skin panel **102**. The fillet bonds **128** may extend along a length of the panel stiffeners **108** and may define a skin-stiffener joint **126** for structurally bonding the panel stiffeners **108** to the skin panel **102**. Although shown as being generally straight, the panel stiffeners **108** may be curved. The structural assembly **100** may be implemented in any one of a variety of different applications. For example, the structural assembly **100** may be implemented in an aircraft. However, the structural assembly **100** may be implemented in any vehicular or non-vehicular application, without limitation.

[0041] The present disclosure provides a testing apparatus **600** (Figure **11**) and a test specimen **300** (Figure **6**) that may advantageously be implemented for characterizing a tension strength of a fillet bond **128** at a skin-stiffener joint **126** of a structural assembly **100**. The test specimen **300** may be configured to substantially duplicate the structure and/or geometry of the fillet bond **128** in a structural assembly **100** between a panel stiffener **108** and a skin panel **102**. The testing apparatus **600** advantageously provides a means for applying a tension test load **500** (Figure **13**) to a test specimen **300** while isolating a fillet bond **328** (Figure **6**) from asymmetric bending moments **510'** (Figure **25**) and/or asymmetric shear forces **512'** (Figure **25**) as described in greater detail below. In addition, the testing apparatus **600** also advantageously provides a means for accurately characterizing the tension bond strength of a fillet bond **328** with a high degree of repeatability and with minimal scatter and disparity in test data for a plurality of substantially similar test specimens. The bond strength of the fillet bond **328** may advantageously be characterized in terms of force unit per unit length such as pounds per inch which may facilitate the determination of the margins of safety of fillet bonds **328** for joint qualification and/or aircraft certification.

[0042] Referring to Figure **2**, shown is a perspective view of a portion of a fillet bond **128** adhesively bonding one of the panel stiffeners **108** to the skin panel **102** of the structural assembly **100**. The panel stiffener **108** is shown having a pair of legs **118** extending outwardly from a base portion **112** and forming a V-shape configuration. The base portion **112** is shown having a generally curved cross-sectional shape **114**. Each one of legs **118** of the panel stiffener **108** may have an inner surface **120** and an outer surface **122**. The apex **116** of the outer surface **106** of the base portion **112** may be disposed in substantially contacting relation to the inner surface **104** of the skin panel **102** at the fillet bond **128**. The fillet bonds **128** may include a fillet face **130** on each one of the opposing sides of the fillet bond **128**. Each one of the fillet faces **130** may have a fillet edge **132** at an adhesive-skin interface **134** and a fillet edge **132** at an adhesive-stiffener interface **136**.

[0043] Referring to Figure **3**, shown is a side view of the structural assembly **100** of Figure **1** illustrating the plurality of panel stiffeners **108** adhesively bonded to the inner surface **104** of the skin panel **102**. The panel stiffeners **108** may be positioned in spaced relation to one another. For example, the panel stiffeners **108** may be spaced apart from one another at a uniform distance between the stiffener axes **123** defining a stiffener pitch **124**. However, the panel stiffeners **108** may be provided at non-uniform spacings or at a combination of uniform and non-uniform spacings. In the embodiment shown, the panel stiffeners **108** may be formed of a fiber-reinforced material such as carbon fiber reinforced polymeric material. The skin panel **102** may be formed of a metallic material. However, the panel stiffeners **108** and the skin panel **102** may be formed of carbon fiber reinforced polymeric material, ceramic material, metallic material, or any combination thereof.

[0044] Referring to Figure **4**, shown is a side view of the structural assembly **100** with a plurality of panel stiffeners **108** bonded to the skin panel **102** and spaced apart from one another at a stiffener pitch **124** (Figure **3**). A substantially uniformly-distributed tension pulloff load **200** is applied to the skin panel **102** which is reacted by a reaction force **202** at each one of the panel stiffeners **108**. The testing apparatus **600** (Figure **11**) may be configured to duplicate, in the test specimen, the loading conditions that occur at the fillet bond **128** of a skin-stiffener joint **126** (Figure **3**) between the skin panel **102** and a panel stiffener **108** during application of a substantially uniformly distributed tension pulloff load **200**. In this regard, the testing apparatus **600** advantageously provides a means for substantially duplicating the internal loads induced in the structural assembly **100** at the fillet bond **128** including the bending moment **204** (Figure **5**), the out-of-plane and/or in-plane shear force **206** (Figure **5**), and the tension load at a given location in the fillet bond

128 in response to a distributed load applied to the skin panel **102** stiffened with panel stiffeners **108.**

[0045] Advantageously, the testing apparatus **600** (Figure **11**) provides a means for substantially duplicating the stresses occurring in the fillet bond **128** including peel loads at the fillet edges **132** (Figure **2**), shear stress and tension stress (e.g., mode I) at the adhesive-skin interface **134** (Figure **2**) due to bending loads in the skin component, stress within the adhesive, and other stresses. The test specimen **300** (Figure **6**) may be configured such that the fillet bond **328** (Figure **6**) is substantially similar to the fillet bond **128** in the structural assembly **100** represented by the test specimen **300**. In this regard, the adhesive material **138** (Figure **2**) in the fillet bond **328** of the test specimen **300** may have bulk mechanical properties (e.g., strength, modulus of elasticity) that are similar to the bulk mechanical properties of the adhesive material **138** in the fillet bond **128** of the structural assembly **100.** In addition, the skin component **302** (Figure **6**) and the stiffener component **308** (Figure **6**) of the test specimen **300** may have the same type and quality of surface treatment at the area of the fillet bond **328** as in the fillet bonds **128** of the structural assembly **100.**

[0046] Referring to Figure **5**, shown is a side view of the fillet bond **128** between the skin panel **102** and the base portion **112** of one of the panel stiffeners **108.** The fillet bond **128** includes fillet faces **130** on opposing sides of the fillet bond **128.** Although the fillet faces **130** are shown with a generally concave shape or configuration, the fillet faces **130** may be provided in any configuration including a planar configuration, a convex configuration, or any other shape or configuration. The apex **116** of the base portion **112** may be disposed in substantially contacting relation to the skin panel **102.** Alternatively, the apex **116** may be positioned in slightly spaced relation with the skin panel **102** and a film of adhesive may extend between the apex **116** and the skin panel **102.** The fillet bond **128** may include a fillet face **130** and a fillet edge **132** on each side of the fillet bond **128** at an adhesive-skin interface **134.**

[0047] Figure **5** further illustrates internal loads induced in the structural assembly **100** during application of a distributed tension pulloff load **200** applied to the skin panel **102** and reacted by a reaction force **202** at the panel stiffener **108.** The internal loads may include a bending moment **204** and an out-of-plane shear force **206** on each side of the fillet bond **128** at each one of the fillet edges **132**. Due to their distance form the stiffener axis **123**, the fillet edges **132** on each side of the fillet bond **128** may comprise locations where induced loads within the fillet bond **128** or at the adhesive-skin interface **134** are relatively high.

[0048] Advantageously, the testing apparatus **600** (Figure **11**) disclosed herein provides a means for substantially duplicating the magnitude of the bending moment **204** (Figure **5**) and the magnitude of the shear force **206** (Figure **5**) induced in the fillet bond **128** (Figure **5**) in response to the application of a distributed tension pulloff load **200** (Figure **5**) to a skin panel **102**. In this regard, the testing apparatus **600** provides a means for substantially duplicating a moment-shear ratio at a given location along the fillet bond **128** of a skin panel **102** stiffened with panel stiffeners **108**. For example, the testing apparatus **600** provides a means for substantially duplicating the moment-shear ratio at the fillet edges **132** on opposite sides of the fillet bond **128** of a structural assembly **100** at the adhesive-skin interface **134** where induced loads may be relatively high and which may correspond to relatively high stresses within the adhesive material **138**, at the adhesive-skin interface **134**, and/or within the skin panel **102** material or panel stiffener **108** material.

[0049] Referring to Figure **6**, shown is a perspective view of a test specimen **300** which may be configured to represent a fillet bond **128** (Figure **5**) between a panel stiffener **108** (Figure **5**) and a skin panel **102** (Figure **5**) of a structural assembly **100** (Figure **5**). The test specimen **300** may include the stiffener component **308** and the skin component **302** joined at a skin-stiffener joint **326** with a fillet bond **328** extending along a fillet bond length **324** which may be substantially equivalent to the width of the test specimen **300**. The skin component **302** may have inner and outer surfaces **304, 306**. The stiffener component **308** may include inner and outer surfaces **320, 322** and a base portion **312** interconnecting a pair of legs **318** extending outwardly from the base portion **312**. The legs **318** may be symmetrical about a stiffener axis **323**. The fillet bond **328** may include a fillet face **330** on each one of the opposing sides of the fillet bond **328**. Each one of the fillet faces **330** may have a fillet edge **332** at an adhesive-skin interface **334** and a fillet edge **332** at an adhesive-stiffener interface **336**. The fillet faces **330** are shown having a concave **340** configuration.

[0050] The stiffener component **308** may have a geometry that may be substantially similar to the geometry of the panel stiffener **108** (Figure **5**) at least in the area of the fillet bond **128** (Figure **5**) of the structural assembly **100** (Figure **5**). Likewise, the skin component **302** may have a geometry that is substantially similar to the geometry of the skin panel **102** (Figure **5**) at least in the area of the fillet bond **128** of the structural assembly **100**. For example, the skin component **302** may have a generally planar configuration to substantially duplicate the planar geometry of the skin panel **102** of the structural assembly **100**. In an embodiment, the stiffener component **308** and the skin component **302** of the test specimen **300** may be formed of materials that are substantially similar to the materials from which the panel stiffener **108** and the skin panel **102** are formed to improve the accuracy of the tension test results.

[0051] Figure **7** is a side view of the test specimen **300** oriented such that the legs **318** of the stiffener component **308** extend generally downwardly from the fillet bond **328** in a V-shaped configuration. The test specimen **300** may be generally symmetrical about a stiffener axis **323** although the test specimen **300** may be asymmetric. In the embodiment shown, the stiffener axis **323** may bisect an angle formed between the legs **318** of the stiffener component **308**. However, the legs **318** of the stiffener component **308** may be formed in any configuration that substantially duplicates the geometry of the legs **118** (Figure **5**) of a panel stiffener **108** (Figure **5**), at least in the area a fillet bond **128** (Figure **5**) of a structural assembly **100** (Figure **5**). Likewise, the skin component **302** may be formed in any configuration that substantially duplicates the geometry of the skin panel **102** (Figure **5**) of a structural assembly **100**, at least in the area of a fillet bond **128** of the structural assembly **100**.

[0052] Figure **8** shows a test specimen **300** with a fillet bond **328** having fillet faces **330** with a generally planar **342** configuration oriented at a non-perpendicular angle relative to the inner surface **304** of the skin component **302**. Figure **9** shows a test specimen **300** with a fillet bond **328** having fillet faces **330** with a planar **342** configuration and oriented at a generally perpendicular angle relative to the skin component **302**. As may be appreciated, the fillet bond **328** in a test specimen **300** may be configured such that the fillet faces **330** are provided with any one of a variety of different configurations that may substantially duplicate the fillet bond **128** (Figure **5**) between a panel stiffener **108** (Figure **5**) and a skin panel **102** (Figure **5**) of a structural assembly **100** (Figure **5**). In test specimen **300** disclosed herein, the thickness of the fillet bond **328** may vary from one side of the fillet bond **328** to an opposite side of the fillet bond **328** as shown in Figure **8**. Advantageously, the testing apparatus **600** (Figure **10**) provides a means for accurately characterizing the tension strength of variable thickness fillet bonds **328**.

[0053] Figure **10** is a side view of a universal testing machine **400** having a testing apparatus **600** mounted therewithin. In the embodiment shown, a test specimen **300** (Figure **6**) may be mounted within the testing apparatus **600** for testing the static tension strength of a fillet bond **328** (Figure **6**) of the test specimen **300**. The testing apparatus **600** may support the test specimen **300** during application of a tension test load **500** to the test specimen **300** to characterize the tension load-carrying capability of the fillet bond **328**. However, the testing apparatus **600** is not limited to static tension testing and may be implemented for performing durability and/or fatigue testing of the fillet bond **328**.

[0054] In Figure **10**, the universal testing machine **400** may include a relatively rigid base **402** which may be mounted on a surface such as a bench or a floor of a test laboratory. The universal testing machine **400** may include a plurality of posts or columns **404** that may extend upwardly from the base **402**. A crosshead **406** may extend across the columns **404**. The crosshead **406** may be vertically movable for applying a tension test load **500** on the test specimen **300**. The universal testing machine **400** may include an engagement mechanism such as a hydraulic grip **412** for gripping the gimbal rod **606** and a hydraulic grip **412** for gripping the shaft **648** of the testing apparatus **600**. The hydraulic grips **412** may be quickly engaged and disengaged from the shaft **648** and the gimbal rod **606** to allow for relatively quick change-out of test specimens **300**.

[0055] The universal testing machine **400** may include an actuator **414** for moving the crosshead **406** up and down for applying a tension test load **500** to the test specimen **300** mounted within the testing apparatus **600**. The actuator **414** may be hydraulically powered, electrically powered, mechanically powered or a combination thereof or the actuator **414** may be powered by other suitable means. The universal testing machine **400** may include an axial load measuring device **408** such as a load cell. In the embodiment shown, the load measuring device **408** may be coupled to an upper rod end **608** of a gimbal rod **606** extending upwardly from a gimbal joint **604** included with the upper fixture **602** of the testing apparatus **600** as described below. The load cell may be configured to measure a magnitude of the tension test load **500** that may be applied to the test specimen **300** along a loading axis **410**.

[0056] Figure **11** is a side view of the testing apparatus **600**. The testing apparatus **600** may include a lower fixture **634** and an upper fixture **602**. The lower fixture **634** may be configured to fixedly position or clamp the stiffener component **308** (Figure **6**) in position to prevent vertical and/or lateral movement thereof. The lower fixture **634** may include an outer clamping block and an inner clamping block **644**. The outer clamping block may include a shaped cutout **642** for receiving the inner clamping block **644**. The shaped cutout **642** of the outer clamping block and the inner clamping block **644** may be configured complementary to the geometry of the legs **318** of the test specimen **300**.

[0057] The upper fixture **602** may be configured to engage the skin component **302** (not shown) at a pair of discrete engagement locations **626** (Figure **13**) on opposite sides of the fillet bond **328** (Figure **6**) of the test specimen **300** (Figure **6**). For example, the upper fixture **602** may include a pair of engagement devices **622** such as load pins **624** that may be positionable at the engagement locations **626** for applying a tension force **504** (Figure **14**) to the skin component **302** (Figure **6**) during application of a tension test load **500** through the gimbal rod **606**. The engagement locations **626** may be spaced apart at an engagement location spacing **628** that may be selected to provide a desired moment-shear ratio at a given location in the fillet bond **328** such as at the fillet edges **332** of the adhesive-skin interface **334**.

[0058] Figure **12** is a perspective view of the testing apparatus **600** illustrating a pair of side plates **630** that may be mounted on opposite sides of a gimbal plate **614** of the upper fixture **602**. The side plates **630** may couple the engagement devices **622** (e.g., the load pins **624**) to the gimbal joint **604**. Each one of the side plates **630** includes pin bores **632** for receiving the load pins **624**. The engagement devices **622** such as the load pins **624** may extend underneath the skin component **302** (Figure **13**). The plate pins **620** may couple the side plates **630** to the gimbal plate **614**. When the actuator **414** (Figure **10**) of the universal testing machine **400** (Figure **10**) applies a tension test load **500** (Figure **10**), the load pins **624** may be placed into contact with the inner surface **304** (Figure **6**) of the skin component **302** (Figure **6**) at engagement locations **626** (Figure **13**).

[0059] In Figure **13**, the load pins **624** may be located at the engagement locations **626** which may be positioned at substantially equivalent distances from the fillet bond **328** on opposite sides thereof such that a substantially equivalent tension force **504** may be applied to the skin component **302** on each side of the fillet bond **328**. The engagement location spacing **628** (Figure **11**) may be defined as the distance between the locations where tension force **504** is applied by the load pins **624**. The load pins **624** may apply the tension force **504** to the skin component **302** as a point load or as a line load on each side of the fillet bond **328**.

[0060] In an embodiment, the engagement location spacing **628** may be less than the stiffener pitch **124** (Figure **3**) of an adjacently-disposed pair of the panel stiffeners **108** (Figure **3**) of a structural assembly **100** (Figure **3**) represented by the test specimen **300**. The engagement spacing **628** may be such that the skin component **302** may be loaded in bending and shear at a magnitude that is substantially equivalent to the bending and shear in the skin panel **102** (Figure **3**) at a fillet bond **128** (Figure **3**) of the structural assembly **100**. The testing apparatus **600** may be configured such that the side plate having pin bores **632** that are spaced at one engagement location spacing **628** may be removed and replaced with a side plate having pin bores **632** spaced at a different engagement location spacing **628**. By installing side plates **630** with a desired engagement location spacing **628** between the pin bores **632**, a desired moment-shear ratio may be induced in the test specimen **300** at a given location (e.g., at the fillet edges **332**) of the fillet bond **328** during tension testing.

[0061] Figure **13** is a cross-sectional view of the testing apparatus **600** illustrating the interconnectivity of the upper and lower fixture **634** and the test specimen **300**. The lower fixture **634** may be configured to clamp the stiffener component **308** (Figure **6**) in a fixed position as indicated above. The stiffener component **308** may include the base portion **312**

(Figure **6**) and at least two legs **318** extending outwardly from the base portion **312**. In the embodiment shown, the base portion **312** may have a generally curved cross-sectional shape **314** (Figure **6**). The base portion **312** may have an apex **316** (Figure **6**) which may be disposed in substantially contacting relation to the inner surface **304** (Figure **6**) of the skin component **306** (Figure **6**).

[0062] The legs **318** may form a V-shape with the base portion **312** (Figure **6**). The inner and outer clamping block **644**, **638** may be configured complementary to the V-shape of the legs **318**. However, the inner and outer clamping block **644**, **638** may be configured complementary to any one of a variety of different stiffener component **308** (Figure **6**) configurations and are not limited to a shape that is complementary to V-shaped legs **318**. Regardless of the shape or configuration of the stiffener component **308**, the lower fixture **634** may be configured to fixedly clamp the legs **318** in a fixed position in such a manner that vertical and lateral movement of the legs **318** is prevented.

[0063] In an embodiment, the lower fixture **634** may include an adjustment mechanism **650** for adjusting the vertical position of the inner clamping block **644** relative to the shaped cutout **642** that may be formed in the outer clamping block. For example, the adjustment mechanism **650** may comprise a threaded portion **652** formed on a shaft **648** extending downwardly from the inner clamping block **644**. The shaft **648** may have a rounded tip **656** shaped complementary to a rounded bore **646** that may be formed in the inner clamping block **644**. The shaft **648** may extend downwardly from the inner clamping block **644** and may terminate at a hex end **660** (Figure **12**).

[0064] The threaded portion **652** may be threadably engaged to a threaded hole **658** formed in the outer clamping block **638**. Rotation of a hex end **660** may facilitate adjustment of the position of the inner clamping block **644** along an axial adjustment direction **654** such that the inner and outer clamping block **644**, **638** are movable into clamping engagement with respective ones of the inner and outer surfaces **320**, **322** of the legs **318**. In this manner, the test specimen **300** may be snugly clamped between the inner clamping block **644** and the outer clamping block **638**. In addition, the threaded engagement of the shaft **648** with the outer clamping block **638** may facilitate relatively rapid installation and removal of different test specimens **300** when testing a large quantity of test specimens **300**.

[0065] Referring to Figure **14**, the testing apparatus **600** may include a gimbal joint **604** that may be mechanically coupled to the upper fixture **602** via the gimbal plate **614**. The gimbal plate **614** may include pin bores **632** that may be sized and configured for receiving a corresponding quantity of plate pins **620** coupling the gimbal plate **614** to the side plates **630**. As indicated earlier, each one of the side plates **630** may include pin bores **632** for receiving engagement devices **622** such as the load pins **624** illustrated in Figure **14**. The load pins **624** and the plate pins **620** may be cylindrically shaped although the load pins **624** and plate pins **620** may be provided in a non-cylindrical embodiment. The outer clamping block **638** may include pin recesses **640** to provide clearance for the load pins **624**. The load pins **624** may be oriented substantially parallel to a length of the fillet bond **328**. The load pins **624** may be sized to provide resistance against bending of the load pins **624** during application of the tension force **504** to the inner surface **304** (Figure **6**) the skin component **302** (Figure **6**).

[0066] In Figure **14**, the gimbal joint **604** may be configured to substantially isolate the fillet bond **328** from asymmetric bending **510'** (Figure **25**) and from asymmetric shear **512'** (Figure **25**) as described in greater detail below. The gimbal joint **604** may include a gimbal rod **606**. The gimbal rod **606** may extend upwardly through an aperture **618** formed in the gimbal plate **614**. The gimbal rod **606** may have an upper rod end **608** and a lower rod end **610**. The upper rod end **608** may be mechanically coupled to the load measuring device **408** (Figure **10**) such as the load cell illustrated in Figure **10**. The lower rod end **610** may have a spherical convex surface **612** that may be slidably engageable to a spherical concave surface **616** formed in the gimbal plate **614** such as on an underside of the gimbal plate **614**. The gimbal plate **614** may be universally rotatable relative to the lower rod end **610**. Application of the tension test load **500** through the upper fixture **500** may result in a reaction force **502** in the lower fixture **600**.

[0067] It should be noted that the configuration of the gimbal joint **604** illustrated in Figure **13** is not to be construed as limiting alternative configurations for the gimbal joint **604**. In this regard, the gimbal joint **604** may be provided in any configuration that may facilitate reorientation **662** (Figure **21**) of the gimbal plate **614** and the engagement devices **622** in a manner allowing the engagement devices **622** (e.g., load pins **624**) to apply a substantially equivalent tension force **504** to the engagement locations **626** on opposite sides of the fillet bond **328** of the test specimen **300**. The gimbal joint **604** shown in Figure **14** may be configured to provide a substantially universally angular range of motion relative to the tension loading axis **410** (Figure **10**).

[0068] In addition, the testing apparatus **600** may be configured such that the tension test load **500** is applied to the test specimen **300** through the gimbal joint **604** regardless of the angular orientation of the gimbal plate **614** and the engagement devices **622**. Advantageously, the gimbal joint **604** may be configured such that the test specimen **300** is substantially isolated from the introduction of the above-mentioned asymmetric bending moments **510'** (Figure **25**) and asymmetric shear forces **512'** (Figure **25**) into the test specimen **300**. The gimbal joint **604** may be configured to accommodate misalignment of the test specimen **300** with the universal testing machine **400** (Figure **10**). Such misalignment may be caused by manufacturing tolerances in the test specimen **300** or misalignments associated with the testing apparatus **600** and/or the universal testing machine **400**. Advantageously, the gimbal joint **604** may improve the repeatability of applying a tension test load **500** to a plurality of test specimens **300**. In this regard, the gimbal joint **604** may increase the accuracy of the test results.

[0069] Referring to Figure **15**, shown is a side view of the fillet bond **328** between the stiffener component **308** and the skin component **302** and illustrating the bending moment **506** and out-of-plane shear force **508** that may be induced in the fillet bond **328** in response to the application of the tension force **504** (Figure **14**) on opposite sides of the fillet bond **328** as shown in Figure **14**. The tension force **504** applied by the load pins **624** (Figure **14**) to the skin component **302** at the engagement locations **626** (Figure **14**) on opposite sides of the bond line results in a pulling force being exerted on the fillet bond **328**. As indicated above, each one of engagement locations **626** represents the location of the tension force **504** applied as a point load or a line load to the inner surface **320** of the skin component **302**. Application of the tension force **504** allows the skin component **302** to bend in a manner similar to bending that may occur in the skin panel **102** (Figure **5**) of the structural assembly **100** as shown in Figure **5**. The tension force **504** applied to the skin component **302** may also result in an out-of-plane shear force **508** induced in the skin component **302** and/or fillet bond **328**.

[0070] As indicated above, the engagement locations **626** (Figure **14**) may be spaced apart at an engagement location spacing **628** (Figure **14**) such that the bending moment **506** and the shear force **508** have a magnitude that is substantially similar to a magnitude of the bending moment **204** and shear force **206** induced in the fillet bond **128** of a structural assembly **100** subjected to a distributed tension pulloff load **200** as shown in Figure **4**. In this manner, the testing apparatus **600** provides a means for substantially duplicating a desired moment-shear ratio at the fillet edges **132** (Figure **4**) of the adhesive-skin interface **134** (Figure **4**) of the structural assembly **100**. By providing a desired moment-shear ratio at the fillet edges **132**, the strength characteristics of the fillet bond **328** (Figure **14**) may be accurately determined.

[0071] Referring to Figure **16**, shown is a side view of the testing apparatus **600** illustrating the side plates **630** mounted on opposite sides of the gimbal plate **614**. The side plates **630** extend downwardly along the sides of the outer clamping block. The load pins **624** are extended through pin bores **632** formed in the side plates **630**. Although the load pins **624** are shown as being coupled to the gimbal joint **604** by means of the side plates **630** and the gimbal plate **614**, the load pins **624** may be mechanically coupled to a gimbal joint **604** in any one of a variety of different configurations. For example, the side plates **630** and the gimbal plate **614** may be formed as a unitized structure. In this regard, the load pins **624** may be mechanically coupled to the gimbal joint **604** in any manner that facilitates substantially universal orientation of the load pins **624** relative to the gimbal rod **606**.

[0072] Referring briefly to Figure **17**, shown is a bottom view looking upwardly at the lower fixture **634**. As indicated earlier, the shaft **648** (Figure **14**) may have a rounded tip **656** (Figure **14**) shaped complementary to a rounded bore **646** (Figure **14**) that may be formed in the inner clamping block **644** (Figure **14**). The shaft **648** may extend downwardly from the inner clamping block **644** (Figure **14**) and may terminate at a hex end

660. The hex end **660** may facilitate engagement of the shaft with a tool such as an open end wrench. In this manner, the hex end **660** may facilitate rotation of the shaft. Rotation of the shaft **648** may facilitate axial movement of the shaft **648** relative to the outer clamping block **638**. Axial movement of the shaft **648** relative to the outer clamping block **638** may move the inner clamping block **644** axially relative to the shaped cutout **642** in the outer clamping block **638** shown in Figure **13** in order to allow for installation and removal of a test specimen **300** from the testing apparatus **600**. Advantageously, the threaded engagement of the shaft **648** with the outer clamping block **638** facilitates relatively rapid change-out of test specimens **300** when performing a series of tension tests.

[0073] Referring to Figure **18**, shown is a flowchart having one or more operations that may be included in a method **700** of characterizing a tension strength of a fillet bond **328** (Figure **13**) joining a stiffener component **308** (Figure **15**) to a skin component **302** (Figure **13**) of a test specimen **300** (Figure **15**). Step **702** of the method may comprise installing a test specimen **300** in a testing apparatus **600**. Advantageously, the testing apparatus **600** is configured to accommodate the testing of test specimens **300** where misalignment may exist in the test specimen **300** (Figure **13**), in the testing apparatus **600** (Figure **13**), and/or in the universal testing machine **400** (Figure **10**). For example, Figure **19** illustrates a test specimen **300** having a skin component **302** (shown in solid) that is oriented at an angular offset **305** (e.g., a non-perpendicular orientation) relative to a nominal orientation **303** of the skin component **302** (shown in phantom).

[0074] Step **704** of the method **700** of Figure **18** may comprise fixedly positioning the stiffener component **308** (Figure **15**) of the test specimen **300** (Figure **13**) by mounting the legs **318** of the stiffener component **308** within the lower fixture **634**. For example, Figure **13** illustrates the length of the lower fixture **634** clamped between the inner clamping block **644** and the shaped cutout **642** in the outer clamping block **638**. Installation of a test specimen **300** in the testing apparatus **600** may comprise rotating the shaft **648** such that the inner clamping block **644** is lowered relative to the shaped cutout **642**. The test specimen **300** may be installed such that the legs **318** are sandwiched between the inner clamping block **644** and the outer clamping block **638**. The adjustment mechanism **650** may be adjusted to clamp the legs **318** between the inner and outer clamping blocks **644**, **638**. In this manner, the inner clamping block **644** may engage the inner surfaces **304** (Figure **6**) of the legs **318** and the outer clamping block **638** may engage the outer surfaces **306** (Figure **6**) of the legs **318** and thereby prevent lateral and vertical movement of the legs **318**.

[0075] Step **706** of the method **700** of Figure **18** may comprise selecting a moment-shear ratio for a fillet edge **332** (Figure **6**) of the fillet bond **328** (Figure **6**). As mentioned above, the moment-shear ratio may be selected to substantially duplicate a moment-shear ratio occurring at a fillet edge **132** of a structural assembly **100** under a substantially uniformly-distributed tension pulloff load **200** acting on a skin panel **102** stiffened by panel stiffeners **108** as illustrated in Figure **3**. The moment-shear ratio may comprise a ratio of bending moment **506** (Figure **15**) to shear force **508** (Figure **15**) induced in the skin component **302** (Figure **6**) at the fillet edge on each side of the fillet bond **328**.

[0076] Step **708** of the method **700** of Figure **18** may comprise engaging the skin component **302** at the engagement locations **626** on opposite sides of the fillet bond **328**. Figure **20** illustrates the skin component **302** on the right hand side of the test specimen **300** being engaged by the load pin **624** and the skin component **302** on the left hand side of the test specimen **300** in spaced relation above the load pin **624**.

[0077] Step **710** of the method **700** of Figure **18** may comprise positioning the engagement location **626** (Figure **20**) on each side of the fillet bond **328** (Figure **20**) such that the tension test load **500** (Figure **14**) on each side of the fillet bond **328** results in the fillet edges **332** (Figure **6**) being subjected to the moment-shear ratio when the tension test load **500** is applied through the gimbal rod **606** (Figure **20**). As indicated above, the engagement location spacing **628** (Figure **17**) may be less than the stiffener pitch **124** (Figure **3**) between the panel stiffeners **108** (Figure **3**) of a structural assembly **100** (Figure **3**) having fillet bonds **128** (Figure **3**) of a configuration that is represented by the test specimen **300** (Figure **6**). The engagement location spacing **628** may be selected to produce a bending moment **506** (Figure **15**) and a shear force **508** (Figure **15**) of a magnitude that is substantially equivalent to the magnitude of the respective bending moment **204** (Figure **5**) and shear force **206** (Figure **5**) in the skin panel **102** (Figure **3**) of the structural assembly **100**.

[0078] Step **712** of the method **700** of Figure **18** may comprise applying a tension test load **500** to the fillet bond **328** at the engagement locations **626**. Figure **21** illustrates a tension test load **500** being applied along the gimbal rod **606**. Advantageously, for test specimens **300** that may be misaligned with the upper fixture **602**, the gimbal joint **604** causes an adjustment of the orientation of the upper fixture **602** which results in the adjustment in the orientation of the load pins **624** from the orientation shown in Figure **20** to the orientation shown in Figure **21**. With the load pins **624** substantially aligned with the inner surface **304** (Figure **20**) of the skin component, a substantially equivalent tension force **504** may be applied to the skin component **302** on opposite sides of the fillet bond **328**.

[0079] Step **714** of the method **700** of Figure **18** may comprise substantially isolating the fillet bond **328** (Figure **22**) from asymmetric bending **510'** (Figure **25**) when applying the tension test load **500** (Figure **21**). In this regard, the reorientation **662** (Figure **21**) of the load pins **624** (Figure **21**) facilitates the alignment of the load pins **624** with the inner surface **304** (Figure **22**) of the skin component **302** (Figure **22**) such that a substantially equivalent tension force **504** (Figure **22**) may be applied at the engagement locations **626** (Figure **22**) on each side of the fillet bond **328**. The substantially equivalent application of tension force **504** at the engagement locations **626** may result in a substantially symmetric bending moment **510** and a substantially symmetric shear force **512** (Figure **22**) on each side of the fillet bond **328** at the fillet edge **332** as shown in the loading diagram of Figure **22**. In this regard, by including the gimbal joint **604** (Figure **21**) in the testing apparatus **600** (Figure **21**), asymmetric bending moment **510'** (Figure **25**) and asymmetric shear force **512'** (Figure **25**) on opposite sides of the fillet bond **328** may be avoided.

[0080] The avoidance of asymmetric bending **510'** (Figure **25**) and asymmetric shear **512'** (Figure **25**) may be illustrated by way of example with reference to Figures **23-25** which show a testing apparatus **600'** for which the gimbal joint **604** (Figure **21**) is omitted. Figure **23** illustrates the test specimen **300** mounted in the testing apparatus **600'**. The load pin **624'** on the right hand side of the fillet bond **328** is in contact with the skin opponent **302**. However, the load pin **624'** on the left hand side of the fillet bond **328** is disposed in spaced relation to the skin component **302**. Figure **24** illustrates the tension test load **500** being applied to the upper fixture **602'**.

[0081] The loading diagram of Figure **25** illustrates a tension force **504** applied to the skin component **302** on the right hand side and the left hand side of the fillet bond **328**. Application of the tension test load **500** (Figure **24**) results in the load pin **624'** (Figure **24**) on the right hand side of the fillet bond **328** (Figure **24**) contacting the inner surface **304** (Figure **24**) of the skin component **302** (Figure **24**) prior to the load pin **624'** (Figure **24**) on the left hand side of the fillet bond **328** (Figure **24**) contacting the inner surface **304** (Figure **24**) of the skin component **302** (Figure **24**). Due to the angular offset **305** (Figure **19**) of the skin component **302** relative to the stiffener axis **323** (Figure **24**), the tension force **504** applied by the load pin **624'** on the right hand side of the skin component **302** may be of greater magnitude than the tension force **504** applied by the load pin **624'** on the left hand side of the skin component **302** resulting in asymmetric bending **510'** and asymmetric shear **512'** in the test specimen **300**. The unequal tension forces **504** result in a bending moment and a shear force **508** on the right hand side of the skin component **302** that is of greater magnitude than the bending moment and the shear force **508** on the left hand side of the skin component **302**. Such asymmetric bending moment **510'** and asymmetric shear force **512'** may compromise the accuracy of the test results.

[0082] Referring to Figure **18**, Step **716** of the method **700** may include determining a static tension capability or tension strength of the fillet bond **328** (Figure **13**). Advantageously, the testing apparatus **600** (Figure **13**) allows for directly determining the load-carrying capability of the fillet bond **328** and avoiding the need to measure and record strain or stress levels in the fillet bond **328** and then correlate the strain or stress levels to strength values as may be required in conventional structural testing. Advantageously, in the present disclosure, the static tension capability of a fillet bond **328** may be directly determined by recording the magnitude of the tension test load **500** (Figure **13**) at the failure of the fillet bond **328**. The magnitude of the tension test load **500** at failure may be divided by the fillet bond length **324** (Figure **6**) to provide a bond strength of the fillet bond in terms of force unit per lineal unit such as pounds per inch.

[0083] The method may include generating test results in the form of strength values for a given fillet bond **328** (Figure **6**) configuration. The test results may include a description of the failure mode of the fillet bond **328**. For example, the failure mode may comprise a cohesive failure of the adhesive material **338** (Figure **6**) within the fillet bond **328**. The failure mode may also comprise an adhesive failure at an interface between the adhesive and the stiffener component **308** (Figure **6**) and/or at an interface between the adhesive and the skin component. The failure mode may further comprise a failure of one of the adherends (i.e., the skin component **302** and the stiffener component) such as a delamination and/or fracture of the skin component **302** (Figure **6**) material and/or the stiffener component **308** material, or other failure modes or combinations of failure modes. The test results may include a description of the environmental conditions (e.g., temperature of the test specimen, relative humidity) associated with each failure and the corresponding margin of safety of the fillet bond **328** as may be used for joint qualification and/or aircraft certification.

[0084] Additional modifications and improvements of the present disclosure may be apparent to those of ordinary skill in the art. Thus, the particular combination of parts described and illustrated herein is intended to represent only certain embodiments of the present disclosure and is not intended to serve as limitations of alternative embodiments or devices within the spirit and scope of the disclosure.

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

1. A testing apparatus for characterizing a tension strength of a fillet bond joining a stiffener component to a skin component of a test specimen, the fillet bond having a fillet face on each one of opposing sides of the fillet bond, comprising:

a lower fixture configured to maintain the stiffener component in a fixed position;

an upper fixture having a pair of engagement devices positionable on opposite sides of the fillet bond and configured to engage the skin component at substantially equal distances from the fillet faces such that substantially equivalent tension forces are applied to the skin component on each side of the fillet bond during application of a tension test load on the test specimen; and

a gimbal joint mechanically coupled to the upper fixture and configured to substantially isolate the fillet bond from asymmetric bending during application of the tension test load to the fillet bond.

2. The testing apparatus of claim **1**, wherein:

the engagement devices are mechanically coupled to the gimbal joint.

3. The testing apparatus of claim **1**, wherein:

the engagement devices comprise cylindrical load pins engageable to an inner surface of the skin component on opposite sides of the fillet bond; and the load pins are oriented substantially parallel to a length of the fillet bond.

4. The testing apparatus of claim **1**, wherein:

the stiffener component includes a base portion and at least two legs extending outwardly from the base portion; and

the lower fixture being configured to fixedly clamp the legs in the fixed position in a manner preventing vertical and lateral movement of the legs.

5. The testing apparatus of claim **1**, wherein:

the lower fixture includes an outer clamping block and an inner clamping block configured to clamp a pair of legs therebetween.

6. The testing apparatus of claim **5**, wherein:

the lower fixture includes an adjustment mechanism for adjusting a position of the inner clamping block relative to the outer clamping block such that the inner and outer clamping block are movable into clamping engagement with respective ones of inner and outer surfaces of the legs.

7. The testing apparatus of claim **1**, wherein:

the fillet bond of the test specimen is configured substantially similar to a fillet bond of a structural assembly having a plurality of panel stiffeners adhesively bonded to a skin panel subjected to a substantially uniformly-distributed tension pulloff load acting on the skin panel, the fillet bond of the structural assembly having fillet edges on opposite sides of the fillet bond;

the fillet bond has a fillet edge on opposite sides of the fillet bond; and

each one of the engagement devices is substantially equidistantly positioned at a distance from the fillet bond such that the fillet edges are subjected to a moment-shear ratio that is substantially equivalent to the moment-shear ratio at the fillet edges of the structural assembly.

8. The testing apparatus of claim **7**, wherein:

at least one adjacently-disposed pair of the panel stiffeners of the structural assembly are spaced apart from one another at a stiffener pitch; and

the engagement devices of the test specimen are spaced apart from one another at an engagement location spacing that is less than the stiffener pitch.

9. The testing apparatus of claim **1**, wherein:

the skin component has a generally planar configuration.

10. A testing apparatus for characterizing a tension strength of a fillet bond joining a stiffener component and a skin component of a test specimen, the fillet bond having a fillet face on each one of opposing sides of the fillet bond, comprising:

a lower fixture configured to maintain the stiffener component in a fixed position;

an upper fixture having a pair of load pins being oriented generally parallel to one another and configured to engage an inner surface of a skin component at substantially equal distances from the fillet faces such that substantially equivalent tension forces are applied to the skin component on each side of the fillet bond during application of a tension test load on the test specimen;

a gimbal joint mechanically coupled to the upper fixture and being configured to substantially isolate the fillet bond from asymmetric bending during application of the tension test load to the fillet bond; and

the load pins being positioned such that fillet edges of the fillet bond are subjected to a moment-shear ratio that is substantially equivalent to the moment-shear ratio at the fillet edges of a structural assembly subjected to a uniformly distributed tension pulloff load.

11. A method of characterizing a tension strength of a fillet bond joining a stiffener component to a skin component of a test specimen, the fillet bond having a fillet face on each one of opposing sides of the fillet bond, comprising:

placing the test specimen in a testing apparatus;

fixedly positioning a stiffener component in a lower fixture of the test specimen;

engaging the skin component using a pair of engagement devices of an upper fixture of the testing apparatus, the engagement devices being positioned on opposite sides of the fillet bond at substantially equal distances from the fillet faces;

applying a tension test load to the fillet bond using the pair of engagement devices;

applying, using the engagement devices, substantially equivalent tension forces to the skin component on each side of the fillet bond during application of the tension test load; and

substantially isolating the fillet bond from asymmetric bending when applying the tension test load.

12. The method of claim **11**, wherein engaging the skin component using the pair of engagement devices comprises:

engaging an inner surface of the skin component using the pair of engagement devices.

13. The method of claim **11**, wherein engaging the skin component comprises:

engaging the skin component with two substantially parallel load pins in contact with an inner surface of the skin component on opposite sides of the fillet bond in an orientation substantially parallel to a length of the fillet bond; and

mechanically coupling the load pins to a gimbal joint.

14. The method of claim **11**, further comprising:

preventing lateral and vertical movement of a pair of legs of the stiffener component.

15. The method of claim **14**, wherein preventing lateral and vertical movement of each one of a pair of legs comprises:

clamping the legs between an outer clamping block and an inner clamping block.

16. The method of claim **15**, further comprising:

adjusting, using an adjustment mechanism, a position of the inner clamping block relative to the outer clamping block such that the inner and outer clamping blocks are movable into clamping engagement with inner and outer surfaces of the legs.

17. The method of claim **11**, further comprising:

determining a static tension test load-carrying capability of the fillet bond by dividing a bond length by a magnitude of the tension test load recorded at failure of the fillet bond.

18. The method of claim **11**, wherein each one of the sides of the fillet bond includes a fillet edge at an adhesive-skin interface and engaging the skin component comprises:

selecting a moment-shear ratio for the fillet edge comprising a ratio of a bending moment to a shear force at the fillet edge, the moment-shear ratio being substantially equivalent to a moment-shear ratio at a fillet edge of a structural assembly under a substantially uniformly-distributed tension pulloff load acting on a skin panel stiffened by panel stiffeners; and positioning the engagement devices on each side of the fillet bond such that the tension test load on each side of the fillet bond causing the fillet edge to be subjected to the moment-shear ratio when applying the tension test load.

19. The method of claim **18**, wherein each side of the fillet bond includes a fillet edge at an adhesive-skin interface, and wherein engaging the skin component comprises:

locating each one of the engagement devices at a distance from the fillet edge such that the fillet bond at each one of the fillet edges is subjected to the moment-shear ratio.

20. The method of claim **18**, wherein engaging the skin component comprises:

positioning the engagement devices at an engagement location spacing that is less than a stiffener pitch between at least one adjacently-disposed pair of panel stiffeners of a structural assembly under a substantially uniformly-distributed tension pulloff load acting on the skin panel.

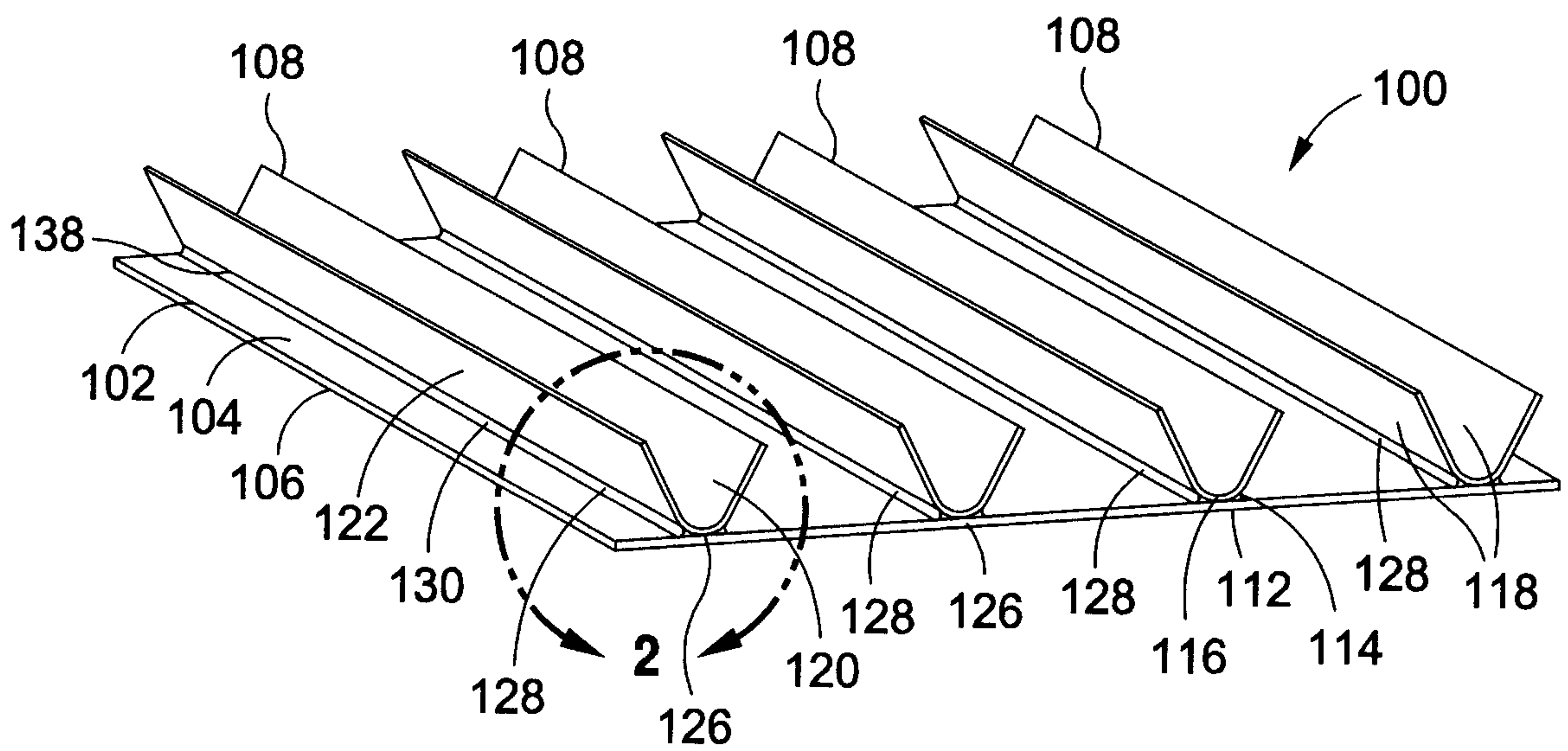
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FIG. 1

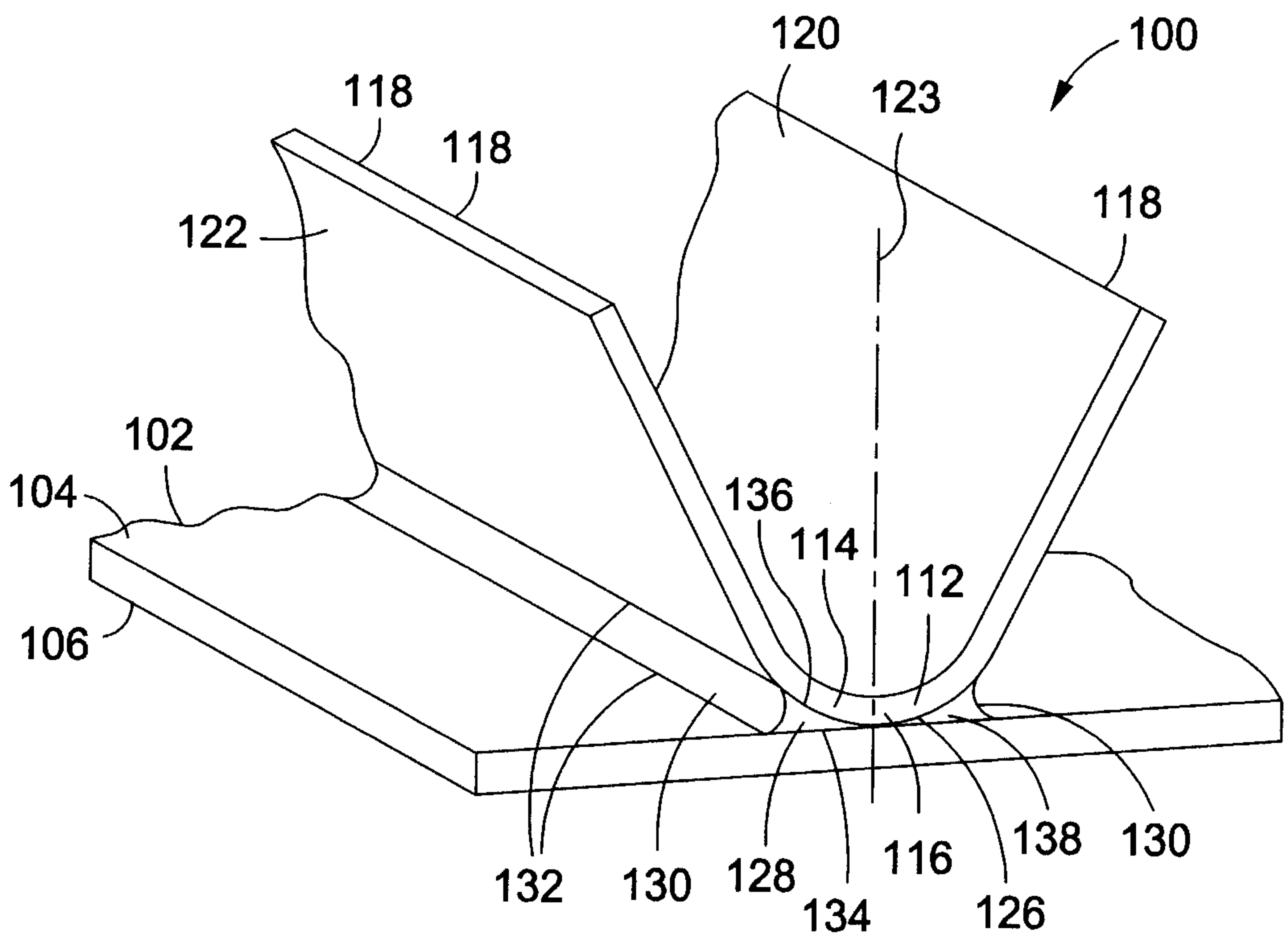
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FIG. 2

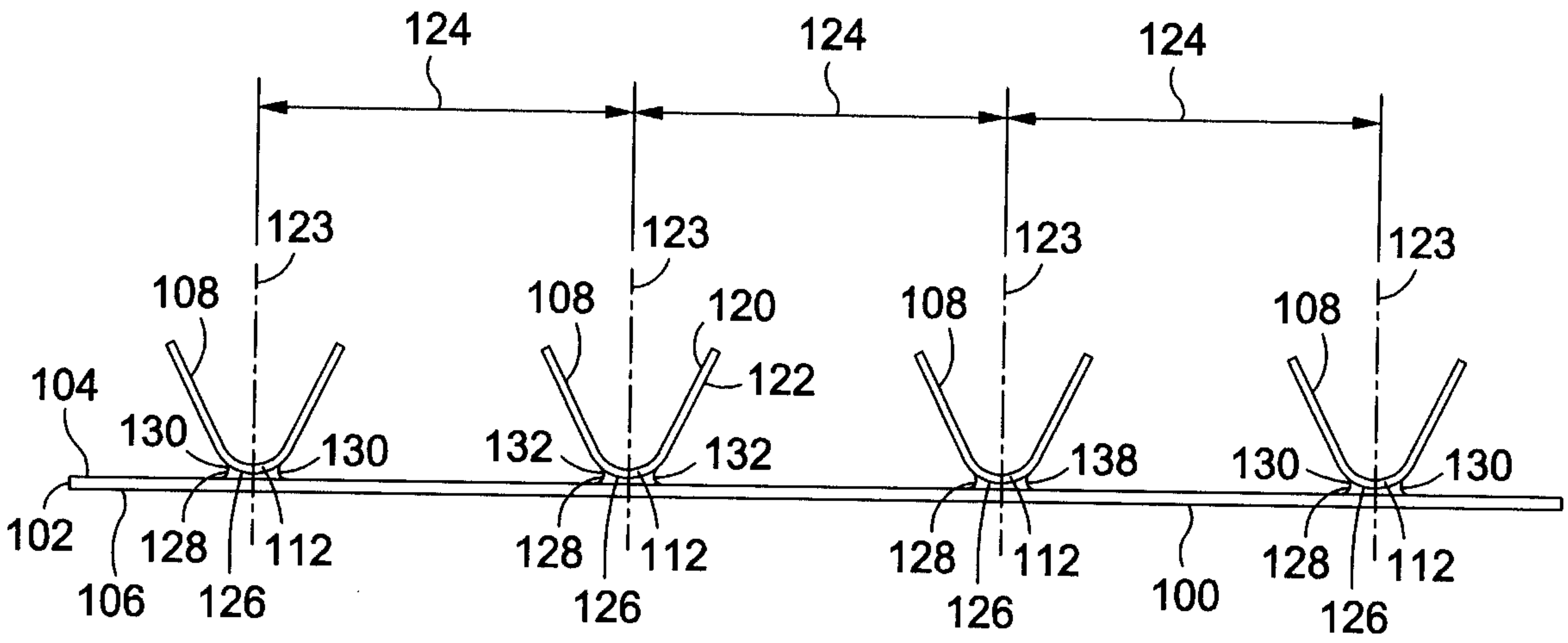
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FIG. 3

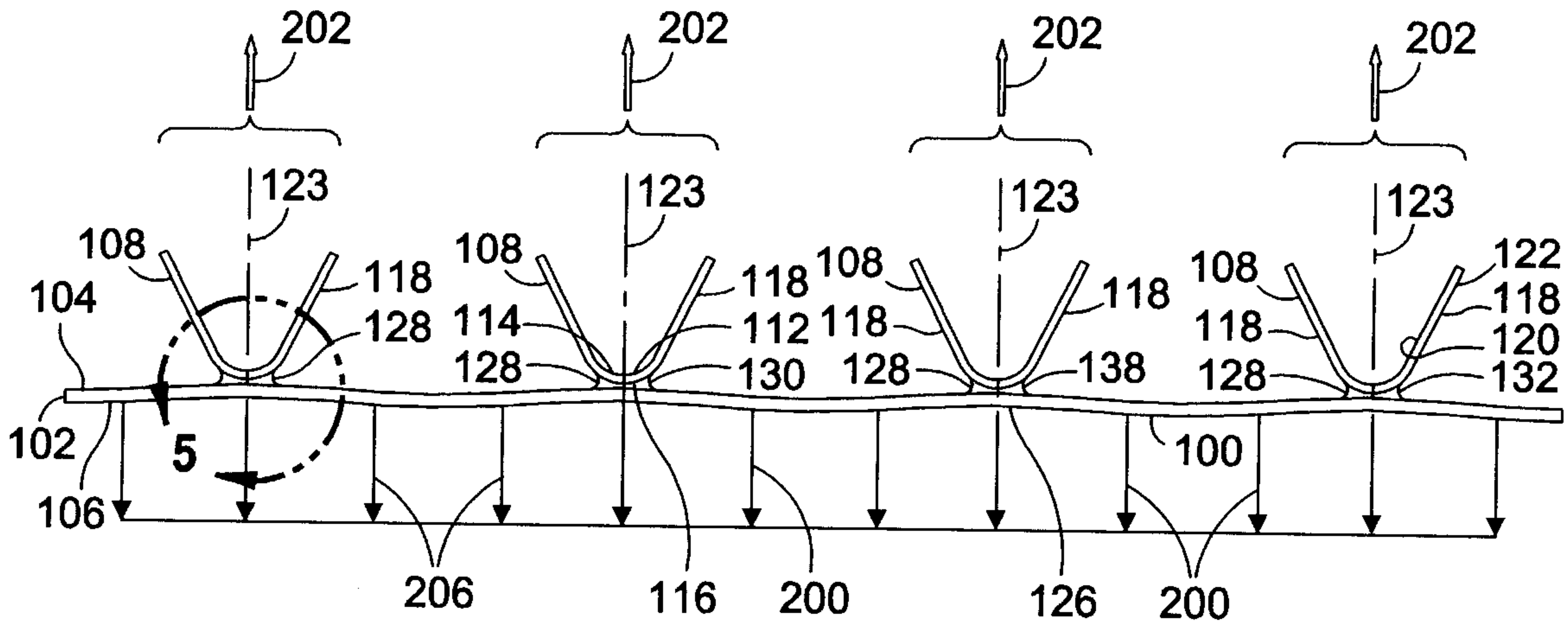
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FIG. 4

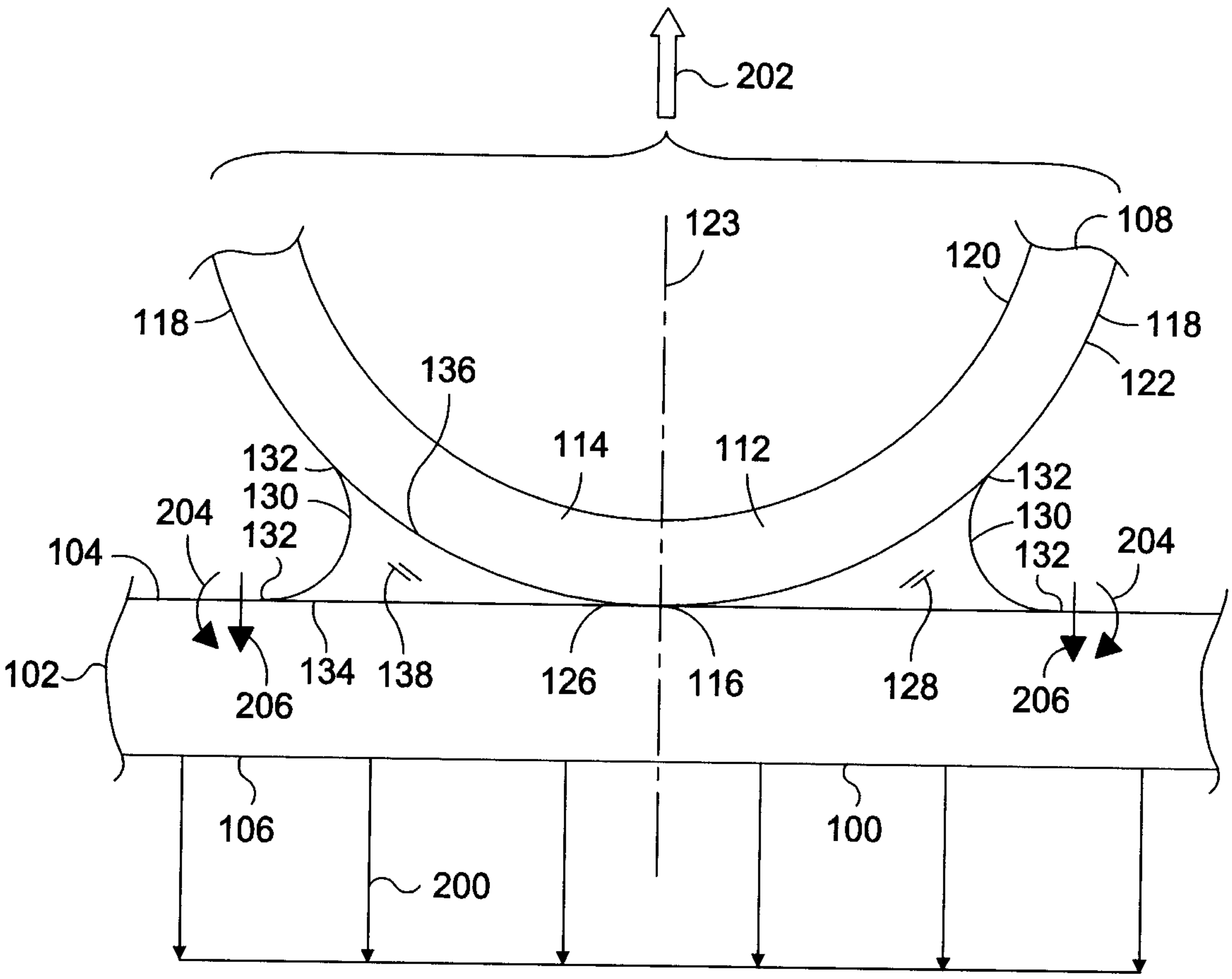
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FIG. 5

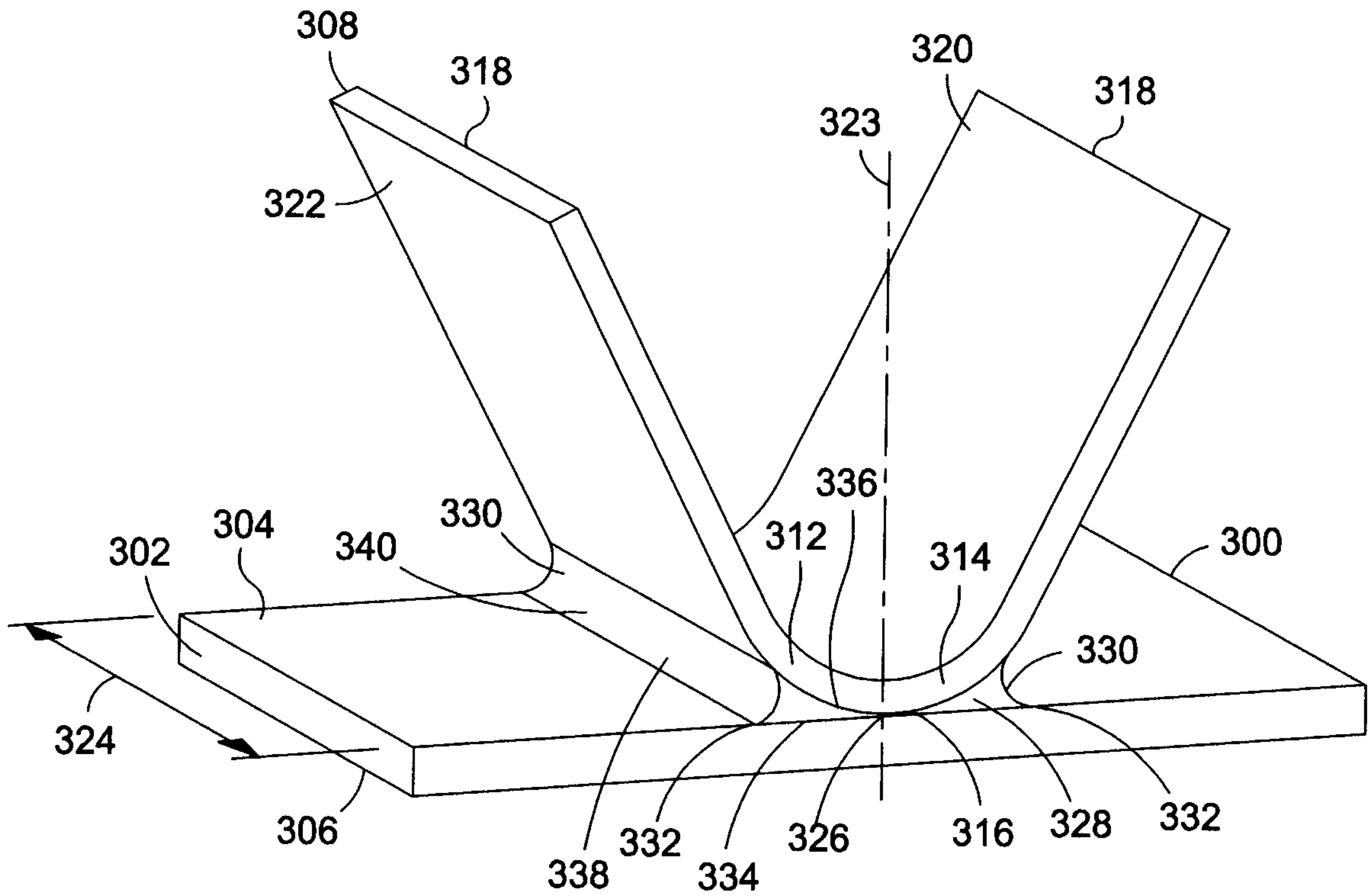
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FIG. 6

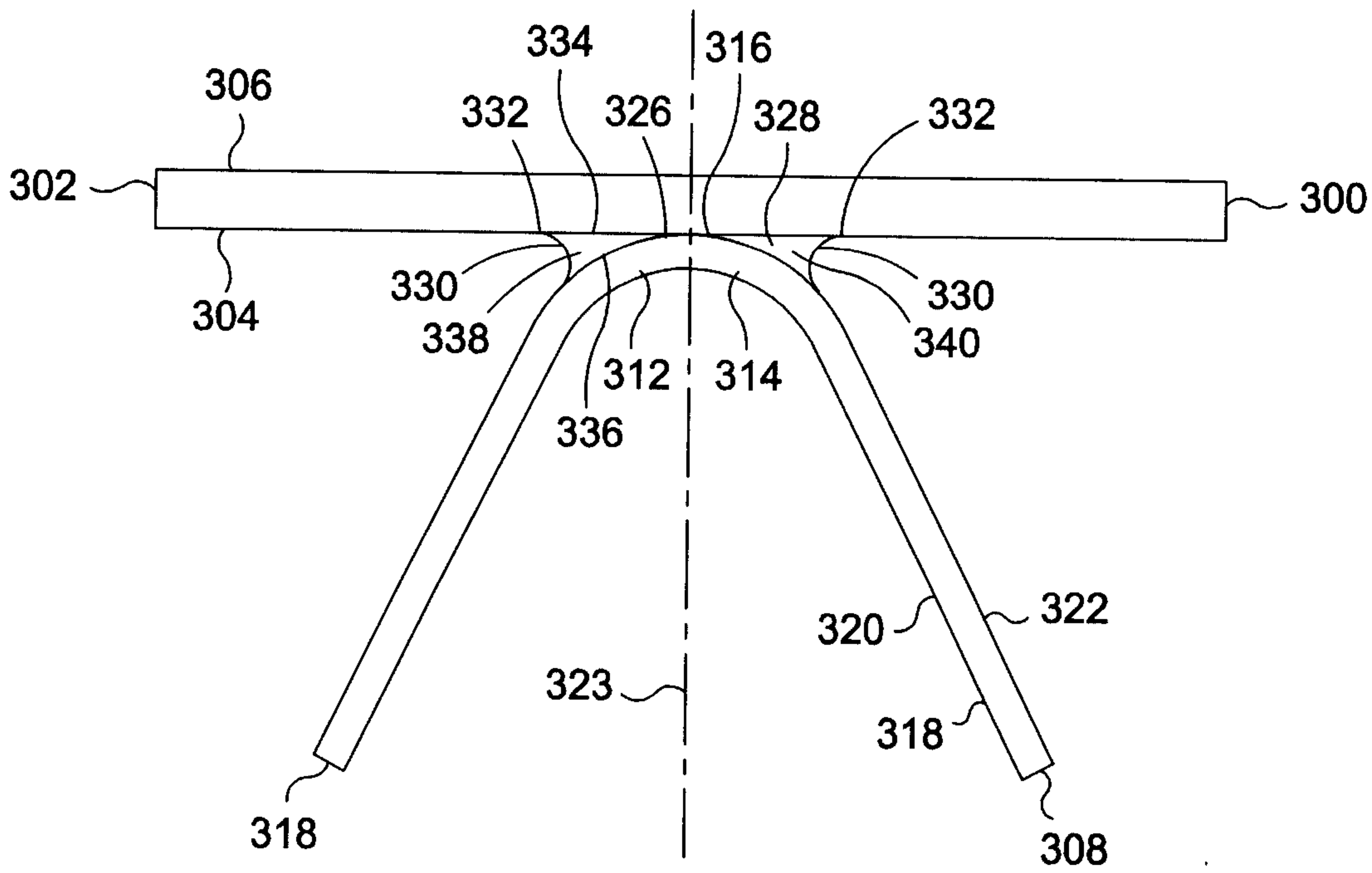
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FIG. 7

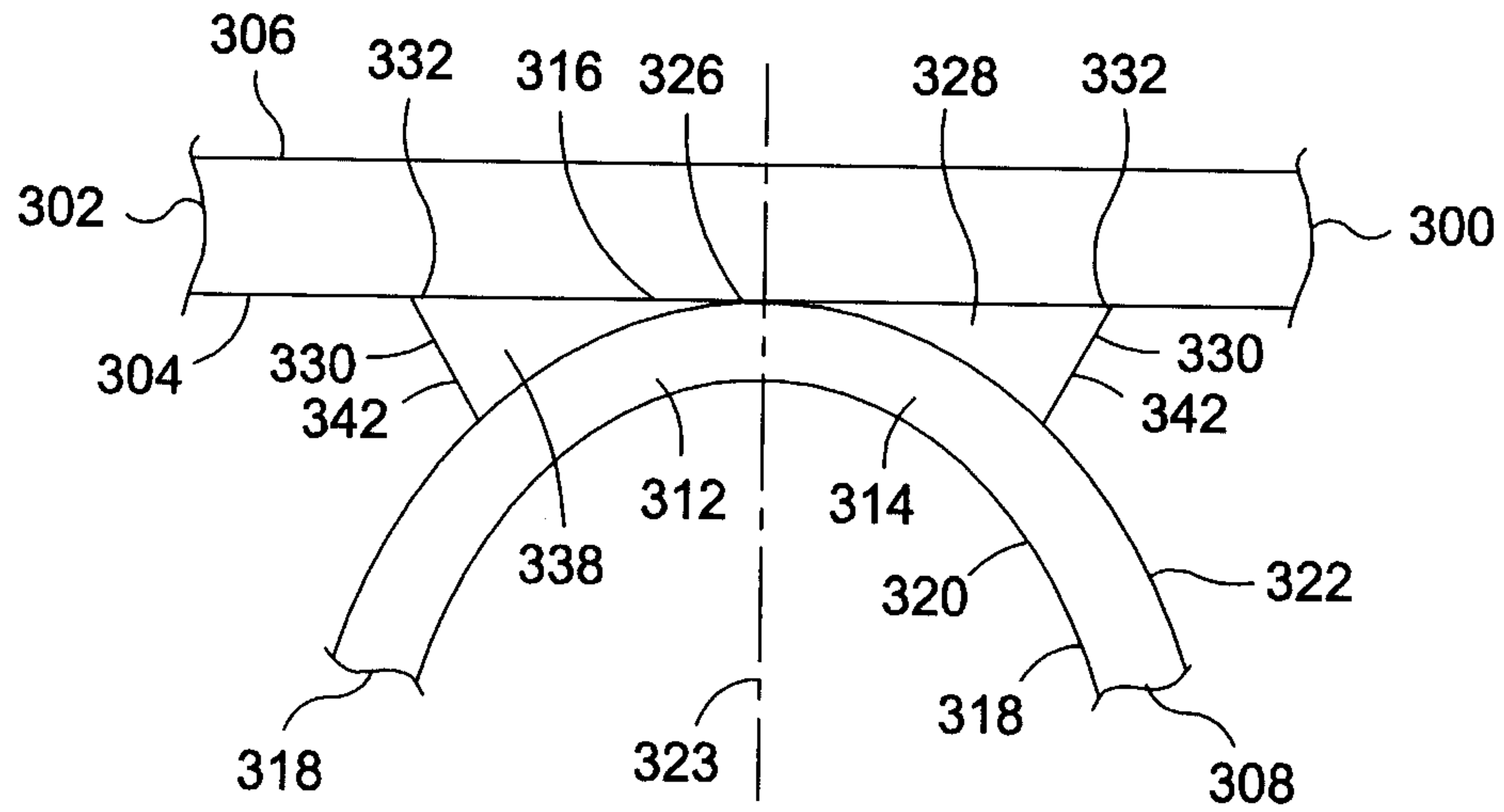
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FIG. 8

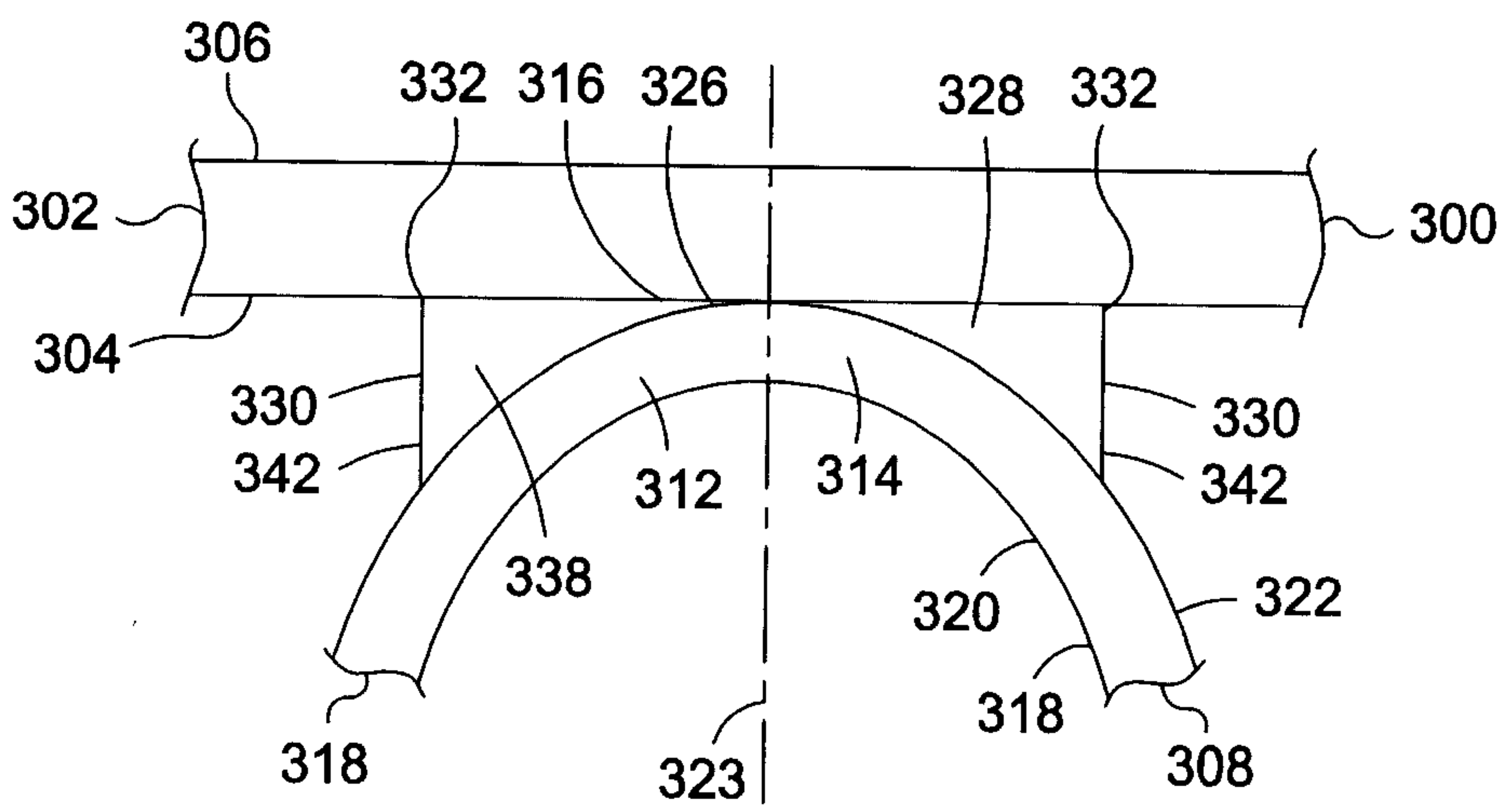
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FIG. 9

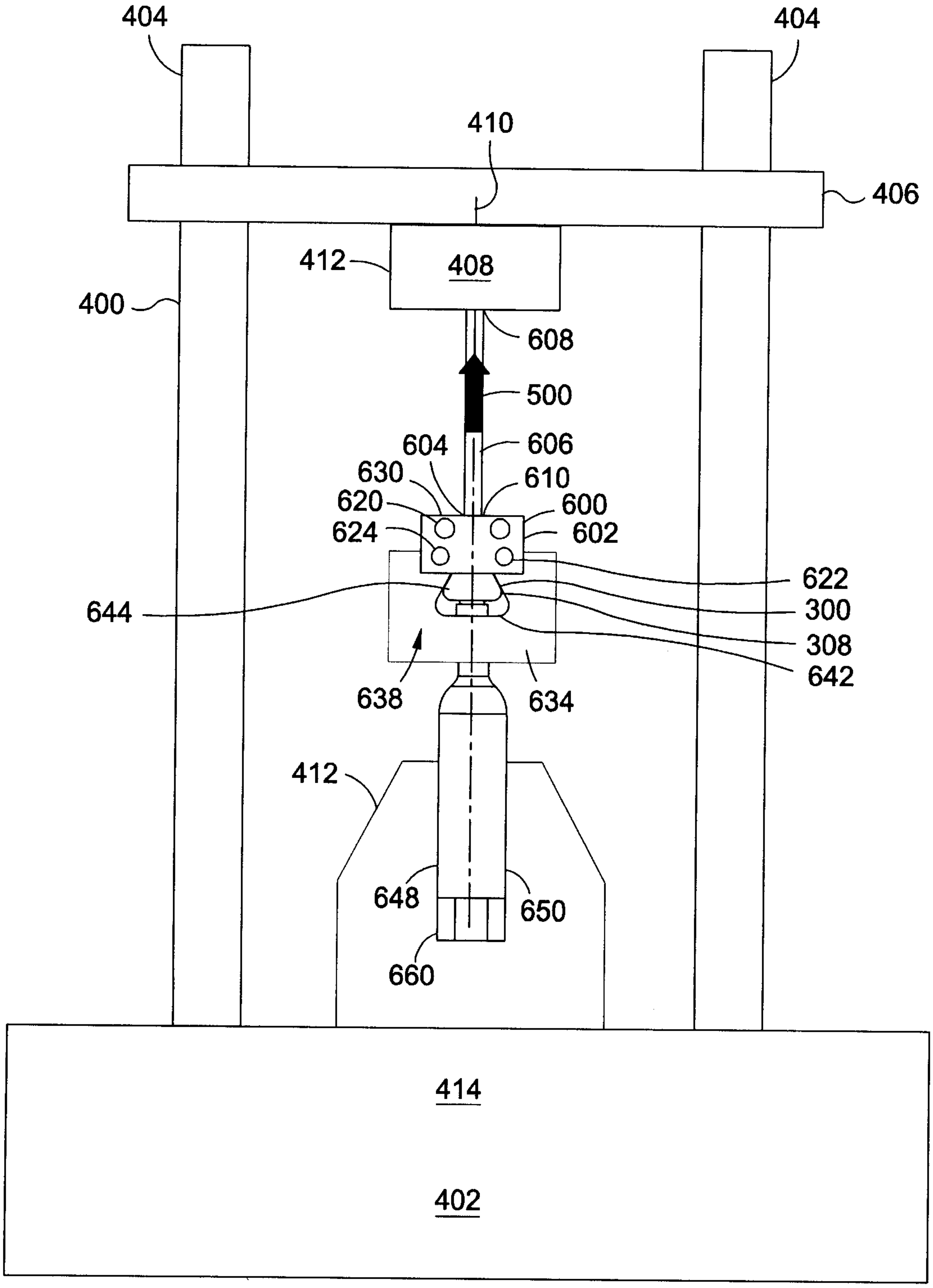
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FIG. 10

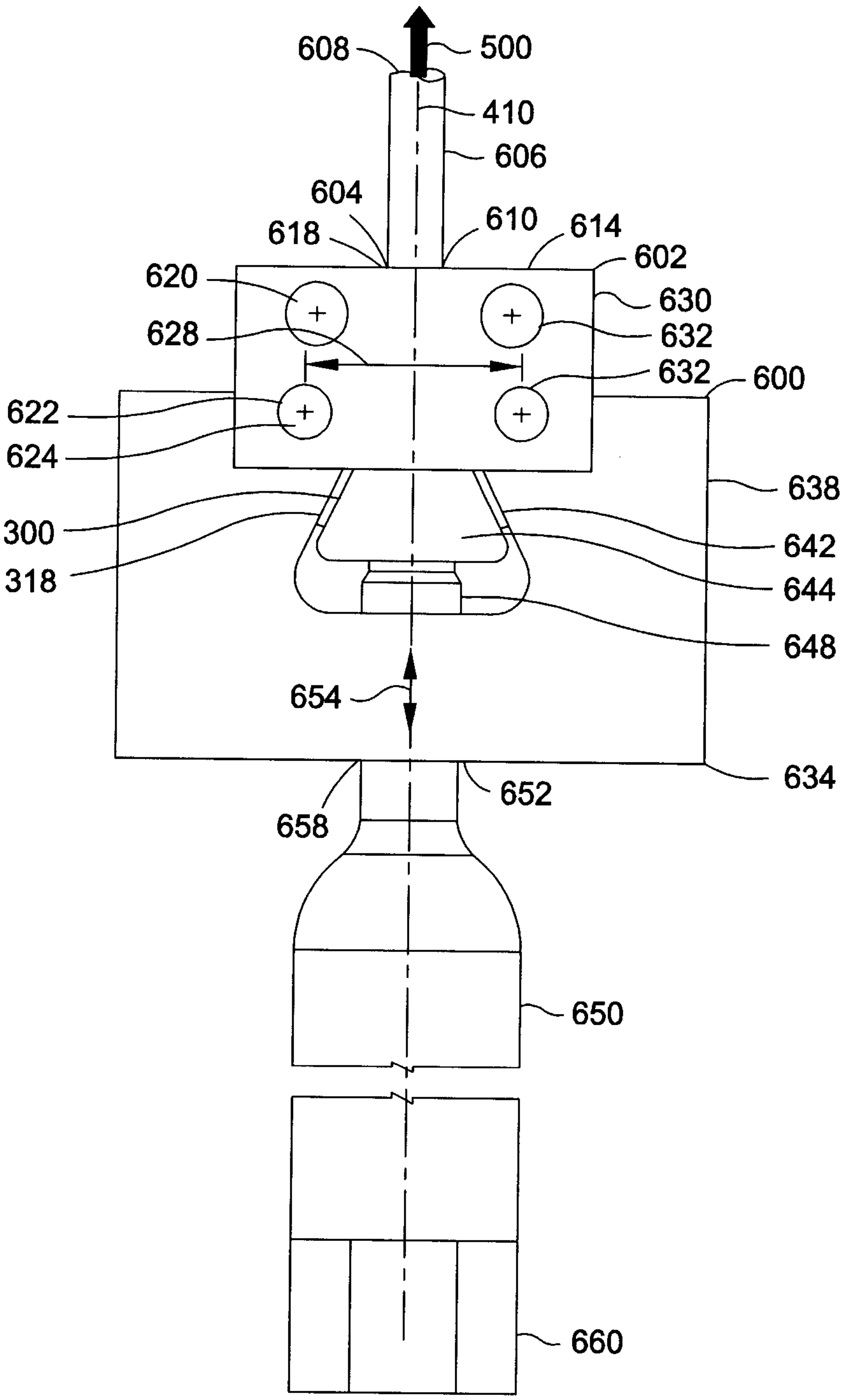
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FIG. 11

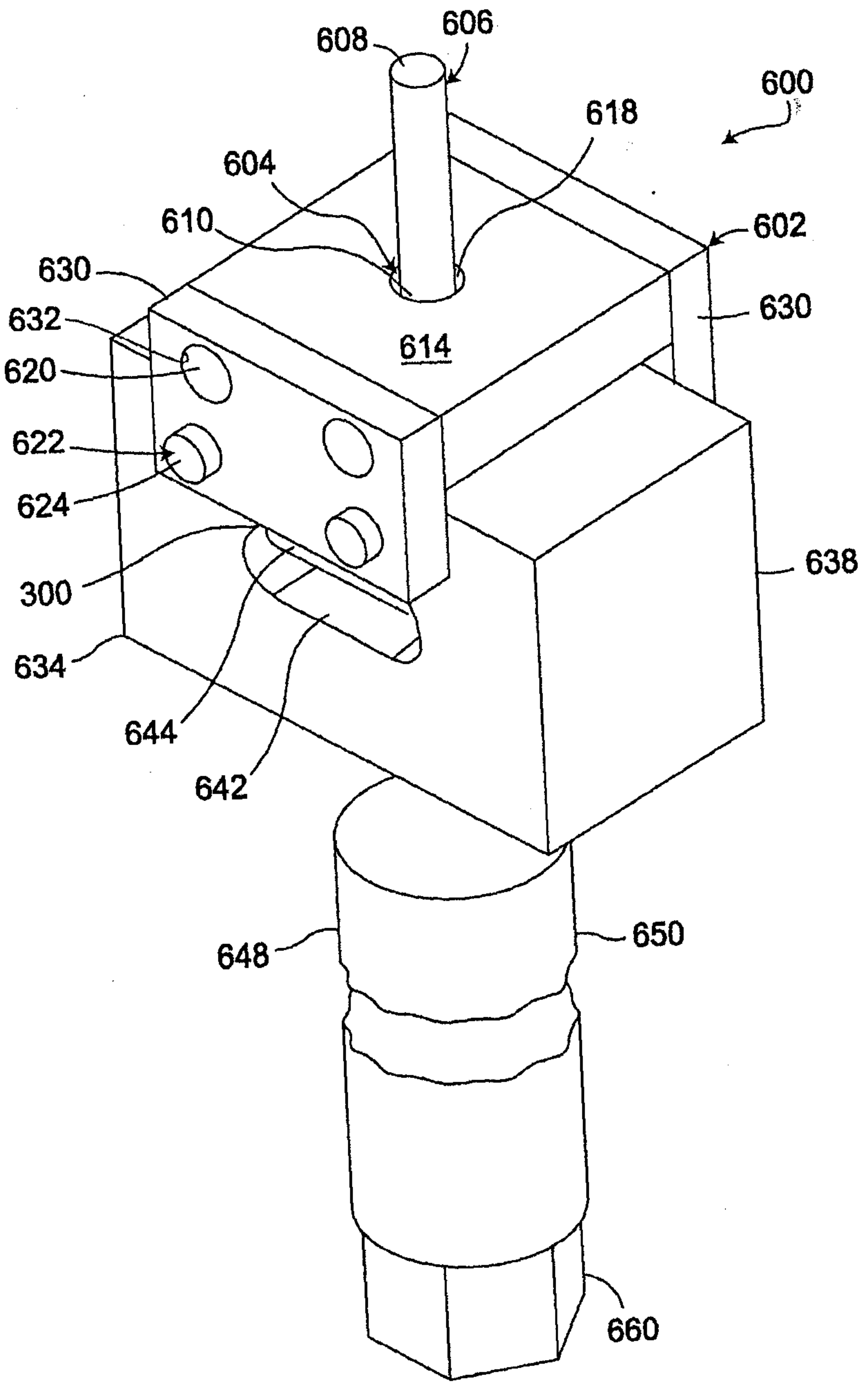
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FIG. 12

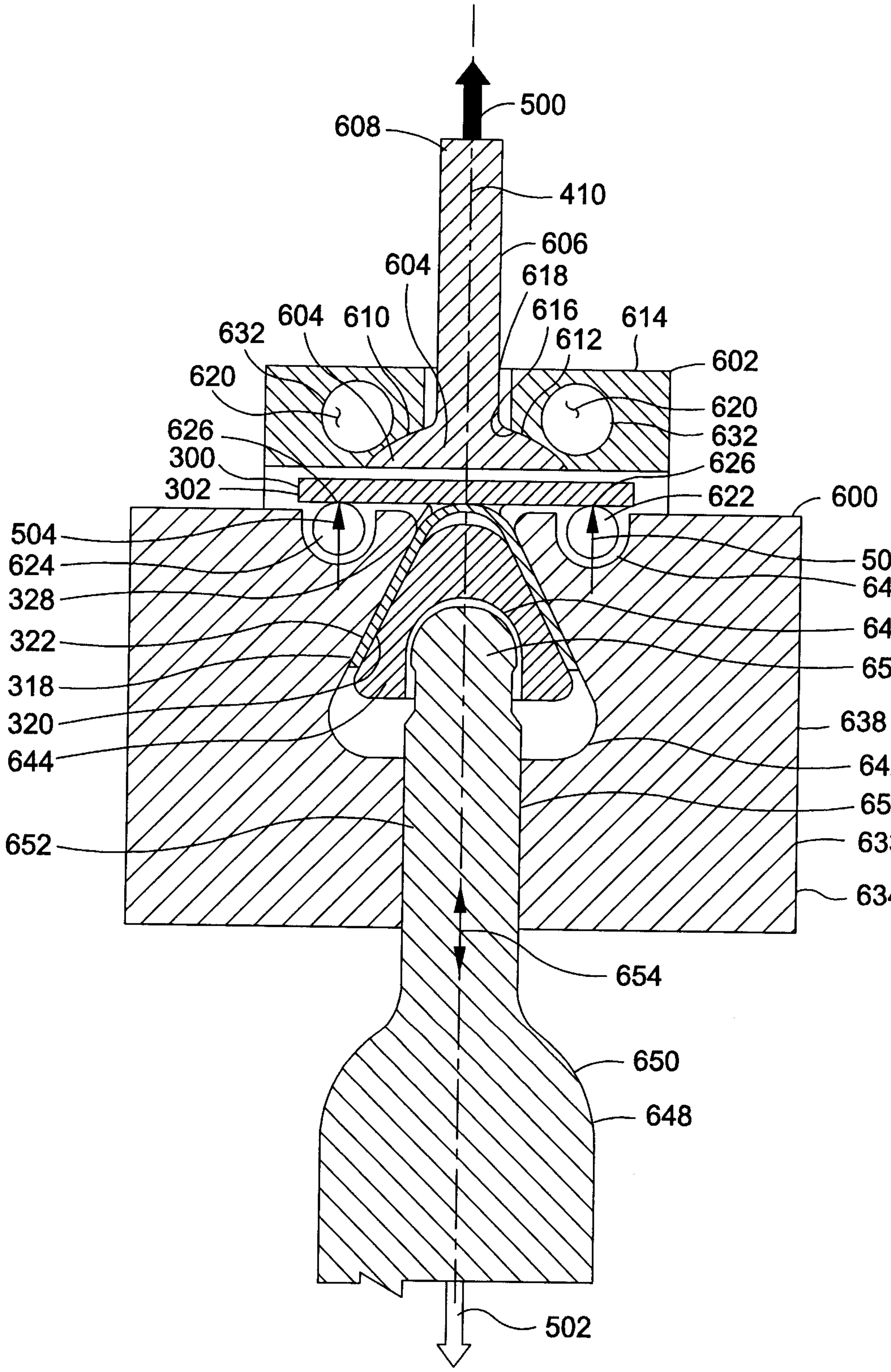
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FIG. 13

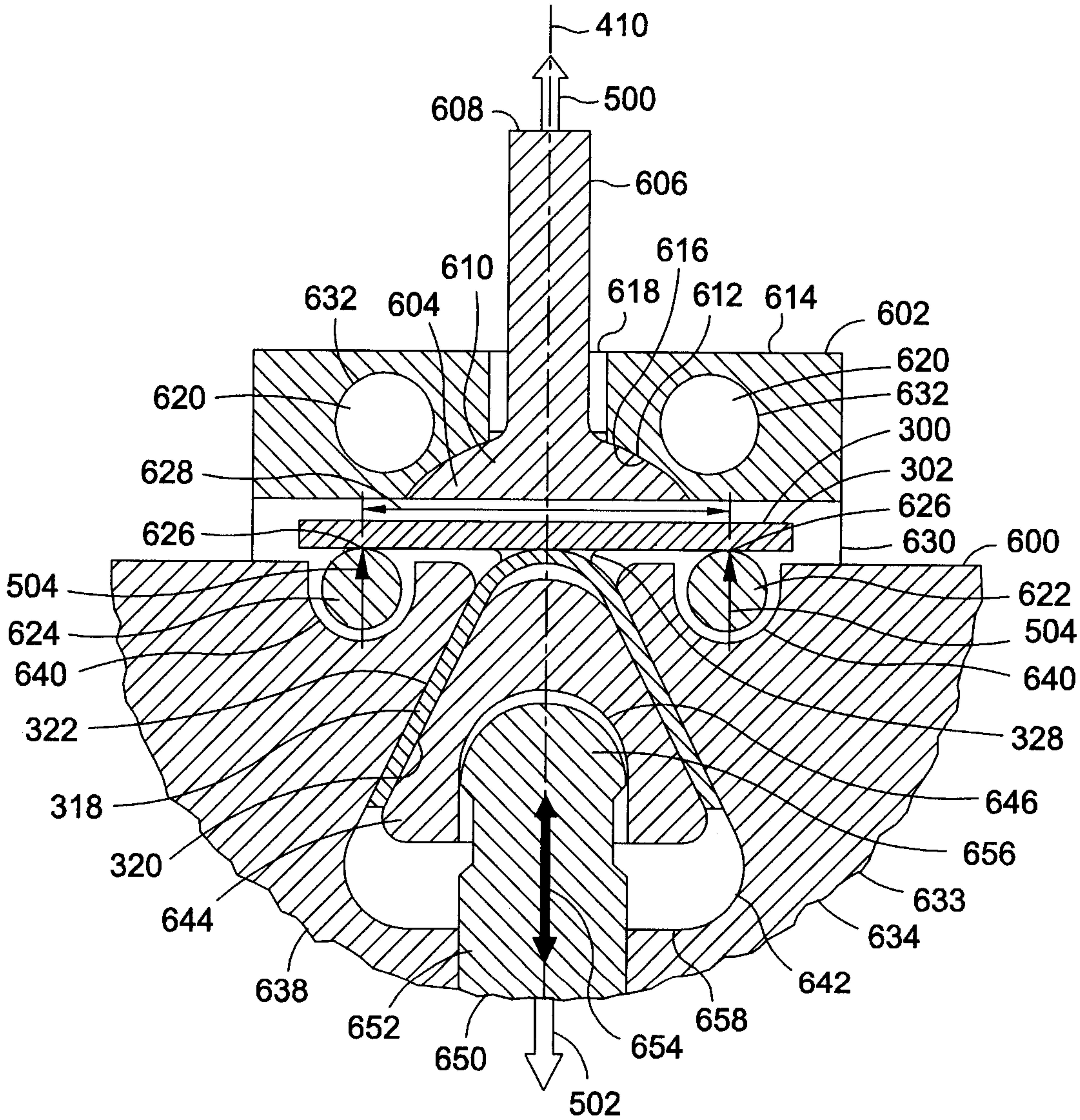
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FIG. 14

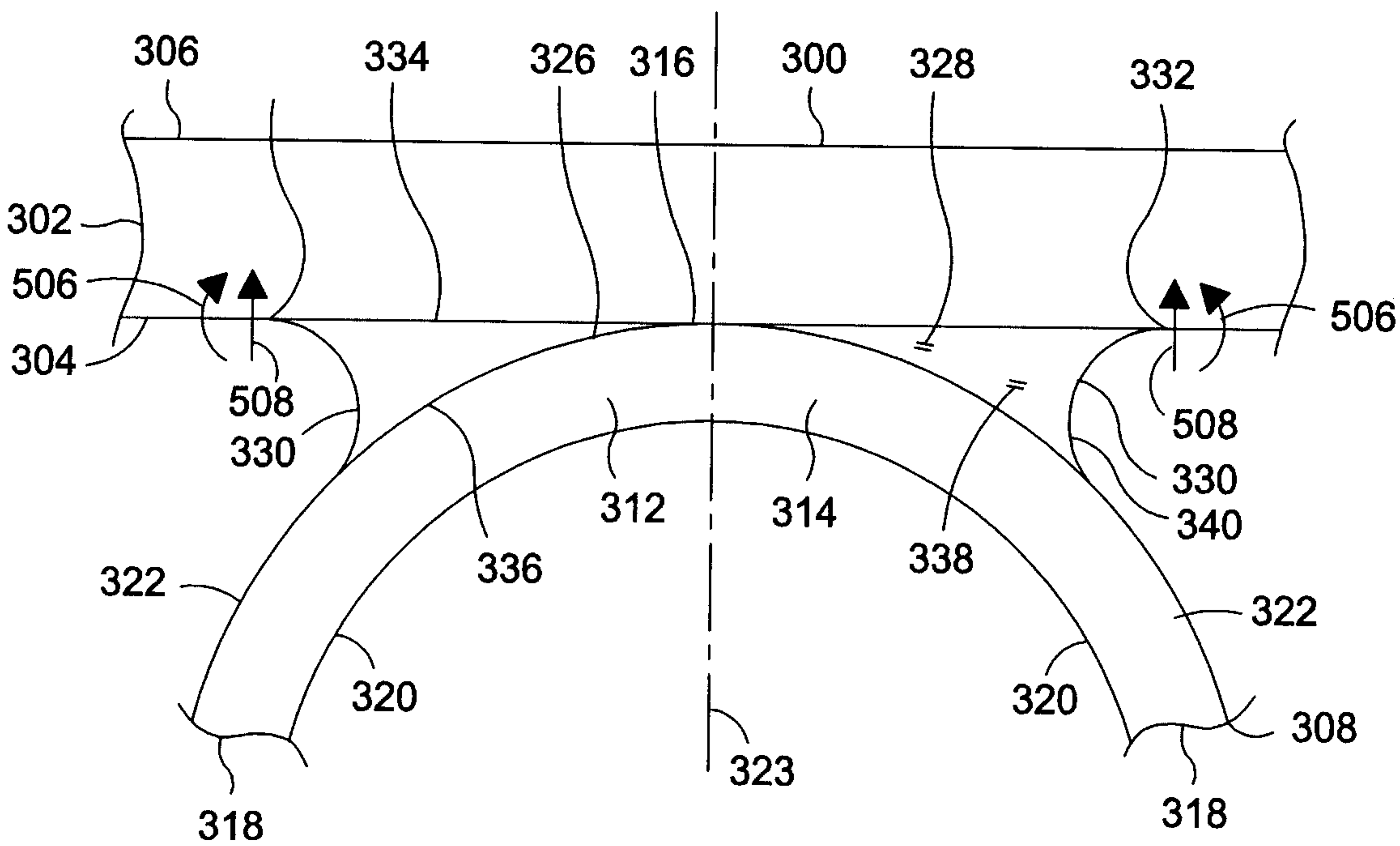
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FIG. 15

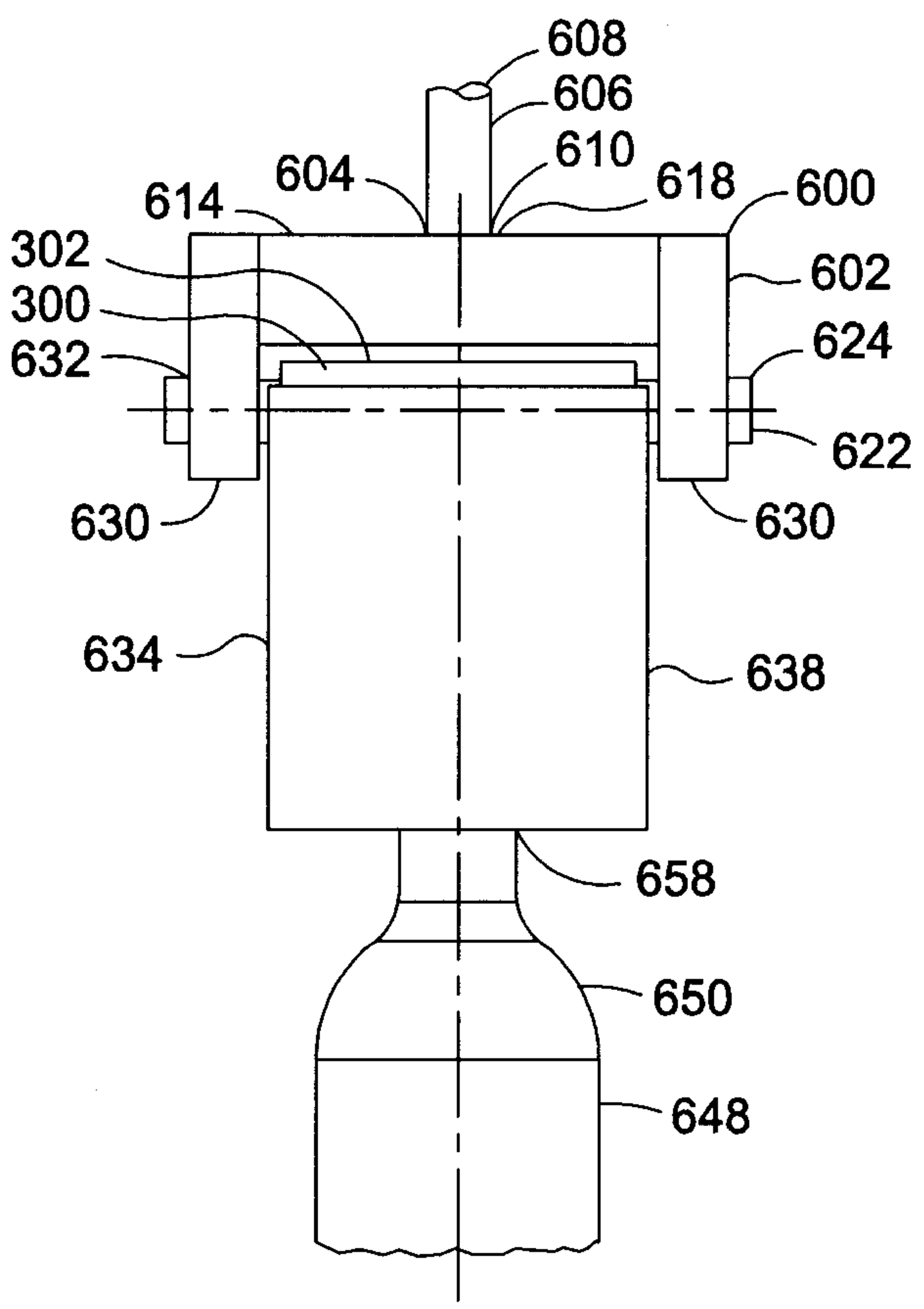
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FIG. 16

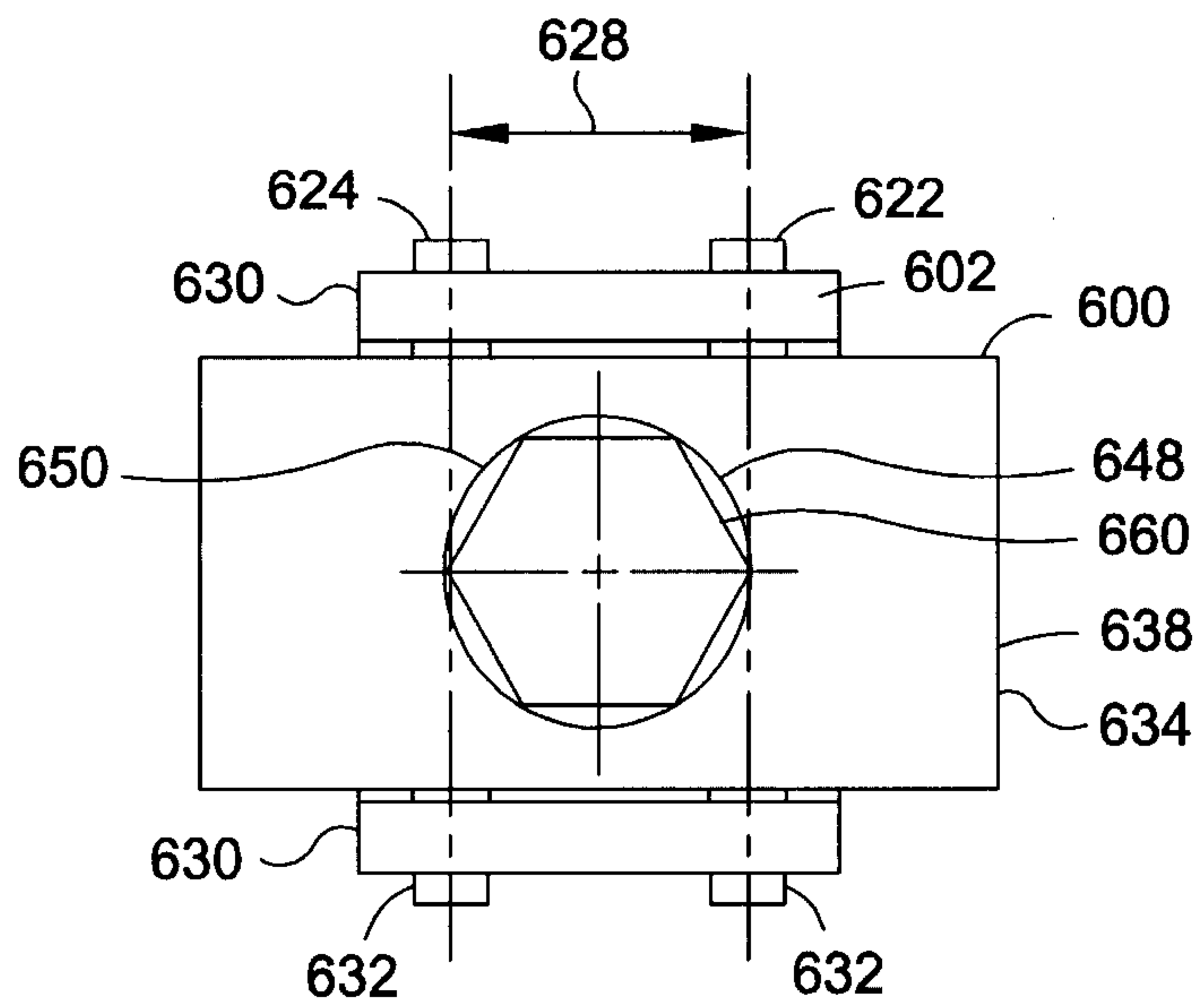
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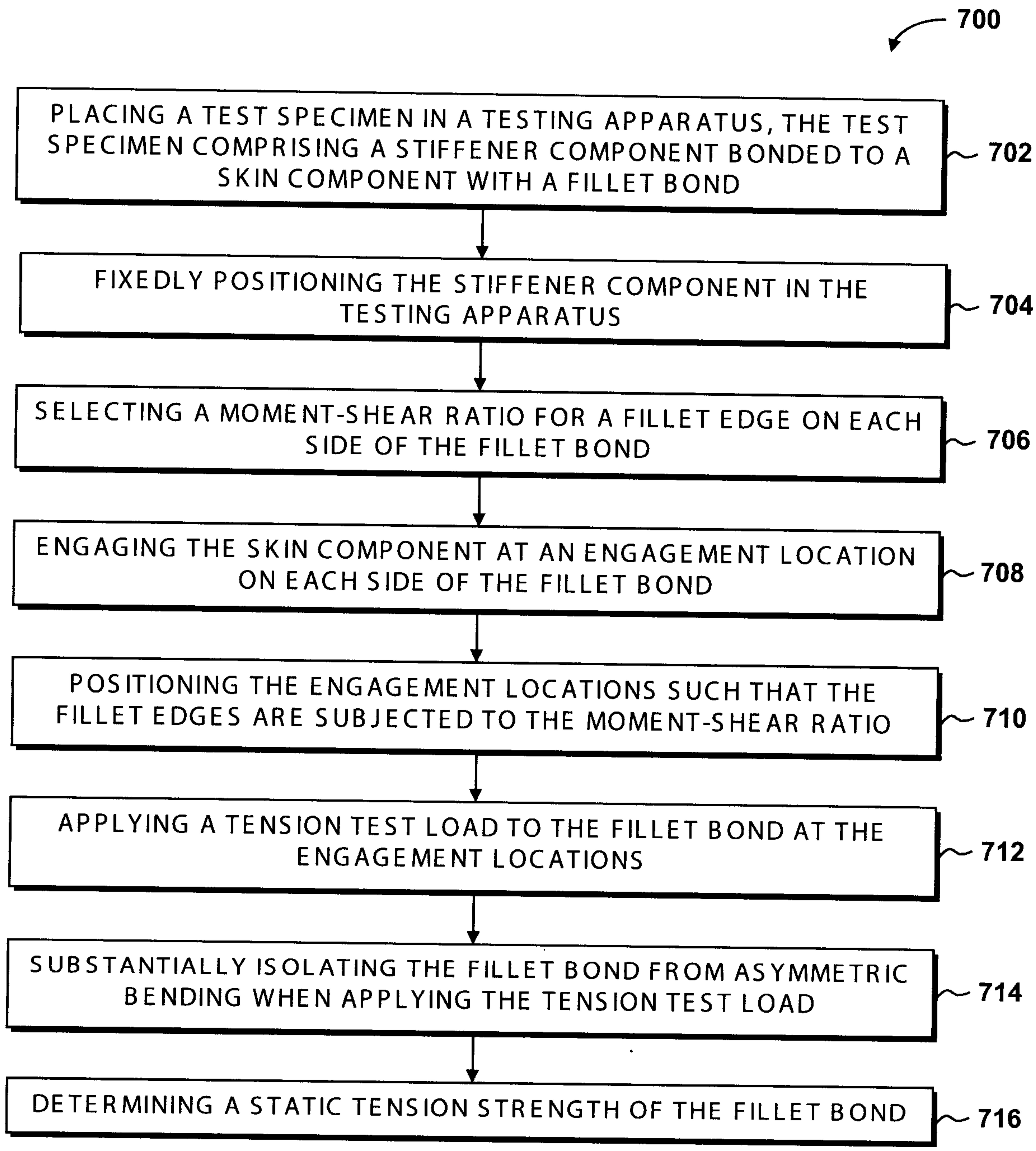
FIG. 17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PLACING A TEST SPECIMEN IN A TESTING APPARATUS, THE TEST SPECIMEN COMPRISING A STIFFENER COMPONENT BONDED TO A SKIN COMPONENT WITH A FILLET BOND
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FIXEDLY POSITIONING THE STIFFENER COMPONENT IN THE TESTING APPARATUS
704
SELECTING A MOMENT-SHEAR RATIO FOR A FILLET EDGE ON EACH SIDE OF THE FILLET BOND
706
ENGAGING THE SKIN COMPONENT AT AN ENGAGEMENT LOCATION ON EACH SIDE OF THE FILLET BOND
708
POSITIONING THE ENGAGEMENT LOCATIONS SUCH THAT THE FILLET EDGES ARE SUBJECTED TO THE MOMENT-SHEAR RATIO
710
APPLYING A TENSION TEST LOAD TO THE FILLET BOND AT THE ENGAGEMENT LOCATIONS
712
SUBSTANTIALLY ISOLATING THE FILLET BOND FROM ASYMMETRIC BENDING WHEN APPLYING THE TENSION TEST LOAD
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DETERMINING A STATIC TENSION STRENGTH OF THE FILLET BOND
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FIG. 18

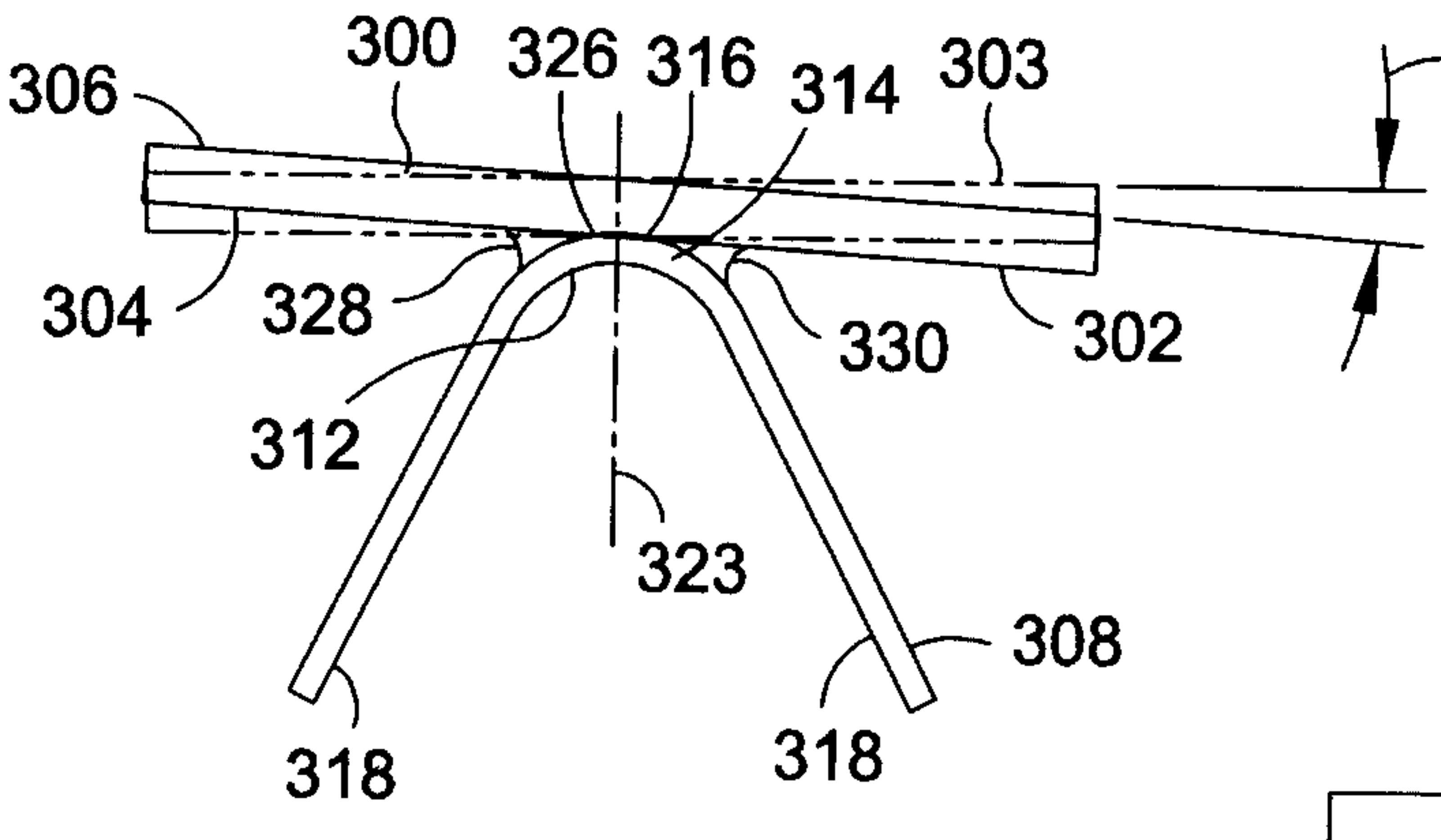


FIG. 19

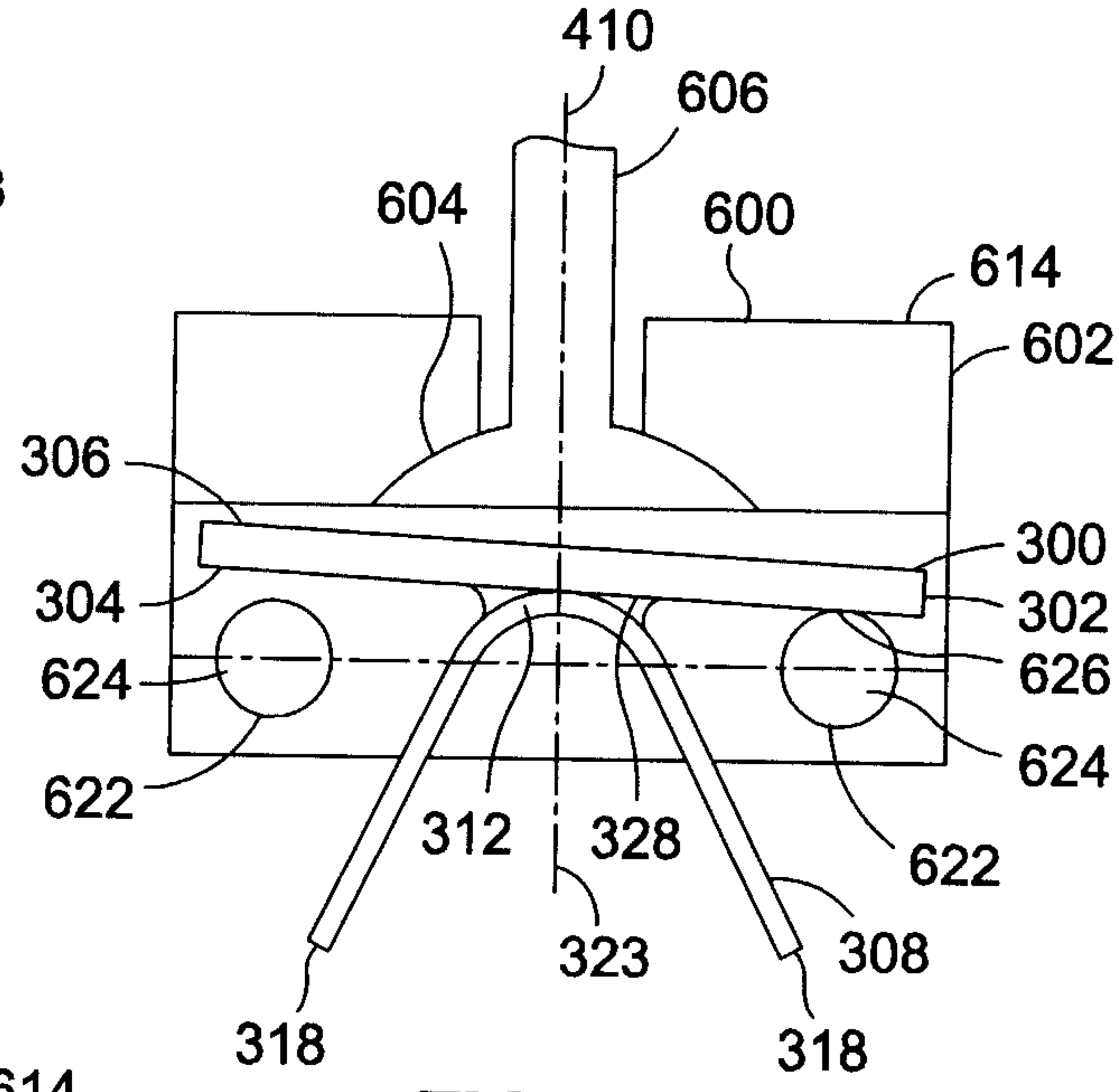
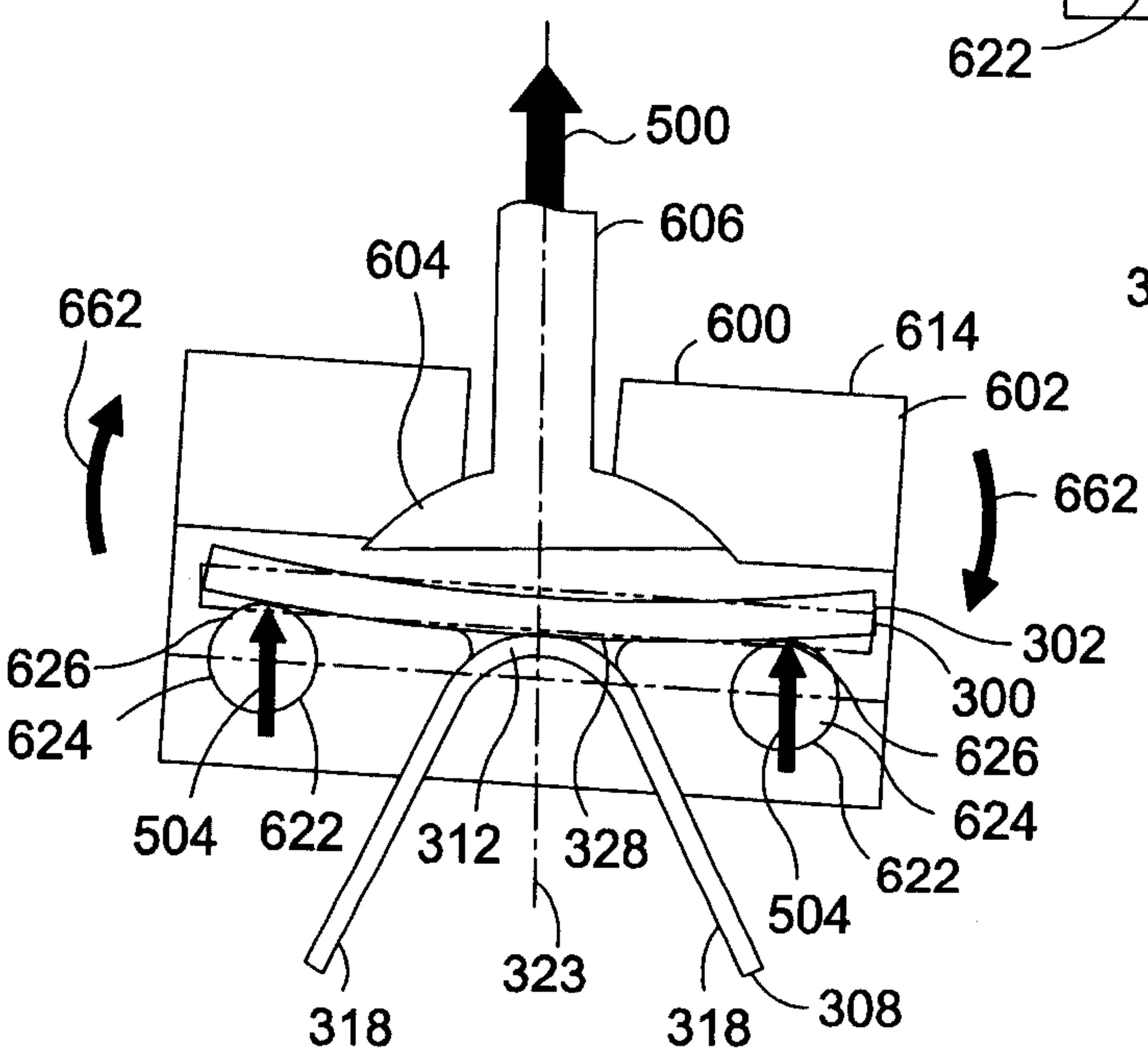


FIG. 20



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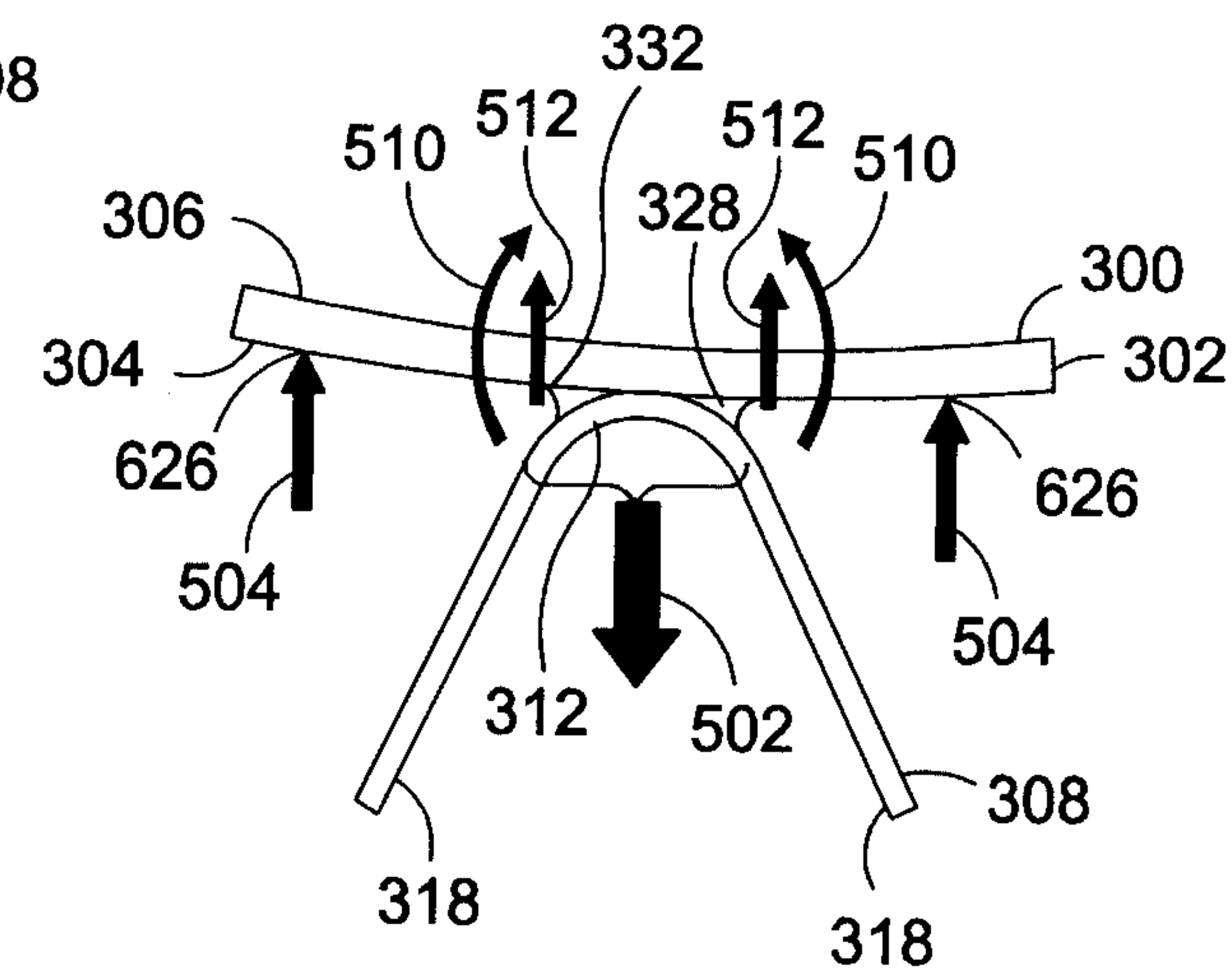


FIG. 22

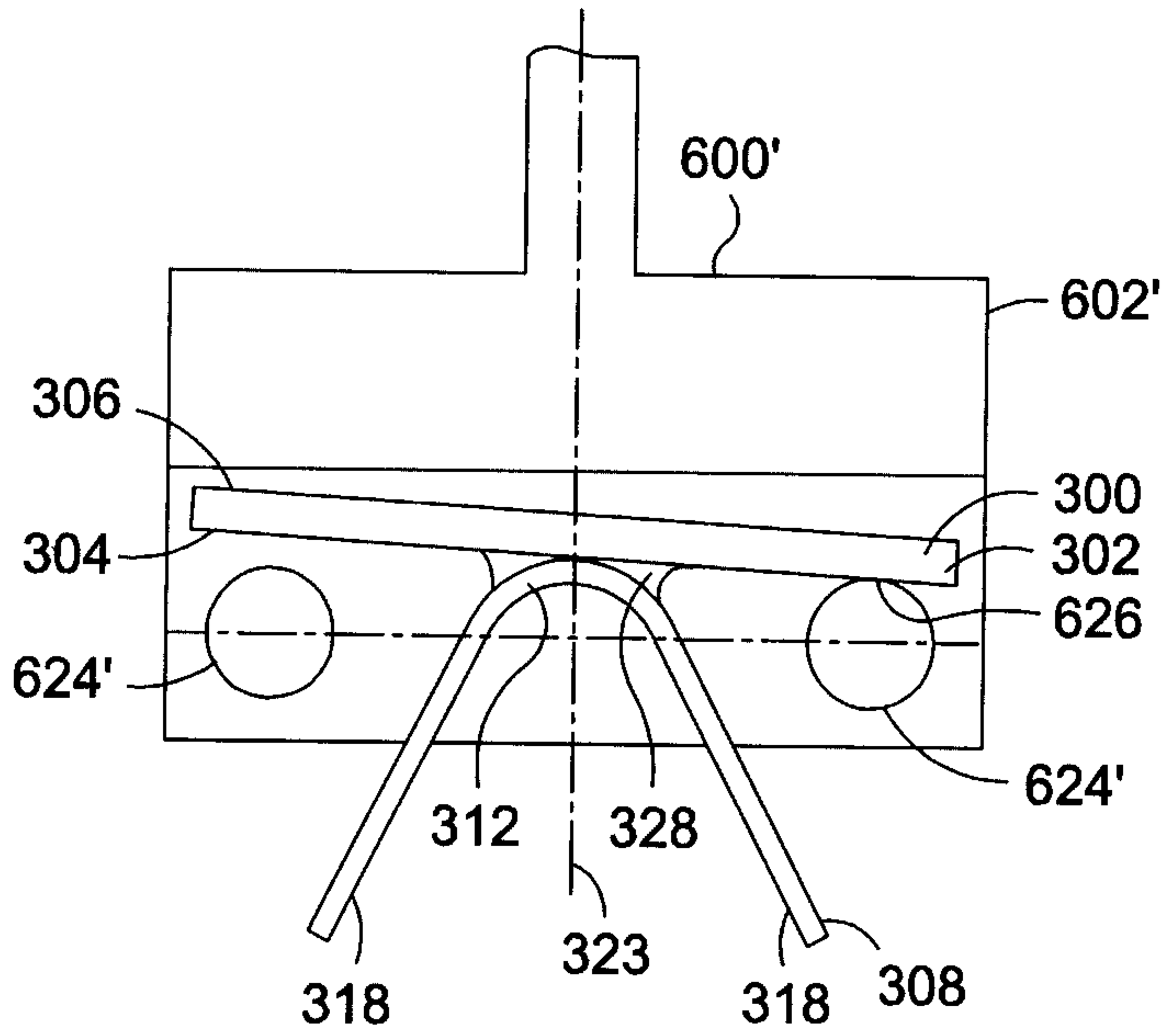


FIG. 23

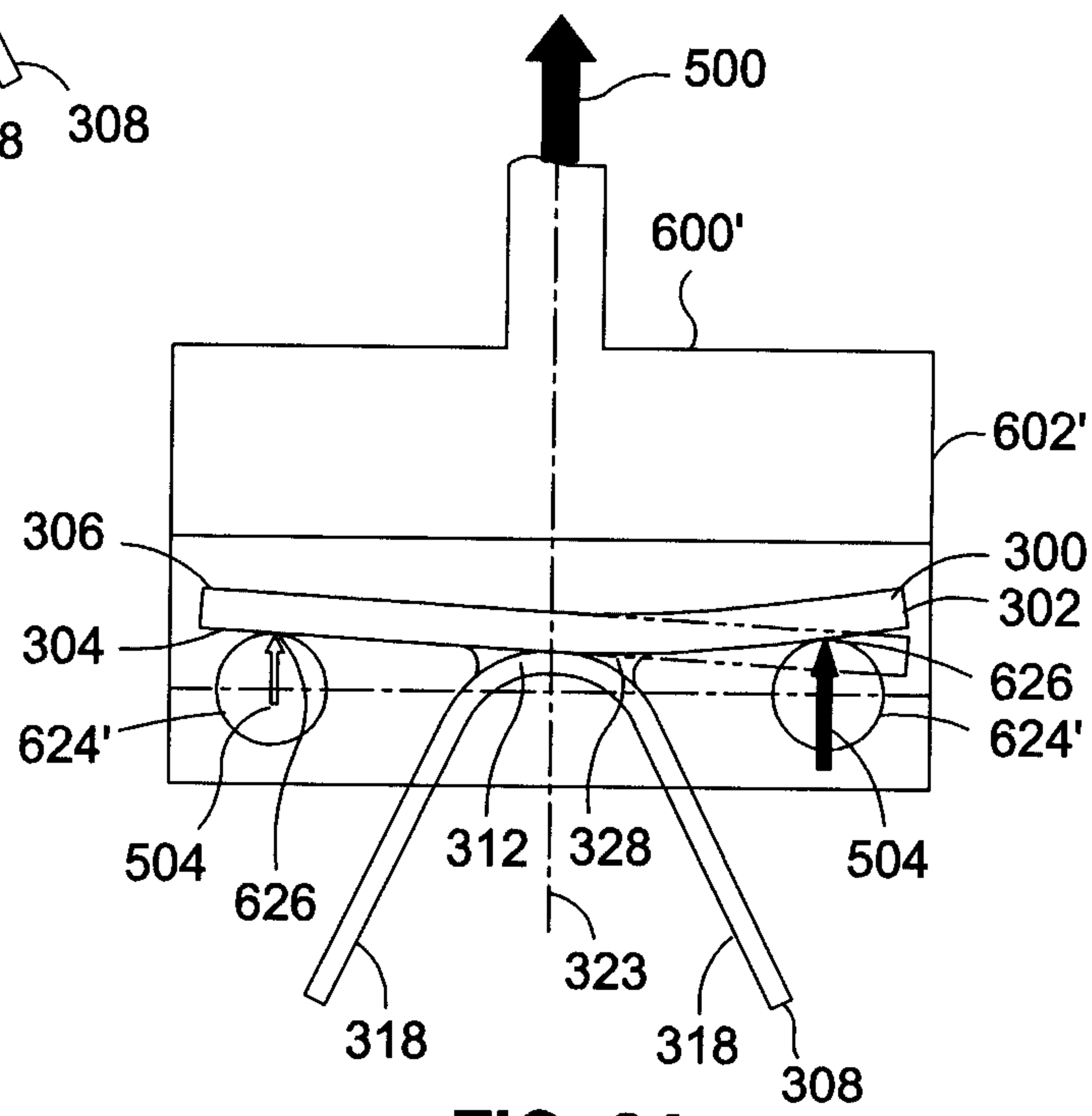


FIG. 24

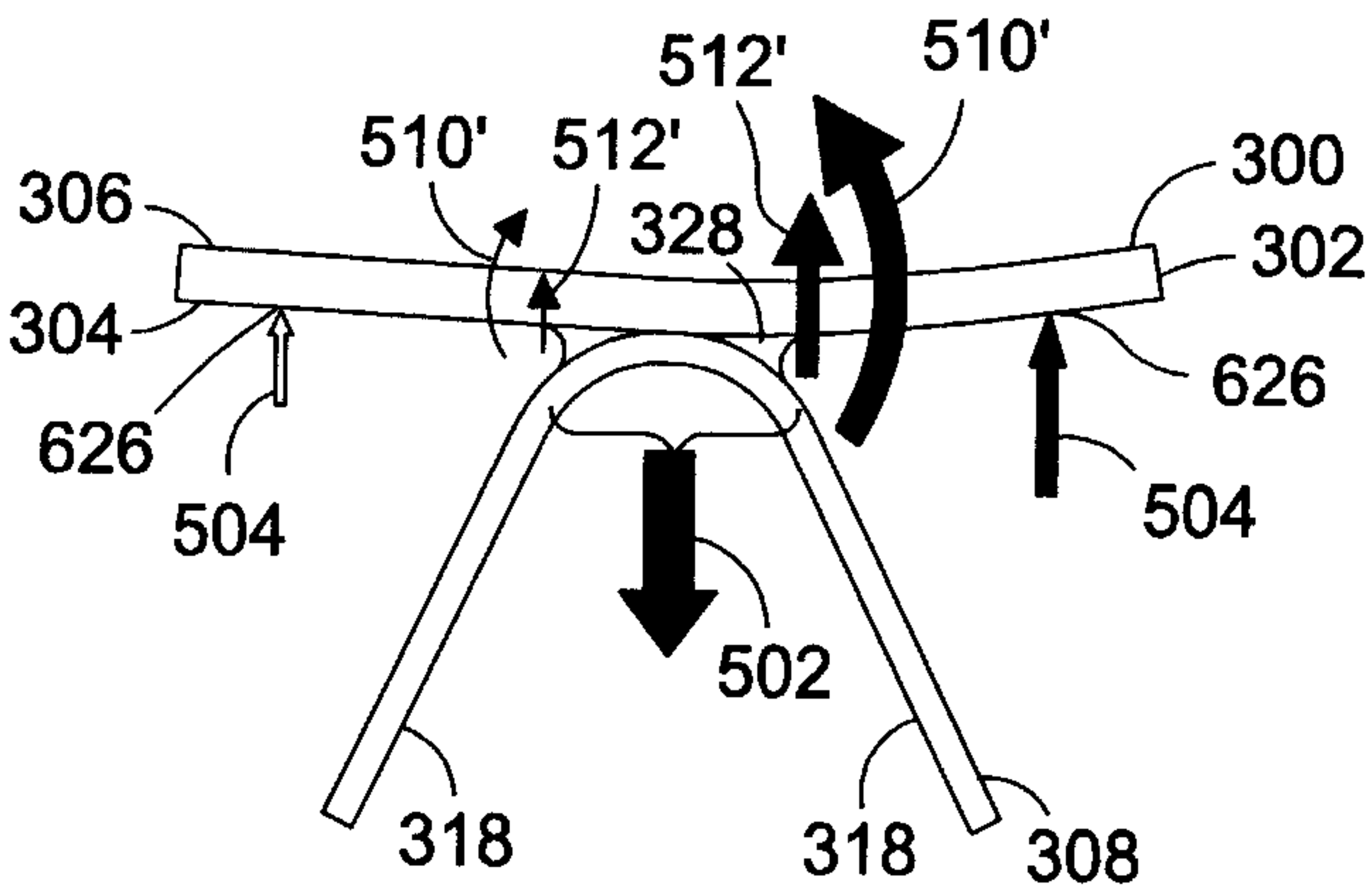
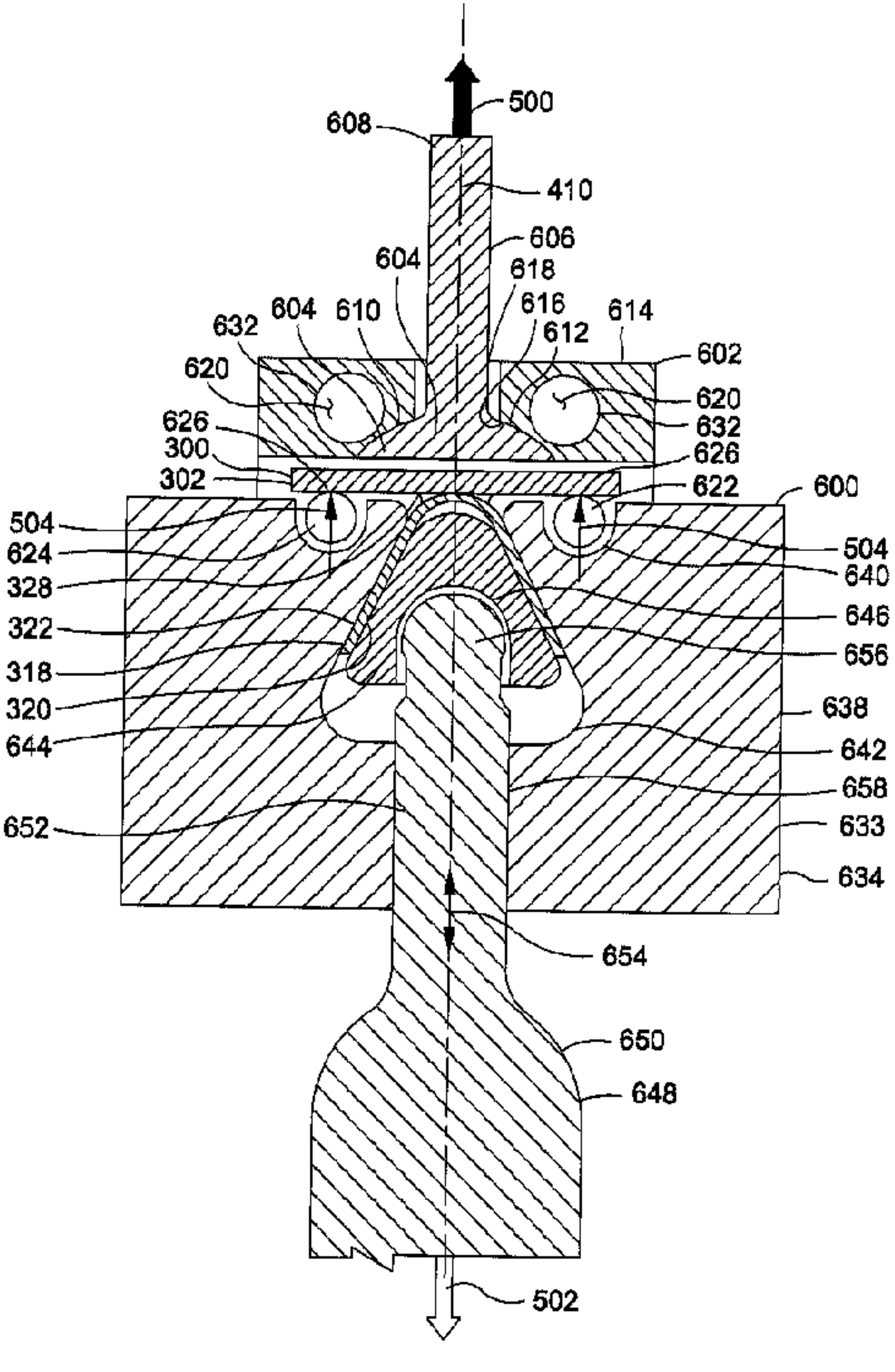


FIG. 25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