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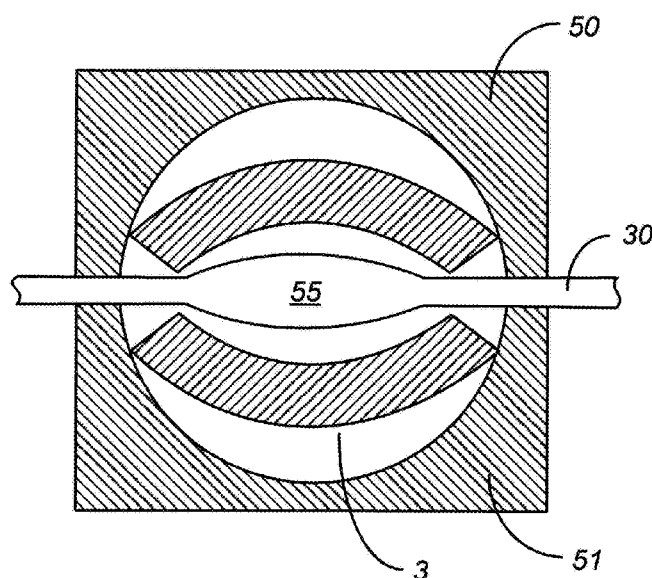


FIG. 4A

(57) Abstract: Hollow variator balls and methods of manufacturing hollow variator balls are disclosed. Certain methods include press forming of a cylindrical body into hollow sphere using counter rotating spherical dies, hot roll forming, skew rolling, and pressurized forging. Various means of rotational support are coupled to the hollow spheres such as axles, half axles, bearings, or sleeves.





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CVT VARIATOR BALL AND METHOD OF CONSTRUCTION THEREOF

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Patent Application No. 61/786,034, filed March 14, 2013 which application is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] A vehicle having a driveline including a tilting ball variator allows an operator of the vehicle or a control system of the vehicle to vary a drive ratio in a stepless manner. A variator is an element of a Continuously Variable Transmission (CVT) or an Infinitely Variable Transmission (IVT). Transmissions that use a variator can decrease the engine's gear ratio as engine speed increases. This keeps the engine within its optimal efficiency while gaining ground speed, or trading speed for hill climbing. Efficiency in this case can be fuel efficiency, decreasing fuel consumption and emissions output, or power efficiency, allowing the engine to produce its maximum power over a wide range of speeds. That is, the variator keeps the engine turning at constant RPMs over a wide range of vehicle speeds.

SUMMARY OF THE INVENTION

[0003] A tilting ball variator includes a first drive ring, a second drive ring, and a plurality of variator balls disposed between the first drive ring and the second drive ring. The plurality of variator balls is simultaneously tilted, which adjusts an axis angle of each of the variator balls, for example, by moving a carrier, the plurality of variator balls are rotatably disposed on. The plurality of variator balls are in driving engagement with the first drive ring and the second drive ring through one of a boundary layer type friction and an elastohydrodynamic film. A gear ratio between the carrier (if driven), the first drive ring, and the second drive ring may be adjusted by changing the axis angle of the plurality of variator balls.

[0004] The conventional variator ball is a solid metal sphere that includes a perforation therethrough, which passes through a center of the variator ball. The axle and a needle bearing are inserted within the perforation to permit the variator ball to rotate thereabout, and the axle is secured at each end to the carrier. As variator balls grow larger to accommodate larger CVT/IVT's loads, the weight and moment of inertia negatively affect the efficiency of the CVT. The variator balls are in driving engagement with the first drive ring and the second drive ring through one of a boundary layer type friction and an elastohydrodynamic film where the increased moment of inertia and weight of large variator balls decrease the effectiveness of the

elastohydrodynamic boundary layer friction coupling between the variator balls and drive rings. Loss of effective frictional coupling leads to decreases in efficiency and performance of the overall CVT. As the diameter of variator balls begins to exceed 3 inches, weight reduction measures may become necessary to preserve performance. Additionally, the elastohydrodynamic boundary layer friction coupling requires a high degree of geometric accuracy. Consequently precise forming of each of the variator balls is required for the tilting ball variator to operate. Operation of the variator balls requires an extremely high degree of rotational symmetry. The axles or sleeves supporting the variator balls must be axially well aligned with the center of the variator ball.

[0005] Provided herein is a method of manufacturing a hollow variator ball comprising a hollow main spherical portion and a rotational support structure having an axis well aligned with a center of the variator ball. In some embodiments, the hollow variator ball is a seamless hollow variator ball.

[0006] In some embodiments, creating the hollow spherical main portion of the variator comprises positioning a deformable cylindrical tubular member of predetermined length and diameter and wall thickness between two separated opposing counter-rotating hemispherical dies rotatable on a common axis coincident with the axis of the cylinder. In some embodiments the method further comprises press forming the deformable cylinder into a hollow sphere having two circular apertures on opposite sides of the sphere by moving the two hemispherical dies towards each other. Some embodiments further comprise coupling the rotational support structure to at least one of the circular apertures such that the axis of rotation of the support structure passes through the center of the hollow spherical main portion. In some embodiments the rotational support structure may comprise: a solid cylindrical axle, a pair of half axles, or a hollow cylindrical sleeve. The rotational support structure may also comprise needle bearings engaged with the circular apertures.

[0007] In some embodiments, coupling the rotational support structure comprises creating an interference fit. Creating an interference fit may comprise press-fitting or shrink fitting. Special surface conditions may facilitate a fully stable shrink fit.

[0008] In some embodiments, the two dies each have an aperture located about their axis of rotation sized to allow an axle to pass therethrough such that the axis of rotation of the axle coincides with the axis of rotation of the deformable cylinder and such that the dies rotate about the axle. In these and other embodiments coupling may comprise positioning the axle inside the deformable cylinder as it is being press-formed into the hollow sphere such that the axle is press fitted into the circular apertures as they are forming.

[0009] In some embodiments, the hollow cylindrical sleeve is sized to seal the interior of the hollow main spherical portion from the exterior of the hollow main spherical portion.

Additionally, needle bearings may be installed inside the hollow cylindrical sleeve such that the variator ball can spin about a central axis.

[0010] In some embodiments of the method described herein, the two dies each have an aperture located about their axis of rotation sized to allow the axle to pass therethrough such that the axis of rotation of the axle coincides with the axis of rotation of the deformable cylinder and such that the dies rotate about the axle. Coupling the rotational support structure may comprise positioning the axle inside the deformable cylinder as it is being press-formed into the hollow sphere such that the axle is press-fitted into the circular apertures as they are forming.

[0011] In some embodiments of the method described herein, the two dies each have an aperture located about their axis of rotation sized to allow the pair of half axles to pass therethrough such that the axis of rotation of the pair of half axles coincides with the axis of rotation of the deformable cylinder and such that the dies rotate about the pair of half axles. Coupling the rotational support structure may comprise positioning the pair of half axles inside the deformable cylinder as it is being press-formed into the hollow sphere such that the pair of half axles is press-fitted into the circular apertures as they are forming.

[0012] In some embodiments of the methods described herein, the two dies each have an aperture located about their axis of rotation sized to allow the hollow cylindrical sleeve to pass therethrough such that the axis of rotation of the hollow cylindrical sleeve coincides with the axis of rotation of the deformable cylinder and such that the dies rotate about the hollow cylindrical sleeve. Coupling the rotational support structure may comprise positioning the hollow cylindrical sleeve inside the deformable cylinder as it is being press-formed into the hollow sphere such that the hollow cylindrical sleeve is press-fitted into the circular apertures as they are forming.

[0013] In various embodiments of the methods described herein, the spherical accuracy of the interior of the hollow spherical main portion may be improved by pressurizing a spherical bladder disposed in the interior of the hollow spherical main portion while simultaneously constraining the hollow spherical main portion inside a sphere shaped die apparatus.

[0014] In some embodiments improving the spherical accuracy of the interior of the hollow spherical main portion comprises detonating an explosive inside the hollow spherical main portion while simultaneously constraining the hollow spherical main portion inside a sphere shaped die apparatus.

[0015] In some embodiments the hollow spherical main portion comprises a metal. In some embodiments the hollow spherical main portion comprises steel.

[0016] Some embodiments of the invention detail a method of producing hollow ceramic variator balls. A spherical pressurized bladder having two fluid lumina diametrically opposed to each other is suspended in a ceramic precursor inside encased between two hemispherical dies, the dies having channels for the fluid lumina. The ceramic precursor is reacted to form a hollow ceramic spherical ball having two apertures diametrically opposed to each other.

[0017] In some embodiments of the invention herein the diameter of the hollow spherical main portion is between 2 and 6 inches. In other embodiments the diameter of the hollow spherical main portion is between 6 and 18 inches. In yet other embodiments the diameter of the hollow spherical main portion is between 18 and 24 inches.

[0018] Provide herein is a method for forming multiple planets simultaneously comprising inserting an inner sleeve or bar support into an elongate cylindrical piece of tube stock. The tube stock is then selectively heated and roll formed into multiple spheroid objects connected by a central cylindrical lumen. The roll forming operation is repeated until the tube stock has been formed into multiple rough spheres joined by the central cylindrical lumen. In some embodiments, the spherical accuracy is improved by turning the multiple rough spheres on a lathe. Cutting the common lumen separates the spheres thereby producing multiple planets, each planet having diametrically opposed apertures. The multiple planets are produced by cutting the common lumen to separate the spheres. In some embodiments, the multiple rough spheres are coupled to a rotational support structure via the diametrically opposed apertures made when cutting the common lumen. The multiple planets may further be coupled to a rotational support structure such as an axle, pair of half axles, or hollow cylindrical sleeve.

[0019] Provide herein is a method for forming multiple individual planets comprising inserting hollow tubular bar stock into forging skew rollers to produce individual, separate planets. In some embodiments, the tubular bar comprises: steel, stainless steel, chromium alloy steel, or vanadium alloy steel. In some embodiments, the interior of the tubular bar comprises a secondary material selectively inserted therein to provide compressive resistance to the forging process and to maintain the internal integrity of the planet. In some embodiments, the secondary material comprises: mica, sand, silicon dioxide, quartz, or feldspar. In some embodiments, the secondary material is captured within the individual planet after forming. In some embodiments, the secondary material is later removed from the individual planet in a subsequent manufacturing process to create a hollow planet.

[0020] Provided herein is a method of producing a hollow variator ball comprising inserting a first end of tube stock into heater coils to raise the temperature of the tube stock to a plastically deformable temperature; pinching the first end to seal it; further induction heating a middle

portion of the tube stock to a plastically deformable temperature and inserting said heated tube stock in a collapsible spherical die; pressurizing the tube stock through a second end to a pressure that plastically deforms the tube stock to conform to the die to form a spherical variator ball; induction heating a second end of the tube stock to a plastically deformable temperature; pinching the second end to seal it; removing the formed spherical variator ball from the collapsible die; machining out the center of the spherical variator ball through the pinched ends; inserting an axle in bored holes; and welding an axle to the hollow sphere.

[0021] In some embodiments, the pinching is performed by a pinch rolling die. In some embodiments the pinching is performed by a swaging tool.

[0022] In some embodiments, the tube stock comprises steel, stainless steel, chromium alloy steel, or vanadium alloy steel.

[0023] In some embodiments, the pressurization step is at least 800 psi.

[0024] In some embodiments, the heating temperature for plastically deforming the tube stock is at least 925 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is at least 975 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is at least 1025 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is at least 1075 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is at least 1125 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is up to 1175 °F.

[0025] In some embodiments, the machining step comprises drilling, boring, turning, water jet cutting, laser cutting, or electrical discharge machining (EDM) process.

[0026] In some embodiments, subsequent manufacturing processes for removing the secondary material captured in the skew formed planet comprise drilling, reaming, vacuuming, high pressure gas, high pressure fluid spray, or water jet processing.

[0027] Provided herein is a method of forming multiple planets comprising: inserting an inner sleeve or bar support into an elongate cylindrical piece of tube stock; selectively heating areas of the tube stock; roll forming the tube stock into multiple spheroid objects connected by a common lumen extending through each of the multiple spheroid objects; repeating the roll forming operation until the multiple spheroid objects form into multiple rough spheres joined by the common lumen; improving the spherical accuracy of each of the multiple rough spheres by turning the multiple rough spheres on a lathe; and cutting the common lumen to separate the spheres, wherein such process produces multiple planets each having diametrically opposed apertures. In some embodiments, the common lumen passes through the center of each of the multiple planets. In some embodiments, the common lumen is cylindrical. In some embodiments,

the multiple rough spheres are coupled to a rotational support structure via the diametrically opposed apertures made when cutting the common lumen. In some embodiments, the rotational support structure is an axle. In some embodiments, the rotational support structure is a pair of half axles. In some embodiments, the rotational support structure is a hollow cylindrical sleeve. In some embodiments, the rotational support structure is dual inner formed lumen.

[0028] Provided herein is a method of forming multiple planets comprising inserting a hollow tubular bar into forging skew rollers to produce individual, separate planets. In some embodiments, the tubular bar comprises steel, stainless steel, chromium alloy steel, or vanadium alloy steel. In some embodiments, the interior of the tubular bar comprises a secondary material that provides compressive resistance to the forging process and that maintains the internal integrity of the planet. In some embodiments, the interior is a core of the tubular bar extending within a central longitudinal axis of the tubular bar. In some embodiments, the secondary material comprises: mica, sand, silicon dioxide, quartz, or feldspar. In some embodiments, the secondary material is captured within each of the multiple planets. In some embodiments, the method comprises removing the secondary material from at least one of the multiple planets to form at least one hollow planet. In some embodiments, removing the secondary material comprises: drilling, reaming, vacuuming, applying high pressure gas, spraying with high pressure fluid, or water jet processing.

[0029] Provided herein is a method of producing a variator ball comprising: inserting a first end of a tube stock into heater coils wherein the tube stock comprises the first end, a middle portion and a second end; heating the first end of the tube stock to a plastically deformable temperature appropriate for the tube stock; sealing the first end forming a first sealed end; heating at least the middle portion to the plastically deformable temperature; inserting the tube stock in a collapsible spherical die; pressurizing the tube stock through the second end and plastically deforming at least the middle portion thereby forming the variator ball having an open end corresponding to the second end of the tube stock and a hollow interior; removing the variator ball from the collapsible spherical die; heating the open end to the plastically deformable temperature; sealing the open end of the variator ball forming a second sealed end; forming a first hole and a second hole in the variator ball by removing a portion of the first sealed end and removing a portion of the second sealed end; attaching a first portion of an axle to the variator ball at the first hole; and attaching a second portion of an axle to the variator ball at the second hole. In some embodiments, sealing the first end comprises pinching the first end. In some embodiments, sealing the second end comprises pinching the second end. In some embodiments, pinching is performed by a pinch rolling die. In some embodiments, heating the first end of the tube stock,

heating the middle portion of the tube stock, or heating the second end of the tube stock is by induction heating. In some embodiments, removing a portion of the first sealed end comprises machining out the center of the first sealed end. In some embodiments, removing a portion of the second sealed end comprises machining out the center of the second sealed end. In some embodiments, the first hole and the second hole are diametrically aligned. In some embodiments, the first axle extends through the variator ball. In some embodiments, the first portion of the axle is separate from the second portion of the axle such that the variator ball is hollow. In some embodiments, the tube stock comprises: steel, stainless steel, chromium alloy steel, or vanadium alloy steel. In some embodiments, pressurizing comprises a pressure of at least 800 psi. In some embodiments, the plastically deformable temperature is at least 925 °F. In some embodiments, the plastically deformable temperature is at least 975 °F. In some embodiments, the plastically deformable temperature is at least 1075 °F. In some embodiments, the plastically deformable temperature is at least 1125 °F. In some embodiments, the machining step comprises: turning, grinding, drilling, boring, laser cutting, or an electrical discharge machining process.

[0030] Provided herein is a manufacturing apparatus that implements any of the methods, in full or in part as described herein or obvious to one of skill in the art upon reading the disclosure herein.

[0031] Provided herein is a variable transmission comprising a variator ball formed by any of the methods of creating one or more variator balls described herein or obvious to one of skill in the art upon reading the disclosure herein.

[0032] Provided herein is a variator ball formed by any of the methods described herein or obvious to one of skill in the art upon reading the disclosure herein.

[0033] Provided herein is a vehicle driveline comprising a variable transmission comprising a variator ball formed by any of the methods of creating one or more variator balls described herein or obvious to one of skill in the art upon reading the disclosure herein.

[0034] Provided herein is a vehicle driveline comprising an engine, a vehicle output, and a variable transmission comprising a variator ball formed by any of the methods described herein or obvious to one of skill in the art upon reading the disclosure herein.

[0035] Provided herein is a vehicle comprising the variable transmission comprising one or more variator balls formed by any of the methods of creating one or more variator balls described herein or obvious to one of skill in the art upon reading the disclosure herein.

INCORPORATION BY REFERENCE

[0036] All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

[0038] **Figures 1A - 1B** depict press-forming a deformable cylindrical tubular member.

[0039] **Figures 2A - 2B** depict press-forming a deformable cylindrical tubular member wherein lumina are present in the die and a rotational support structure is coupled to the hollow sphere as it is formed.

[0040] **Figures 3A - 3D** depict cross sections of the variator balls with different rotational support structures.

[0041] **Figures 4A - 4B** show a pressurized fluid bladder used to improve the internal spherical accuracy of a hollow sphere or aid in the assistance of a ceramic sphere.

[0042] **Figures 5A - 5B** depict the use of explosive detonation to improve the internal spherical accuracy of a hollow sphere.

[0043] **Figures 6A - 6E** depict a method of forming multiple planets in a batch.

[0044] **Figures 7A - 7C** depict a method of forming multiple planets from one piece of tube stock.

[0045] **Figures 8A - 8H** depict a method of forming planets using induction heating and high pressure gas forming in collapsible dies.

DETAILED DESCRIPTION OF THE INVENTION

[0046] While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

[0047] Provided herein is a method of manufacturing a hollow variator ball comprising a hollow main spherical portion and a rotational support structure having an axis well aligned with a center of the variator ball.

[0048] In some embodiments, the variator (CVP) of a variable transmission itself works with a traction fluid. In some embodiments, the lubricant between the ball and the conical rings acts as a solid at high pressure, transferring the power from the first ring assembly, through the variator balls, to the second ring assembly. By tilting the variator balls' axles, the ratio can be changed between input and output. When the axle of each of the variator balls is horizontal, the ratio is one. When the axles are tilted, the distance between the axles and the contact point changes, modifying the overall ratio. In some embodiments, all the variator balls' axles are tilted at the same time with a mechanism included in the cage.

[0049] In some embodiments, creating the hollow spherical main portion of the variator comprises positioning a deformable cylindrical tubular member of predetermined length and diameter and wall thickness between two separated opposing counter-rotating hemispherical dies rotatable on a common axis coincident with the axis of the cylinder. In some embodiments the method further comprises press forming the deformable cylinder into a hollow sphere having two circular apertures on opposite sides of the sphere by moving the two hemispherical dies towards each other. Some embodiments further comprise coupling the rotational support structure to at least one of the circular apertures such that the axis of rotation of the support structure passes through the center of the hollow spherical main portion. In some embodiments the rotational support structure may comprises: a solid cylindrical axle, a pair of half axles, or a hollow cylindrical sleeve. The rotational support structure may also comprise needle bearings engaged with the circular apertures.

[0050] In some embodiments, coupling the rotational support structure comprises creating an interference fit. In some embodiments, creating an interference fit may comprise press-fitting or shrink fitting. In some embodiments, special surface conditions may facilitate a fully stable shrink fit. In some embodiments, rotational support structures (axles) are welded into place following formation and semi-finishing of the planet. Laser welding is one preferred method. Welding in an inert gas field and pre-heating the material may also be necessary due to material composition. Alternately, the spinning press-forming operation results in a spin-welding or fusion welding process that couples the support structures to the sphere.

[0051] In some embodiments, the two dies each have an aperture located about their axis of rotation sized to allow an axle to pass therethrough such that the axis of rotation of the axle coincides with the axis of rotation of the deformable cylinder and such that the dies rotate about

the axle. In these and other embodiments coupling may comprise positioning the axle inside the deformable cylinder as it is being press-formed into the hollow sphere such that the axle is press fitted into the circular apertures as they are forming.

[0052] In some embodiments, the hollow cylindrical sleeve is sized to seal the interior of the hollow main spherical portion from the exterior of the hollow main spherical portion.

Additionally, in some embodiments needle bearings are installed inside the hollow cylindrical sleeve such that the variator ball can spin about a central axis.

[0053] In some embodiments of the method described herein, the two dies each have an aperture located about their axis of rotation sized to allow the axle to pass therethrough such that the axis of rotation of the axle coincides with the axis of rotation of the deformable cylinder and such that the dies rotate about the axle. Coupling the rotational support structure may comprise positioning the axle inside the deformable cylinder as it is being press-formed into the hollow sphere such that the axle is press-fitted into the circular apertures as they are forming.

[0054] In some embodiments of the method described herein, the two dies each have an aperture located about their axis of rotation sized to allow the pair of half axles to pass therethrough such that the axis of rotation of the pair of half axles coincides with the axis of rotation of the deformable cylinder and such that the dies rotate about the pair of half axles. Coupling the rotational support structure may comprise positioning the pair of half axles inside the deformable cylinder as it is being press-formed into the hollow sphere such that the pair of half axles is press-fitted into the circular apertures as they are forming.

[0055] In some embodiments of the methods described herein, the two dies each have an aperture located about their axis of rotation sized to allow the hollow cylindrical sleeve to pass therethrough such that the axis of rotation of the hollow cylindrical sleeve coincides with the axis of rotation of the deformable cylinder and such that the dies rotate about the hollow cylindrical sleeve. Coupling the rotational support structure may comprise positioning the hollow cylindrical sleeve inside the deformable cylinder as it is being press-formed into the hollow sphere such that the hollow cylindrical sleeve is press-fitted into the circular apertures as they are forming.

[0056] In various embodiments of the methods described herein, the spherical accuracy of the interior of the hollow spherical main portion may be improved by pressurizing a spherical bladder disposed in the interior of the hollow spherical main portion while simultaneously constraining the hollow spherical main portion inside a sphere shaped die apparatus.

[0057] In some embodiments, improving the spherical accuracy of the interior of the hollow spherical main portion comprises detonating an explosive inside the hollow spherical main portion while simultaneously constraining the hollow spherical main portion inside a sphere

shaped die apparatus. In some embodiments, multiple detonations of an explosive may be required to obtain the desired shape of the hollow sphere.

[0058] Provide herein is a method for forming multiple planets simultaneously comprising inserting an inner sleeve or bar support into an elongate cylindrical piece of tube stock. The tube stock is then selectively heated and roll formed into multiple spheroid objects connected by a central cylindrical lumen. The roll forming operation is repeated until the tube stock has been formed into multiple rough spheres joined by the central cylindrical lumen. In some embodiments, the spherical accuracy is improved by turning the multiple rough spheres on a lathe. Cutting the common lumen separates the spheres thereby producing multiple planets, each planet having diametrically opposed apertures. The multiple planets are produced by cutting the common lumen to separate the spheres. In some embodiments, the multiple rough spheres are coupled to a rotational support structure via the diametrically opposed apertures made when cutting the common lumen. The multiple planets may further be coupled to a rotational support structure such as an axle, pair of half axles, or hollow cylindrical sleeve.

[0059] Provide herein is a method for forming multiple individual planets comprising inserting hollow tubular bar stock into forging skew rollers to produce individual, separate planets. In some embodiments, the tubular bar comprises: steel, stainless steel, chromium alloy steel, or vanadium alloy steel. In some embodiments, the interior of the tubular bar comprises a secondary material selectively inserted therein to provide compressive resistance to the forging process and to maintain the internal integrity of the planet. In some embodiments, the secondary material comprises: mica, sand, silicon dioxide, quartz, or feldspar. In some embodiments, the secondary material is captured within the individual planet after forming. In some embodiments, the secondary material is later removed from the individual planet in a subsequent manufacturing process to create a hollow planet.

[0060] Provided herein is a method of forming a hollow variator ball comprising inserting a first end of tube stock into heater coils to raise the temperature of the tube stock to a plastically deformable temperature; pinching the first end to seal it; further induction heating a middle portion of the tube stock to a plastically deformable temperature and inserting said heated tube stock in a collapsible spherical die; pressurizing the tube stock through a second end to a pressure that plastically deforms the tube stock to conform to the die to form a spherical variator ball; removing the formed spherical variator ball from the collapsible die and induction heating a second end of the tube stock to a plastically deformable temperature; pinching the second end to seal it; machining out the center of the spherical variator ball through the pinched ends; inserting an axle in bored holes; and welding an axle to the hollow sphere.

[0061] In some embodiments, the pinching is performed by a pinch rolling die. In some embodiments the pinching is performed by a swaging tool.

[0062] In some embodiments, the tube stock comprises steel, stainless steel, chromium alloy steel, or vanadium alloy steel.

[0063] In some embodiments, the pressurization step is at least 800 psi.

[0064] In some embodiments, the heating temperature for plastically deforming the tube stock is at least 925 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is at least 975 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is at least 1025 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is at least 1075 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is at least 1125 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is up to 1175 °F.

[0065] In some embodiments, the machining step comprises drilling, boring, laser cutting, or electrical discharge machining (EDM).

[0066] In some embodiments, the hollow spherical main portion comprises a metal. In some embodiments, the hollow spherical main portion comprises steel. In still other embodiments and manufacturing methods described herein, the hollow spherical main portion comprises a ceramic.

[0067] Some embodiments of the invention detail a method of producing hollow ceramic variator balls. A spherical pressurized bladder having two fluid lumina diametrically opposed to each other is suspended in a ceramic precursor inside encased between two hemispherical dies, the dies having channels for the fluid lumina. The ceramic precursor is reacted to form a hollow ceramic spherical ball having two apertures diametrically opposed to each other.

[0068] As defined herein a lumen (or lumina, pl.) is the inner bore diameter of a tubular structure, or central cavity of a hollow structure.

[0069] In some embodiments of the invention herein the diameter of the hollow spherical main portion is between 2 and 6 inches. In other embodiments the diameter of the hollow spherical main portion is between 6 and 18 inches. In yet other embodiments the diameter of the hollow spherical main portion is between 18 and 24 inches.

[0070] Some embodiments provide methods for forming multiple planets comprising inserting an inner sleeve or bar support into an elongated cylindrical piece of tube stock. The tube stock is then selectively heated and roll formed into multiple spheroid objects connected by a central cylindrical lumen. The roll forming operation is repeated until the tube stock has been formed into multiple rough spheres joined by the central cylindrical lumen. In some embodiments, the spherical accuracy is improved by turning the multiple rough spheres on a lathe. Cutting the

common lumen separates the spheres thereby producing multiple planets, each planet having diametrically opposed apertures. The multiple planets are produced by cutting the common lumen to separate the spheres. In some embodiments, the multiple planets have a ground finish. In some embodiments the multiple planets having a ground finish by using standard ball finishing techniques. In some embodiments, the multiple rough spheres are coupled to a rotational support structure via the diametrically opposed apertures made when cutting the common lumen. The multiple planets may further be coupled to a rotational support structure such as an axle, pair of half axles, or hollow cylindrical sleeve.

[0071] Provided herein is a method of forming multiple planets comprising: inserting an inner sleeve or bar support into an elongate cylindrical piece of tube stock; selectively heating areas of the tube stock; roll forming the tube stock into multiple spheroid objects connected by a common lumen extending through each of the multiple spheroid objects; repeating the roll forming operation until the multiple spheroid objects form into multiple rough spheres joined by the common lumen; improving the spherical accuracy of each of the multiple rough spheres by turning the multiple rough spheres on a lathe; and cutting the common lumen to separate the spheres, wherein such process produces multiple planets each having diametrically opposed apertures. In some embodiments, the common lumen passes through the center of each of the multiple planets. In some embodiments, the common lumen is cylindrical. In some embodiments, the multiple rough spheres are coupled to a rotational support structure via the diametrically opposed apertures made when cutting the common lumen. In some embodiments, the rotational support structure is an axle. In some embodiments, the rotational support structure is a pair of half axles. In some embodiments, the rotational support structure is a hollow cylindrical sleeve. In some embodiments, the rotational support structure is dual inner formed lumen.

[0072] Provided herein is a method of forming multiple planets comprising inserting a hollow tubular bar into forging skew rollers to produce individual, separate planets. In some embodiments, the tubular bar comprises steel, stainless steel, chromium alloy steel, or vanadium alloy steel. In some embodiments, the interior of the tubular bar comprises a secondary material that provides compressive resistance to the forging process and that maintains the internal integrity of the planet. In some embodiments, the interior is a core of the tubular bar extending within a central longitudinal axis of the tubular bar. In some embodiments, the secondary material comprises: mica, sand, silicon dioxide, quartz, or feldspar. In some embodiments, the secondary material is captured within each of the multiple planets. In some embodiments, the method comprises removing the secondary material from at least one of the multiple planets to form at least one hollow planet. In some embodiments, removing the secondary material

comprises: drilling, reaming, vacuuming, applying high pressure gas, spraying with high pressure fluid, or water jet processing.

[0073] Provided herein is a method of producing a variator ball comprising: inserting a first end of a tube stock into heater coils wherein the tube stock comprises the first end, a middle portion and a second end; heating the first end of the tube stock to a plastically deformable temperature appropriate for the tube stock; sealing the first end forming a first sealed end; heating at least the middle portion to the plastically deformable temperature; inserting the tube stock in a collapsible spherical die; pressurizing the tube stock through the second end and plastically deforming at least the middle portion thereby forming the variator ball having an open end corresponding to the second end of the tube stock and a hollow interior; removing the variator ball from the collapsible spherical die; heating the open end to the plastically deformable temperature; sealing the open end of the variator ball forming a second sealed end; forming a first hole and a second hole in the variator ball by removing a portion of the first sealed end and removing a portion of the second sealed end; attaching a first portion of an axle to the variator ball at the first hole; and attaching a second portion of an axle to the variator ball at the second hole. In some embodiments, sealing the first end comprises pinching the first end. In some embodiments, sealing the second end comprises pinching the second end. In some embodiments, pinching is performed by a pinch rolling die. In some embodiments, heating the first end of the tube stock, heating the middle portion of the tube stock, or heating the second end of the tube stock is by induction heating. In some embodiments, removing a portion of the first sealed end comprises machining out the center of the first sealed end. In some embodiments, removing a portion of the second sealed end comprises machining out the center of the second sealed end. In some embodiments, the first hole and the second hole are diametrically aligned. In some embodiments, the first axle extends through the variator ball. In some embodiments, the first portion of the axle is separate from the second portion of the axle such that the variator ball is hollow. In some embodiments, the tube stock comprises: steel, stainless steel, chromium alloy steel, or vanadium alloy steel. In some embodiments, pressurizing comprises a pressure of at least 800 psi. In some embodiments, the plastically deformable temperature is at least 925 °F. In some embodiments, the plastically deformable temperature is at least 975 °F. In some embodiments, the plastically deformable temperature is at least 1075 °F. In some embodiments, the plastically deformable temperature is at least 1125 °F. In some embodiments, the machining step comprises: turning, grinding, drilling, boring, laser cutting, or an electrical discharge machining process.

[0074] **Figures 1A – 1B** depict the press forming of a deformable cylindrical tubular member **1** into a hollow sphere **3** having two circular apertures **9** by two opposing counter-rotating die **2a**, **2b**.

[0075] As one skilled in the art would understand after reading this disclosure, the length of the deformable cylindrical tubular member **1** can be predetermined and the size of the apertures **9** can be closely controlled.

[0076] **Figures 2A – 2B** depict the press forming of a deformable cylindrical tubular member **1** into a hollow sphere **3** wherein the die have lumina **6** that allow rotational support structure **4** to be coupled to sphere **3** during the forming operation.

[0077] The spinning press-forming operation results in a spin-welding or fusion welding process that couples the support structures to the sphere.

[0078] **Figures 3A - 3D** show cross-sections of various hollow spherical main portions having different rotational support structures. **Figure 3A** shows a solid axle **11**, **Figure 3B** shows a pair of half axles **8**, **Figure 3C** shows a hollow cylindrical sleeve **12**, and **Figure 3D** shows a dual inner formed lumen **13**.

[0079] **Figures 3A and 3C** illustrate rotational support structures that are routinely inserted in secondary operations after the sphere has been formed and had at least a minimum number of finishing operations performed thereon. **Figures 3B and 3D** illustrate rotational support structures which can be inserted during the spinning press-forming operation resulting in a spin-welding or fusion welding process or manually inserted in secondary operations after the sphere has been formed.

[0080] In some embodiments, rotational support structures (axles) are welded into place following formation and semi-finishing of the planet. Laser welding is one preferred method. Welding in an inert gas field may also be necessary due to material composition.

[0081] **Figure 4A – 4B** depicts using fluid pressure to increase spherical accuracy inside a hollow sphere. Upper die **50** and lower die **51** are seen confining hollow sphere **3** while pressure **55** builds inside bladder **30**. Also shown in **Figure 4B** is ceramic precursor **25** which may be used in the manufacture of ceramic variator balls in much the same fashion.

[0082] As one skilled in the art will recognize after reading this disclosure, the ceramic may be “pre-machined” in the green state to allow for the placement of an axle prior to sintering. Alternatively, an axle can be brazed to the ceramic after sintering.

[0083] **Figure 5A– 5B** depicts using a detonation **53** from an explosive located within a deformable cylindrical tube **1** confined by upper die **50** and lower die **51** in order to increase internal spherical accuracy of hollow sphere **3**.

[0084] **Figures 6A – 6E** show a method of creating multiple planets. Inner sleeve or bar support **41** is inserted into tube stock **40**, as illustrated in **FIG. 6B**. The step **42** of selective heating and rolling is used to form rough spheres **45**, as illustrated in **FIG. 6C**. This is repeated, and, in step **43**, a lathe, grinder, or comparable finishing process is used to increase spherical accuracy of spheres **46**, as illustrated in **FIG. 6D**. The step **44** of cutting of the common lumen material **47** produces multiple hollow spheres (planets) **3**, as illustrated in **FIG. 6E**.

[0085] As one skilled in the art would understand after reading this disclosure, the step 42 of selective heating and rolling may be performed once or several times, depending on the process and or equipment utilized, in order to produce a near-net finished sphere (planet) that is ready for secondary finishing (step 43) and separation (step 44). Lumen **47** can be removed by secondary machining operations (step 44); or if no inner sleeve is used, hollow sleeves can have external lumen similar to Figure 3B.

[0086] **Figures 7A – 7C** illustrate another method **70** of creating multiple planets. Using a variant of skew rolling, a hollow piece of tube stock **71** packed with a secondary material **72**, such as mica, sand, silicon dioxide, quartz, or feldspar, as non-limiting examples, inserted into the tube stock to help maintain the tube's integrity (provide compressive resistance) while being rolled through the skew rollers **70a, 70b**. Skew rolling is a metal forging process that uses two specially designed opposing rolls that rotate continuously. Round stock is fed into the skew rollers, and the material is forged by each of the grooves **76** in the rolls and emerges from the end as a metal ball **74**. However, in this case, each metal ball **74**, comprises an outer shell **73** with the secondary material **72** trapped inside.

[0087] The stock is fed through the rolls continuously, but each ball **74** is produced separately, thus it is a discrete process and not a continuous one. Skew rolling, similar to roll forging, is a manufacturing process that bears qualities of both metal rolling and metal forging. Once the forging process of skew rolling is complete, outer surface finish of the planet **73** can be finish machined and/or the secondary material **72** could then be removed to create a hollow planet **77** when a through-bore **78** is cut in preparation for insertion of an axle **79**. The order of finish processing is highly dependent on manufacturing equipment and desired final configuration.

[0088] The internal volume of the planet may be evacuated of secondary material via numerous processes such as machining, vacuuming, high pressure gas, or high pressure fluid spray, such as a water jet process.

[0089] **Figures 8A – 8H** illustrate yet another method **80** of creating individual planets **89**. Using a combination of methods comprising inserting a first end **81a** of tube stock **81** into heater coils **100** to raise the temperature of the tube stock to a plastically deformable temperature;

pinching **110** the first end **81a** to seal it; further induction heating **100** a middle portion **81b** of the tube stock **81** to a plastically deformable temperature and inserting said heated tube stock in a collapsible spherical die **120a**, **120b**; pressurizing (PSI) the tube stock through a second end **81c** to a pressure that plastically deforms the tube stock to conform to the die to form a rough- shaped spherical variator ball **84** with a hollow center **87**; removing the rough- shaped spherical variator ball **84** from the collapsible die **120a**, **120b** and induction heating **100** a second end **81c** of the tube stock to a plastically deformable temperature; pinching **110** the second end **81c** to seal it; machining out the center **87** of the spherical variator ball through the pinched ends **81a**, **81b**, creating one or more machining diameters or bored holes **86** and finishing the OD of the planet **89**; inserting a thru-axle **88** in bored holes **86**; and welding **85** the axle **88** to the hollow sphere **84** to create a finished variator planet **89**.

[0090] In some embodiments, the pinching is performed by a pinch rolling die **100**. In some embodiments the pinching is performed by a swaging tool (not shown).

[0091] In some embodiments, the tube stock **81** comprises steel, stainless steel, chromium alloy steel, or vanadium alloy steel.

[0092] In some embodiments, the pressurization step is at least 800 psi.

[0093] In some embodiments, the heating temperature for plastically deforming the tube stock is at least 925 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is at least 975 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is at least 1025 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is at least 1075 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is at least 1125 °F. In some embodiments, the heating temperature for plastically deforming the tube stock is up to 1175 °F.

[0094] In some embodiments, the machining steps to bore the center of the hollow sphere and finish the OD of the planet comprises turning, grinding, drilling, boring, water-jet cutting, laser cutting, or electrical discharge machining EDM.

[0095] Provided herein is a variable transmission comprising a variator ball formed by any of the methods of creating one or more variator balls described herein or obvious to one of skill in the art upon reading the disclosure herein.

[0096] Provided herein is a variator ball formed by any of the methods described herein or obvious to one of skill in the art upon reading the disclosure herein.

[0097] Provided herein is a vehicle driveline comprising a variable transmission comprising a variator ball formed by any of the methods of creating one or more variator balls described herein or obvious to one of skill in the art upon reading the disclosure herein.

[0098] Provided herein is a vehicle driveline comprising an engine, a vehicle output, and a variable transmission comprising a variator ball formed by any of the methods described herein or obvious to one of skill in the art upon reading the disclosure herein.

[0099] Provided herein is a vehicle comprising the variable transmission comprising one or more variator balls formed by any of the methods of creating one or more variator balls described herein or obvious to one of skill in the art upon reading the disclosure herein.

[00100] Provided herein is a manufacturing apparatus that implements any of the methods, in full or in part as described herein or obvious to one of skill in the art upon reading the disclosure herein.

[00101] Embodiments of the variable transmission described herein or that would be obvious to one of skill in the art upon reading the disclosure herein, are contemplated for use in a variety of vehicle drivelines. For non-limiting example, the variable transmissions disclosed herein may be used in bicycles, mopeds, scooters, motorcycles, automobiles, electric automobiles, trucks, sport utility vehicles (SUV's), lawn mowers, tractors, harvesters, agricultural machinery, all-terrain vehicles (ATV's), jet skis, personal watercraft vehicles, airplanes, trains, helicopters, buses, forklifts, golf carts, motorships, steam powered ships, submarines, space craft, or other vehicles that employ a transmission.

CLAIMS

WHAT IS CLAIMED IS:

1. A method of manufacturing a variator ball comprising a hollow spherical main portion and a rotational support structure having an axis of rotation well aligned with the center of the hollow spherical main portion, the method comprising:

- creating the hollow spherical main portion of the variator ball by
 - positioning a deformable cylindrical tubular member of predetermined length, diameter and wall thickness between two separated opposing counter-rotating hemispherical dies rotatable on a common axis coincident with the axis of the cylinder, and
 - press forming the deformable cylinder into a hollow sphere having two circular apertures on opposite sides of the sphere by moving the two hemispherical dies towards each other; and

- coupling the rotational support structure to at least one of the circular apertures such that the axis of rotation of the support structure passes through the center of the hollow spherical main portion,

wherein the rotational support structure comprises a solid cylindrical axle passing through the two circular apertures.

2. A method of manufacturing a variator ball comprising a hollow spherical main portion and a rotational support structure having an axis of rotation well aligned with the center of the hollow spherical main portion, the method comprising:

- creating the hollow spherical main portion of the variator ball by
 - positioning a deformable cylindrical tubular member of predetermined length diameter and wall thickness between two separated opposing counter-rotating hemispherical dies rotatable on a common axis coincident with the axis of the cylinder, and
 - press forming the deformable cylinder into a hollow sphere having two circular apertures on opposite sides of the sphere by moving the two hemispherical dies towards each other; and

- coupling the rotational support structure to at least one of the circular apertures such that the axis of rotation of the support structure passes through the center of the hollow spherical main portion,

wherein the rotational support structure comprises a pair of half axles, each coupled to one of the circular apertures.

3. A method of manufacturing a variator ball comprising a hollow spherical main portion and a rotational support structure having an axis of rotation well aligned with the center of the hollow spherical main portion, the method comprising:

- creating the hollow spherical main portion of the variator ball by
 - positioning a deformable cylindrical tubular member of predetermined length diameter and wall thickness between two separated opposing counter-rotating hemispherical dies rotatable on a common axis coincident with the axis of the cylinder,
 - press forming the deformable cylinder into a hollow sphere having two circular apertures on opposite sides of the sphere by moving the two hemispherical dies towards each other; and
- coupling the rotational support structure to at least one of the circular apertures such that the axis of rotation of the support structure passes through the center of the hollow spherical main portion,
 - wherein the rotational support structure comprises a hollow cylindrical sleeve that passes through the two circular apertures.

4. A method of manufacturing a variator ball comprising a hollow spherical main portion and a rotational support structure having an axis of rotation well aligned with the center of the hollow spherical main portion, the method comprising:

- creating the hollow spherical main portion of the variator ball by
 - positioning a deformable cylindrical tubular member of predetermined length diameter and wall thickness between two separated opposing counter-rotating hemispherical dies rotatable on a common axis coincident with the axis of the cylinder, and
 - press forming the deformable cylinder into a hollow sphere having two circular apertures on opposite sides of the sphere by moving the two hemispherical dies towards each other; and
- coupling the rotational support structure to at least one of the circular apertures such that the axis of rotation of the support structure passes through the center of the hollow spherical main portion,
 - wherein the rotational support structure comprises a dual inner formed lumen coupled to one of the circular apertures.

5. The method of claim 3, wherein the hollow cylindrical sleeve is sized to seal the interior of the hollow main spherical portion from the exterior of the hollow main spherical portion.

6. The method of claim 3 or 5, further comprises installing needle bearings inside the hollow cylindrical sleeve such that the variator ball can spin about a central axis.

7. The method of one of claims 1-6, wherein coupling the rotational support structure comprises creating an interference fit.
8. The method of claim 7, wherein creating an interference fit comprises press-fitting or shrink fitting
9. The method of one of claims 1-8, wherein the two separated opposing counter-rotating hemispherical dies each have an aperture located about their axis of rotation sized to allow the axle to pass therethrough such that the axis of rotation of the axle coincides with the axis of rotation of the deformable cylinder and such that the dies rotate about the axle; and wherein coupling comprises positioning the axle inside the deformable cylinder as it is being press-formed into the hollow sphere such that the axle is press-fitted into the circular apertures as they are forming.
10. The method of claim 3, wherein the two dies each have an aperture located about their axis of rotation sized to allow the hollow cylindrical sleeve to pass therethrough such that the axis of rotation of the hollow cylindrical sleeve coincides with the axis of rotation of the deformable cylinder and such that the dies rotate about the hollow cylindrical sleeve; and
wherein coupling comprises positioning the hollow cylindrical sleeve inside the deformable cylinder as it is being press-formed into the hollow sphere such that the hollow cylindrical sleeve are press-fitted into apertures as they are forming.
11. The method of one of claims 1-10, further comprising improving the spherical accuracy of the interior of the hollow spherical main portion by pressurizing a spherical bladder disposed inside the hollow spherical main portion while simultaneously constraining the hollow spherical main portion inside a sphere shaped die apparatus.
12. The method of one of claims 1-11, further comprising improving the spherical accuracy of the interior of the hollow spherical main portion by detonating an explosive inside the hollow spherical main portion while simultaneously constraining the hollow spherical main portion inside a sphere shaped die apparatus.
13. The method of one of claims 1-12, wherein the hollow spherical main portion comprises a metal.
14. The method of one of claims 1-13, wherein the hollow spherical main portion comprises steel.
15. The method of one of claims 1-14, where in a diameter of a hollow spherical main portion of the hollow ceramic spherical ball is between 2 and 6 inches.
16. The method of one of claims 1-14, where in a diameter of the hollow spherical main portion is between 6 and 18 inches.

17. The method of one of claims 1-14, where in a diameter of the hollow spherical main portion is between 18 and 24 inches.
18. A method of producing a hollow ceramic variator ball comprising:
 - suspending a spherical pressurized bladder having two fluid lumina diametrically opposed to each other within a ceramic precursor encased between two hemispherical dies, the dies having channels for the fluid lumina; and
 - reacting the ceramic precursor to form a hollow ceramic spherical ball having two apertures diametrically opposed to each other.
19. The method of claim 18, further comprising press-fitting a hollow sleeve into a lumen defined by the two apertures.
20. The method of claim 19, further comprising installing needle bearings in the hollow sleeve in order to permit the ceramic variator ball to spin about a central axis.
21. A method of forming multiple planets comprising:
 - inserting an inner sleeve or bar support into an elongate cylindrical piece of tube stock;
 - selectively heating areas of the tube stock;
 - roll forming the tube stock into multiple spheroid objects connected by a common lumen extending through each of the multiple spheroid objects;
 - repeating the roll forming operation until the multiple spheroid objects form into multiple rough spheres joined by the common lumen;
 - improving the spherical accuracy of each of the multiple rough spheres by turning the multiple rough spheres on a lathe; and
 - cutting the common lumen to separate the spheres,
 - wherein such process produces multiple planets each having diametrically opposed apertures.
22. The method of claim 21, wherein the common lumen passes through the center of each of the multiple planets.
23. The method of claim 21 or 22, wherein the common lumen is cylindrical.
24. The method of one of claims 21-23, wherein the multiple rough spheres are coupled to a rotational support structure via the diametrically opposed apertures made when cutting the common lumen.
25. The method of claim 24, wherein the rotational support structure is an axle.
26. The method of claim 24 or 25, wherein the rotational support structure is a pair of half axles.

27. The method any one of claims 24- 26, wherein the rotational support structure is a hollow cylindrical sleeve.
28. The method any one of claims 24- 26, wherein the rotational support structure is dual inner formed lumen.
29. A method of forming multiple planets comprising inserting a hollow tubular bar into forging skew rollers to produce individual, separate planets.
30. The method of claim 29, wherein the tubular bar comprises:
- steel,
 - stainless steel,
 - chromium alloy steel, or
 - vanadium alloy steel.
31. The method of claim 29 or 30, wherein the interior of the tubular bar comprises a secondary material that provides compressive resistance to the forging process and that maintains the internal integrity of the planet.
32. The method of claim 31, wherein the interior is a core of the tubular bar extending within a central longitudinal axis of the tubular bar.
33. The method of claim 31 or 32, wherein the secondary material comprises:
- mica,
 - sand,
 - silicon dioxide,
 - quartz, or
 - feldspar.
34. The method of one of claims 31-33, wherein the secondary material is captured within each of the multiple planets.
35. The method of one of claims 31-34, comprising removing the secondary material from at least one of the multiple planets to form at least one hollow planet.
36. The method of claim 35, wherein removing the secondary material comprises:
- drilling,
 - reaming,
 - vacuuming,
 - applying high pressure gas,
 - spraying with high pressure fluid, or
 - water jet processing.

37. A method of producing a variator ball comprising:
- inserting a first end of a tube stock into heater coils wherein the tube stock comprises the first end, a middle portion and a second end;
 - heating the first end of the tube stock to a plastically deformable temperature appropriate for the tube stock;
 - sealing the first end forming a first sealed end;
 - heating at least the middle portion to the plastically deformable temperature;
 - inserting the tube stock in a collapsible spherical die;
 - pressurizing the tube stock through the second end and plastically deforming at least the middle portion thereby forming the variator ball having an open end corresponding to the second end of the tube stock and a hollow interior;
 - removing the variator ball from the collapsible spherical die;
 - heating the open end to the plastically deformable temperature;
 - sealing the open end of the variator ball forming a second sealed end;
 - forming a first hole and a second hole in the variator ball by removing a portion of the first sealed end and removing a portion of the second sealed end;
 - attaching a first portion of an axle to the variator ball at the first hole; and
 - attaching a second portion of an axle to the variator ball at the second hole.
38. The method of claim 37, wherein sealing the first end comprises pinching the first end.
39. The method of claim 37 or 38, wherein sealing the second end comprises pinching the second end.
40. The method of claim 38 or claim 39, wherein the pinching is performed by a pinch rolling die.
41. The method of one of claims 37-40, wherein heating the first end of the tube stock, heating the middle portion of the tube stock, or heating the second end of the tube stock is by induction heating.
42. The method of one of claims 37-41, wherein removing a portion of the first sealed end comprises machining out the center of the first sealed end.
43. The method of one of claims 37-42, wherein removing a portion of the second sealed end comprises machining out the center of the second sealed end.
44. The method of one of claims 37-43, wherein the first hole and the second hole are diametrically aligned.
45. The method of one of claims 37-44, wherein the first axle extends through the variator ball.

46. The method of one of claims 37-45, wherein the first portion of the axle is separate from the second portion of the axle such that the variator ball is hollow.
47. The method of any one of claims 37-46, wherein the tube stock comprises:
- steel,
 - stainless steel,
 - chromium alloy steel, or
 - vanadium alloy steel.
48. The method of any one of claims 37-47, wherein the pressurizing comprises a pressure of at least 800 psi.
49. The method of any one of claims 37-48, wherein the plastically deformable temperature is at least 925 °F.
50. The method of any one of claims 37-49, wherein the plastically deformable temperature is at least 975 °F.
51. The method of any one of claims 37-50, wherein the plastically deformable temperature is at least 1075 °F.
52. The method of any one of claims 37-51, wherein the plastically deformable temperature is at least 1125 °F.
53. The method of any one of claims 42-43, wherein the machining step comprises:
- turning,
 - grinding,
 - drilling,
 - boring,
 - laser cutting, or
 - an electrical discharge machining process.
54. A variator ball formed by any of the methods of claims 1-53.
55. A variable transmission comprising the variator ball of claim 54.
56. The variable transmission of claim 55, comprising a traction fluid.
57. A vehicle driveline comprising an engine, a variable transmission comprising the variator ball of claim 54, and a vehicle output.
58. A vehicle comprising the variable transmission of claim 56.
59. A manufacturing apparatus that implements any of the methods, in full or in part, of claims 1-53.

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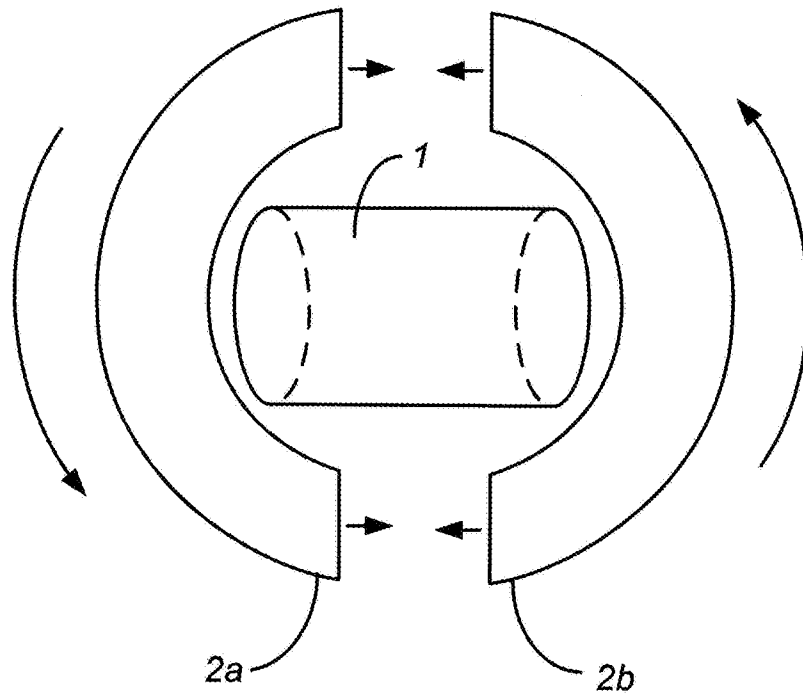


FIG. 1A

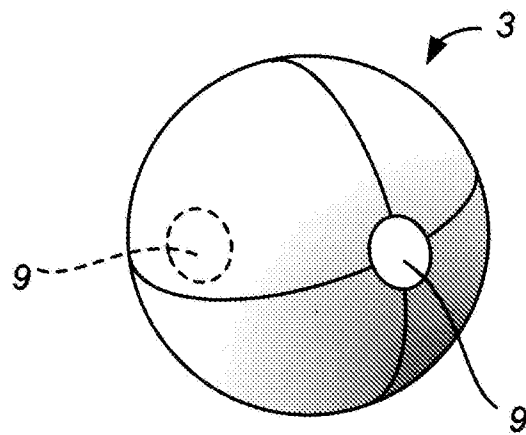


FIG. 1B

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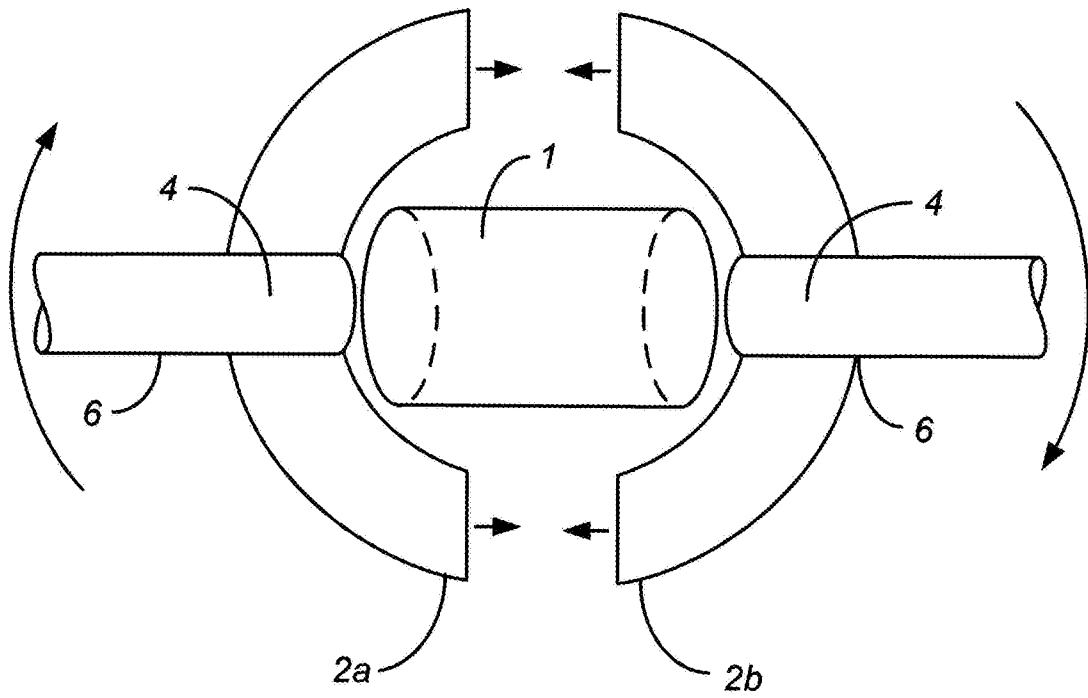


FIG. 2A

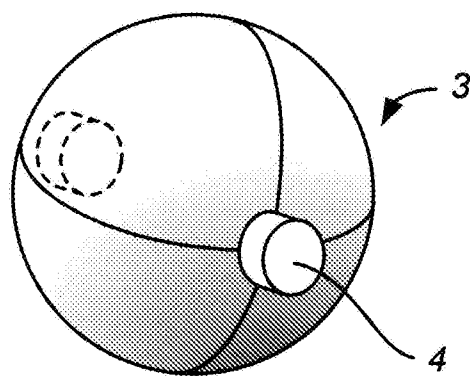


FIG. 2B

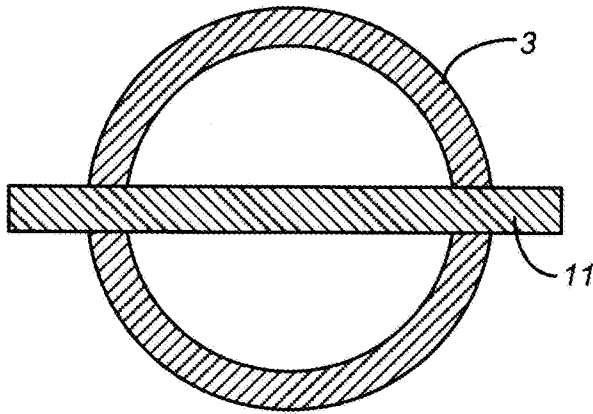


FIG. 3A

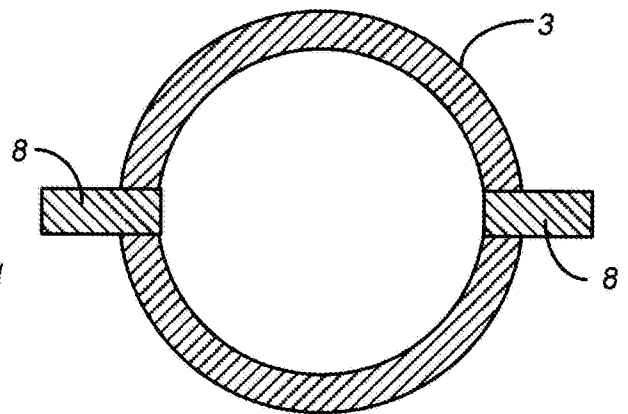


FIG. 3B

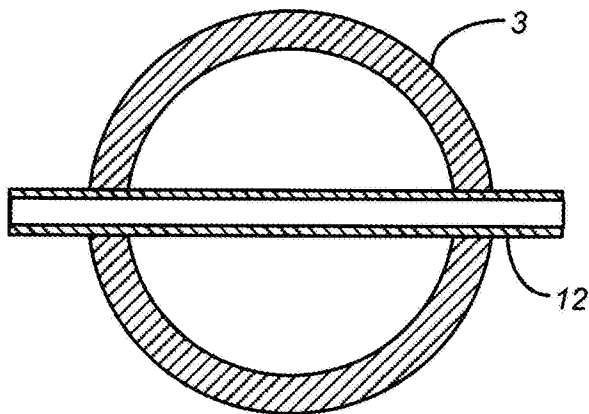


FIG. 3C

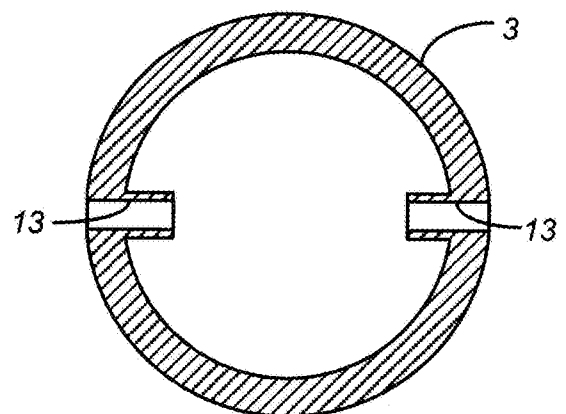


FIG. 3D

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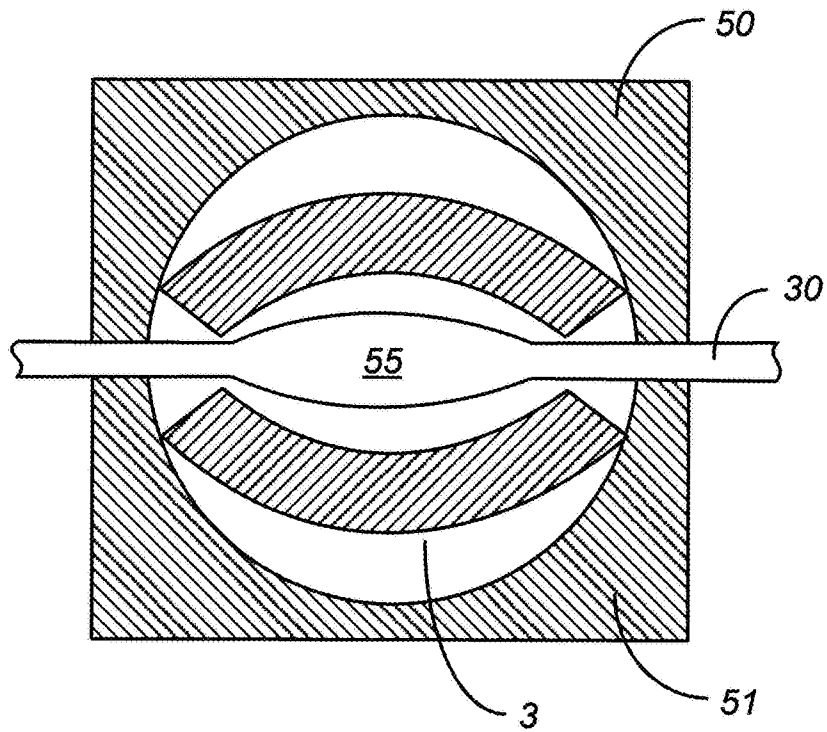


FIG. 4A

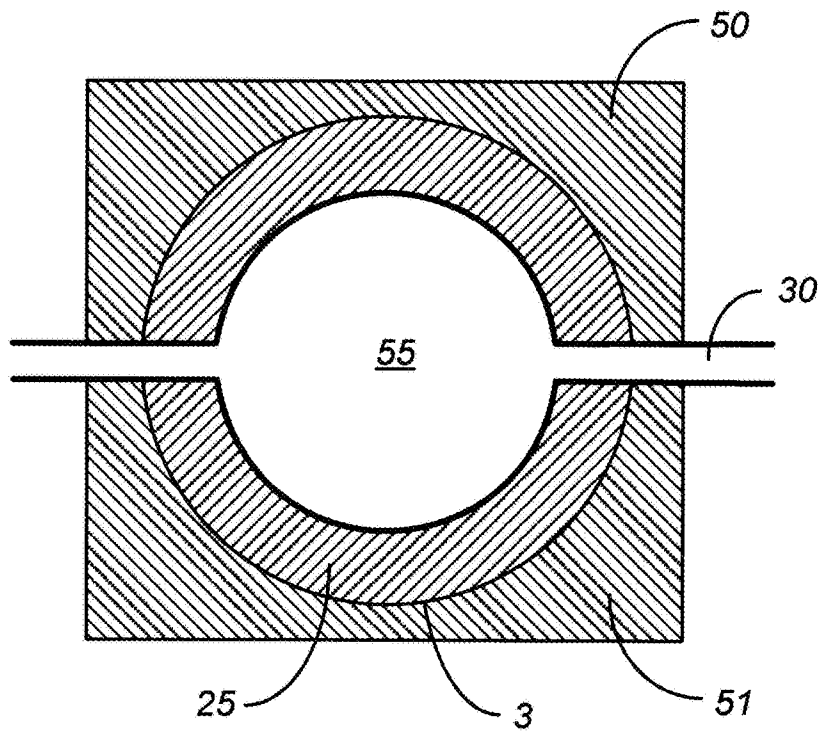


FIG. 4B

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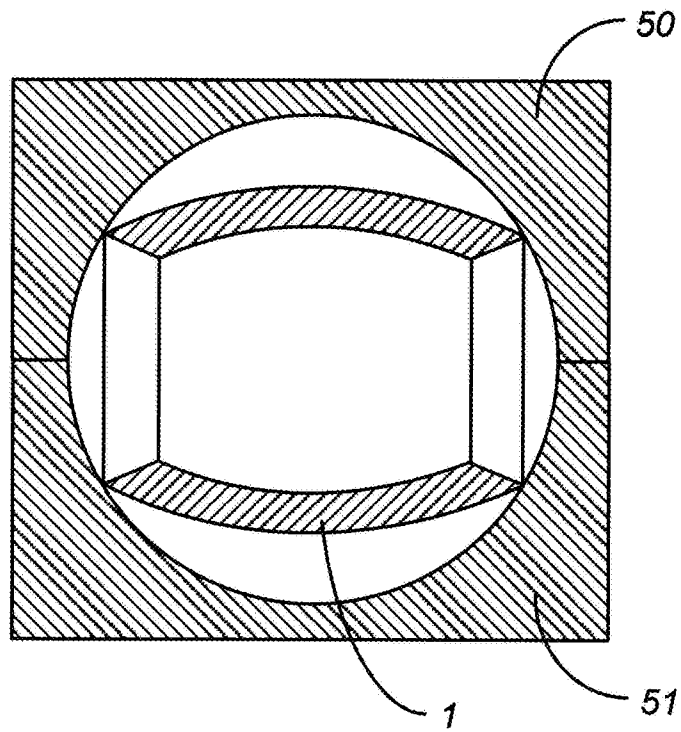


FIG. 5A

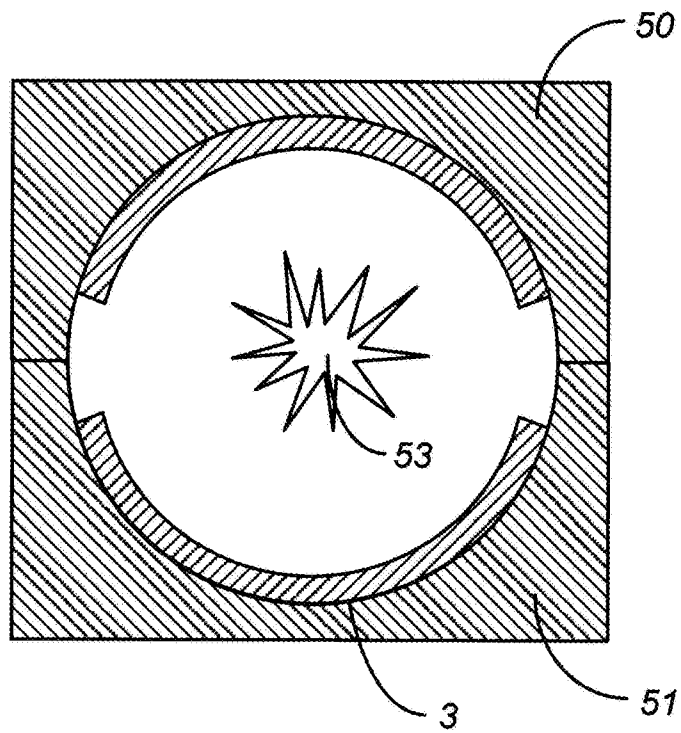


FIG. 5B

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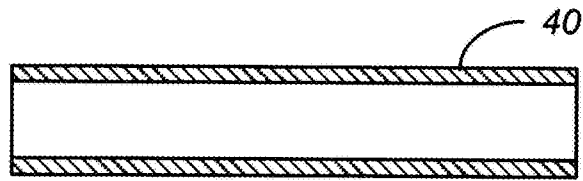


FIG. 6A

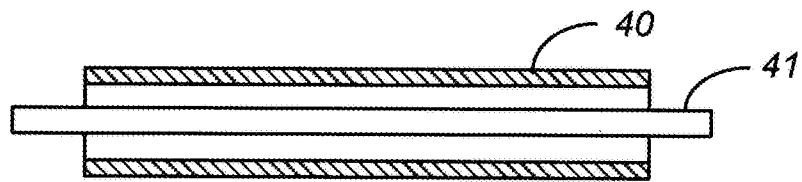


FIG. 6B

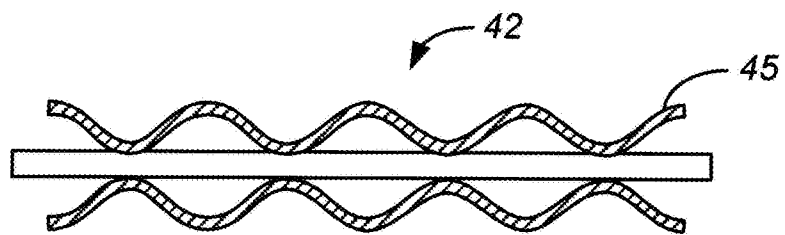


FIG. 6C

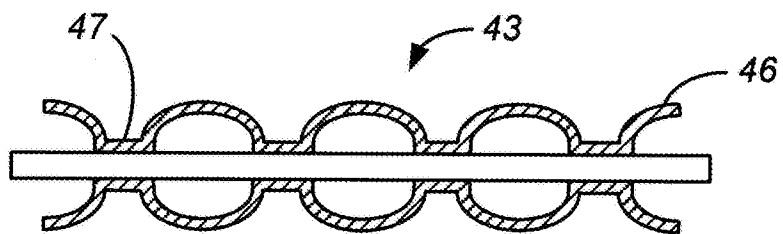


FIG. 6D

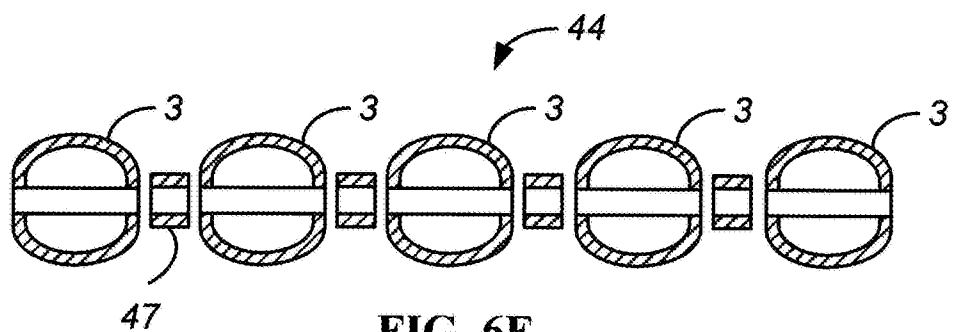
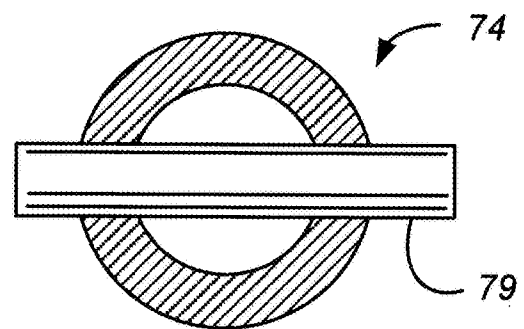
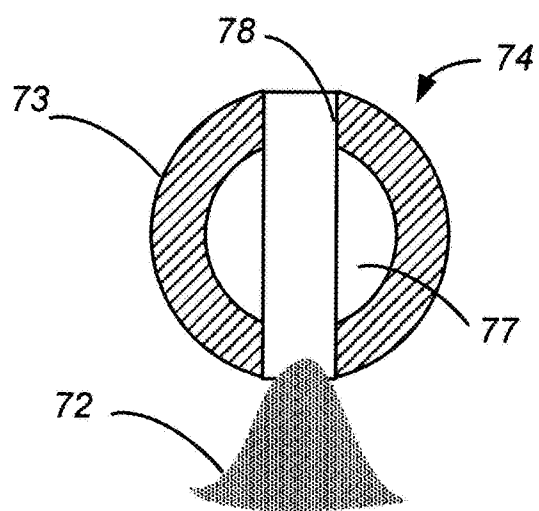
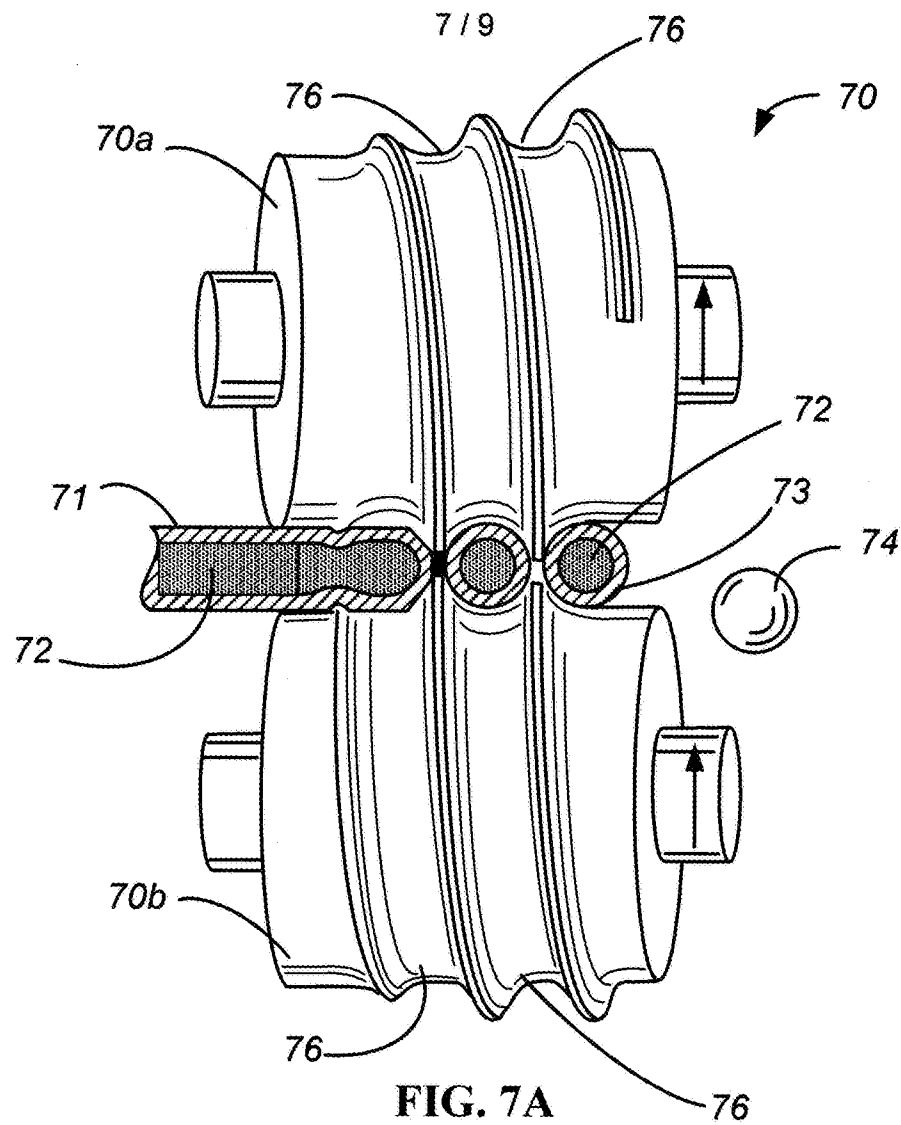


FIG. 6E



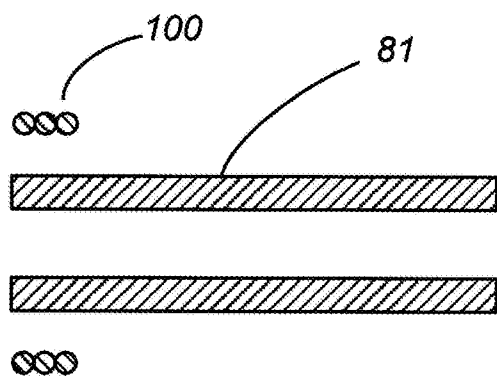


FIG. 8A

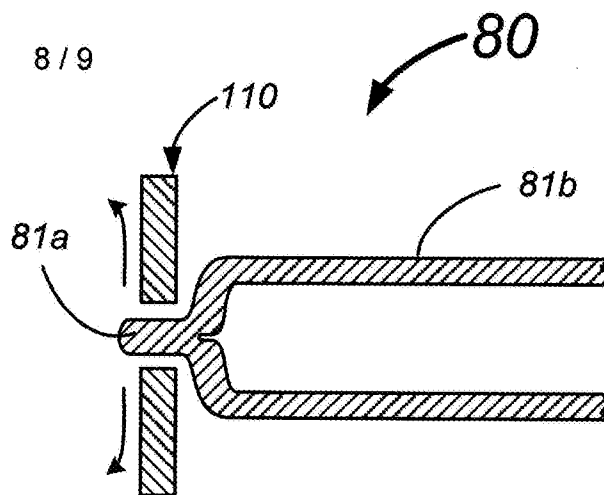


FIG. 8B

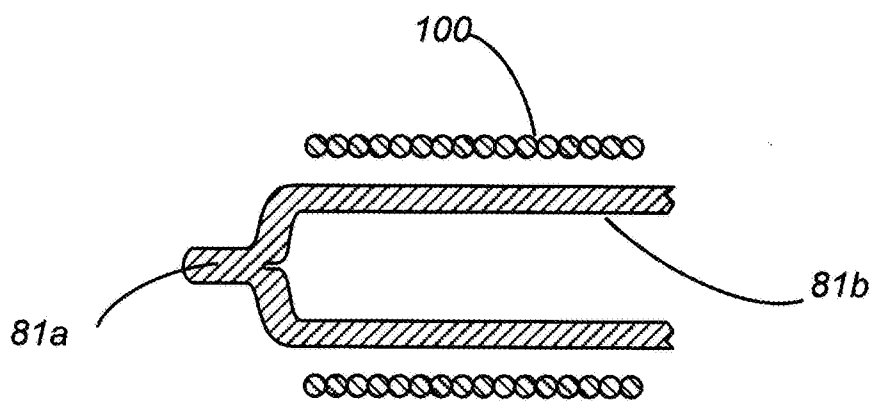


FIG. 8C

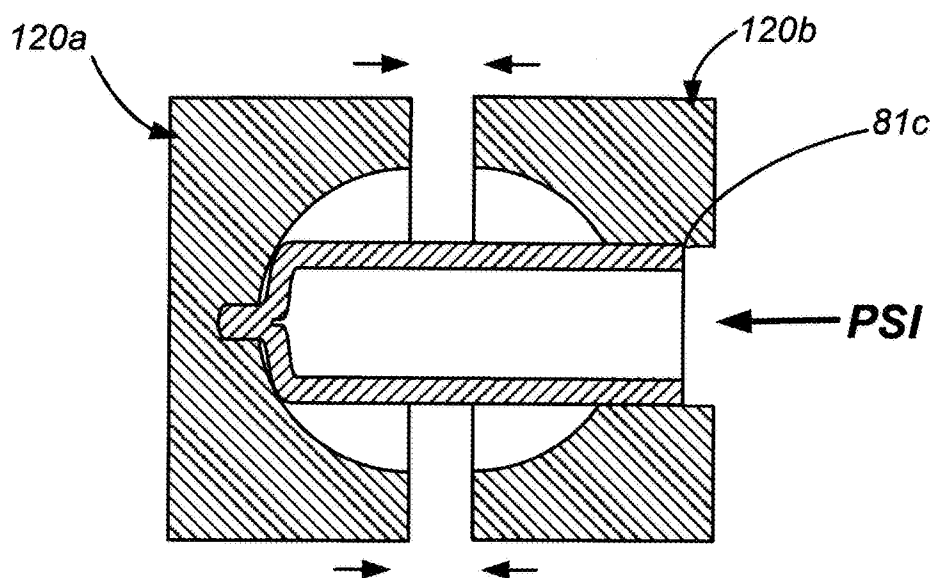


FIG. 8D

