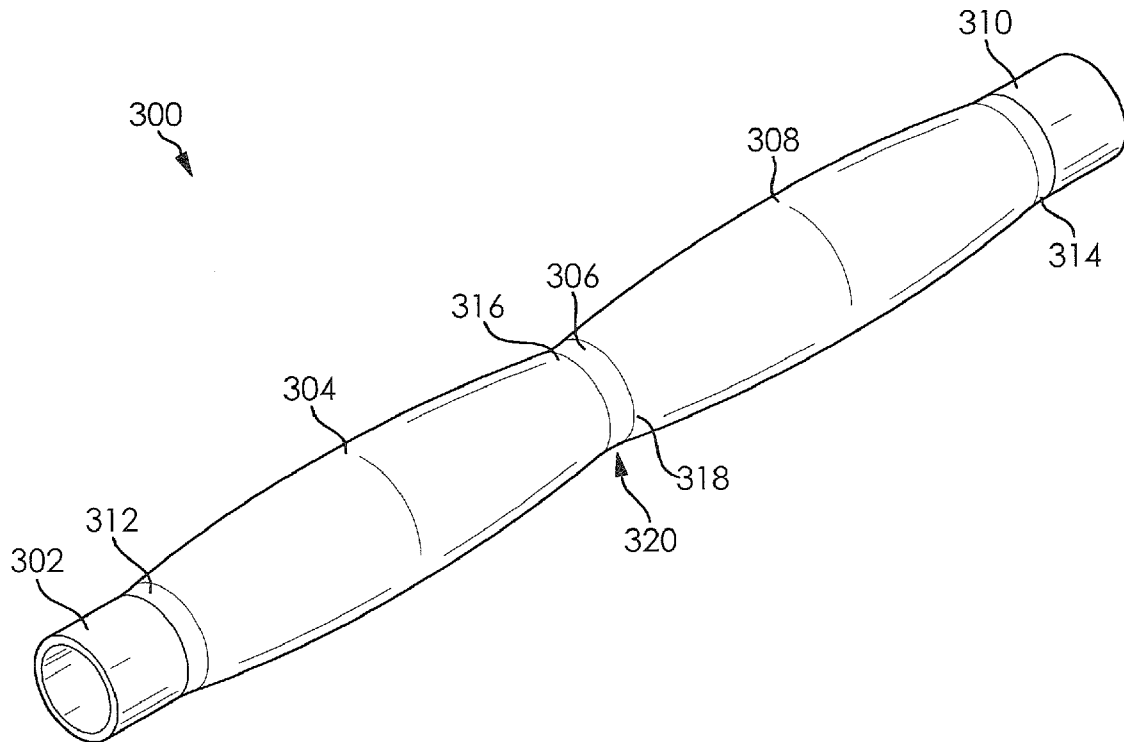


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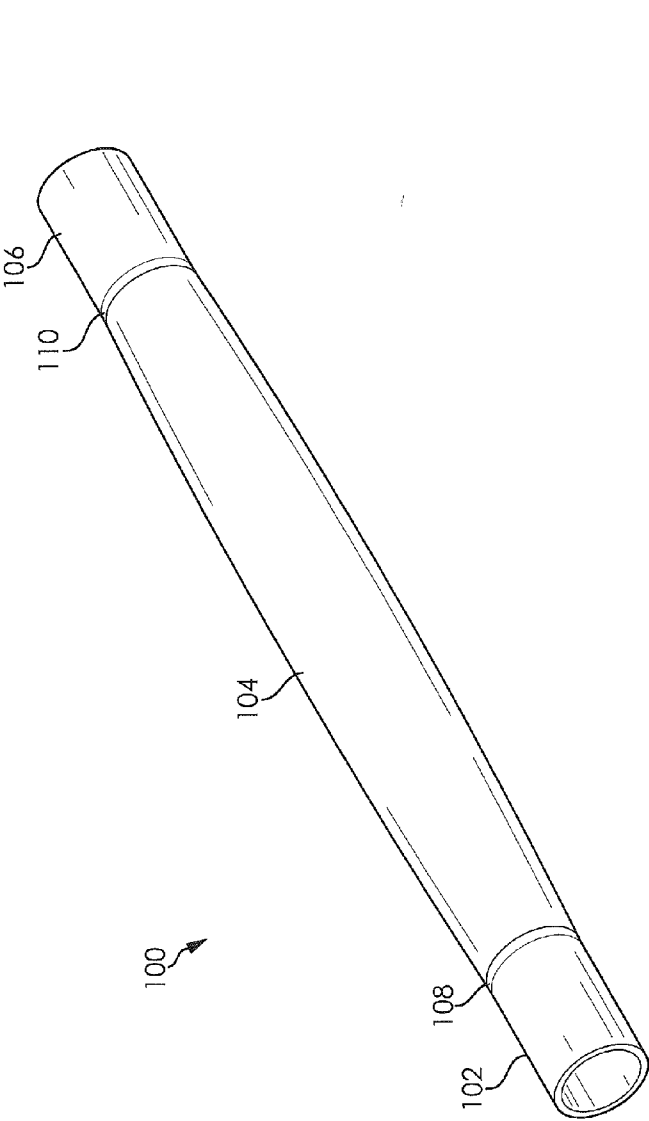


FIG. 1A

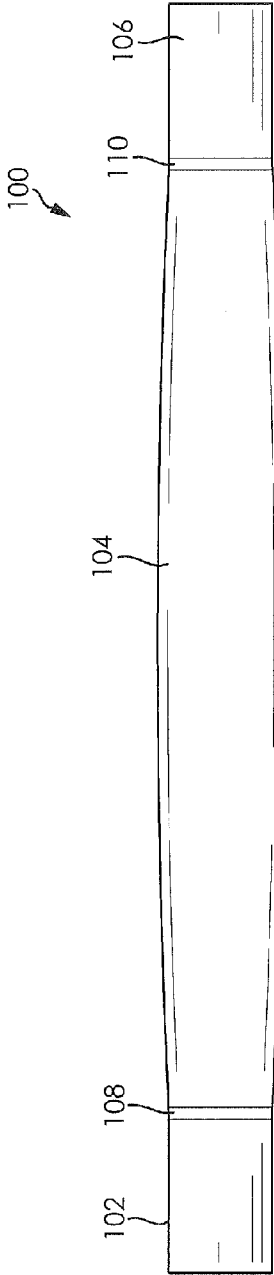


FIG. 1B

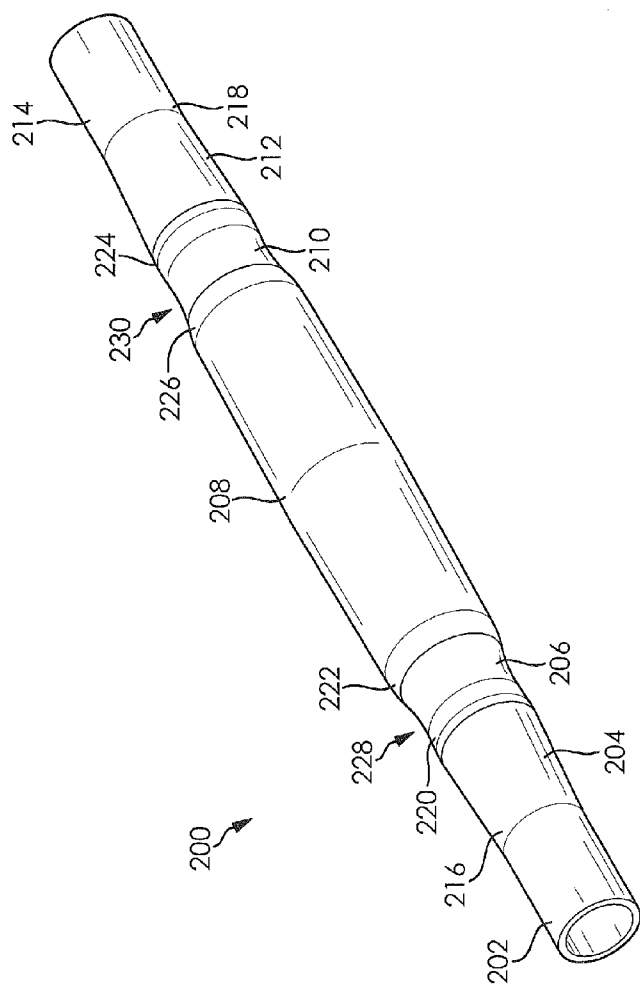


FIG. 2A

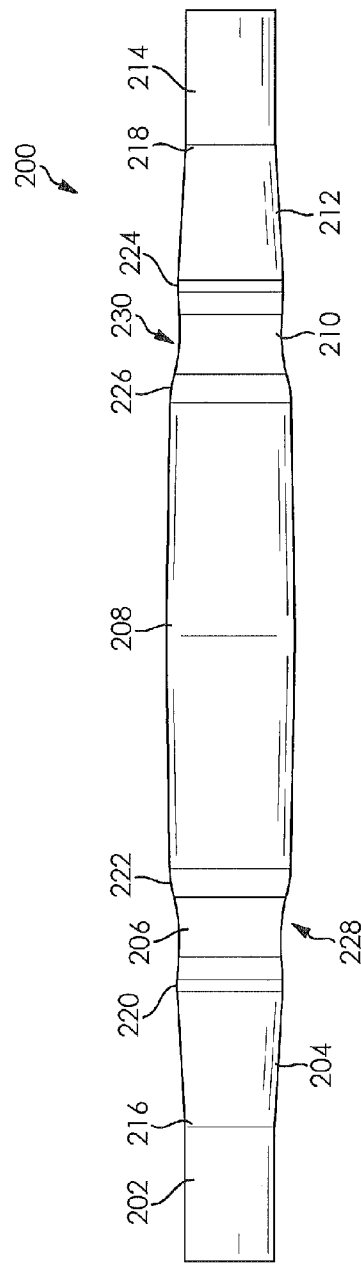


FIG. 2B

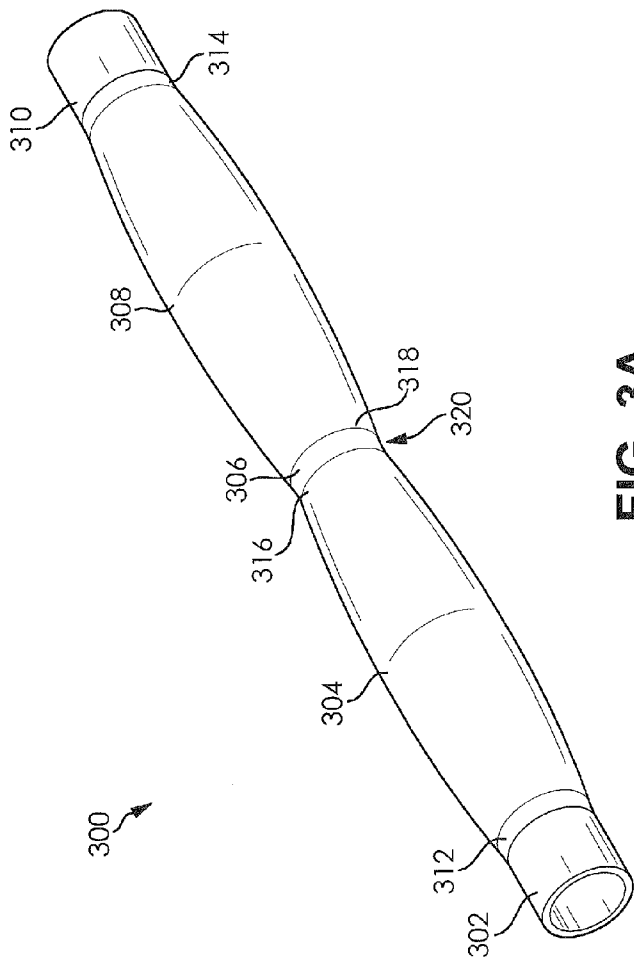


FIG. 3A

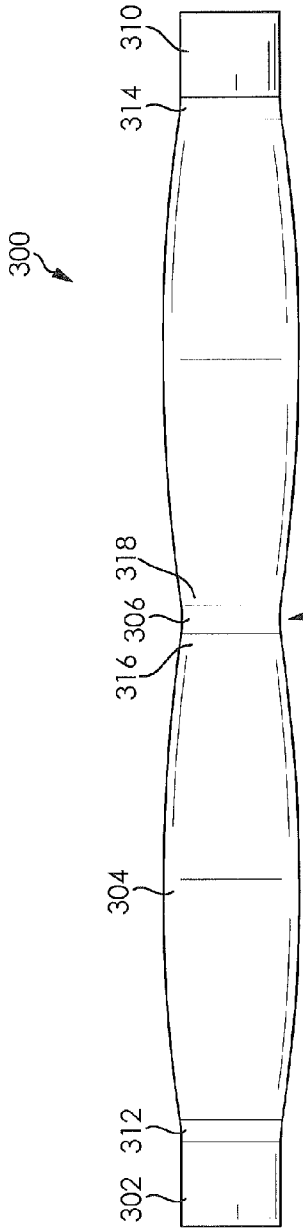


FIG. 3B

	Critical Speed (Hz)	Breathing Mode Frequency (Hz)	Percentage change in Critical Speed Over Straight Tubing (Diameter of end portion 102,106,202,214, 302,310)	Percentage change in Breathing Mode Frequency Over Straight Tubing (Greatest diameter of middle portion 104,208, or distension 304,308)
<b>Tubing Length 1</b>				
Straight Tubing (Diameter of end portion 202,214)	70	1380	Control	N/A
Second Driveshaft Tube 200	90	490	28.6%	51.7%
Straight Tubing (Greatest diameter of middle portion 208)	106	323	N/A	Control
<b>Tubing Length 2</b>				
Straight Tubing (Diameter of end portion 102,106,302,310)	111	1083	Control	N/A
Third Driveshaft Tube 300	136	680	22.3%	105.4%
First Driveshaft Tube 100	140	553	25.9%	67.1%
Straight Tubing (Greatest diameter of middle portion 104 or distension 304,308)	150	331	N/A	Control
<b>Tubing Length 3</b>				
Straight Tubing (Diameter of end portion 102,106,302,310)	63	1081	Control	N/A
Third Driveshaft Tube 300	75	680	19.9%	111.8%
First Driveshaft Tube 100	77	553	23.1%	72.3%
Straight Tubing (Greatest diameter of middle portion 104 or distension 304,308)	85	321	N/A	Control

**FIG. 4**

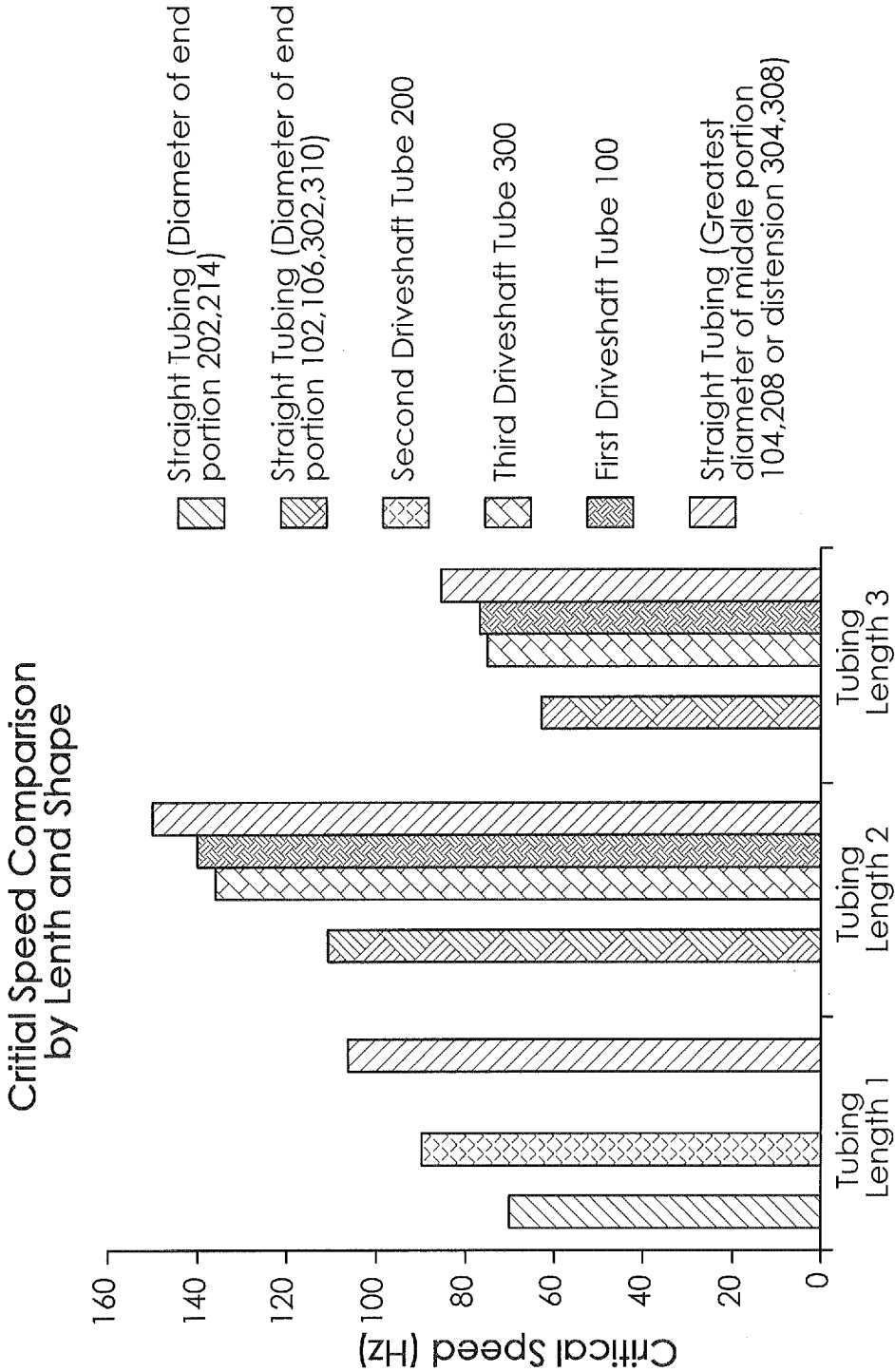


FIG. 5

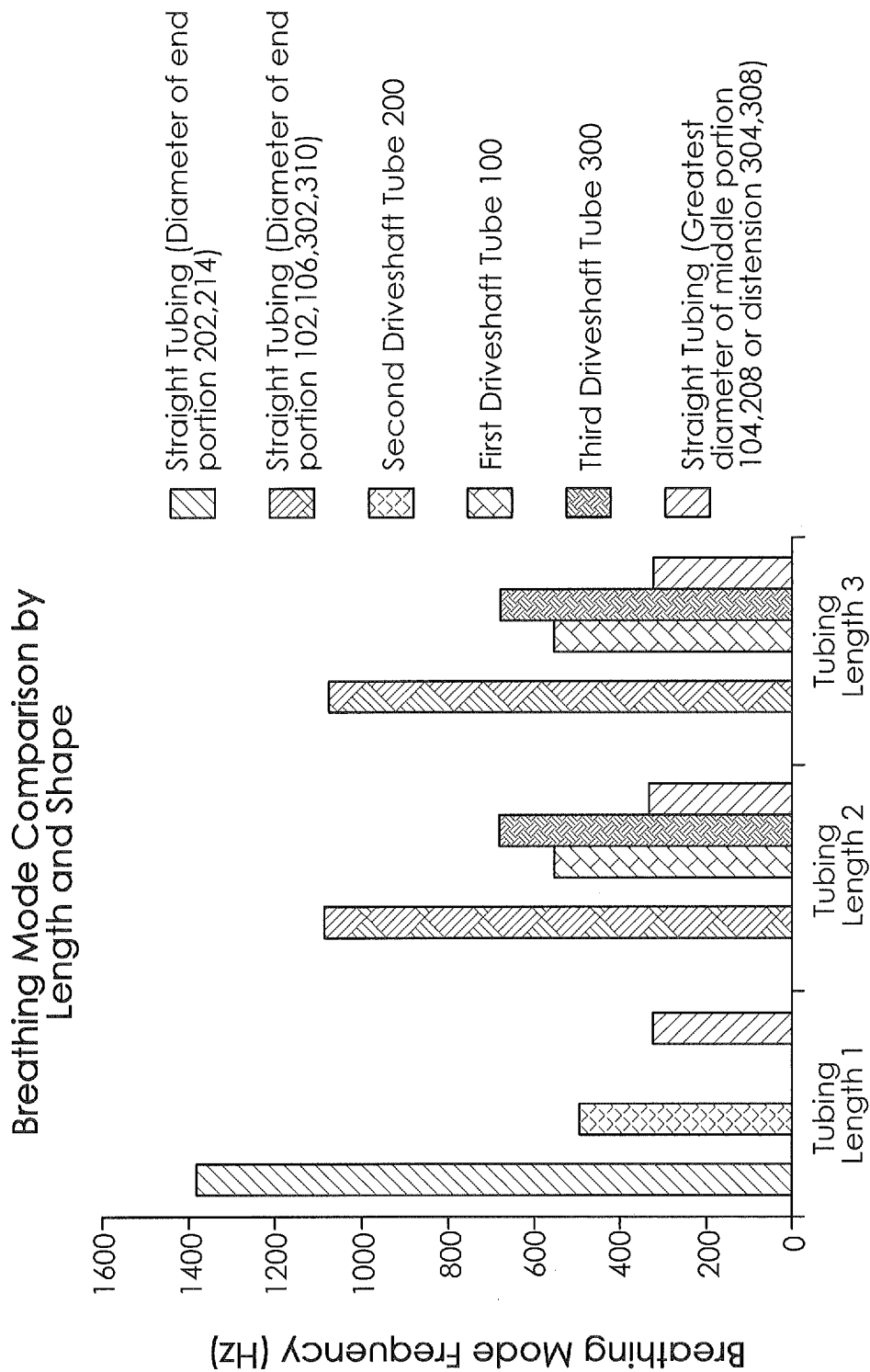


FIG. 6

## HYDROFORMED DRIVESHAFT TUBE WITH SECONDARY SHAPE

### CLAIM OF PRIORITY

**[0001]** The present application claims the benefit of priority to U.S. Provisional Application No. 61/724,154 filed on Nov. 8, 2012, which is incorporated herein in its entirety by reference.

### FIELD OF THE INVENTION

**[0002]** The present invention relates to driveshafts and more specifically to driveshafts for vehicle formed using a hydroforming process.

### BACKGROUND OF THE INVENTION

**[0003]** Rotation of a driveshaft at or near a resonating frequency of the driveshaft may lead to an undesired vibration of the driveshaft. Further, rotation of a driveshaft which is unbalanced may also lead to the undesired vibration of the driveshaft, resulting in customer dissatisfaction. Rotation of the driveshaft with the undesired vibration, regardless of its source, may also lead to excessive wear of a plurality of components of the driveshaft. Center bearings, shaft end components (such as yokes), universal joint crosses, needle bearings, and a tubular portion of the driveshaft may all be excessively worn by the undesired vibration of the driveshaft.

**[0004]** Typically, as a length of the driveshaft increases, the resonating frequency decreases. In vehicles having long lengths of driveshaft between a vehicle powertrain and a drive axle, such as commercial trucks, the resonating frequency of the driveshaft may approach an operational speed of the driveshaft. To relieve the undesired vibration, the driveshaft may comprise a plurality of sections joined by joints. Unfortunately, adding joints to the driveshaft greatly increases a cost and a weight of the driveshaft, and thus a vehicle the driveshaft is incorporated in.

**[0005]** Alternately, to relieve the undesired vibration, the diameter of the driveshaft, and thus a diameter of the shaft end components, may be increased. However, increasing the diameter of the driveshaft and the diameter of the shaft end components also greatly increases the cost of the driveshaft, and thus the vehicle the driveshaft is incorporated in.

**[0006]** Following manufacture of the driveshaft but prior to installation of the driveshaft in the vehicle, the driveshaft is typically balanced. Through the use of a dynamic balancing machine, a mass and a location of a balancing weight on the driveshaft is determined. After application of the balancing weight, the driveshaft is substantially balanced, reducing the undesired vibration of the driveshaft during operation. However, balancing of the driveshaft increases a time of manufacture of the driveshaft and therefore increases the cost of the driveshaft, and thus the vehicle the driveshaft is incorporated in.

**[0007]** The driveshaft formed from aluminum reduces the weight of the driveshaft. Where formed using a hydroforming process, the driveshaft has an increased resonating frequency and a decreased manufacturing cost. Consequently, the driveshaft formed from aluminum using the hydroforming process is advantageous over the driveshaft formed from a steel using the hydroforming process. However, conventional methods used to hydroform driveshafts as applied to aluminum have

been unsuccessful, as a maximum strain limit for forming aluminum is less than a maximum strain limit for forming steel.

**[0008]** It would be advantageous to develop a driveshaft that may be formed using a hydroforming process, reduces a cost of the driveshaft, and has an increased critical speed.

### SUMMARY OF THE INVENTION

**[0009]** Presently provided by the invention, a driveshaft that may be formed using a hydroforming process, reduces a cost of the driveshaft, and has an increased critical speed, has surprisingly been discovered.

**[0010]** In one embodiment, the present invention is directed to a hydroformed driveshaft tube. The hydroformed driveshaft tube comprises a first end portion, a second end portion, and a middle portion. The middle portion is at least partially defined by a circular arc shaped surface of revolution. At least a portion of the middle portion has a diameter greater than a diameter of the first end portion and the second end portion. The middle portion is formed between the first end portion and the second end portion. The middle portion affects a critical speed and a breathing mode frequency of the hydroformed driveshaft tube.

**[0011]** In another embodiment, the present invention is directed to a hydroformed driveshaft tube. The hydroformed driveshaft tube comprises a first end portion, a second end portion, and a middle portion. The middle portion is at least partially defined by a circular arc shaped surface of revolution. At least a portion of the middle portion has a diameter greater than a diameter of the first end portion and the second end portion. The middle portion comprises a first distension, a constriction, and a second distension. The middle portion is formed between the first end portion and the second end portion. The constriction is formed between the first distension and the second distension. The middle portion affects a critical speed and a breathing mode frequency of the hydroformed driveshaft tube.

**[0012]** In another embodiment, the present invention is directed to a hydroformed driveshaft tube. The hydroformed driveshaft tube comprises a first end portion, a second end portion, and a middle portion. The middle portion is at least partially defined by a circular arc shaped surface of revolution. At least a portion of the middle portion has a diameter greater than a diameter of the first end portion and the second end portion. The middle portion comprises a first transition portion, a first constriction portion, a second constriction portion, and a second transition portion. The middle portion is formed between the first constriction portion and the second constriction portion. The middle portion affects a critical speed and a breathing mode frequency of the hydroformed driveshaft tube.

**[0013]** Various aspects of this invention will become apparent to those skilled in the art from the following detailed description of the preferred embodiment, when read in light of the accompanying drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0014]** The above, as well as other advantages of the present invention will become readily apparent to those skilled in the art from the following detailed description when considered in the light of the accompanying drawings in which:

**[0015]** FIG. 1A is a perspective view of a driveshaft tube according to an embodiment of the present invention;



[0016] FIG. 1B is a side plan view of the driveshaft tube illustrated in FIG. 1A;

[0017] FIG. 2A is a perspective view of a driveshaft tube according to another embodiment of the present invention;

[0018] FIG. 2B is a side plan view of the driveshaft tube illustrated in FIG. 2A;

[0019] FIG. 3A is a perspective view of a driveshaft tube according to another embodiment of the present invention;

[0020] FIG. 3B is a side plan view of the driveshaft tube illustrated in FIG. 3A;

[0021] FIG. 4 is a table displaying experimental data collected from straight tubing used as a control, the driveshaft tube illustrated in FIG. 1A, the driveshaft tube illustrated in FIG. 2A, and the driveshaft tube illustrated in FIG. 3A;

[0022] FIG. 5 is a bar style chart illustrating a portion of the experimental data shown in FIG. 4, comparing a critical speed by a length and a shape of straight tubing used as a control, the driveshaft tube illustrated in FIG. 1A, the driveshaft tube illustrated in FIG. 2A, and the driveshaft tube illustrated in FIG. 3A; and

[0023] FIG. 6 is a bar style chart illustrating a portion of the experimental data shown in FIG. 4, comparing a breathing mode frequency by a length and a shape of straight tubing used as a control, the driveshaft tube illustrated in FIG. 1A, the driveshaft tube illustrated in FIG. 2A, and the driveshaft tube illustrated in FIG. 3A.

#### DETAILED DESCRIPTION OF THE INVENTION

[0024] It is to be understood that the invention may assume various alternative orientations and step sequences, except where expressly specified to the contrary. It is also to be understood that the specific devices and processes illustrated in the attached drawings, and described in the following specification are simply exemplary embodiments of the inventive concepts defined in the appended claims. Hence, specific dimensions, directions or other physical characteristics relating to the embodiments disclosed are not to be considered as limiting, unless the claims expressly state otherwise.

[0025] FIGS. 1A and 1B illustrate a first driveshaft tube 100 formed using a hydroforming process. The first driveshaft tube 100 is formed from a 6061 aluminum alloy; however, it is understood that other alloys may be used. A tubular aluminum blank (not illustrated) used to form the first driveshaft tube 100 using the hydroforming process may be formed using an extrusion process or a seam welding process. The tubular aluminum blank is a cylindrical aluminum tube.

[0026] The first driveshaft tube 100 includes a first end portion 102, a middle portion 104, and a second end portion 106. Once fitted with a pair of shaft end components (not shown), the first driveshaft tube 100 forms a portion of a driveshaft assembly (not shown) for use with a vehicle.

[0027] The first end portion 102 and the second end portion 106 are substantially cylindrical in shape and comprise about 13% of a length of the first driveshaft tube 100, but it is understood that other ratios may also be used. A wall thickness of the first end portion 102 and the second end portion 106 are substantially constant. The first end portion 102 and the second end portion 106 respectively meet the middle portion 104 at a first tangential transition 108 and a second tangential transition 110. A radius of a substantially circular arc of a surface of revolution forming the first tangential transition 108 and the second tangential transition 110 is about four times greater than a radius of the first end portion

102 and the second end portion 106. A shape of the middle portion 104 is a surface of revolution formed by rotating a substantially circular arc about an axis of the first end portion 102 and the second end portion 106. As a non-limiting example, the substantially circular arc of the surface of revolution of the middle portion 104 may be defined by an acute angle of about 4 degrees, but it is understood that other angle may also be used. Further, a radius of the substantially circular arc of the surface of revolution of the middle portion 104 is about 200 times greater than a radius of the first end portion 102 and the second end portion 106, but it is understood that other ratios may also be used. A wall thickness of the middle portion 104 is not constant due to the hydroforming process used to form the first driveshaft tube 100. A thickness of the middle portion 104 at a thinnest point, at a midpoint of the first driveshaft tube 100, is about 90% of a thickness of the first end portion 102 and the second end portion 106, but it is understood that other ratios may be used. The shape of the middle portion 104 of the first driveshaft tube 100 may be commonly described as a barrel shape.

[0028] The first driveshaft tube 100 increases a critical speed or a first bending mode of the driveshaft having a first length by an average of approximately 26% when compared to straight tubing used as a control, the straight tubing having an outer diameter substantially equal to the diameter of the end portions 102, 106. The first driveshaft tube 100 increases a critical speed or a first bending mode of the driveshaft having a second length by an average of approximately 23% when compared to straight tubing used as a control, the straight tubing having an outer diameter substantially equal to the diameter of the end portions 102, 106. The critical speed of the first driveshaft tube 100 is highly dependent on the average diameter of the tubing, so with adjustments to the shape of the forming and percentage of straight tubing forming the first driveshaft tube 100, this increase in critical speed can be adjusted.

[0029] It has also been discovered through experimentation that a breathing mode frequency of the first driveshaft tube 100 is significantly increased when compared to straight tubing used as a control, the straight tubing having an outer diameter substantially equal to a greatest diameter of the middle portion 104. The first driveshaft tube 100 having a first length offers an increase over the straight tubing used as a control of about 67%. The first driveshaft tube 100 having a second length offers an increase over the straight tubing used as a control of about 72%. Breathing modes are natural modes of tubing where the circumference of the tube is bent to a non-perfect circle. As this occurs it acts as an amplifying agent to any other noises in the vehicle, typically a whine of a transmission or an axle gear.

[0030] FIGS. 2A and 2B illustrate a second driveshaft tube 200 formed using a hydroforming process. The second driveshaft tube 200 is formed from a 6061 aluminum alloy; however, it is understood that other alloys may be used. A tubular aluminum blank (not illustrated) used to form the second driveshaft tube 200 using the hydroforming process may be formed using an extrusion process or a seam welding process. The tubular aluminum blank is a cylindrical aluminum tube.

[0031] The second driveshaft tube 200 includes a first end portion 202, a first transition portion 204, a first constriction portion 206, a middle portion 208, a second constriction portion 210, a second transition portion 212, and a second end portion 214. Once fitted with a pair of shaft end components

(not shown), the second driveshaft tube **200** forms a portion of a driveshaft assembly (not shown) for use with a vehicle.

[0032] The first end portion **202** and the second end portion **214** are substantially cylindrical in shape and each comprise about 11% of a length of the second driveshaft tube **200**, but it is understood that other ratios may be used. A wall thickness of the first end portion **202** and the second end portion **214** are substantially constant. The first end portion **202** and the second end portion **214** respectively meet the first transition portion **204** and the second transition portion **212** in a first tangential transition **216** and a second tangential transition **218**. A radius of a substantially circular arc of a surface of revolution forming the first tangential transition **216** and the second tangential transition **218** is about 4.5 times greater than a radius of the first end portion **202** and the second end portion **214**.

[0033] A shape of the first transition portion **204**, the middle portion **208**, and the second transition portion **212** corresponds in shape to a surface of revolution formed by rotating a substantially circular arc about an axis of the first end portion **204** and the second end portion **214**. The first transition portion **204** and the second transition **212** portion each comprise about 11% of a length of the second driveshaft tube **200**, but it is understood that other ratios may be used. The middle portion **208** comprises about 40% of a length of the second driveshaft tube **200**, but it is understood that other ratios may be used. As a non-limiting example, the substantially circular arc of the surface of revolution corresponding in shape to the first transition portion **204**, the middle portion **208**, and the second transition portion **212** may be defined by an acute angle of about 7 degrees, but it is understood that other angles may be used. Further, a radius of the substantially circular arc of the surface of revolution corresponding in shape to the first transition portion **204**, the middle portion **208**, and the second transition portion **212** is about 150 times greater than a radius of the first end portion **202** and the second end portion **214**, but it is understood that other ratios may be used. A wall thickness of the middle portion **208** is not constant due to the hydroforming process used to form the second driveshaft tube **200**. A thickness of the middle portion **208** at a thinnest point, at a midpoint of the middle portion **208**, is about 90% of a thickness of the first end portion **202** and the second end portion **214**, but it is understood that other ratios may be used. The shape of the first transition portion **204**, the middle portion **208**, and the second transition portion **212** is divided by the first constriction portion **206** and the second constriction portion **210**.

[0034] The first constriction portion **206** and the second constriction portion **210** are each a surface of revolution formed by rotating a substantially circular arc about an axis of the first end portion **202** and the second end portion **214**. As a non-limiting example, the substantially circular arc of the surface of revolution of the first constriction portion **206** and the second constriction portion **210** may each be defined by an acute angle of about 20 degrees, but it is understood that other angles may be used. Further, a radius of the substantially circular arc of the surface of revolution of the first constriction portion **206** and the second constriction portion **210** is about 4.5 times greater than a radius of the first end portion **202** and the second end portion **214**, but it is understood that other ratios may be used. A concavity of the first constriction portion **206** and the second constriction portion **210** is opposite a concavity of the first transition portion **204**, the middle portion **208**, and the second transition portion **212**. A wall thick-

ness of the first constriction portion **206** and the second constriction portion **210** are substantially equal to a thickness of the first end portion **202** and the second end portion **214**. A diameter of the first constriction portion **206** and the second constriction portion **210** is about 16% greater than a diameter of the first end portion **202** and the second end portion **214**. The first constriction portion **206** respectively tangentially meets the first transition portion **204** and the middle portion **208** in a third tangential transition **220** and a fourth tangential transition **222**. A radius of a substantially circular arc of a surface of revolution forming the third tangential transition **220** and the fourth tangential transition **222** is about 4.5 times greater than a radius of the first end portion **202** and the second end portion **214**. The second constriction portion **210** respectively tangentially meets the second transition portion **212** and the middle portion **208** in a fifth tangential transition **224** and a sixth tangential transition **226**. A radius of a substantially circular arc of a surface of revolution forming the fifth tangential transition **224** and the sixth tangential transition **226** is about 4.5 times greater than a radius of the first end portion **202** and the second end portion **214**.

[0035] The first constriction portion **206** and the second constriction portion **210** of the second driveshaft tube **200** respectively provide a tertiary datum **226** and a quaternary datum **228** (in addition to the first end portion **202** and the second end portion **214**) to militate against tube buckling which may occur during the hydroforming process. As a result, the first constriction portion **206** and the second constriction portion **210** of the second driveshaft tube **200** reduce an amount of axial runout that is generated in the second driveshaft tube **200** during the hydroforming process. The first constriction portion **206** and the second constriction portion **210** of the second driveshaft tube **200** are created by a shape of a hydroforming die. The diameter of the second driveshaft tube **200** at the first constriction portion **206** and the second constriction portion **210** is greater than the diameter of the first end portion **202** and the second end portion **214**, which allow the hydroforming die to secure the second driveshaft tube **200** with respect to the first end portion **202** and the second end portion **214** during the hydroforming process.

[0036] The second driveshaft tube **200** increases a critical speed or a first bending mode of the driveshaft having a first length by an average of approximately 29% when compared to straight tubing used as a control, the straight tubing having an outer diameter substantially equal to the diameter of the end portions **202**, **214**. The critical speed of the second driveshaft tube **200** is highly dependent on the average diameter of the tubing, so with adjustments to the shape of the forming and percentage of straight tubing forming the second driveshaft tube **200**, this increase in critical speed can be adjusted.

[0037] It has also been discovered through experimentation that a breathing mode frequency of the second driveshaft tube **200** is significantly increased when compared to straight tubing used as a control, the straight tubing having an outer diameter substantially equal to a greatest diameter of the middle portion **208**. The second driveshaft tube **200** having a first length offers an increase over the straight tubing used as a control of about 52%.

[0038] FIGS. 3A and 3B illustrate a third driveshaft tube **300** formed using a hydroforming process. The third driveshaft tube **300** is formed from a 6061 aluminum alloy; however, it is understood that other alloys may be used. A tubular aluminum blank (not illustrated) used to form the third driveshaft tube **300** using the hydroforming process may be

formed using an extrusion process or a seam welding process. The tubular aluminum blank is a cylindrical aluminum tube.

[0039] The third driveshaft tube 300 includes a first end portion 302, a first distension 304, a constriction 306, a second distension 308, and a second end portion 310. Once fitted with a pair of shaft end components (not shown), the third driveshaft tube 300 forms a portion of a driveshaft assembly (not shown) for use with a vehicle.

[0040] The first end portion 302 and the second end portion 310 are substantially cylindrical in shape and each comprise about 7% of a length of the third driveshaft tube 300, but it is understood that other ratios may be used. A wall thickness of the first end portion 302 and the second end portion 310 are substantially constant. The first end portion 302 and the second end portion 310 respectively meets the first distension 304 and the second distension 308 at a first tangential transition 312 and a second tangential transition 314. A radius of a substantially circular arc of a surface of revolution forming the first tangential transition 312 and the second tangential transition 314 is about four times greater than a radius of the first end portion 302 and the second end portion 310.

[0041] A shape of the first distension 304 is a surface of revolution formed by rotating a substantially circular arc about an axis of the first end portion 302 and the second end portion 310. As a non-limiting example, the substantially circular arc of the surface of revolution of the first distension 304 may be defined by an acute angle of about 10 degrees, but it is understood that other angles may be used. Further, a radius of the substantially circular arc of the surface of revolution of the first distension 304 is about 40 times greater than a radius of the first end portion 302 and the second end portion 310, but it is understood that other ratios may be used. A wall thickness of the first distension 304 is not constant due to the hydroforming process used to form the third driveshaft tube 300. A thickness of the first distension 304 at a thinnest point, at a midpoint of the first distension 304, is about 90% of a thickness of the first end portion 302 and the second end portion 310, but it is understood that other ratios may be used. The shape of the first distension 304 of the third driveshaft tube 300 may be commonly described as a barrel shape.

[0042] The constriction 306 is a surface of revolution formed by rotating a substantially circular arc about an axis of the first end portion 302 and the second end portion 310. As a non-limiting example, the substantially circular arc of the surface of revolution of the constriction 306 may be defined by an acute angle of about 6 degrees, but it is understood that other angles may be used. Further, a radius of the substantially circular arc of the surface of revolution of the constriction 306 is about four times greater than a radius of the first end portion 302 and the second end portion 310, but it is understood that other ratios may be used. A concavity of the constriction 306 is opposite a concavity of the first distension 304 and the second distension 308. A wall thickness and a diameter of the constriction 306 are substantially equal to a thickness and a diameter of the first end portion 302 and the second end portion 310. The constriction 306 respectively meets the first distension 304 and the second distension 308 at a third tangential transition 316 and a fourth tangential transition 318. A radius of a substantially circular arc of a surface of revolution forming each of the third tangential transition 316 and the fourth tangential transition 318 is about 4 times greater than a radius of the first end portion 302 and the second end portion 310.

[0043] A shape of the second distension 308 is a surface of revolution formed by rotating a substantially circular arc about an axis of the first end portion 302 and the second end portion 310. As a non-limiting example, the substantially circular arc of the surface of revolution of the second distension 308 may be defined by an acute angle of about 10 degrees, but it is understood that other angles may be used. Further, a radius of the substantially circular arc of the surface of revolution of the second distension 308 is about 40 times greater than a radius of the first end portion 302 and the second end portion 310, but it is understood that other ratios may be used. A wall thickness of the second distension 308 is not constant due to the hydroforming process used to form the third driveshaft tube 300. A thickness of the second distension 308 at a thinnest point, at a midpoint of the second distension 308, is about 90% of a thickness of the first end portion 302 and the second end portion 310, but it is understood that other ratios may be used. The shape of the second distension 308 of the third driveshaft tube 300 may be commonly described as a barrel shape.

[0044] The constriction 306 of the third driveshaft tube 300 provides a tertiary datum 320 (in addition to the first end portion 302 and the second end portion 310) to militate against tube buckling which may occur during the hydroforming process. As a result, the constriction 306 of the third driveshaft tube 300 reduces an amount of axial runout that is generated in the third driveshaft tube 300 during the hydroforming process. The constriction 306 of the third driveshaft tube 300 is created by a shape of a hydroforming die. The diameter of the third driveshaft tube 300 at the constriction 306 is the same diameter as the first end portion 302 and the second end portion 310, which allows the hydroforming die to secure a center of the third driveshaft tube 300 with respect to the first end portion 302 and the second end portion 310 during the hydroforming process.

[0045] The third driveshaft tube 300 increases a critical speed or a first bending mode of the driveshaft having a first length by an average of approximately 22% when compared to straight tubing used as a control, the straight tubing having an outer diameter substantially equal to the diameter of the end portions 302, 310. The third driveshaft tube 300 also increases a critical speed or a first bending mode of the driveshaft having a second length by an average of approximately 20% when compared to straight tubing used as a control, the straight tubing having an outer diameter substantially equal to the diameter of the end portions 302, 310. The critical speed of the third driveshaft tube 300 is highly dependent on the average diameter of the tubing, so with adjustments to the shape of the forming and percentage of straight tubing forming the third driveshaft tube 300, this increase in critical speed can be adjusted.

[0046] It has also been discovered through experimentation that a breathing mode frequency of the third driveshaft tube 300 is significantly increased when compared to straight tubing used as a control, the straight tubing having an outer diameter substantially equal to a greatest diameter of the distensions 304, 308. The third driveshaft tube 300 having a first length offers an increase over the straight tubing used as a control of about 105%. The third driveshaft tube 300 having a second length offers an increase over the straight tubing used as a control of about 112%.

[0047] FIG. 4 is a table which includes experimental data collected from straight tubing used as a control, the first driveshaft tube 100, the second driveshaft tube 200, and the

third driveshaft tube **300**. The aforementioned results are shown and based upon the experimental data shown in FIG. 4. [0048] FIG. 5 is a bar style chart comparing the critical speed by a length and a shape of straight tubing used as a control (in three instances), the first driveshaft tube **100**, the second driveshaft tube **200**, and the third driveshaft tube **300**. The bar style chart display the experimental data shown in FIG. 4.

[0049] FIG. 6 is a bar style chart comparing the breathing mode by a length and a shape of straight tubing used as a control (in three instances), the first driveshaft tube **100**, the second driveshaft tube **200**, and the third driveshaft tube **300**. The bar style chart display the experimental data shown in FIG. 4.

[0050] As can be appreciated from FIGS. 4-6, the drive-shaft tube **100**, **200**, **300** has an increased critical speed when compared to straight tubing used as a control, the straight tubing having an outer diameter substantially equal to the diameter of the end portions **102**, **106**, **202**, **214**, **302**, **310**. Such a benefit allows the driveshaft assembly including the driveshaft tube **100**, **200**, **300** to have critical speed characteristics of a driveshaft tube having a greater diameter than a driveshaft formed from straight tubing having an outer diameter substantially equal to the diameter of the end portions **102**, **106**, **202**, **214**, **302**, **310**. The driveshaft assembly including the driveshaft tube **100**, **200**, **300** is compatible with driveshaft end fittings having a reduced diameter, which greatly reduces a cost of the driveshaft assembly including the driveshaft tube **100**, **200**, **300**.

[0051] As can be appreciated from FIGS. 4-6, the drive-shaft tube **100**, **200**, **300** has an increased breathing mode frequency when compared to straight tubing used as a control, the straight tubing having an outer diameter substantially equal to a greatest diameter of the middle portion **104**, **208** or the distensions **304**, **308**. Such a benefit allows the driveshaft assembly including the driveshaft tube **100**, **200**, **300** to have breathing mode frequency characteristics of a driveshaft tube having a reduced diameter, while still obtaining the critical speed benefits of a driveshaft tube having an increased diameter.

[0052] In accordance with the provisions of the patent statutes, the present invention has been described in what is considered to represent its preferred embodiments. However, it should be noted that the invention can be practiced otherwise than as specifically illustrated and described without departing from its spirit or scope.

What is claimed is:

1. A hydroformed driveshaft tube, comprising:
  - a first end portion;
  - a second end portion; and
  - a middle portion at least partially defined by a circular arc shaped surface of revolution and at least a portion of the middle portion having a diameter greater than a diameter of the first end portion and the second end portion, wherein the middle portion is formed between the first end portion and the second end portion and the middle portion affects a critical speed and a breathing mode frequency of the hydroformed driveshaft tube.
2. The hydroformed driveshaft tube according to claim 1, wherein the middle portion comprises a first distension, a constriction, and a second distension, the constriction formed between the first distension and the second distension.
3. The hydroformed driveshaft tube according to claim 2, further comprising a first tangential transition and a second

tangential transition, the first tangential transition formed between the first end portion and the first distension and the second tangential transition formed between the second end portion and the second distension.

4. The hydroformed driveshaft tube according to claim 3, further comprising a third tangential transition and a fourth tangential transition, the third tangential transition formed between the constriction and the first distension and the fourth tangential transition formed between the constriction and the second distension.

5. The hydroformed driveshaft tube according to claim 2, wherein at least one of the first distension and the second distension is defined by the circular arc shaped surface of revolution, the circular arc shaped surface of revolution having a radius about 40 times greater than a radius of the first end portion and the second end portion.

6. The hydroformed driveshaft tube according to claim 2, wherein a concavity of the constriction is opposite a concavity of the first distension and the second distension.

7. The hydroformed driveshaft tube according to claim 2, wherein the constriction provides a datum to militate against tube buckling which may occur during a hydroforming process used to form the hydroformed driveshaft tube.

8. The hydroformed driveshaft tube according to claim 1, further comprising a first transition portion, a first constriction portion, a second constriction portion, and a second transition portion, the middle portion formed between the first constriction portion and the second constriction portion.

9. The hydroformed driveshaft tube according to claim 8, wherein the circular arc shaped surface of revolution corresponds in shape to the first transition portion, the middle portion, and the second transition portion.

10. The hydroformed driveshaft tube according to claim 9, wherein the circular arc shaped surface of revolution has a radius about 150 times greater than a radius of the first end portion and the second end portion.

11. The hydroformed driveshaft tube according to claim 8, wherein a concavity of the first constriction and the second constriction is opposite a concavity of the first transition portion, the middle portion, and the second transition portion.

12. The hydroformed driveshaft tube according to claim 8, wherein the first constriction and the second constriction each provide a datum to militate against tube buckling which may occur during a hydroforming process used to form the hydroformed driveshaft tube.

13. The hydroformed driveshaft tube according to claim 8, wherein a diameter of the first constriction and the second constriction is greater than the diameter of the first end portion and the second end portion.

14. The hydroformed driveshaft tube according to claim 1, wherein the circular arc shaped surface of revolution has a radius about 200 times greater than a radius of the first end portion and the second end portion.

15. A hydroformed driveshaft tube, comprising:

- a first end portion;
- a second end portion; and
- a middle portion at least partially defined by a circular arc shaped surface of revolution and at least a portion of the middle portion having a diameter greater than a diameter of the first end portion and the second end portion, the middle portion comprising a first distension, a constriction, and a second distension, wherein the middle portion is formed between the first end portion and the second end portion, the constriction is formed between

the first distension and the second distension, and the middle portion affects a critical speed and a breathing mode frequency of the hydroformed driveshaft tube.

**16.** The hydroformed driveshaft tube according to claim **15**, further comprising a first tangential transition and a second tangential transition, the first tangential transition formed between the first end portion and the first distension and the second tangential transition formed between the second end portion and the second distension.

**17.** The hydroformed driveshaft tube according to claim **16**, further comprising a third tangential transition and a fourth tangential transition, the third tangential transition formed between the constriction and the first distension and the fourth tangential transition formed between the constriction and the second distension.

**18.** The hydroformed driveshaft tube according to claim **15**, wherein at least one of the first distension and the second distension is defined by the circular arc shaped surface of revolution, the circular arc shaped surface of revolution having a radius about 40 times greater than a radius of the first end portion and the second end portion.

**19.** A hydroformed driveshaft tube, comprising:

a first end portion;

a second end portion; and

a middle portion at least partially defined by a circular arc shaped surface of revolution and at least a portion of the middle portion having a diameter greater than a diameter of the first end portion and the second end portion, the middle portion comprising a first transition portion, a first constriction portion, a second constriction portion, and a second transition portion, wherein the middle portion is formed between the first constriction portion and the second constriction portion and the middle portion affects a critical speed and a breathing mode frequency of the hydroformed driveshaft tube.

**20.** The hydroformed driveshaft tube according to claim **19**, wherein the circular arc shaped surface of revolution corresponds in shape to the first transition portion, the middle portion, and the second transition portion.

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