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Sun et al.

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(54) **METHOD FOR ATTENUATING DRIVELINE VIBRATIONS**

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B23P 17/00 (2006.01)

(52) **U.S. Cl.** **29/407.07**; 29/896.93

(58) **Field of Classification Search** 29/407.07, 29/428, 888, 889.61, 896.93; 464/127, 180, 464/181, 183; 180/381, 380, 379, 378; 188/372, 188/379

See application file for complete search history.

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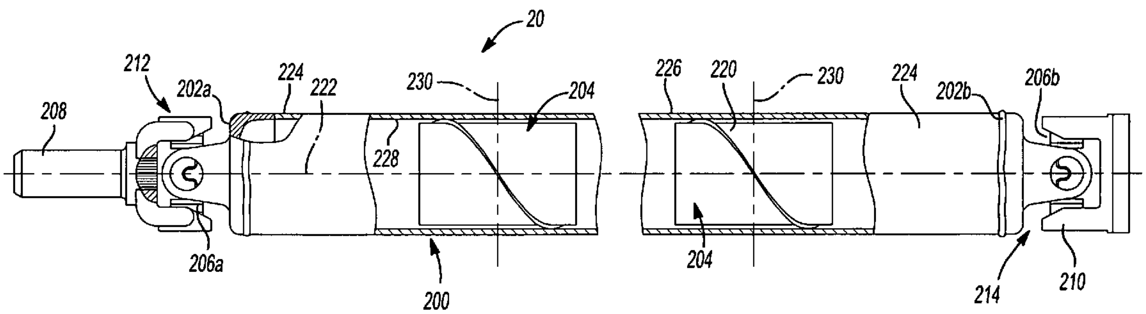
(57) **ABSTRACT**

A method for attenuating vibration in a driveline having a shaft assembly that transmits torque between first and second driveline components. The shaft assembly can have a hollow shaft member and at least one liner. The liner has a mass and a stiffness that are tuned such that the liner is a tuned resistive absorber for attenuating shell mode vibrations as well as at least one of a tuned reactive absorber for attenuating bending mode vibrations and a tuned reactive absorber for attenuating torsion mode vibrations. The tuned liner is inserted into the shaft member.

36 Claims, 6 Drawing Sheets



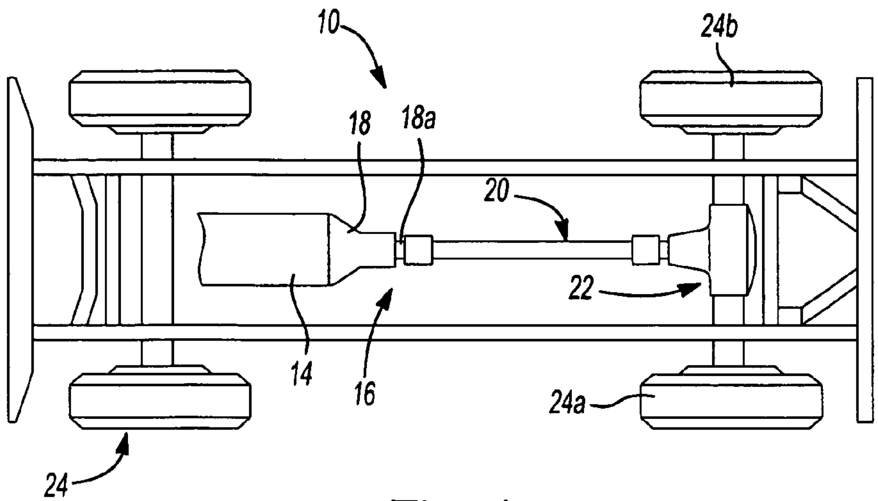

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Fig-1

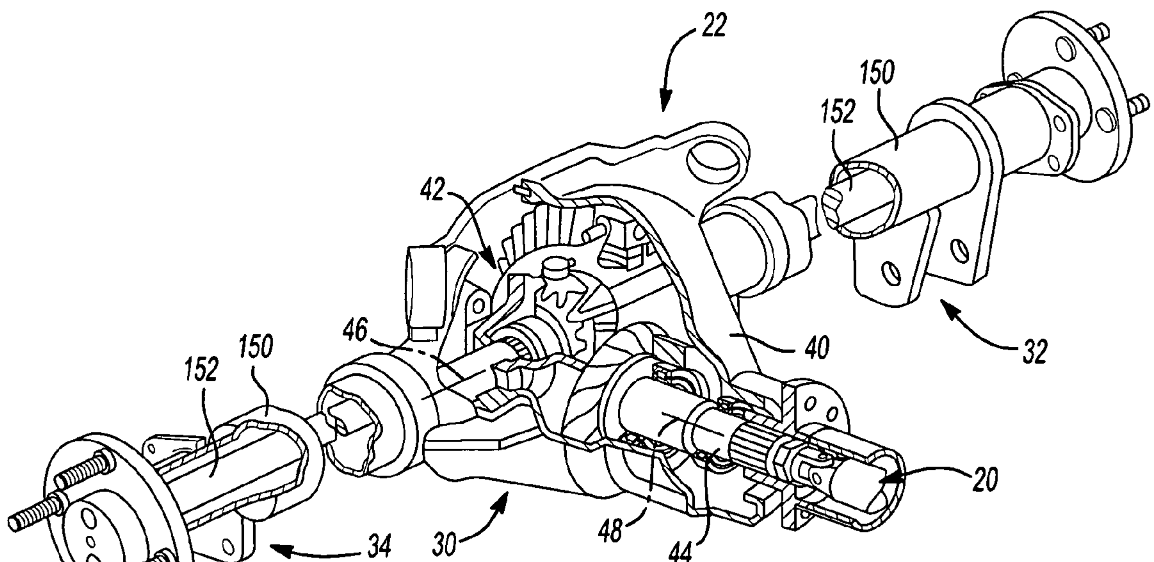
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Fig-2

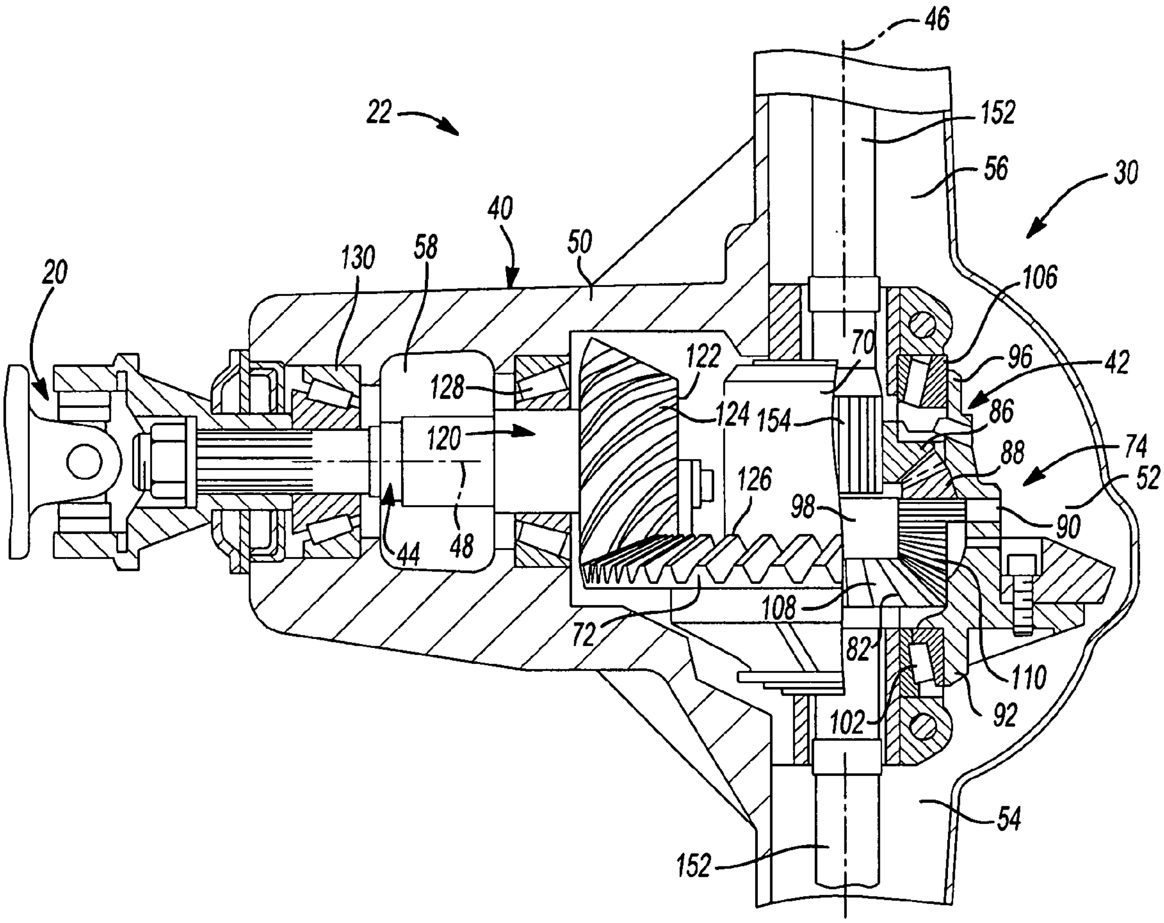
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Fig-3

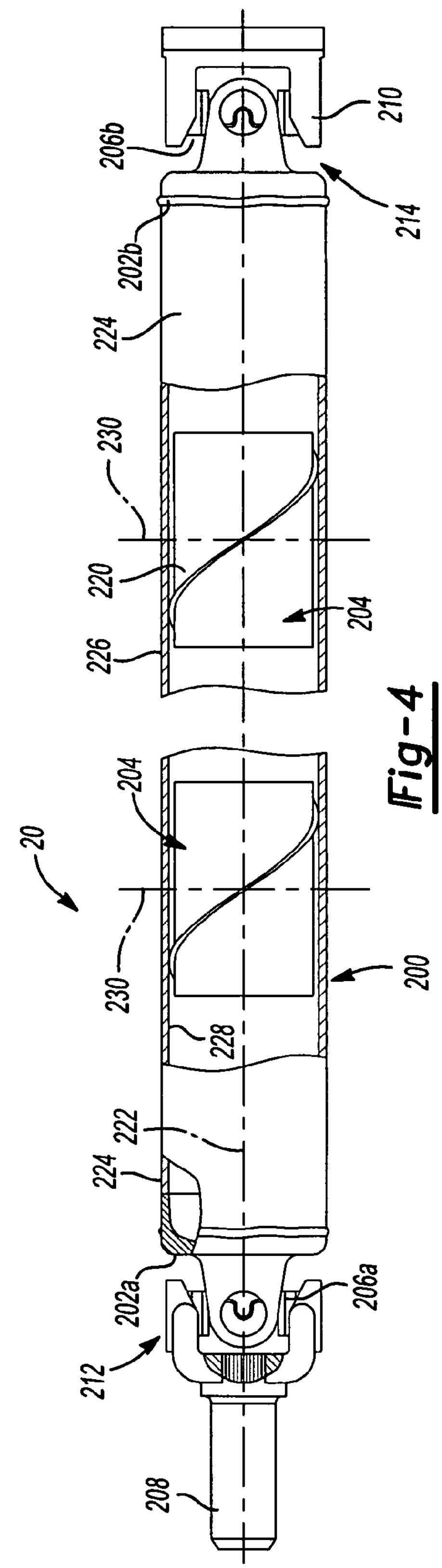

Fig-4

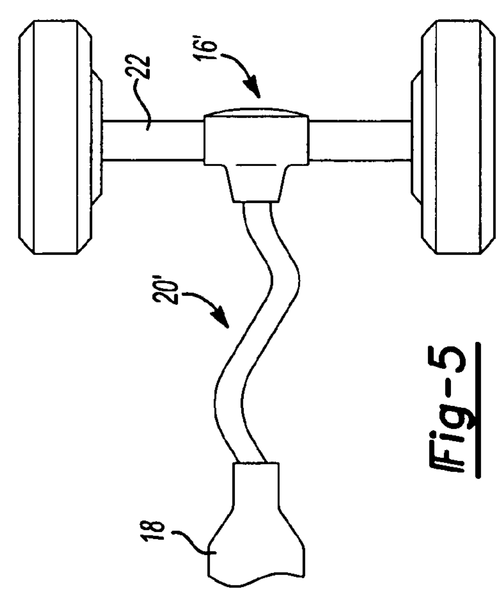

Fig-5

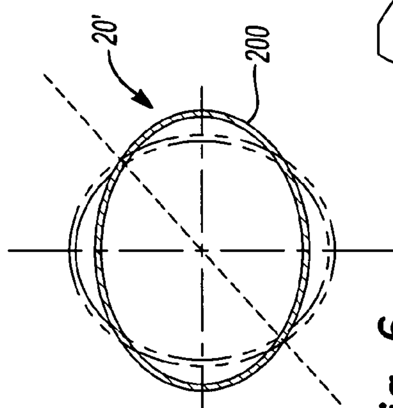

Fig-6

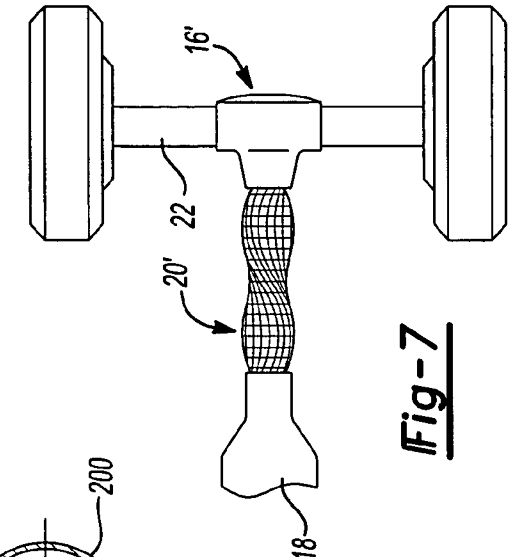

Fig-7

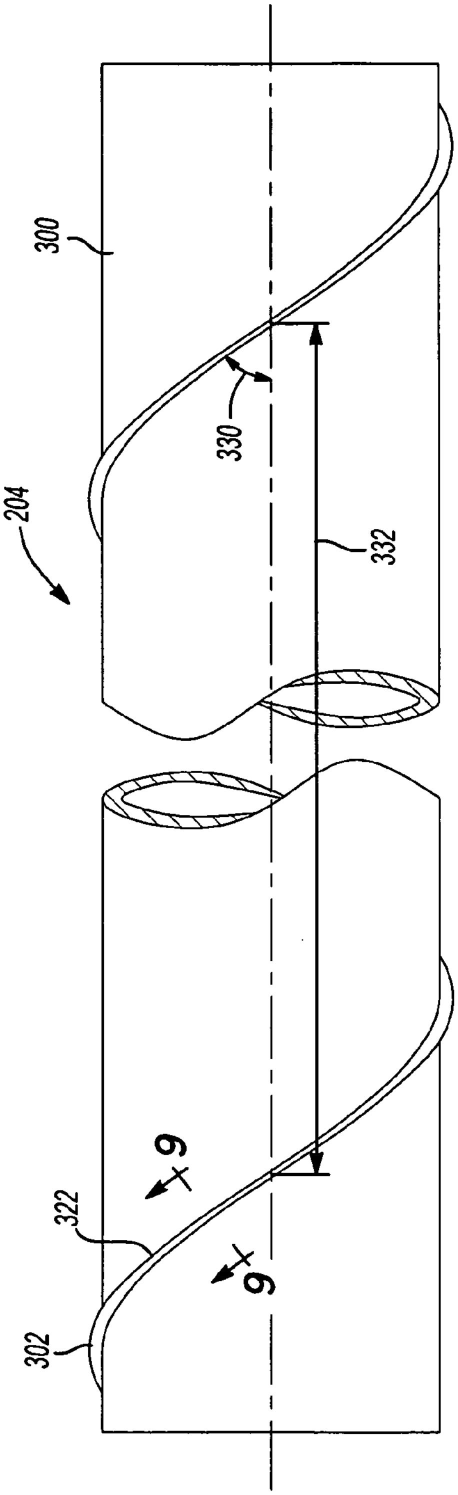

Fig-8

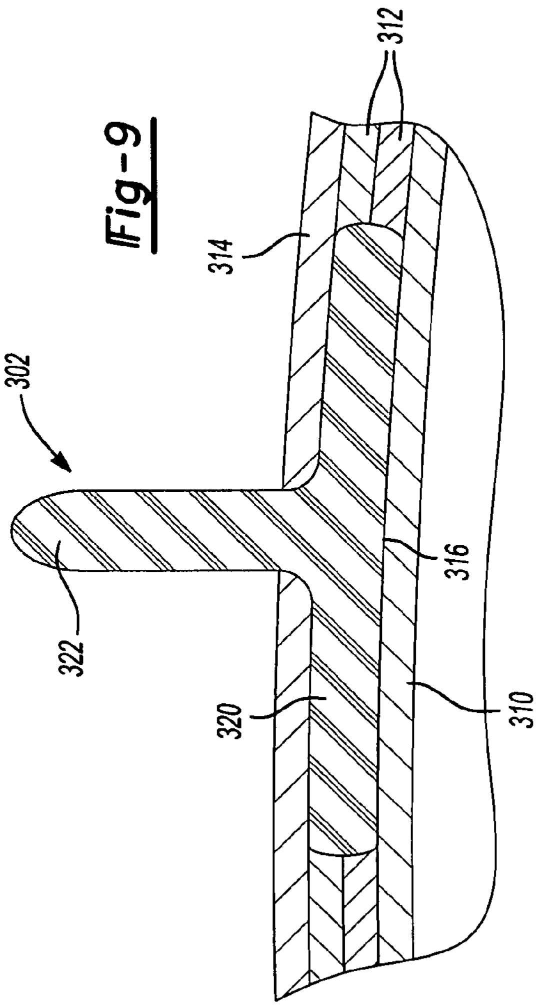

Fig-9

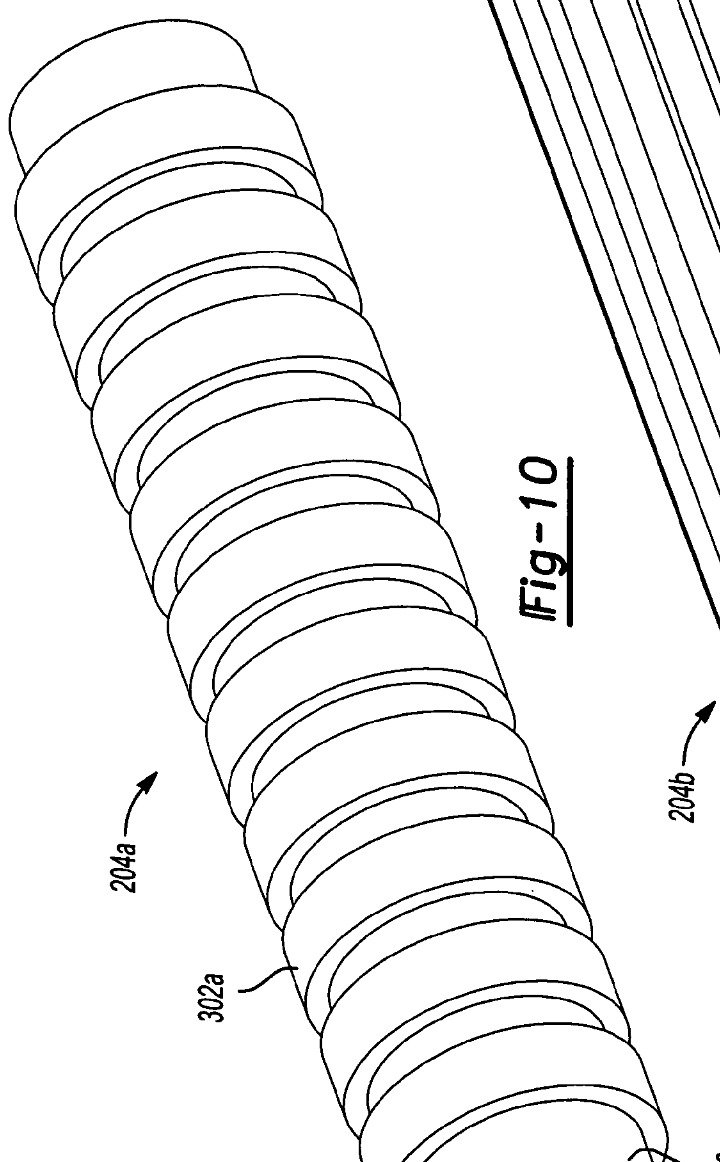

Fig-10

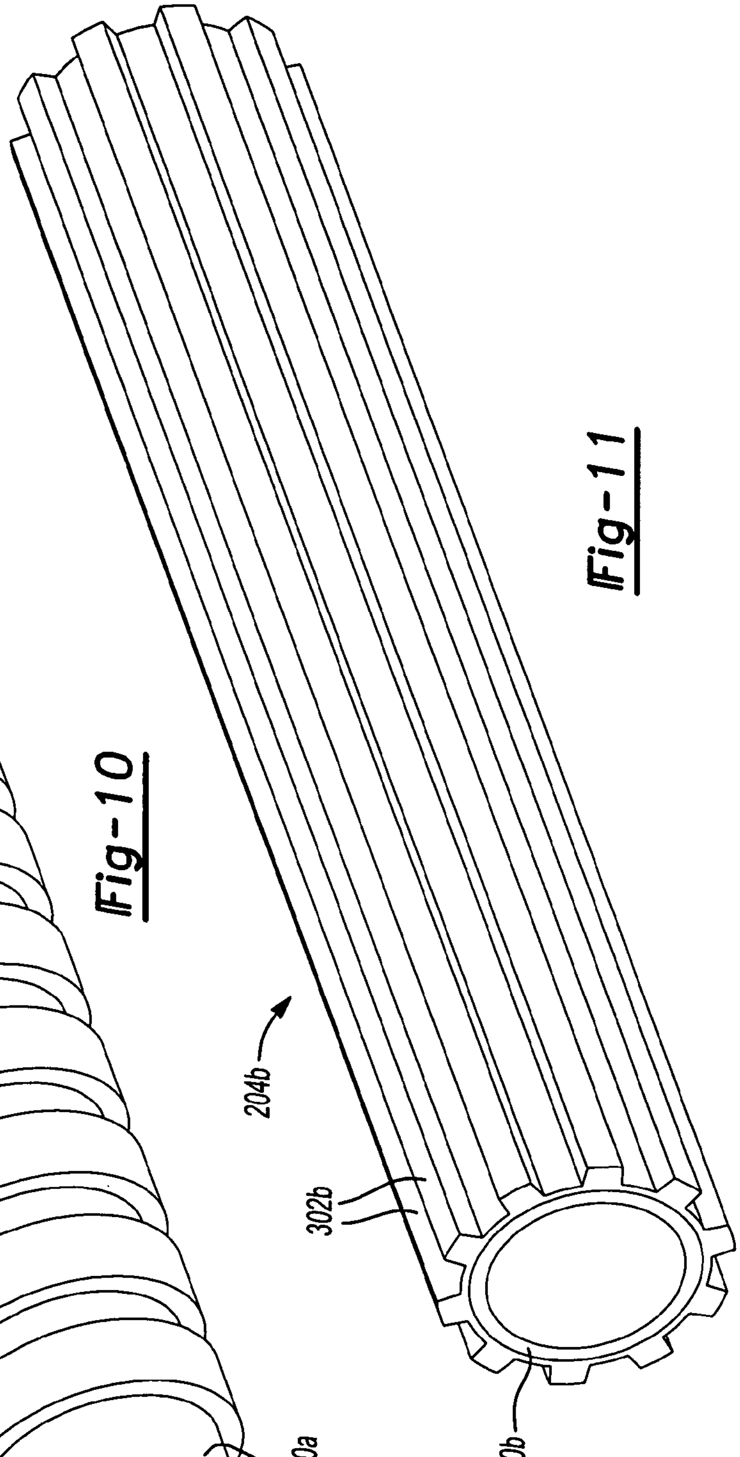

Fig-11

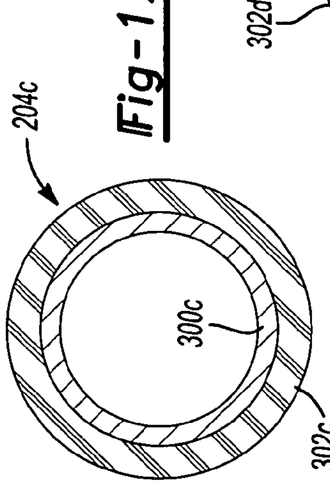

Fig-12

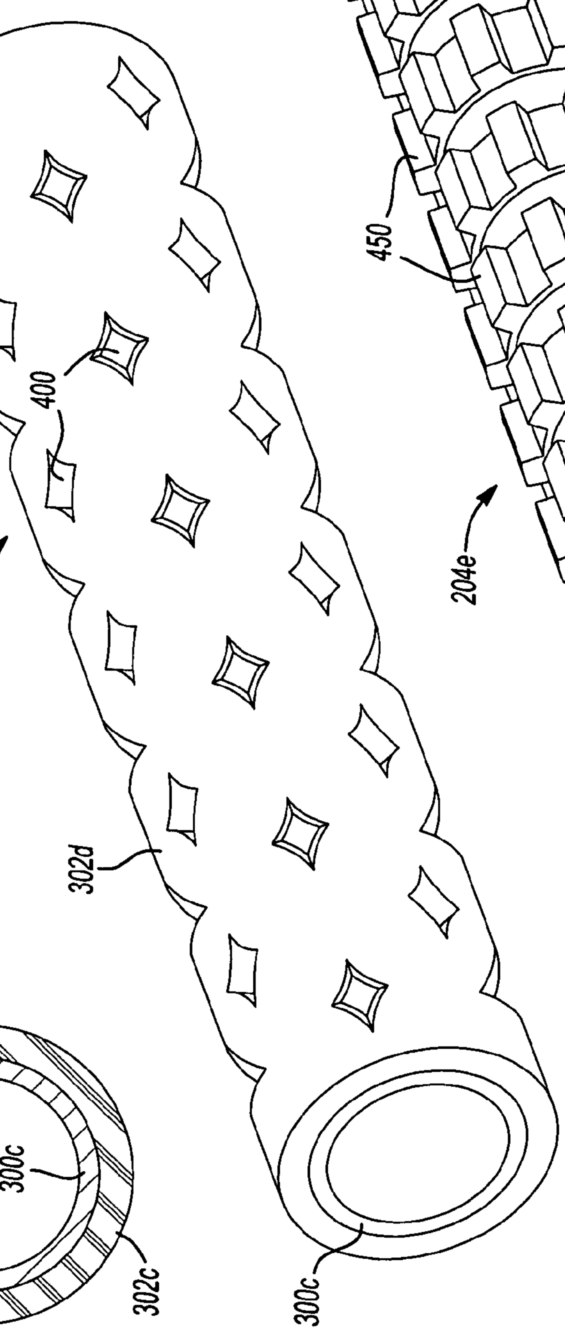

Fig-13

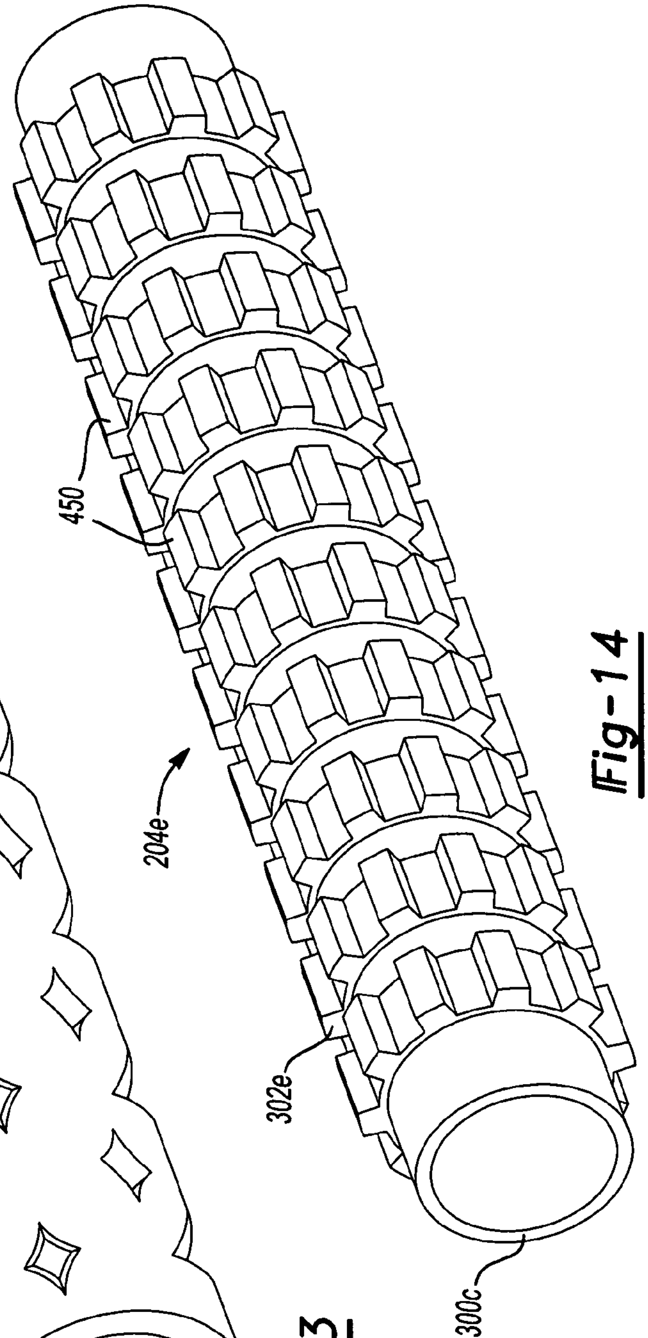

Fig-14

METHOD FOR ATTENUATING DRIVELINE VIBRATIONS

The present invention generally relates to shaft assemblies for transmitting rotary power in a driveline and more particularly to a method for attenuating driveline vibrations transmitted through a shaft assembly.

The consumers of modern automotive vehicles are increasingly influenced in their purchasing decisions and in their opinions of the quality of a vehicle by their satisfaction with the vehicle's sound quality. In this regard, consumers increasingly expect the interior of the vehicle to be quiet and free of noise from the power train and driveline. Consequently, vehicle manufacturers and their suppliers are under constant pressure to reduce noise to meet the increasingly stringent expectations of consumers.

Driveline components and their integration into a vehicle typically play a significant role in sound quality of a vehicle as they can provide the forcing function that excites specific driveline, suspension and body resonances to produce noise. Since this noise can be tonal in nature, it is usually readily detected by the occupants of a vehicle regardless of other noise levels. Common driveline excitation sources can include driveline imbalance and/or run-out, fluctuations in engine torque, engine idle shake, and motion variation in the meshing gear teeth of the hypoid gear set (i.e., the pinion gear and the ring gear of a differential assembly).

Motion variation is the slight variation in angular displacement between the input and output gears of a gear set. This variation is typically very small and can be on the order of tens of millionths of an inch (measured tangentially at the pitch line of the gear) for a modern automotive differential assembly. Motion variation is typically not constant (e.g., it will typically vary as a function of load, temperature, gearset build position, and break-in wear) and moreover, it cannot be reduced beyond certain levels without severe economic penalties.

Propeller (prop) shafts are typically employed to transmit rotary power in a driveline. Modern automotive propshafts are commonly formed of relatively thin-walled steel or aluminum tubing and as such, can be receptive to various driveline excitation sources. The various excitation sources can typically cause the propshaft to vibrate in a bending (lateral) mode, a torsion mode and a shell mode. Bending mode vibration is a phenomenon wherein energy is transmitted longitudinally along the shaft and causes the shaft to bend at one or more locations. Torsion mode vibration is a phenomenon wherein energy is transmitted tangentially through the shaft and causes the shaft to twist. Shell mode vibration is a phenomenon wherein a standing wave is transmitted circumferentially about the shaft and causes the cross-section of the shaft to deflect or bend along one or more axes.

Several techniques have been employed to attenuate vibrations in propshafts including the use of weights and liners. U.S. Pat. No. 2,001,166 to Swennes, for example, discloses the use of a pair of discrete plugs or weights to attenuate vibrations. The weights of the '166 patent are frictionally engaged to the propshaft at experimentally-derived locations and as such, it appears that the weights are employed as a resistive means to attenuate bending mode vibration. As used herein, resistive attenuation of vibration refers to a vibration attenuation means that deforms as vibration energy is transmitted through it (i.e., the vibration attenuation means) so that the vibration attenuation means absorbs (and thereby attenuates) the vibration energy. While this technique can be effective, the additional mass of the weights can require changes in the propshaft mounting hardware and/or propshaft geometry (e.g., wall thickness) and/or can change the critical speed of the propshaft. Moreover, as the plugs tend to be relatively short, they typically would not effectively attenuate shell mode vibration or torsion mode vibration.

U.S. Pat. No. 3,075,406 to Butler Jr., et al. appears to disclose a single damper that is inserted to a hollow shaft. The damper includes a pair of resilient members, which frictionally engage the interior surface of the hollow shaft, and a metal bar that is suspended within the interior of the hollow shaft by the resilient members. The '406 patent explains that at the resonant vibration frequency of the propeller shaft, "the motion of the mass is out of phase with the radial motion of the tubular propeller shaft". Accordingly, the damper of the '406 patent appears to be a reactive damper for attenuating bending mode vibration. As used herein, reactive attenuation of vibration refers to a mechanism that can oscillate in opposition to the vibration energy to thereby "cancel out" a portion of the vibration energy. The damper of the '406 patent appears to be ineffective at attenuating torsion mode vibration and shell mode vibration due to its relatively short length and its contact with a relatively small portion of the interior surface of the propshaft.

U.S. Pat. No. 2,751,765 to Rowland et al., U.S. Pat. No. 4,014,184 to Stark and U.S. Pat. Nos. 4,909,361 and 5,976,021 to Stark et al. disclose hollow liners for a propshaft. The '765 and '184 patents appear to disclose hollow multi-ply cardboard liners that are press-fit to the propshaft; the cardboard liners are relatively long and appear to extend substantially coextensively with the hollow shaft. The '361 and '021 patents appear to disclose liners having a hollow cardboard core and a helical retaining strip that extends a relatively short distance (e.g., 0.03 inch) from the outside diameter of the core. The retaining strip has high frictional properties to frictionally engage the propshaft. Accordingly, the liners of the '765, '184, '361 and '021 patents appear to disclose a resistive means for attenuating shell mode vibration. These liners, however, do not appear to be suitable for attenuating bending mode vibration or torsion mode vibration.

In view of the foregoing, there remains a need in the art for an improved method for damping various types of vibrations in a hollow shaft. This method facilitates the damping of shell mode vibration as well as the damping of bending mode vibration and/or torsion mode vibration.

SUMMARY

In one form, the present teachings provide a method for manufacturing a shaft assembly of a driveline system. The driveline system can include a first driveline component and a second driveline component and the shaft assembly can be configured to transmit torque between the first driveline component and the second driveline component. The method can include: providing a hollow shaft member; and inserting at least one liner into the shaft member, the at least one liner being configured for damping shell mode vibrations in the shaft member by an amount that is greater than or equal to about 2%, the at least one liner also being configured for damping bending mode vibrations in the shaft member, the at least one liner being tuned to within about ±20% of a bending mode natural frequency of the shaft assembly as installed in the driveline system.

In another form, the present teachings provide a method for manufacturing a shaft assembly of a driveline system. The driveline system can include a first driveline component and a second driveline component and the shaft assembly can be configured to transmit torque between the first driveline component and the second driveline component. The method can

include: providing a hollow shaft member; and inserting at least one liner into the shaft member, the at least one liner being configured for damping shell mode vibrations in the shaft member by an amount that is greater than or equal to about 2%, the at least one liner also being tuned to within about ±20% of a natural frequency of the driveline system in a torsion mode.

In another form, the present teachings provide a method for manufacturing a shaft assembly of a driveline system. The driveline system can include a first driveline component and a second driveline component and the shaft assembly can be configured to transmit torque between the first driveline component and the second driveline component. The method can include: providing a hollow shaft member; tuning a mass and a stiffness of at least one liner; and inserting the at least one liner into the shaft member. The at least one liner is a tuned resistive absorber for attenuating shell mode vibrations and is a tuned reactive absorber for attenuating bending mode vibrations.

In still another form, the present teachings provide a method for manufacturing a shaft assembly of a driveline system. The driveline system can include a first driveline component and a second driveline component and the shaft assembly can be configured to transmit torque between the first driveline component and the second driveline component. The method can include: providing a hollow shaft member; tuning a mass and a stiffness of at least one liner; and inserting the at least one liner into the shaft member. The at least one liner is a tuned resistive absorber for attenuating shell mode vibrations and is a tuned reactive absorber for attenuating torsion mode vibrations.

Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

FIG. **1** is a schematic illustration of an exemplary vehicle constructed in accordance with the teachings of the present disclosure;

FIG. **2** is a top partially cut-away view of a portion of the vehicle of FIG. **1** illustrating the rear axle and the propshaft assembly in greater detail;

FIG. **3** is a sectional view of a portion of the rear axle and the propshaft assembly;

FIG. **4** is a top, partially cut away view of the propshaft assembly;

FIG. **5** is a schematic illustration of a portion of a driveline illustrating an undamped propshaft vibrating in a second bending mode;

FIG. **6** is a sectional view of a portion of the undamped propshaft taken perpendicular to the longitudinal (rotational) axis of the propshaft illustrating the propshaft vibrating in a first shell mode;

FIG. **7** is a schematic illustration of a portion of a driveline illustrating an undamped propshaft vibrating in a torsion mode;

FIG. **8** is a side view of a liner for damping a propshaft in accordance with the teachings of the present disclosure;

FIG. **9** is a section view of a portion of the liner illustrating the coupling of the resilient member to the structural portion in more detail;

FIG. **10** is a perspective view of a second liner for damping a propshaft in accordance with the teachings of the present disclosure;

FIG. **11** is a perspective view of a third liner for damping a propshaft in accordance with the teachings of the present disclosure;

FIG. **12** is a section view of a fourth liner for damping a propshaft in accordance with the teachings of the present disclosure;

FIG. **13** is a perspective view of a fifth liner for damping a propshaft in accordance with the teachings of the present disclosure; and

FIG. **14** is a perspective view of a sixth liner for damping a propshaft in accordance with the teachings of the present disclosure.

DETAILED DESCRIPTION OF THE VARIOUS EMBODIMENTS

With reference to FIG. **1** of the drawings, an exemplary vehicle constructed in accordance with the teachings of the present disclosure is generally indicated by reference numeral **10**. The vehicle **10** can include an engine **14** and a driveline **16**. The driveline **16** can include a transmission **18**, a propshaft assembly **20**, a rear axle **22** and a plurality of wheels **24**. The engine **14** can produce rotary power that can be transmitted to the transmission **18** in a conventional and well known manner. The transmission **18** can be conventionally configured and can include a transmission output shaft **18*a*** and a gear reduction unit (not specifically shown). As is well known in the art, the gear reduction unit can change the speed and torque of the rotary power provided by the engine such that a rotary output of the transmission **18** (which can be transmitted through the transmission output shaft **18*a***) can have a relatively lower speed and higher torque than that which was input to the transmission **18**. The propshaft assembly **20** can be coupled for rotation with the transmission output member **18*a*** to permit drive torque to be transmitted from the transmission **18** to the rear axle **22** where it can be selectively apportioned in a predetermined manner to the left and right rear wheels **24*a*** and **24*b***, respectively.

It will be appreciated that while the vehicle in the particular example provided employs a driveline with a rear-wheel drive arrangement, the teachings of the present disclosure have broader applicability. In this regard, a shaft assembly constructed in accordance with the teachings of the present disclosure may interconnect a first driveline component with a second driveline component to transmit torque therebetween. In the context of an automotive vehicle, the driveline components could be a transmission, a transfer case, a viscous coupling, an axle assembly, or a differential, for example.

With reference to FIG. **2**, the rear axle **22** can include a differential assembly **30**, a left axle shaft assembly **32** and a right axle shaft assembly **34**. The differential assembly **30** can include a housing **40**, a differential unit **42** and an input shaft assembly **44**. The housing **40** can support the differential unit **42** for rotation about a first axis **46** and can further support the input shaft assembly **44** for rotation about a second axis **48** that is perpendicular to the first axis **46**.

With additional reference to FIG. **3**, the housing **40** can be formed in a suitable casting process and thereafter machined as required. The housing **40** can includes a wall member **50** that can define a central cavity **52** that can have a left axle aperture **54**, a right axle aperture **56**, and an input shaft aperture **58**. The differential unit **42** can be disposed within the central cavity **52** of the housing **40** and can include a case **70**, a ring gear **72**, which can be fixed for rotation with the case **70**, and a gearset **74** that can be disposed within the case **70**. The gearset **74** can include first and second side gears **82** and **86** and a plurality of differential pinions **88**, which can be rotatably supported on pinion shafts **90** that can be mounted to the case **70**. The case **70** can include a pair of trunnions **92** and **96** and a gear cavity **98**. A pair of bearing assemblies **102** and **106** can support the trunnions **92** and **96**, respectively, for rotation about the first axis **46**. The left and right axle assemblies **32** and **34** can extend through the left and right axle apertures **54** and **56**, respectively, where they can be coupled for rotation about the first axis **46** with the first and second side gears **82** and **86**, respectively. The case **70** can be operable for supporting the plurality of differential pinions **88** for rotation within the gear cavity **98** about one or more axes that can be perpendicular to the first axis **46**. The first and second side gears **82** and **86** each include a plurality of teeth **108** which meshingly engage teeth **110** that are formed on the differential pinions **88**.

The input shaft assembly **44** can extend through the input shaft aperture **58** where it can be supported in the housing **40** for rotation about the second axis **48**. The input shaft assembly **44** can include an input shaft **120**, a pinion gear **122** having a plurality of pinion teeth **124** that meshingly engage the teeth **126** that are formed on the ring gear **72**, and a pair of bearing assemblies **128** and **130** that can cooperate with the housing **40** to rotatably support the input shaft **120**. The input shaft assembly **44** can be coupled for rotation with the propshaft assembly **20** and can be operable for transmitting drive torque to the differential unit **42**. More specifically, drive torque received by the input shaft **120** can be transmitted by the pinion teeth **124** to the teeth **126** of the ring gear **72** such that drive torque is distributed through the differential pinions **88** to the first and second side gears **82** and **86**.

The left and right axle shaft assemblies **32** and **34** can include an axle tube **150** that can be received into the associated axle aperture **54** and **56**, respectively, and an axle half-shaft **152** that can be supported for rotation in the axle tube **150** about the first axis **46**. Each of the axle half-shafts **152** can include an externally splined portion **154** that can meshingly engage a mating internally splined portion (not specifically shown) that can be formed into the first and second side gears **82** and **86**, respectively.

With reference to FIG. **4**, the propshaft assembly **20** can include a shaft structure **200**, first and second trunnion caps **202***a* and **202***b*, at least one liner **204**, first and second spiders **206***a* and **206***b*, a yoke assembly **208** and a yoke flange **210**. The first and second trunnion caps **202***a* and **202***b*, the first and second spider **206***a* and **206***b*, the yoke assembly **208** and the yoke flange **210** can be conventional in their construction and operation and as such, need not be discussed in detail. Briefly, the first and second trunnion caps **202***a* and **202***b* can be fixedly coupled to the opposite ends of the shaft structure **200**, typically via a weld. Each of the first and second spiders **206***a* and **206***b* can be coupled to an associated one of the first and second trunnion caps **202***a* and **202***b* and to an associated one of the yoke assembly **208** and the yoke flange **210**. The yoke assembly **208**, first spider **206***a*, and first trunnion cap **202***a* can collectively form a first universal joint **212**, while the yoke flange **210**, second spider **206***b* and second trunnion cap **202***b* can collectively form a second universal joint **214**.

A splined portion of the yoke assembly **208** can be rotatably coupled with the transmission output shaft **18***a* and the yoke flange **210** can be rotatably coupled with the input shaft **120**. The first and second universal joints **212** and **214** can facilitate a predetermined degree of vertical and horizontal offset between the transmission output shaft **18***a* and the input shaft **120**.

The shaft structure **200** can be generally cylindrical, having a hollow central cavity **220** and a longitudinal axis **222**. The shaft structure **200** can be formed of any suitable material. In the particular example provided, the shaft structure **200** is formed of welded seamless 6061-T6 aluminum tubing conforming to ASTM B-210. Also in the particular embodiment illustrated, the shaft structure **200** is uniform in diameter and cross-section between the ends **224**, but it will be appreciated that the shaft structure could be otherwise formed. For example, the ends **224** of the shaft structure **200** could be necked-down (e.g., via rotary swaging) relative to the central portion **226** of the shaft structure **200**.

With reference to FIGS. **5** through **7**, it will be appreciated that an undamped propshaft assembly **20'** (e.g., the propshaft assembly **20** without the at least one liner **204**) could be susceptible to several types of vibration. In FIG. **5**, for example, the undamped propshaft assembly **20'** is illustrated as vibrating at a bending mode natural frequency (i.e., a second bending mode (n=2) natural frequency) of the propshaft assembly **20'** as installed in the driveline **16'**. In this regard, those of ordinary skill in the art will appreciate that the bending mode natural frequency is a function of not only the propshaft assembly **20'**, but also of the "boundary conditions" (i.e., the manner in which the propshaft assembly **20'** is coupled to the driveline **16'**). Consequently, the term "propshaft assembly as installed in the driveline" will be understood to include not only the shaft assembly but also the boundary conditions under which the shaft assembly is installed to the two driveline components.

In FIG. **6**, the propshaft assembly **20'** is illustrated as vibrating at a shell mode natural frequency (i.e., a first (n=1) shell mode natural frequency) of the shaft structure **200**.

In FIG. **7**, the propshaft assembly **20'** is illustrated as vibrating at a natural torsion frequency of the driveline **16'** in a torsion mode (i.e., a first (n=1) torsion mode). In this regard, those of ordinary skill in the art will appreciate that the natural torsion frequency is a function of not only the propshaft assembly **20'**, but also of the first and second driveline components (e.g., the transmission **18** and the rear axle **22**) to which the propshaft assembly is coupled.

Returning to FIG. **4**, the propshaft assembly **20** of the particular example provided includes two liners **204** that are identically configured. It will be appreciated in view of this disclosure, however, that other quantities of liners **204** may be utilized and that the liners **204** need not be identically configured (i.e., each insert **204** can have different damping characteristics and a first one of the liners **204** can be different from a second one of the liners **204**).

With additional reference to FIGS. **8** and **9**, the liner **204** can be constructed in a manner that is similar to that which is described in U.S. Pat. No. 4,909,361, the disclosure of which is hereby incorporated by reference as if fully set forth in its entirety herein. Briefly, the liner **204** can include a structural portion **300** and one or more resilient members **302** that are coupled to the structural portion **300**. The liners **204** are sized such that the structural portion **300** is smaller than the inner diameter of the shaft member **200** but the resilient member(s) **302** is/are sized to frictionally engage the inner diameter of the shaft member **200**.

In the example provided, the structural portion **300** includes a hollow core **310**, one or more intermediate members **312** and a cover member **314**. The core **310** can be formed of a fibrous material, such as cardboard. In the particular example provided, the core **310** is formed of a suitable number of plies of helically wound paperboard. The intermediate members **312** can also be formed of a paperboard and can be helically wound onto and adhered (via a suitable adhesive) to the core **310** in a manner that forms one or more helical gaps **316**. In the particular example provided, one helical gap **316** is formed. It will be appreciated that the structural portion **300** could be formed of any appropriate material, including cardboard, plastic resins, carbon fiber, fiberglass, metal and combinations thereof. It will also be appreciated that the structural portion **300** need not include an intermediate member **312** or a cover member **314** and need not define one or more gaps **316**. It will further be appreciated that the gaps **316**, if used, need not be helical in shape but rather could be formed in other manners, such as circumferentially or longitudinally.

The resilient members **302** can be formed of an appropriate elastomer and can include a base **320** and one or more lip members **322** that can be coupled to the base **320**. The base **320** can be fixedly coupled to the structural portion **300** via a suitable adhesive such that the lip members **322** extend radially outwardly therefrom. The cover member **314** can be wrapped over the intermediate member(s) **312** and the base **320** and can be employed to further secure the resilient members **302** to the structural portion **300**.

It will be appreciated from this disclosure that where two or more resilient members **302** are employed, the resilient members **302** can be formed of the same material and are coupled to the structural portion **300** such that their bases **320** are received in an associated gap **316**. It will also be appreciated from this disclosure that in the alternative, the resilient members **302** may be formed differently (e.g., with different materials, different sizes and/or different cross-sections).

With reference to FIGS. **1**, **4** and **8**, it will be further appreciated from this disclosure that the mass and the stiffness of the liner(s) **204** are tuned to the driveline **16** such that the liner(s) **204** acts or act as (a) a tuned resistive absorber for attenuating shell mode vibrations; and (b) as one or more of (i) a tuned reactive absorber for attenuating bending mode vibrations, and (ii) a tuned reactive absorber for attenuating torsion mode vibrations. The liner(s) **204** may be tuned such that a ratio of the mass of the liner(s) **204** to a mass of the shaft member **200** is about 5% to about 30%. In the particular example provided, the ratio of the mass of the liners **204** to the mass of the shaft member **200** is about 16.9%.

Preferably, the liner(s) **204** is/are tuned to a natural frequency corresponding to at least one of a first shell mode, a second shell mode and a third shell mode. Where the liner(s) **204** is/are employed to attenuate bending mode vibrations, they are preferably tuned to a natural frequency corresponding to at least one of a first bending mode, a second bending mode and a third bending mode of the propshaft assembly **20** as installed to the driveline **16**. Where the liner(s) **204** is/are employed to attenuate torsion mode vibrations, they are preferably tuned to a natural frequency of the driveline **16** in a torsion mode, such as to a frequency that is less than or equal to about 600 Hz.

It will also be appreciated from this disclosure that various characteristics of the liner **204** can be controlled to tune its damping properties in the shell mode and in one or both of the bending mode and the torsion mode. In the particular example provided, the following variables were controlled: mass, length and outer diameter of the liner **204**, diameter and wall thickness of the structural portion **300**, material of which the structural portion **300** was fabricated, the quantity of the resilient members **302**, the material of which the resilient members **302** was fabricated, the helix angle **330** and pitch **332** with which the resilient members **302** are fixed to the structural portion **300**, the configuration of the lip member(s) **322** of the resilient member **302**, and the location of the liners **204** within the shaft member **200**. In the particular example provided:

- the shaft member **200** can have an outside diameter of about 4.0 inches, a wall thickness of about 0.08 inch, a length of about 64 inches, and can have a mass of about 3.2 kg;
- the liners **204** can have an outer diameter (over the resilient member(s) **302**) of about 4.0 inches, a length of about 14 inches, a mass of about 270 grams, the structural portion **300** of the liner **204** can be formed of paperboard and can have a wall thickness of about 0.07 inch and an inner diameter of about 3.56 inch, one resilient member **302** can be coupled to the structural portion **300** at a helix angle **330** of about 22.5° and a pitch **332** of about 4.5 inches, the resilient member **302** can have a single lip member **322** and can be formed of a silicon material that conforms to ASTM D2000 M2GE505 having a durometer of about 45 Shore A to about 55 Shore A; and
- each of the liners **204** can be inserted into an associated end of the shaft member **200** such that they are disposed generally symmetrically about an associated one of the second (n=2) bending nodes **230** (FIG. **4**).

It will be appreciated that in certain situations it may not be possible to exactly tune the liner **204** to the two or more relevant frequencies associated with a given propshaft assembly **20**, as when a particular liner **204** is used across a family of propshaft assemblies. As such, it will be understood that a liner **204** will be considered to be tuned to a relevant frequency if it is effective in attenuating vibration at the relevant frequency. For example, the liner **204** can be considered to be tuned to a relevant frequency if a frequency at which it achieves maximum attenuation is within ±20% of that relevant frequency. Preferably, the liner **204** is considered to be tuned to the relevant frequency if the frequency at which it achieves maximum attenuation is within ±15% of the relevant frequency. More preferably, the liner **204** is considered to be tuned to the relevant frequency if the frequency at which it achieves maximum attenuation is within ±10% of the relevant frequency. Still more preferably, the liner **204** is considered to be tuned to the relevant frequency if the frequency at which it achieves maximum attenuation is within ±5% of the relevant frequency.

As another example, the liner **204** can be considered to be tuned to a relevant shell mode frequency if it damps shell mode vibrations by an amount that is greater than or equal to about 2%.

While the propshaft assembly **20** has been described thus far as including a liner **204** having a resilient member **302** that is disposed helically about and along a structural portion **300**, it will be appreciated that the methodology of the present disclosure, in its broader aspects, may be performed somewhat differently. In this regard, the liner can be constructed as shown in FIGS. **10** through **14**.

In FIG. **10**, for example, the liner **204***a* includes a plurality of circumferentially-extending resilient members **302***a* that are coupled to the structural portion **300***a*. The resilient members **302***a* are spaced apart from one another along the longitudinal axis of the structural portion **300***a*. It will be appreciated that while the resilient members **302***a* are illustrated as having a generally flat outer surface, they could be formed to include one or more lip members (similar to the lip member **322** of FIG. **9**). In such case, the lip member(s) may be extend in a desired manner, such as circumferentially.

In FIG. **11**, the liner **204***b* includes a plurality of longitudinally-extending resilient members **302***b* that are coupled to the structural portion **300***b*. The resilient members **302***b* are spaced circumferentially apart from one another about the circumference of the structural portion **300***b*. It will be appreciated that while the resilient members **302***b* are illustrated as having an arcuate outer surface, they could be formed to include one or more lip members (similar to the lip member **322** of FIG. **9**). In such case, the lip member(s) may be extend in a desired manner, such as longitudinally.

In FIG. **12**, the liner **204***c* includes a resilient member **302***c* that covers substantially the entire outer surface of the structural portion **300***c*. The resilient member **302***c* can be a discrete component that is separately formed and thereafter assembled to the structural portion **300***c*. In this regard, the resilient member **302***c* can be formed as a sheet and then bonded to outer surface of the structural portion **300***c* via a suitable adhesive. Alternatively, the resilient member **302***c* could be overmolded onto the structural portion **300***c*.

The liner **204***d* of FIG. **13** is similar to the liner **204***c* of FIG. **12** except that a plurality of void spaces **400** may be formed into the resilient member **302***d* to control the stiffness of the liner **204***d* in a desired direction. While the void spaces **400** are illustrated to be diamond-shaped holes that extend completely through the resilient member **302***d*, it will be appreciated that the void spaces **400** need not extend completely through the resilient member **302***d* and thus could form blind holes, channels and/or grooves. Moreover, it will be appreciated that the void spaces **400** may be shaped and arranged in any desired manner.

The liner **204***e* of FIG. **14** can be similar to the liner **204***d* of FIG. **13**, except that the resilient member **302***e* includes a plurality of fingers **450**. Each finger **450** can be shaped in a desired manner, such as a prism, a pyramid, a cylinder, a cone, a plinth, or as a portion of a doubled-curved surface, such as a sphere, torus or ellipsoid. It may be beneficial to shape the fingers **450** in the shape of a prism, especially a rectangular parallelepiped, so as to more easily tailor the stiffness of the fingers **450** in two or more directions. In this regard, the width and depth of the cross section of the fingers **450** and the height of the fingers **450** may be controlled independently of one another.

In some situations it may be beneficial to chill the liners prior to their installation to a shaft member to reduce the overall diameter of the liner and/or to provide sufficient rigidity to the resilient member(s).

It may also be beneficial in some situations to provide a secondary means for retaining the liner to the shaft member. The secondary means can be employed to resist or inhibit axial movement of the liner within the shaft member and can comprise a structure that is axially offset from the liner and coupled to the shaft member. The structure can be configured to effectively reduce the inside diameter of the shaft member at a desired location to an extent that resists or inhibits axial movement of the liner. The structure can be formed via an adhesive, a weld, a dimple, or a necked-down (e.g., rotary swaged) section, for example.

While specific examples have been described in the specification and illustrated in the drawings, it will be understood by those of ordinary skill in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the present disclosure as defined in the claims. Furthermore, the mixing and matching of features, elements and/or functions between various examples is expressly contemplated herein so that one of ordinary skill in the art would appreciate from this disclosure that features, elements and/or functions of one example may be incorporated into another example as appropriate, unless described otherwise, above. Moreover, many modifications may be made to adapt a particular situation or material to the teachings of the present disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular examples illustrated by the drawings and described in the specification as the best mode presently contemplated for carrying out this invention, but that the scope of the present disclosure will include any embodiments falling within the foregoing description and the appended claims.

What is claimed is:

1. A method for manufacturing a shaft assembly of a driveline system, the driveline system further including a first driveline component and a second driveline component, the shaft assembly being adapted to transmit torque between the first driveline component and the second driveline component, the method comprising:

providing a hollow shaft member;

tuning at least one liner to attenuate at least two types of vibration transmitted through the shaft member; and

positioning the at least one liner within the shaft member such that the at least one liner is configured to damp shell mode vibrations in the shaft member by an amount that is greater than or equal to about 2%, and the at least one liner is also configured to damp bending mode vibrations in the shaft member, the at least one liner being tuned to within about ±20% of a bending mode natural frequency of the shaft assembly as installed in the driveline system.

2. The method of claim **1**, wherein the at least one liner is tuned within ±15% of the bending mode natural frequency of the shaft assembly as installed in the driveline system.

3. The method of claim **2**, wherein the at least one liner is tuned to within ±10% of the bending mode natural frequency of the shaft assembly as installed in the driveline system.

4. The method of claim **3**, wherein the at least one liner is tuned to within ±5% of the bending mode natural frequency of the shaft assembly as installed in the driveline system.

5. The method of claim **3**, wherein the shell mode is at least one of a first shell mode, a second shell mode and a third shell mode.

6. The method of claim **5**, wherein the bending mode is at least one of a first bending mode, a second bending mode and a third bending mode.

7. The method of claim **3**, wherein the liner is further tuned within ±20% to a natural frequency of the driveline system in a torsion mode.

8. The method of claim **7**, wherein the liner is tuned to within ±15% to the natural frequency of the driveline system in the torsion mode.

9. The method of claim **8**, wherein the liner is tuned to within ±10% to the natural frequency of the driveline system in the torsion mode.

10. The method of claim **9**, wherein the liner is tuned within ±5% to the natural frequency of the driveline system in the torsion mode.

11. The method of claim **9**, wherein the natural frequency of the driveline system is below about 600 Hz.

12. The method of claim **3**, wherein the at least one liner includes a structural portion and at least one resilient member that is coupled to the structural portion, the liner being inserted to the shaft member such that a wall of the shaft member contacts the at least one resilient member.

13. The method of claim **12**, wherein the at least one resilient member extends helically about and along the structural portion.

14. The method of claim **12**, wherein the at least one resilient member extends longitudinally along the structural portion.

15. The method of claim **12**, wherein the at least one resilient member extends circumferentially about the structural portion.

16. The method of claim **12**, wherein a first one of the resilient members is formed of a first material and a second one of the resilient members is formed of a second material that is different from the first material.

17. The method of claim **12**, wherein the at least one resilient member is overmolded to the structural portion.

18. The method of claim **12**, wherein the at least one resilient member includes a plurality of fingers, each of the fingers being disposed between the shaft member and the structural portion.

19. The method of claim **12**, wherein the structural portion is formed of a material selected from a group consisting of cardboard, plastic resin, carbon fiber, fiberglass, metal and combinations thereof.

20. The method of claim **3**, wherein a first one of the liners is positioned along the shaft member symmetrically about a bending anti-node.

21. The method of claim **20**, wherein a second one of the liners is positioned along the shaft member symmetrically about another bending anti-node.

22. A method for manufacturing a shaft assembly of a driveline system, the driveline system further including a first driveline component and a second driveline component, the shaft assembly being adapted to transmit torque between the first driveline component and the second driveline component, the method comprising:

providing a hollow shaft member;

tuning a mass and a stiffness of at least one liner; and

inserting the at least one liner into the shaft member;

wherein the at least one liner is a tuned resistive absorber for attenuating shell mode vibrations and wherein the at least one liner is a tuned reactive absorber for attenuating bending mode vibrations.

23. The method of claim **22**, wherein the at least one liner is tuned to at least one of a first shell mode, a second shell mode and a third shell mode.

24. The method of claim **23**, wherein the at least one liner is tuned to at least one of a first bending mode, a second bending mode and a third bending mode.

25. The method of claim **24**, wherein the at least one liner further acts as a tuned reactive absorber for attenuating torsion mode vibrations.

26. The method of claim **24**, wherein the at least one liner includes a structural portion and at least one resilient member that is coupled to the structural portion, the at least one liner being inserted to the shaft member such that a wall of the shaft member contacts the at least one resilient member.

27. The method of claim **26**, wherein the at least one resilient member extends helically about and along the structural portion.

28. The method of claim **26**, wherein the at least one resilient member extends longitudinally along the structural portion.

29. The method of claim **26**, wherein the at least one resilient member extends circumferentially about the structural portion.

30. The method of claim **26**, wherein a first one of the resilient members is formed of a first material and a second one of the resilient members is formed of a second material that is different from the first material.

31. The method of claim **26**, wherein the structural portion is formed of a material selected from a group consisting of cardboard, plastic resin, carbon fiber, fiberglass, metal and combinations thereof.

32. The method of claim **26**, wherein the at least one resilient member is overmolded to the structural portion.

33. The method of claim **26**, wherein the at least one resilient member includes a plurality of fingers, the fingers being disposed between the structural portion and the shaft member.

34. The method of claim **22**, wherein a first one of the liners is positioned along the shaft member symmetrically about a bending anti-node.

35. The method of claim **34**, wherein a second one of the liners is positioned along the shaft member symmetrically about another bending anti-node.

36. A method for manufacturing a shaft assembly of a driveline system, the driveline system further including a first driveline component and a second driveline component, the shaft assembly being adapted to transmit torque between the first driveline component and the second driveline component, the method comprising:

providing a hollow shaft member;

tuning a mass and a stiffness of at least one liner; and

inserting the at least one liner into the shaft member;

wherein a ratio of a mass of the at least one liner to a mass of the shaft member is about 5% to about 30%;

wherein the at least one liner is a tuned resistive absorber for attenuating shell mode vibrations; and

wherein the at least one liner is a tuned reactive absorber for attenuating at least one of bending mode vibrations and torsion mode vibrations.

* * * * *