



- (51) **International Patent Classification:**
G06F 19/00 (2011.01)
- (21) **International Application Number:**
PCT/US2013/058545
- (22) **International Filing Date:**
6 September 2013 (06.09.2013)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
61/697,904 7 September 2012 (07.09.2012) US
61/779,372 13 March 2013 (13.03.2013) US
- (71) **Applicant:** DANA LIMITED [US/US]; P.o. Box 1000, Maumee, OH 43537 (US).
- (72) **Inventors:** REMBOSKI, Donald, J.; 885 Oakdale Road, Ann Arbor, MI 48105 (US). VERSTEYHE, Mark, R. J.; Rivierstraat 7, B-8020 Oostkamp (BE). TASKIRAN, Evrim; Rue De La Violette 26, B-1000 Brussels (BE).
- (74) **Agent:** HAVRANEK, Kristin; Wilson Sonsini Goodrich & Rosati, 650 Page Mill Road, Palo Alto, CA 94304 (US).

(81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

[Continued on next page]

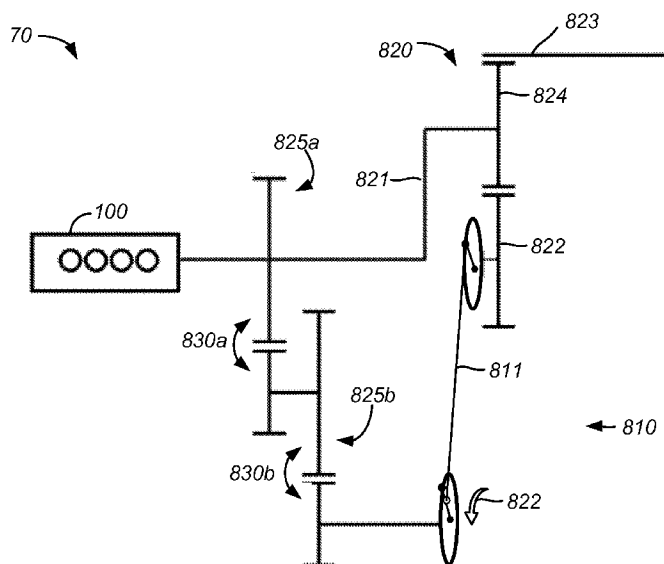
(54) **Title:** ACTIVE TORQUE RIPPLE RECTIFIER

FIG. 8A

(57) **Abstract:** The present disclosure provides systems, devices, and methods for reducing torsional vibration and torque ripple in engines and nearby associated components. Torque ripple may be reduced by measuring the torque ripple of an engine output, calculating an addition signal, and applying the addition signal to the engine output with an electric motor coupled to the output shaft of the engine or a starter motor coupled to a fly wheel, roller-crank mechanism, or other mechanical mechanism. In some cases, the engine may be coupled to a continuously variable transmission (CVT). Torque can be measured at the CVT, a multiplication signal can be calculated, and the multiplication signal can be applied to the CVT with a servo mechanism or a ball-ramp mechanism.

**Declarations under Rule 4.17:**

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

- *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

ACTIVE TORQUE RIPPLE RECTIFIER

CROSS-REFERENCE

[0001] This application claims the benefit of U.S. Provisional Application No. 61/697,904, filed September 7, 2012 and U.S. Provisional Application No. 61/779,372, filed March 13, 2013, which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

[0002] There is a globally increasing trend towards engine downsizing as a result of the recent improvements on combustion engine technology. The objective of this research can be stated as providing more efficient vehicles, while keeping the same vehicle body and performance characteristics. This technology implies the use of superchargers/turbochargers to reach this target. Increasing the power output using these technologies provides the possibility for downsizing (smaller engine displacement and reduced number of cylinders). Moreover, higher torque potential enables the use of longer gear ratios, which in turn makes down-speeding possible (i.e. operating at lower engine speeds). Developing smaller size combustion engines can result in the following benefits:

- the fuel economy can be significantly improved,
- engine operation is shifted into highest efficiency area, and
- CO₂ emissions can be reduced.
- Weight and cost of the engine may be reduced, as well as packaging.

SUMMARY OF THE INVENTION

[0003] Downsizing and down-speeding usually lead to higher torque peaks at low engine speed, requiring additional technologies to avoid transferring these torque ripples to the powertrain.

[0004] Systems, devices, and methods for reducing torsional vibration and torque ripple in engines and nearby associated components are disclosed. Torque ripples at low engine speeds are compensated for by adding a compensation signal, for example, with various motors or other mechanical mechanisms. Alternatively or in combination, torque ripples are compensated for by multiplication with an additional signal, for example, at the power transmission coupled to the engine.

[0005] An aspect of the disclosure provides a method of reducing torsional vibration in an output of an engine. A torque ripple of an engine output is measured. A correction signal for

reducing the measured torque ripple is determined. The correction signal is applied to an output shaft of the engine such that the torque ripple of the engine output is reduced. The torque ripple of the engine output can be measured with a torque sensor coupled to the output shaft of the engine. In one embodiment, the correction signal is determined by evaluating a Fourier series transformation of the measured torque ripple. In one embodiment, the correction signal is applied by actuating an electric motor or a starter motor mechanically coupled to the output shaft.

[0006] Another aspect of the disclosure provides another method of reducing torsional vibration in an output of an engine. A gear set is coupled to an output shaft of the engine. The gear set comprises a roller crank mechanism. A correction signal is introduced to the output shaft of the engine with the roller crank mechanism. In one embodiment, the correction signal is determined by evaluating a Fourier series transformation of the measured torque ripple. The correction signal reduces a torque ripple of the engine output. The gear set typically comprises a planetary gear set. The number of reductions in the gear chain may depend on the order of the main ripple harmonics of the engine output that has to be compensated with this device. The roller crank mechanism may comprise an adjustment mechanism for adjusting a phase of the correction signal.

[0007] Yet another aspect of the disclosure provides yet another method for reducing torsional vibration in an output of an engine. A continuously variable transmission (CVT) is coupled to an output shaft of the engine. An input torque to the CVT and/or an output torque from the CVT is measured. A correction signal is applied with the CVT based on the measured torque such that the output of the CVT has reduced torsional vibration compared with the output of the engine. The correction signal may be applied by a servo motor mechanically coupled to the CVT, for example by adjusting the speed ratio of the CVT to reduce torque ripple. Alternatively or in combination, the correction signal may be applied with a ball ramp mechanism mechanically coupled to the CVT.

[0008] A further aspect of the disclosure provides a system for transmitting power having reduced torsional vibration in its output. The system comprises an engine having an output shaft and means for applying a correction signal to the output shaft.

[0009] The means for applying the correction signal may comprise an electric motor or a starter motor mechanically coupled to the output shaft. The output of the electric motor or the starter motor may depend on a torque measurement from a torque sensor coupled to the output shaft.

[0010] The means for applying the correction signal comprises a corrective gear set coupled to the output shaft of the engine. The corrective gear set may comprise a planetary gear set. The corrective gear set may comprise a roller crank mechanism. The roller crank mechanism may comprise an adjustment mechanism for adjusting a phase of the correction signal. The number of gear sets used may depend on the order of ripple harmonics of the engine output.

[0011] The means for applying the correction signal may comprise a continuously variable transmission (CVT) coupled to the output shaft of the engine. The means for applying the correction signal may further comprise one or more of an input torque sensor and an output torque sensor coupled to the CVT, a servo motor mechanically coupled to the CVT and configured to apply the correction signal to the CVT based on a measured torque from the input torque sensor or the output torque sensor, and a ball ramp mechanism mechanically coupled to the CVT and configured to apply the correction signal to the CVT based on a measured torque from at least one of the input torque sensor or the output torque sensor.

INCORPORATION BY REFERENCE

[0012] 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

[0013] 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:

[0014] Figure 1 is a graph depicting engine power delivery during a four-stroke cycle;

[0015] Figure 2 is a sectional view of a flywheel and damper solution for reducing torque ripple in an engine;

[0016] Figure 3A is a block diagram of a system with reduced torque ripple and torsional vibration using a torque sensor and an electric motor according to an embodiment of the disclosure;

[0017] Figure 3B is a block diagram of a system with reduced torque ripple and torsional vibration using an electric motor without a torque sensor according to another embodiment of the disclosure;

[0018] Figure 4A is a block diagram of a system with reduced torque ripple and torsional vibration using a torque sensor and a starter motor according to another embodiment of the disclosure;

[0019] Figure 4B is a block diagram of a system with reduced torque ripple and torsional vibration using a starter motor without a torque sensor according to another embodiment of the disclosure;

[0020] Figure 5 is a block diagram of a system with reduced torque ripple and torsional vibration using an electric starter motor for adding the compensation signal based on the torque measured by the engine output torque sensor according to another embodiment of the disclosure;

[0021] Figure 6 is a block diagram of a system with reduced torque ripple and torsional vibration using an electric starter motor for adding the compensation signal without the engine output torque sensor according to another embodiment of the disclosure;

[0022] Figure 7 shows graphs depicting the torque ripple of an engine, a transform computed for compensating for the torque ripple, and a compensation signal according to an embodiment of the disclosure;

[0023] Figure 8A is a block diagram of a system with reduced torque ripple and torsional vibration using a planetary gear set and a crank-rocker mechanism according to another embodiment of the disclosure;

[0024] Figure 8B is a block diagram of the crank-rocker mechanism of Figure 8A which enables the system to modify the coupler connection position up and down;

[0025] Figure 9 is a block diagram of a system with reduced torque ripple and torsional vibration using torque sensors, a continuously variable transmission, and a servo according to another embodiment of the disclosure;

[0026] Figure 10 is a block diagram of a system with reduced torque ripple and torsional vibration without using torque sensors, a continuously variable transmission, and a servo according to another embodiment of the disclosure;

[0027] Figure 11 is a block diagram of a system with reduced torque ripple and torsional vibration using torque sensors, direct torque control implemented on the CVT device and a ball-ramp mechanism according to another embodiment of the disclosure; and

[0028] Figure 12 is a block diagram of a system with reduced torque ripple and torsional vibration without using torque sensors, direct torque control implemented on the CVT device and a ball-ramp mechanism according to another embodiment of the disclosure.

DETAILED DESCRIPTION OF THE INVENTION

Torque Ripple

[0029] Torque ripple is a periodic increase or decrease in output torque as the output shaft rotates. As suggested in **FIG. 1**, it is measured as the difference in maximum and minimum torque over one complete revolution. As a result the above mentioned potential advantages, downsizing together with down-speeding can be seen as one of the mainstream improvements on engine technology. Despite the promising advancements this technology can achieve, the drivability and performance should remain satisfactory. One important negative aspect caused by down-speeding is the degraded transient response at the lowest engine speeds. The torque ripple at the engine output significantly rises with lower idle speed.

[0030] The issue of torque ripples can cause many problems such as increased stresses and wear, large vibrations on the components near the engine, thus damaging the powertrain and resulting in poor vehicle drivability. In order to improve the smooth operation and overall performance of the engine, these stress and vibrations must be compensated by an engine balancing method. On multi-cylinder configurations, many solutions can be suggested to eliminate this vibration.

[0031] In many conventional vehicles, the vibration and torque ripples are compensated by using a flywheel **2**, as illustrated in **FIG. 2**, and by means of dampers and absorbers together. In some cases, dual-mass flywheel mechanisms are used. The inertia of the flywheel smooths out the rotational movement of the crankshaft **4**; which keeps the engine running at a constant speed. At this point, the decision on the flywheel weight plays a significant role in the sense that a lighter flywheel would accelerate faster but lose the speed quicker, while a heavier flywheel can retain the speed further but will be more difficult to slow down or accelerate. On the other hand, with a heavier flywheel the power delivery will be smoother, but this will make the engine less responsive (i.e. the ability to control the speed precisely is reduced). Also considering the weight constraints, the flywheel can be replaced by other solutions.

FIG. 2 shows an example flywheel solution to compensate for vibration and/or torque ripples including a damper that comprises at least a damper plate **8**, a tension spring **10**, and one or more shims **6**. **FIG. 2** shows a friction facing **12** and a fiber bushing **14** as well as a gasket **16**, sleeve **18**, a rubber cone **20**, and a fan pulley **22**, all which coordinate to compensate for the vibration and/or torque ripples of a conventional vehicle.

[0032] For at least the above reasons, improved systems, devices, and methods for reducing vibration and torque ripple in engines and associated components are desired.

[0033] This disclosure focuses on two solutions to reduce and minimize the torsional vibration occurring at the engine output in an active controlled way.

Example 1:

[0034] One solution proposed to minimize the torque ripple at low engine speeds is described as “compensation by addition”. The deviation from the desired torque value can be eliminated by applying feedback (or feed-forward) techniques in several configurations.

Example Configuration 1.1a1

[0035] A first proposed configuration as shown in **FIG. 3A** (1.1a1) comprises a first servo configuration **10**. The torque ripple value can be measured using a torque sensor **101** mounted on output **102** of an engine **100** and an addition signal **103** can be computed to cancel out some or all of the ripple. The engine **100** in this configuration is shown coupled to a damper **107**. This signal can then be applied by the actuator (e.g. an electric motor) **104** to the original system through a set of gears (for example: counter shaft gear **105**, and main shaft gear **102**). The electric motor can easily be synchronized to match the engine output speed.

Example Configuration 1.1a2

[0036] A variant of this configuration shown in **FIG. 3A** comprises a second servo configuration **20** without torque sensor, might be considered as shown in **FIG. 3B**. The torque ripple characteristics **201** to compensate might come from many other sources in the absence of a torque sensor. The first possible source might be an offline map providing the phase, amplitude and any other relevant information on the torque ripple, based on the ICE parameters (speed, throttle, etc...). The information might also come from a vibration sensor along the driveline or from any other sensor that might give an indication of the characteristics of the torque ripples. The working principle of the configuration is otherwise the same as in **FIG. 3A** and thus elements labeled in **FIG. 3B** common to that of **FIG. 3A** function similarly as described within the description of **FIG. 3A**.

Example Configuration 1.1b1

[0037] In an alternative configuration to **FIG. 3A** or **3B**, which add the compensation signal **103** by an electric motor, a third configuration **30** still includes a torque sensor **101**, an engine **100**, and a damper **107**, but varies by directly integrating the electric motor **304** on the main shaft which may be the output shaft **102** as shown in **FIG. 4A** or another shaft. This third configuration includes a rotor **308** and a stator **310** which coordinate with the electric motor **304** that computes the addition signal **103** to cancel out some or all of the ripple. This variant

requires more axial length but avoids using gears and thus avoids some or all backlash problems that may or may not occur in other variations.

Example Configuration 1.1b2

[0038] A variant of the configuration of **FIG. 4A** is a fourth configuration **40** comprising an integrated electric motor **304**, without torque sensor, an example of which is shown in **FIG. 4B**. Such servo configuration **40** still includes an engine **100**, and a damper **107**, however, the torque ripple characteristics **201** to compensate might come from many other sources in the absence of a torque sensor. The first possible source might be an offline map providing the phase, amplitude and any other relevant information on the torque ripple, based on the ICE parameters (speed, throttle, etc). The information might also come from vibration sensor along the driveline or from any other sensor that might give indication on the characteristics of the torque ripples. The working principle of this configuration is the same as that of **FIG. 4A**. This third configuration includes a rotor **308** and a stator **310** which coordinate with the electric motor **304** that computes the addition signal **103** to cancel out some or all of the ripple.

Example Configuration 1.1c1

[0039] In a fifth configuration **50**, adding the compensation signal by an electric motor is not necessary, rather the fifth servo configuration **50** utilizes the starter motor for this purpose as shown in **FIG. 5**. By installing a high-torque (larger) starter motor **501** than would otherwise be necessary for simple starting functions, the compensation torque can be directly sent to the flywheel **502**, based on the torque measured by the engine output torque sensor **101**. Depicted in **FIG. 5** is the starter motor **501** and torque sensor **101** in relation to the engine **100** (which may be a combustion engine) and a damper **107** on a main shaft **503**, wherein the starter motor is coupled to the flywheel **502** prior to the damper **107** on the main shaft **503**, and the torque sensor **101** also sits between the engine **100** and the damper **107**. Other arrangements of elements are contemplated, however, so long as the starter motor serves the function of ripple and/or vibrational reduction and/or elimination.

Example Configuration 1.1c2

[0040] A sixth configuration **60** comprises a starter motor **501** without torque sensor, for non-limiting example, as shown in **FIG. 6**. The torque ripple characteristics **201** to compensate might come from many other sources in the absence of a torque sensor. The first possible source might be an offline map providing the phase, amplitude and any other relevant information on the torque ripple, based on the ICE parameters (speed, throttle, etc.). The information might also come from vibration sensor along the driveline or from any other

sensor that might give indication on the characteristics of the torque ripples. The working principle of this configuration is the same as shown in **FIG. 5** as described herein. By installing a high-torque (larger) starter motor **501** than would otherwise be necessary for simple starting functions, the compensation torque can be directly sent to the flywheel **502** based on torque ripple characteristics **201** from the above-noted other sources. Depicted in **FIG. 6** is the starter motor **501** in relation to the engine **100** (which may be a combustion engine) and a damper **107** on a main shaft **503**, wherein the starter motor is coupled to the flywheel **502** prior to the damper **107** on the main shaft **503**. Other arrangements of elements are contemplated, however, so long as the starter motor serves the function of ripple and/or vibrational reduction and/or elimination.

Example Configuration 1.2

[0041] A seventh example **70** vibration and/or ripple reduction or elimination configuration comprises a solution by the use of a crank and rocker mechanism. The characteristic of the torque ripple will often be dependent on the engine cycle (e.g. 2-stroke, 4-stroke etc.) and the number of cylinders. Based on the form of the ripple, a different cancellation would be required (2nd, 3rd, 4th order harmonic cancellation or combinations). Simply put, if a torque ripple exists as shown in **FIG. 7**, the system can be designed by evaluating the ripple by its Fourier series transformation.

[0042] As illustrated in **FIG. 8A**, cancellation may occur by means of a planetary gearset **820** having a planet **824**, sun gear **822**, a carrier **821**, and a ring gear **823**. The internal combustion engine (ICE) **100** may be connected to the carrier **821** of the planetary gearset **820**, the compensation can be added to the system by the sun gear **822** and the ring gear **823** is the regulated output value. Initially, in order to generate the adding torque control signal, the speed of the ICE may be multiplied by a single, double (or more) up-speed gear ratios **830a**, **830b** of one or more up-speed gears **825a**, **825b** depending on the order of ripple harmonics to be compensated, meaning that the deviations in the ICE output torque may be reflected on the sun gear **822**. The deviation generated on the sun gear **822** turns the rocker via a direct mechanical connection **811**, so that the sum of both motions gives the compensated output on the ring gear **823**.

[0043] Furthermore, a generic roller-crank mechanism **810** enable the system to modify the coupler connection position up and down, as shown in **FIG. 8B**, (left). This linear movement may adjust the amplitude of the correction torque signal and the generic mechanism can be mechanical (e.g. slider mechanism), hydraulic, electrical or something else. The phase of the correction signal can be modified by adjusting the relative angle between the crank **814** and

the gear rotating **815**, (right, 1 and 2). Thus, the sun gear will typically only have a limited rotational range to compensate as shown by arrows on the figure. These two adjustment mechanisms **814**, **815** can be operated separately, to adjust the amplitude **812**, the phase **813** or both.

Example Configuration 2

[0044] A second general configuration is designed to eliminate the output torque ripples by means of “multiplication” with an additional signal that cancels out the ripple. By connecting a continuously variable transmission (CVT) device **901** after the engine **100**, the fluctuations in the torque value can be regulated by applying several methods, described below. The CVT device **901** may also be after the damper **107**. Example configurations of this multiplication-based elimination are shown in **FIGS. 9-12**, and/or as described in the following examples.

Example Configuration 2.1a

[0045] In the first “multiplication” configuration **90**, a control signal can be applied on the torque value using the servo **910** (servo motor) mounted on the CVT device **901**. This control signal can be used to compensate the torque oscillations by changing the speed ratio (depicted as the double-headed arrow in **FIG. 9**) of the CVT device **901** (i.e., shifting actuators). By implementing an actuator (e.g. servo motor) with a high frequency, ensuring fast response for the ratio change, the vibrations on the output torque can be compensated. The control signal will depend on the actual torque value read by the torque sensor **101** located either on the input or the output of the CVT transmission or both the input and the output of the CVT transmission for more precise control. As shown in **FIG. 9**, this solution is illustrated with a ball type CVT, however, any other type of CVT might be used. **FIG. 9** depicts an embodiment using both an input torque sensor **101a**, and an output torque sensor **101b** read and/or interpreted by the servo motor **910** which can compensate for the torque oscillations by changing the speed ratio (depicted as the double-headed arrow in **FIG. 9**) of the CVT device **901**. The output of the CVT device **901** can then provide input to the transmission via a shaft **903** with reduced or eliminated torque ripple and/or reduced or eliminated torque oscillations and/or reduced or eliminated torque vibrations.

Example Configuration 2.1b

[0046] A variant of the configuration of **FIG. 9** is a second “multiplication” configuration **1000**, comprising a servo **910** mounted on the CVT device **901**, without torque sensors, might be considered as shown in **FIG. 10**. As was depicted in **FIG. 9**, and described with regard to the same, such configuration **1000** may include a control signal that can be applied using the servo **910** (servo motor) mounted on the CVT device **901**. This control signal can be used to

compensate the torque oscillations by changing the speed ratio (depicted as the double-headed arrow in **FIG. 10**) of the CVT device **901** (i.e., shifting actuators). By implementing an actuator (e.g. servo motor) with a high frequency, ensuring fast response for the ratio change, the vibrations on the output torque can be compensated. Different from **FIG. 9**, however, is that the torque ripple characteristics **201** this present configuration **1000** can compensate might come from many other sources in the absence of a torque sensor, or in addition thereto. The first possible source might be an offline map providing the phase, amplitude and any other relevant information on the torque ripple, based on the ICE parameters (speed, throttle, etc.). The information might also come from vibration sensor along the driveline or from any other sensor that might give indication on the characteristics of the torque ripples. Otherwise, however, the working principle of the configuration is the same as depicted in **FIG. 9** and described with regard to the same. This present solution configuration **1000** is illustrated with a ball type CVT, however, any other type of CVT might be used. **FIG. 10** depicts an embodiment using torque ripple characteristics **201** read and/or interpreted by the servo motor **910** which can compensate for the same by changing the speed ratio (depicted as the double-headed arrow in **FIG. 10**) of the CVT device **901**. The output of the CVT device **901** can then provide input to the transmission via a shaft **903** with reduced or eliminated torque ripple and/or reduced or eliminated torque oscillations and/or reduced or eliminated torque vibrations.

Example Configuration 2.2a

[0047] In a third “multiplication” configuration **1100**, similar to the configuration of **FIGS. 9 and 10**, direct torque control using a direct torque controller **1120** can be implemented on the CVT device **901** now by using a ball-ramp mechanism **1140**, instead of actuating by a servo motor.

[0048] **FIG. 11** shows the working principle of such third “multiplication” configuration **1100**. The vibrations on the ICE (engine **100**) output torque may be measured using at least one of the sensors **101a**, **101b** on the input side (input torque sensor **101a**) or the output side (output torque sensor **101b**) of the CVT device **901** and this signal can then be used to compute by the controller **1120** the control input (i.e. desired input **1142**) to compensate this vibration. A mechanical system **1140** (e.g. ball-ramp mechanism) may be introduced to generate this correction torque (applied **1144**). The ball-ramp pushes the lever back and forth to cancel out the ripple by changing the CVT speed ratio. This control signal may also be compared with the ideal input computed from the sensor and finally applied in a closed feedback system. The output of the CVT device **901** can then provide input to the

transmission via a shaft **903** with reduced or eliminated torque ripple and/or reduced or eliminated torque oscillations and/or reduced or eliminated torque vibrations.

Example Configuration 2.2b

[0049] A fourth “multiplication” configuration **1200** does not use torque sensors, for non-limiting example as shown in **FIG. 12**. The torque ripple characteristics **201** to compensate might come from many other sources in the absence of a torque sensor. The first possible source might be an offline map providing the phase, amplitude and any other relevant information on the torque ripple, based on the ICE parameters (speed, throttle,...). The information might also come from vibration sensor along the driveline or from any other sensor that might give indication on the characteristics of the torque ripples. Other than the source of the torque ripple, however, the working principle of the fourth “multiplication” configuration **1200** is the same as described in Configuration 2.2a, and/or as shown in **FIG. 12**.

[0050] 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.

CLAIMS

WHAT IS CLAIMED IS:

1. A method of reducing torsional vibration in an output of an engine, the method comprising:
 - measuring a torque ripple of an engine output;
 - determining a correction signal, using a controller or processor, for reducing the measured torque ripple; and
 - applying the correction signal to an output shaft of the engine such that the torque ripple of the engine output is reduced.
2. The method of claim 1, wherein the torque ripple of the engine output is measured with a torque sensor coupled to the output shaft of the engine.
3. The method of claim 1, wherein determining the correction signal comprises evaluating a Fourier series transformation of the measured torque ripple.
4. The method of claim 1, wherein applying the correction signal comprises actuating an electric motor or a starter motor mechanically coupled to the output shaft.
5. A method of reducing torsional vibration in an output of an engine, the method comprising:
 - coupling a gear set to an output shaft of the engine, wherein the gear set comprises a roller crank mechanism; and
 - introducing a correction signal to the output shaft of the engine with the roller crank mechanism, wherein the correction signal reduces a torque ripple of the engine output.
6. The method of claim 5, wherein the gear set comprises a planetary gear set.
7. The method of claim 5, wherein a gear ratio of the gear set depends on the order of ripple harmonics of the engine output.
8. The method of claim 5, wherein determining the correction signal comprises evaluating a Fourier series transformation of the measured torque ripple.
9. The method of claim 5, wherein the roller crank mechanism comprises an adjustment mechanism for adjusting a phase of the correction signal.
10. The method of claim 5, wherein the roller crank mechanism comprises an adjustment mechanism for adjusting amplitude of the correction signal.
11. A method of reducing torsional vibration in an output of an engine, the method comprising:
 - coupling a continuously variable transmission (CVT) to an output shaft of the engine;

measuring at least one of an input torque to the CVT and an output torque from the CVT; and

applying a correction signal with the CVT based on the measured torque such that the output of the CVT has reduced torsional vibration compared with the output of the engine.

12. The method of claim 11, wherein the correction signal is applied with a servo motor mechanically coupled to the ratio shifter of the CVT.

13. The method of claim 11, wherein the correction signal is applied with a ball ramp mechanism mechanically coupled to the ratio shifter of the CVT.

14. A system for transmitting power having reduced torsional vibration in its output, the system comprising:

an engine having an output shaft; and

means for applying a correction signal to the output shaft.

15. The system of claim 14, wherein the means for applying the correction signal comprises an electric motor or a starter motor mechanically coupled to the output shaft.

16. The system of claim 15, wherein the output of the electric motor or a starter motor depends on a torque measurement from an input torque sensor coupled to the output shaft.

17. The system of claim 14, wherein the means for applying the correction signal comprises a corrective gear set coupled to the output shaft of the engine.

18. The system of claim 17, wherein the corrective gear set comprises a planetary gear set.

19. The system of claim 17, wherein the corrective gear set comprises a roller crank mechanism.

20. The system of claim 19, wherein the roller crank mechanism comprises an adjustment mechanism for adjusting a phase of the correction signal.

21. The system of claim 19, wherein the roller crank mechanism comprises an adjustment mechanism for adjusting amplitude of the correction signal.

22. The system of claim 17, wherein a gear ratio of the gear set depends on the order of ripple harmonics of the engine output.

23. The system of claim 14, wherein the means for applying the correction signal comprises a continuously variable transmission (CVT) coupled to the output shaft of the engine.

24. The system of claim 23, wherein the means for applying the correction signal further comprises at least one of an input torque sensor and an output torque sensor coupled to the ratio shifter of the CVT.

25. The system of claim 24, wherein the means for applying the correction signal further comprises a servo motor mechanically coupled to the ratio shifter of the CVT and configured to apply the correction signal to the CVT based on a measured torque from at least one of the input torque sensor or the output torque sensor.

26. The system of claim 24, wherein the means for applying the correction signal further comprises a ball ramp mechanism mechanically coupled to the ratio shifter of the CVT and configured to apply the correction signal to the CVT based on a measured torque from at least one of the input torque sensor or the output torque sensor.

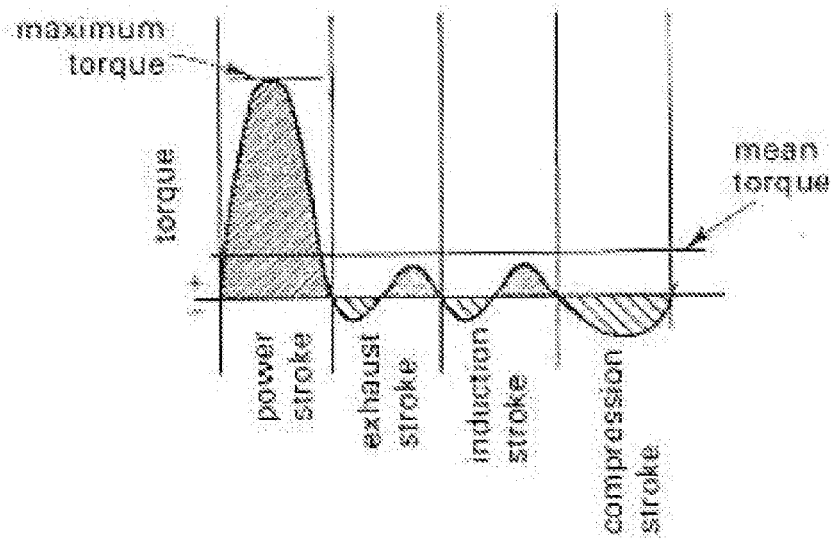


FIG. 1

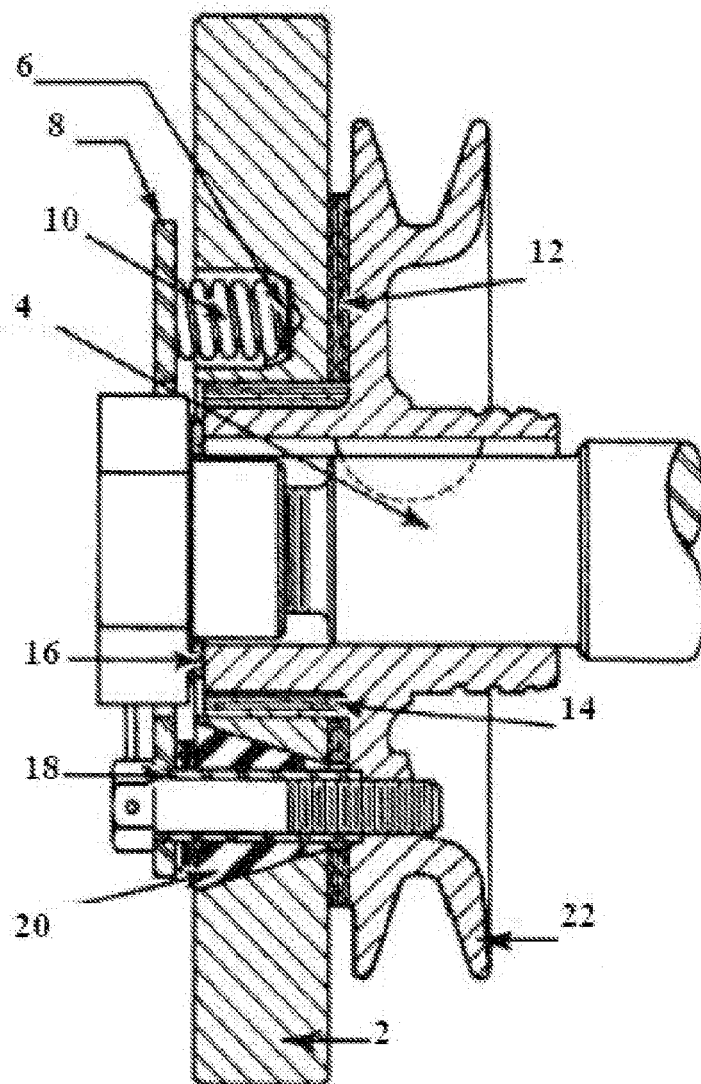


FIG. 2

2/7

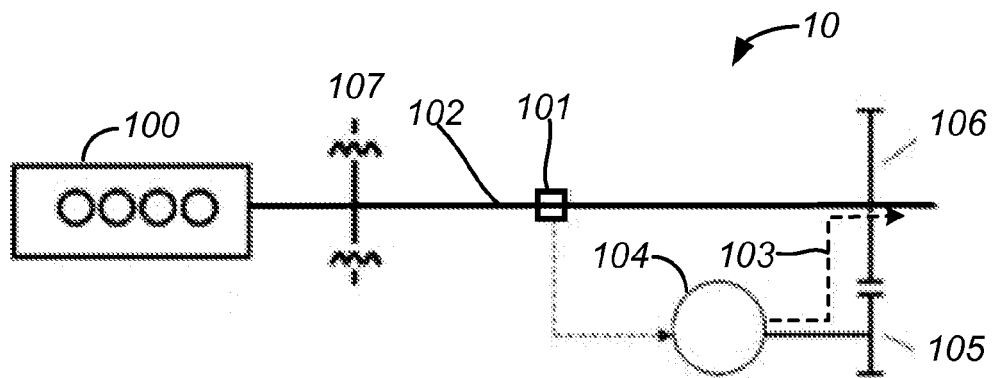


FIG. 3A

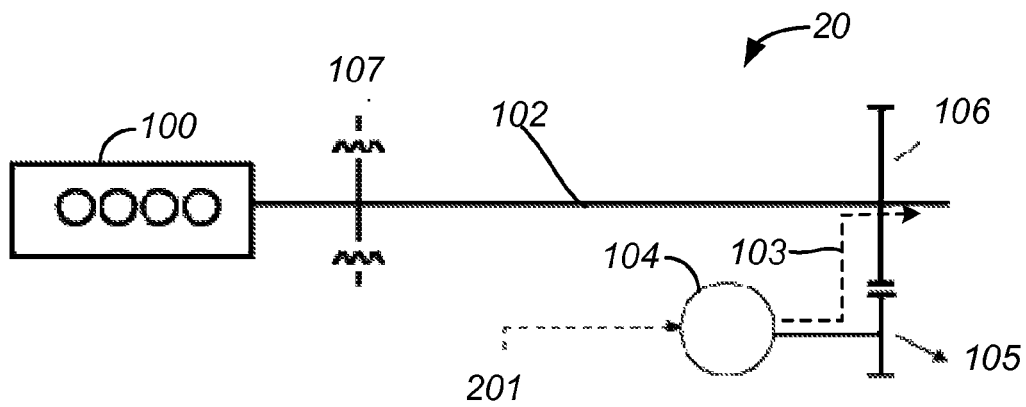


FIG. 3B

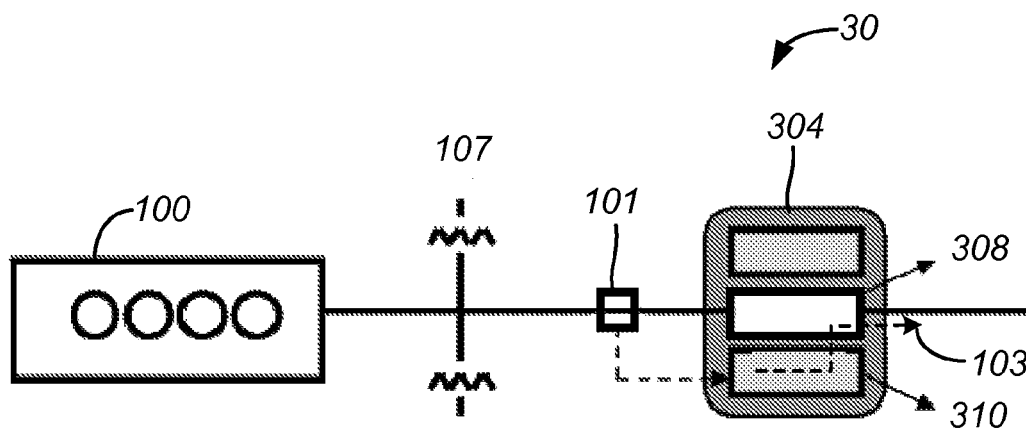


FIG. 4A

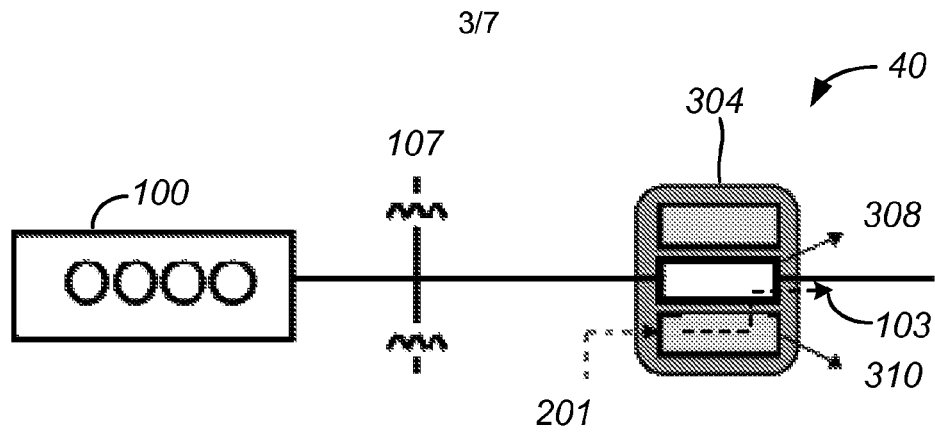


FIG. 4B

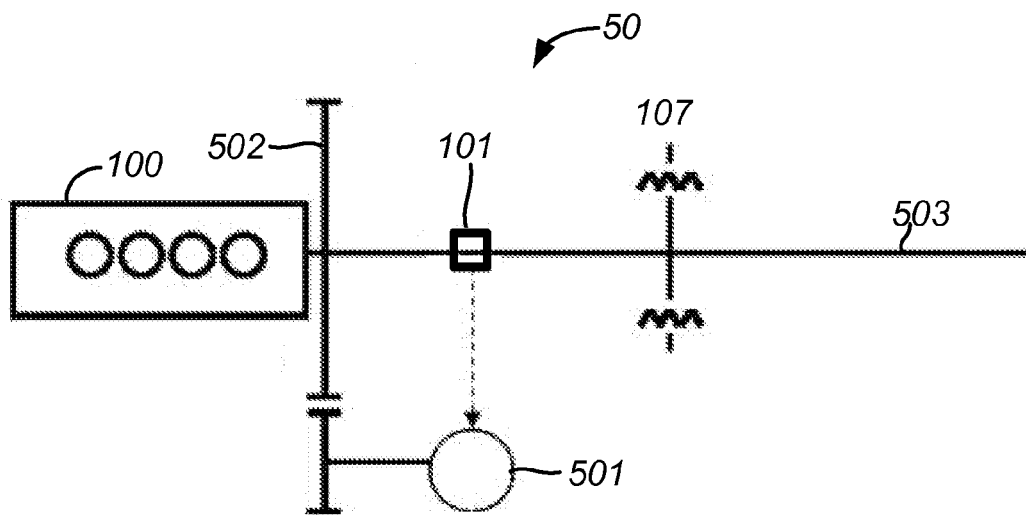


FIG. 5

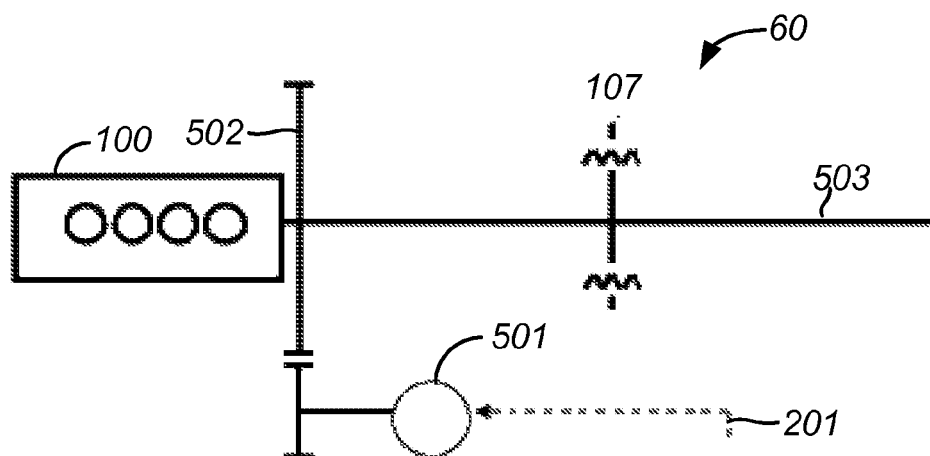


FIG. 6

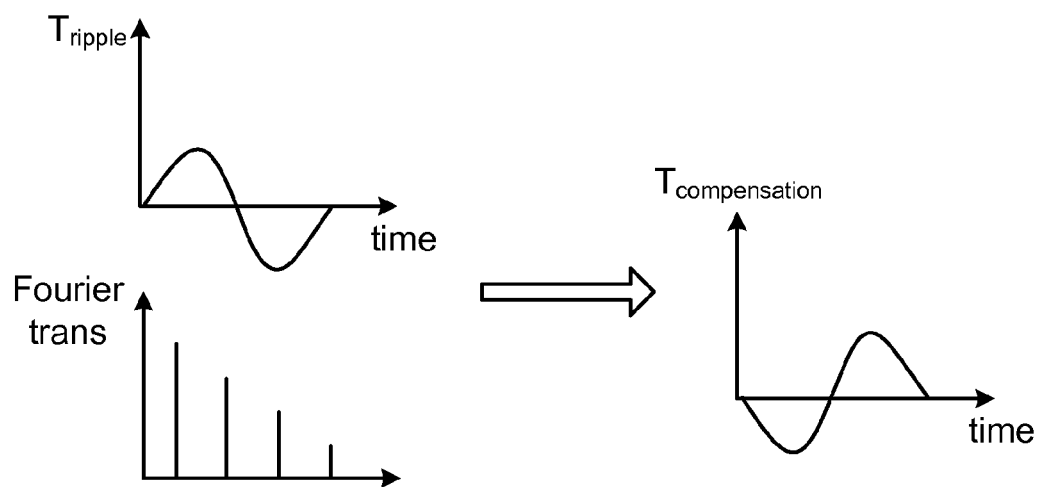


FIG 7

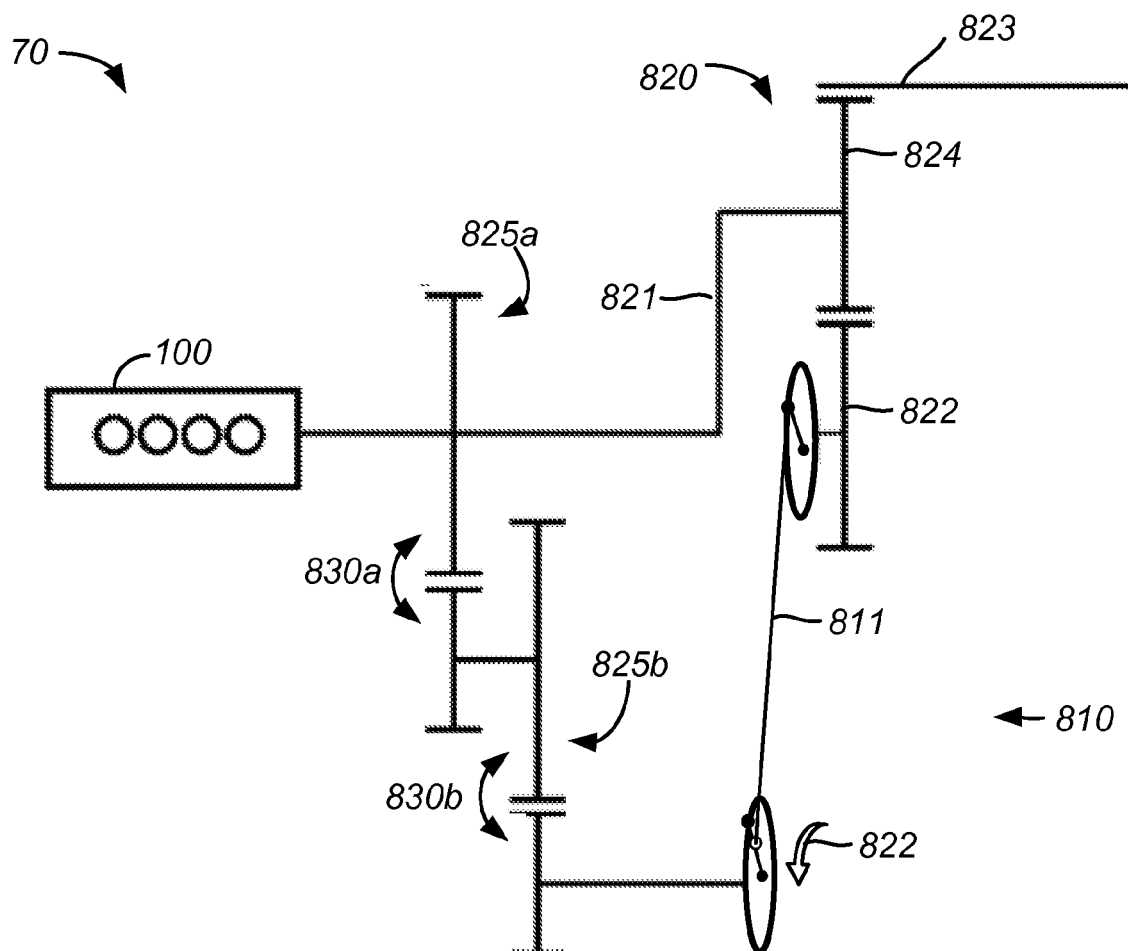


FIG. 8A

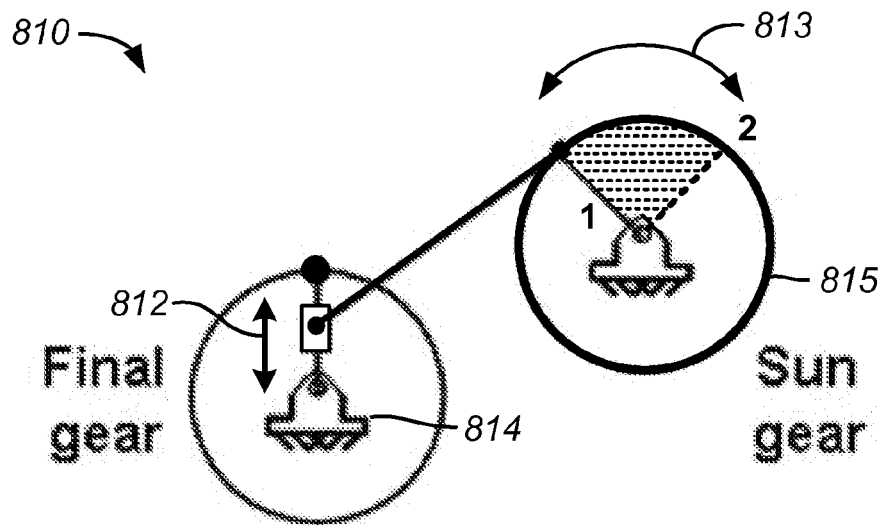


FIG. 8B

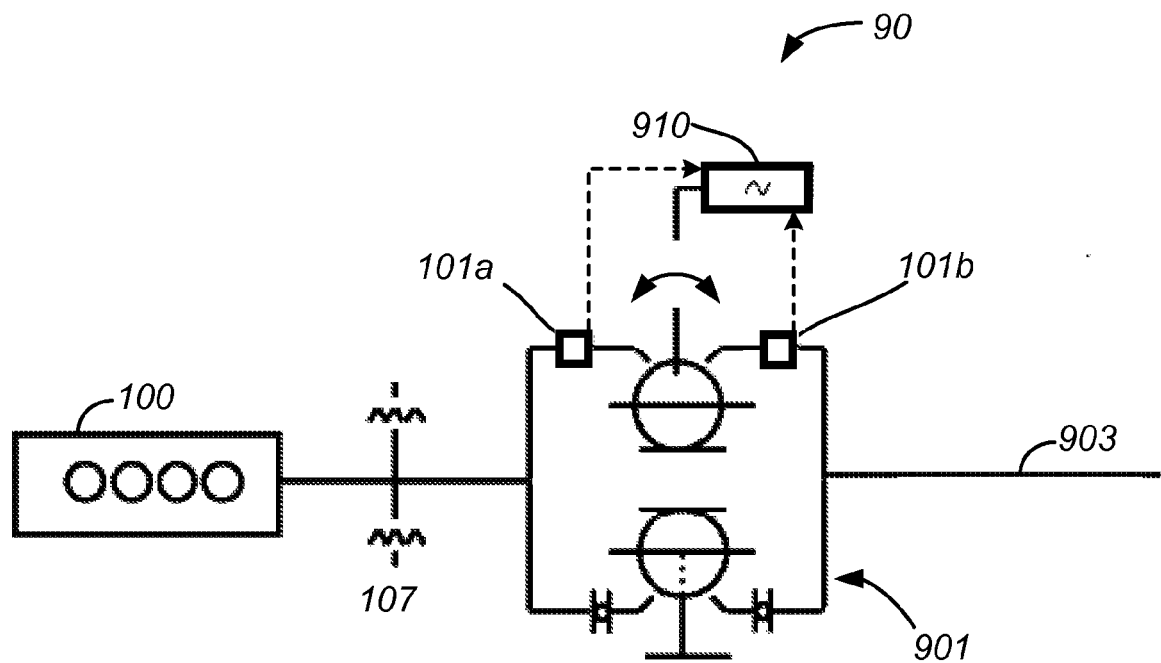
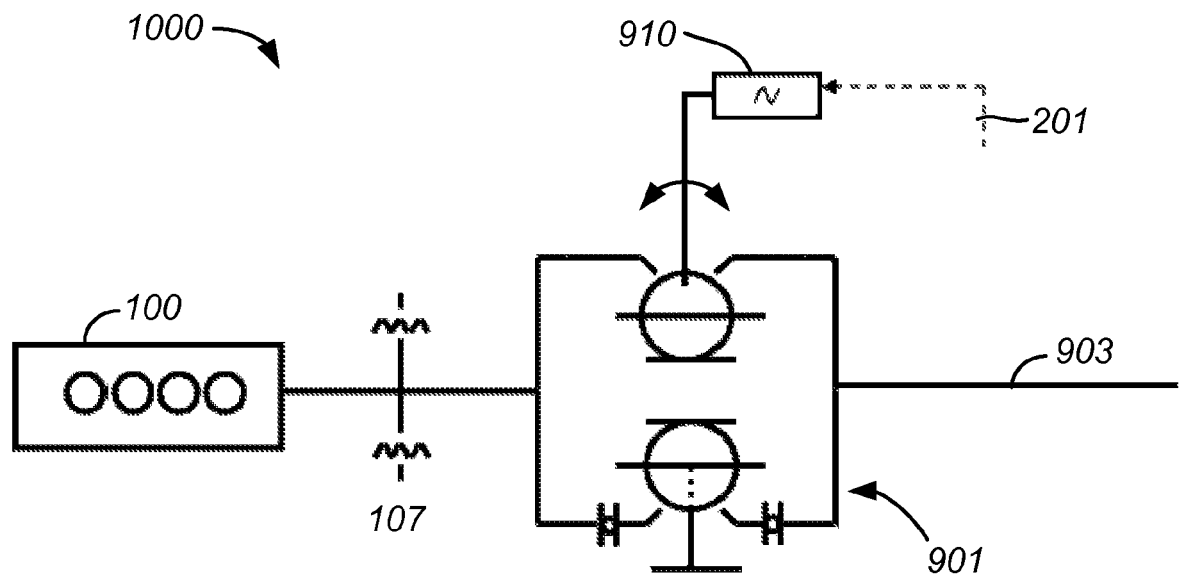
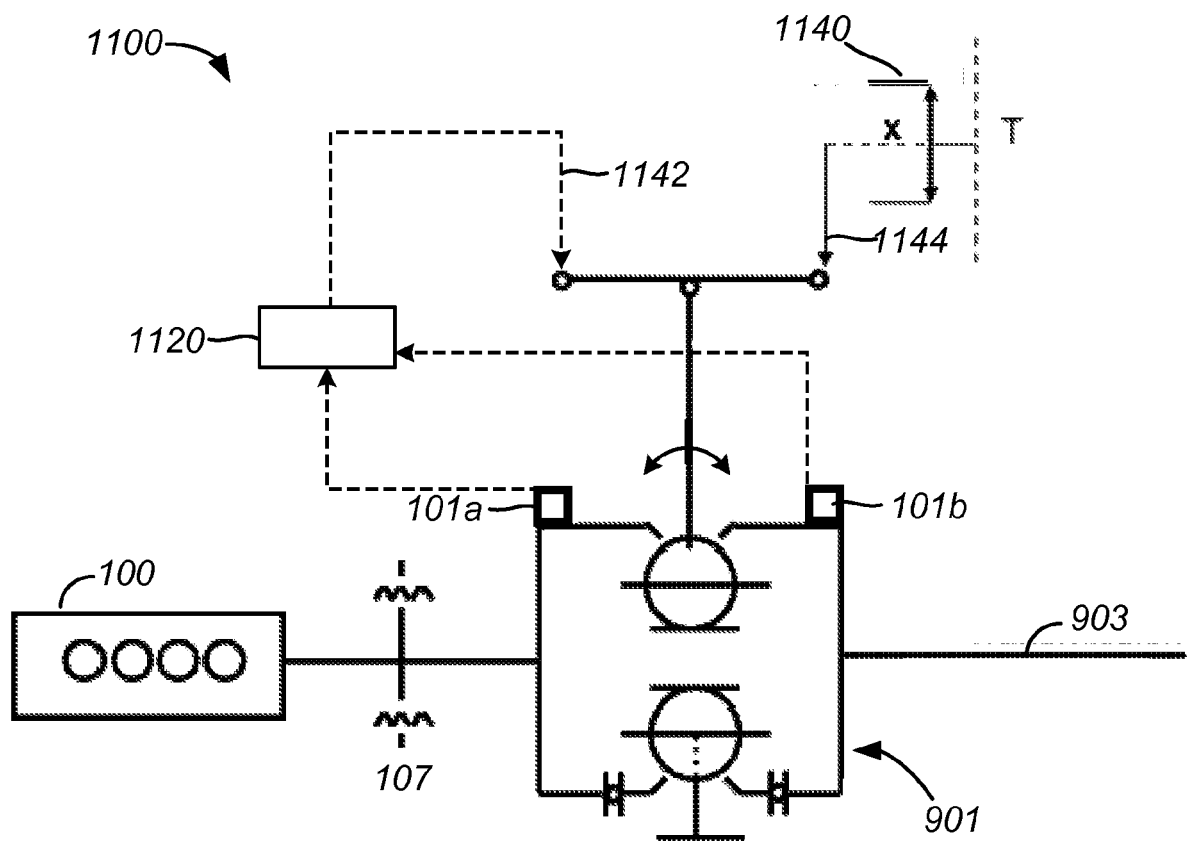


FIG. 9

6/7

**FIG. 10****FIG. 11**

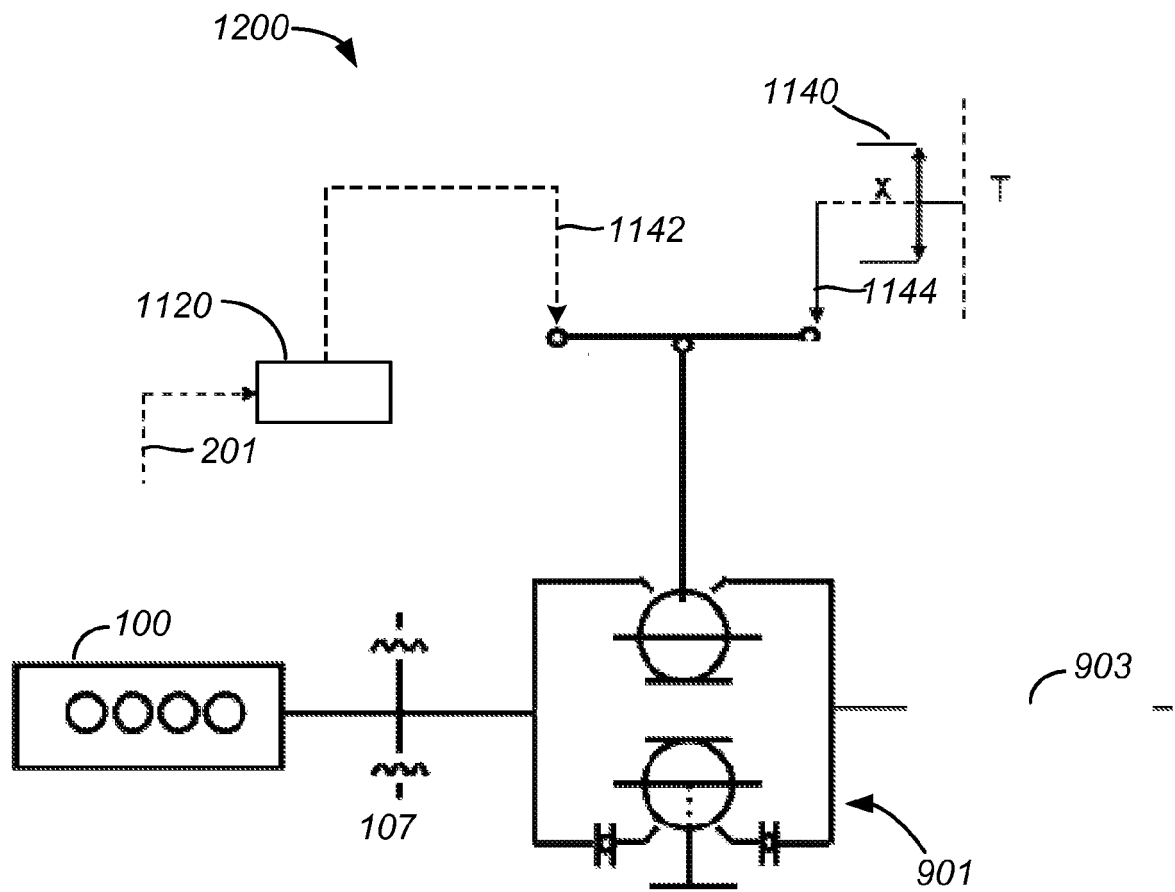


FIG. 12