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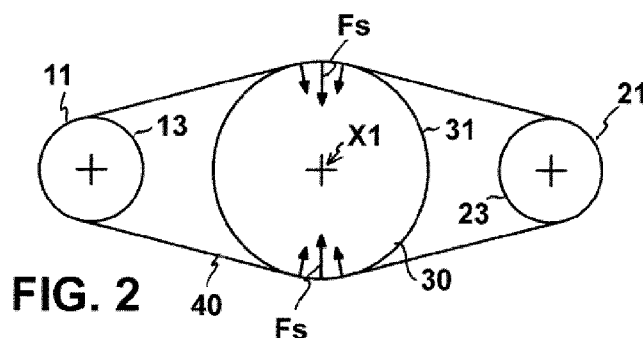
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(54) Title: BELT DRIVEN FLYWHEEL SYSTEM



(57) Abstract: A pair of flywheels (10, 20) drive a belt transmission system via respective flywheel pulleys (11, 21) which may be arranged, for example, in diametrically opposed relation on opposite sides of at least one output pulley (30). At least a major proportion of the belt pressure forces (F_s , F_d) applied by the tensioned belt (40) towards the output axis (X_1) of the at least one output pulley (30) act in mutual opposition, so that the torque transmission capacity of the belt transmission is not limited by the side loading limit (L) of the output pulley bearings. The belt transmission may provide a continuously variable ratio and may be arranged for example to improve the acceleration of a prime mover (60) under load, or in conjunction with a continuously variable primary transmission (80) to maintain output shaft speed while the prime mover (60) accelerates to match the increasing power demand of the load (90).



DescriptionBELT DRIVEN FLYWHEEL SYSTEM5 Technical Field

This disclosure relates to systems in which a flywheel is coupled via a belt transmission to a system driven by a prime mover, to store and release rotational energy from and to the system.

Background

10 A high speed flywheel coupled via an endless belt to a system driven by a prime mover such as an internal combustion engine can be a cost effective way to recover energy from the system and subsequently return it to the system, for example, to improve performance or efficiency.

In such systems the torque transmission capacity of the belt drive
15 is a function of belt tension, which in turn is limited by the permissible side loading of the bearings of the pulleys around which the belt rotates. For example, where the belt drive is arranged to transmit rotational energy to and from an output pulley mounted on the crankshaft of an internal combustion engine, the maximum permissible side load of the crankshaft bearings will limit the belt
20 tension and hence the power that can be delivered from or to the flywheel at any given crank speed.

By way of example, Fig. 1 shows how in an example belt transmission system the torque transmission capacity T of a V-belt transmission pulley of 230mm or 460mm diameter D , having a V belt angle of 15° and a
25 coefficient of friction of 0.25 between the belt and the pulley, varies with the side load L applied by the belt normal to the axis of rotation of the pulley.

Summary

In a first aspect the present disclosure provides an apparatus including:

- at least one flywheel operatively connected to at least one flywheel pulley to drive the at least one flywheel pulley in rotation;
- at least one output pulley mounted for rotation about an output axis; and
- at least one endless belt engaged with the at least one flywheel pulley and the at least one output pulley to transmit rotational energy from the at least one flywheel via the at least one flywheel pulley to the at least one output pulley;
- the at least one endless belt being tensioned to apply belt pressure forces acting against the at least one output pulley towards the output axis;
- wherein the at least one flywheel includes:
 - a first flywheel, and
 - a second flywheel;
- and the at least one flywheel pulley includes
 - at least one first flywheel pulley driven by the first flywheel, and
 - at least one second flywheel pulley driven by the second flywheel.

In accordance with the first aspect and further in accordance with the method of a second, related aspect, the apparatus is configured as above and the first and second flywheel pulleys are positioned in spaced relation to direct at least a major proportion of said belt pressure forces to act against the at least one output pulley in mutual opposition.

In embodiments, the first and second flywheel pulleys may be arranged in diametrically opposed relation on opposite sides of the output axis. In such embodiments, the at least one endless belt may comprise at least a first

endless belt which is looped around respective ones of each of the first and second flywheel pulleys and the at least one output pulley.

Optionally, the at least one endless belt, the at least one output pulley, and the first and second flywheel pulleys may be configured to provide a variable belt transmission ratio between each respective flywheel pulley and the at least one output pulley.

Further features and advantages will become apparent from the various illustrative embodiments which will now be described, purely by way of example and with reference to the accompanying drawings, in which:

10 Brief Description of the Drawings

Fig. 1 is a graph showing how torque transmission capacity T varies with side load L in an example belt transmission system;

Fig. 2 shows the belt transmission of a first embodiment comprising first and second flywheel pulleys arranged in diametrically opposed relation on opposite sides of the output axis of an output pulley, with arrows representing the static belt pressure forces applied by the endless belt towards the output axis;

Fig. 3 shows the belt transmission of a second embodiment similar to the first but having a higher fixed belt transmission ratio;

Fig. 4 shows the belt transmission of a third, similar embodiment, with arrows representing the dynamic tension forces applied by the endless belt;

Fig. 5 shows the belt transmission of the third embodiment with arrows indicating how the belt tension forces are resolved with the resultant belt pressure forces acting in mutual opposition towards the output axis;

Fig. 6 shows the first and second flywheel pulleys and the output pulley of a belt transmission with an actuator mechanism according to a fourth embodiment, providing a continuously variable belt transmission ratio, in a high ratio condition;

Fig. 7 corresponds to Fig. 6, showing the belt transmission of the fourth embodiment in a low ratio condition;

Fig. 8 shows a fifth embodiment in which the belt transmission provides a continuously variable ratio and the output pulley is coupled to the
5 output shaft of the prime mover, with the flywheels helping to accelerate the prime mover under load; and

Fig. 9 shows a sixth embodiment in which the belt transmission provides a continuously variable ratio and the output pulley is coupled to the output shaft of a continuously variable primary transmission to help maintain the
10 rotational speed of the load as the prime mover accelerates responsive to increasing load.

Reference numerals and characters appearing in more than one of the figures indicate the same or corresponding parts in each of them.

Detailed Description

15 Referring to Figs. 8 and 9, in the illustrated embodiments, the at least one flywheel consists of a first flywheel 10 and a second flywheel 20, each having a respective, first or second flywheel pulley 11, 21 which is driven in rotation by the flywheel when the flywheel decelerates to supply rotational energy to the system, and which may drive the flywheel in rotation when the
20 flywheel accelerates to store rotational energy from the system.

In alternative embodiments more than two flywheels could be provided, and each flywheel could have more than one flywheel pulley.

The first and second flywheels 10, 20 may be operatively connected, each to its respective at least one flywheel pulley 11, 21 by direct
25 coupling, so that the or each flywheel pulley 11, 21 is mounted coaxially with its respective flywheel 10, 20 and rotates in fixed relation to its respective flywheel.

Alternatively, as in the illustrated embodiments, the first flywheel 10 may be operatively connected to the at least one first flywheel pulley 11 via a first flywheel transmission 12, with the second flywheel 20 being operatively

connected to the at least one second flywheel pulley 21 via a second flywheel transmission 22.

In this specification, a transmission ratio means a ratio between the speed of first and second components connected via a transmission. Thus, a
5 higher ratio means more difference in speed, and a lower ratio means less difference in speed. A reduction ratio from a first component to a second component means a transmission ratio in which the second component rotates at a lower speed than the first component.

Each of the first and second flywheel transmissions 12, 22 may
10 provide a reduction ratio (which may be a fixed or variable reduction ratio) from the respective flywheel 10, 20 to the respective flywheel pulley 11, 21 - which is to say, the flywheel transmission allows the flywheel pulley to rotate more slowly than the flywheel. Ceteris paribus, for any given rotational inertia of the flywheel, the higher the reduction ratio - which is to say, the higher the rotational speed of
15 the flywheel relative to the flywheel pulley - the more energy can be stored in the flywheel.

At least one output pulley 30 is mounted for rotation about an output axis X1, and at least one endless belt 40 is engaged with the at least one flywheel pulley 11, 21 and the at least one output pulley 30 to transmit rotational
20 energy from and to the at least one flywheel 10, 20 via the at least one flywheel pulley 11, 21 to and from the at least one output pulley 30.

It will be understood of course that the at least one output pulley serves to transmit rotational energy from the load to the flywheels as well as from the flywheels to the load.

25 In each of the illustrated embodiments, the at least one output pulley consists of a single output pulley 30, and the at least one endless belt consists of a single endless belt 40.

Alternative embodiments may provide more than one output pulley and/or a plurality of endless belts, the belts passing around different

pulleys or around different, parallel grooves of the same pulleys to increase the torque transmission capacity of the system.

In each of the illustrated embodiments, the first and second flywheel pulleys 11, 21 are arranged in diametrically opposed relation on opposite sides of the output axis X1 of the output pulley 30, as best seen in Figs. 2 - 5.

In alternative embodiments, other configurations are possible. For example, where more than two flywheel pulleys are provided with the at least one endless belt acting between the more than two flywheel pulleys and a common output axis X1, the more than two flywheel pulleys may be arranged, e.g. symmetrically about the output axis X1, to balance the applied belt pressure forces, as further discussed below.

Figs. 2 - 5 show the belt transmission (which is to say, the endless belt 40 in combination with the flywheel pulleys 11, 21 and the output pulley 30) in a direction along the output axis X1.

Referring particularly to Figs. 2 - 5, in each of the illustrated embodiments, the single, first endless belt 40 is looped around each of the first and second flywheel pulleys 11, 21 and the output pulley 30.

In alternative embodiments, where more than one, first or second output pulley and/or more than one output pulley is provided, the endless belt may be looped about respective ones of each of the first and second flywheel pulleys and the at least one output pulley.

Where more than one endless belt is provided, each endless belt might similarly be looped about the same respective ones, or different respective ones, of each of the first and second flywheel pulleys and the output pulley (or one of the output pulleys). That is to say, each endless belt may be looped about each of a first flywheel pulley, a second flywheel pulley, and an output pulley, optionally together with another one or ones of the endless belts, and whether in a diametrically opposed arrangement as illustrated or otherwise.

As illustrated in each of Figs. 1 - 5, of said respective ones of the first and second flywheel pulleys 11, 21 and the at least one output pulley 30 about which the endless belt 40 is looped, the respective output pulley 30 may have a larger diameter than each respective one of the first and second flywheel pulleys 11, 21. This provides a reduction ratio from each flywheel pulley to the output pulley - which is to say, the output pulley rotates at a lower rotational speed than the flywheel pulleys - and so allows the flywheels to rotate relatively faster than the prime mover (and so to store relatively more energy).

The example of Fig. 2 shows that the belt transmission provides a reduction ratio of about 2 : 1 from the flywheel pulley to the output pulley, while the example of Fig. 3 shows a reduction ratio of about 4.2 : 1.

The belt transmission may be configured to provide a variable belt transmission ratio between each respective flywheel pulley and the at least one output pulley.

In the embodiments of Figs. 2 - 5 the belt transmission has a fixed transmission ratio (which is to say, it cannot be varied).

In the embodiments of Figs. 6 - 9 the belt transmission has a variable ratio, but may also provide a reduction ratio from the flywheel pulleys to the output pulley throughout its range, as can be seen by comparing the high reduction ratio condition of Fig. 6 with the lower reduction ratio condition of Fig. 7.

As discussed above with reference to Fig. 1, and as shown in each of Figs. 2 - 9, the endless belt 40 is tensioned in use to engage it frictionally against the respective surface of rotation 13, 23 of each of the first and second flywheel pulleys 11, 21 and against the respective surface of rotation 31 of the output pulley 30, each respective surface of rotation having a respective diameter D.

By increasing the reduction ratio, for example, from that of Fig. 2 to that of Fig. 3, the contact area between the endless belt 40 and the respective

surface of rotation 31 of the output pulley 30 is also increased, which (since the output pulley torque capacity is likely to be the limiting factor in the capacity of the belt transmission system) increases the total torque transmission capacity of the belt transmission.

5 As best seen in Figs. 1 - 5, in each of the illustrated embodiments, the first and second flywheel pulleys 11, 21 are positioned in spaced relation to direct at least a major proportion of the belt pressure forces to act against the at least one output pulley 30 in mutual opposition.

10 In the examples of Figs. 1 and 2, the arrows represent the static belt pressure forces F_s which are applied by the static tensioned belt 40 acting against the output pulley 30 towards the output axis $X1$ when considered in a direction of the output axis $X1$.

15 In Fig. 4 the broken arrows represent the unequal, dynamic tension forces applied to the output pulley 30 by the endless belt 40 when the flywheel pulleys 11, 21 drive the output pulley 30 in rotation. For clarity the frictional forces between the belt and pulley are resolved within the belt tension forces as illustrated in Figs. 4 and 5.

20 Fig. 5 shows how these dynamic belt tension and friction forces represented by the broken arrows resolve to equal and opposite, dynamic belt pressure forces F_d represented by the solid arrows which act against the output pulley 30 in mutual opposition towards the output axis $X1$. The applied torque is represented by the angular direction of the solid arrows about the output axis $X1$ and drives the output pulley in rotation in the direction of the curved arrow R .

25 In typical prior art arrangements employing a belt transmission, unbalanced static and dynamic belt pressure forces F_s , F_d acting towards the output axis $X1$ will result in a net side load (L , Fig. 1). That is to say, the unbalanced forces will tend to urge the output pulley 30 in a direction normal to the output axis $X1$, so that the forces must be reacted by the shaft bearings which support the output pulley.

In the illustrated embodiments, both static and dynamic belt pressure forces F_s , F_d applied by the endless belt 40 against the output pulley 30 and acting in a direction towards the output axis $X1$ are equal and opposite, so that the belt transmission applies a reduced side load, preferably as shown a zero or negligible side load L (Fig. 1), against the shaft defining the output axis $X1$ in a direction normal to the axis.

Referring now to Figs. 6 and 7, the endless belt 40 may be a smooth V-belt (which is to say, a belt having a generally V-shaped or other tapering sectional profile) or any other suitable type as known in the art.

Where the belt transmission provides a variable belt transmission ratio, the apparatus may include an actuator mechanism 50 configured to adjust simultaneously the diameter D of the respective surface of rotation 13, 23, 31 of each of the first and second flywheel pulleys 11, 21 and the at least one output pulley 30 while maintaining equal the diameter D of the respective surfaces of rotation 13, 23 of the first and second flywheel pulleys 11, 21.

The surface of rotation 13, 23, 31 of each pulley is taken as that portion of the surface or opposed surfaces of the pulley which is contacted by the endless belt 40. In V-belt or similar arrangements where the sides of the belt make contact with the pulley as the two halves of the pulley are moved axially together and apart by the actuator mechanism 50, the diameter D is taken across the average or mid-point of the radially innermost and outermost circumferential boundaries of said portion in any given position of the belt. The axial movement may be stepwise or continuously variable, providing a stepwise or continuously variable belt transmission ratio.

Thus, the first and second flywheels 10, 20 may have an equal and variable belt transmission ratio relative to the output pulley 30, so that the flywheels 10, 20 all have the same power input or output as the belt transmission ratio changes. By increasing the diameter D of the output pulley 30 in synchrony with and in inverse relation to the diameter D of the flywheel pulleys 11, 21, the

belt 40 is maintained in constant tension as the belt transmission ratio is adjusted between the high ratio condition (Fig. 6) and the low ratio condition (Fig. 7).

By progressively reducing the reduction ratio from the Fig. 6 condition towards the Fig. 7 condition, rotational energy may be transmitted progressively from the flywheels 10, 20 to the output pulley 30. By increasing the reduction ratio from the Fig. 7 condition towards the Fig. 6 condition, rotational energy may be transmitted from the output pulley 30 to accelerate the flywheels 10, 20.

The actuator mechanism 50 may comprise at least one actuator 51 which may be controlled by a controller responsive to sensor input indicating for example the rotational speed of one or more of the prime mover, the output pulley 30, the flywheels 10, 20, the load, the primary transmission between prime mover and load, and any other system components so as to match the belt transmission ratio to the changing rotational speed of the respective components while transmitting rotational energy in the desired direction..

The at least one actuator 51 may comprise a single electric motor, hydraulic or pneumatic ram, or other moving part with a suitable linkage 52, 53 to transmit motion to two or more pulleys simultaneously. Alternatively the at least one actuator 51 may comprise a plurality of such motors, rams or other moving parts, all controlled to act in synchrony, each acting individually on a single one of the pulleys.

Alternatively, the actuator mechanism 50 may further include at least one resilient bias mechanism such as one or more spring packs 54 to control the axial adjustment of either of the at least one output pulley and the flywheel pulleys, with the actuator 51 acting only on the other of the output pulley and the pair of flywheel pulleys.

Example embodiments of both possible arrangements are illustrated in Figs. 6 and 7, wherein each of the output pulley 30 and the flywheel pulleys 11, 21 comprises a pair of sheaves, one of which is movable axially

relative to the other. In the first example arrangement, linkages 53 are provided while resilient bias elements 54 are not provided. In the second example arrangement, resilient bias elements 54 are provided while linkages 53 are not provided. Thus, features 53 and 54 as shown in Figs. 6 and 7 are alternative
5 rather than complementary.

In the first example arrangement, the at least one actuator 51 is connected via a linkage 52 to the output pulley 30 and via linkages 53 to the flywheel pulleys 11, 21 so as to act directly on each pulley while maintaining equal the diameter D of the surface of rotation of each of the flywheel pulleys. In
10 this arrangement, linkages 53 are provided while spring packs 54, further discussed below, are not provided.

In the second example arrangement, linkages 53 are not provided, and instead at least one resilient bias element is provided, which may comprise at least one spring pack 54, optionally a plurality of spring packs 54 acting on
15 different ones of the flywheel pulleys. Each spring pack 54 or other resilient bias element is arranged to apply a resilient restoring force which urges together in the axial direction the respective opposed sheaves of each flywheel pulley 11, 21.

The resilient restoring force of each spring pack 54 is opposed by the tension of the belt 40. As the actuator 51 acts via linkage 52 to change the
20 diameter D of the surface of rotation of the output pulley 30, the belt tension opposes the restoring force applied by each spring pack 54 so that the balanced forces result in a new axial position of the movable sheave of each flywheel pulley 11, 21, defining a new diameter D of the surface of rotation of each flywheel pulley. The spring packs 54 apply equal forces on both flywheel pulleys
25 and so maintain equal the diameter D of the surface of rotation of each of the flywheel pulleys 11, 21.

The actuator 51 may comprise an electric stepper motor providing stepwise movement which has a sufficiently high resolution to be considered as a continuously variable system, or a motor or other actuator may act on a

screwthread or other adjustment mechanism to generate continuously variable axial motion between the two pulley halves (which is to say, axial motion that is functionally equivalent to an infinite number of possible steps within the limits of its axial range).

5 Thus, in this specification, “continuously variable” is taken to include a stepwise variation that is fine enough to be functionally equivalent to an infinite number of steps in the particular application concerned. For example, a stepwise variation will be considered as continuously variable if it is fine enough to maintain output shaft speed at a constant value (e.g. within a defined range
10 representing an acceptable margin of error from a target value) in an apparatus configured in accordance with the Fig. 9 embodiment as further discussed below.

Fig. 8 shows how the novel apparatus may be configured to transmit rotational energy from the flywheels to improve the rate of acceleration of a prime mover under load.

15 Referring to Fig. 8, the apparatus may comprise a prime mover 60 having an output shaft 61, with the at least one output pulley 30 being operatively connected to the output shaft 61 to rotate in fixed relation to the output shaft 61. A load 90 may be driven in rotation either directly or indirectly from the output shaft 61.

20 For example, the prime mover 60 may be an internal combustion engine with the output shaft 61 being the crankshaft of the engine, and the at least one output pulley 30 being mounted on the crankshaft to rotate in fixed relation with the crankshaft. In this case the output pulley 30 may be supported against side loads L applied normal to the output axis X1 (the rotational axis of the
25 crankshaft) at least in part by the crankshaft bearings of the engine, with the flywheels 10, 20 improving the performance of the engine when accelerating under load.

The belt transmission ratio is a reduction ratio from each respective flywheel pulley 11, 21 to the at least one output pulley 30, with the

reduction ratio being continuously variable by the actuator mechanism 50. The belt transmission may be arranged for example as shown in the example of Figs. 6 and 7.

The actuator mechanism 50 may be controlled by a controller 70 which may control the prime mover 60 (for example, inter alia to regulate the fuel or other energy supply to the prime mover). The controller 70 may receive input from sensors (not shown) for sensing the speed of rotation of the engine, flywheels, output pulley, load, and/or other system components as well as engine manifold pressure and/or other parameters. The controller 70 may comprise an electronic processor, memory and other hardware and software elements and may comprise for example an engine control unit with other functions as known in the art.

The actuator mechanism 50 is arranged (for example, by suitably programming the controller 70) to reduce the reduction ratio progressively to transfer rotational energy from the at least one flywheel 10, 20 to the output shaft 61 of the prime mover 60 as the prime mover 60 accelerates from a first speed to a second speed, and then, after the prime mover 60 reaches the second speed, to increase the reduction ratio progressively to transfer rotational energy from the output shaft 61 of the prime mover 60 to accelerate the at least one flywheel 10, 20.

In this way the flywheels 10, 20 decelerate as they supply rotational energy to help the engine or other prime mover 60 to accelerate more rapidly under heavy load, and then, once the load has returned to a constant value and the engine speed is constant at a value matched to the new power demand of the load 90, the engine can supply rotational energy back to the flywheels to accelerate them again to their normal operating speed.

Fig. 9 shows how the apparatus may be configured to help maintain a constant output shaft speed during transient increases in load.

Referring to Fig. 9, the apparatus may include a prime mover 60 and a primary transmission 80. The primary transmission 80 has an input 81, which may be an input shaft as shown, and an output shaft 82, and is operable to provide a variable primary transmission ratio between the input 81 and the output shaft 82.

The prime mover 60 is arranged to supply rotational energy to the input 81 of the primary transmission 80 to drive a load 90 which is operatively connected to the output shaft 82 of the primary transmission. For example, the load 90 may be an alternator, and may be coupled directly or indirectly to the output shaft 82 to rotate at a fixed speed ratio relative to the output shaft 82 (for example, at the same speed as the output shaft 82).

In this example the belt transmission provides rotational energy to the output shaft 82 which drives the load in rotation, and may assist in maintaining the rotational speed of the load 90 (hence, the frequency of the electrical current generated by the alternator) as the load increases, whether to a new, sustained level or only briefly during a transient spike in the load.

The belt transmission provides a reduction ratio from each respective flywheel pulley 11, 21 to the at least one output pulley 30, and the reduction ratio is continuously variable by the actuator mechanism 50.

The belt transmission, actuator mechanism 50 and controller 70 may be configured generally as described above with reference to the Fig. 8 embodiment, except that the at least one output pulley 30 is operatively connected to the output shaft 82 of the primary transmission instead of the output shaft of the prime mover. For example, the output pulley 30 may be mounted on the output shaft 82 to rotate together with the output shaft 82.

Where a controller 70 is provided, in addition to controlling the actuator mechanism 50 and prime mover 60, the controller may also control the transmission ratio of the primary transmission 80 in synchrony with the transmission ratio of the belt transmission.

- The primary transmission ratio is continuously variable to maintain a constant rotational speed of the output shaft 82 of the primary transmission 80 as the prime mover 60 accelerates from a first speed to a second speed at which its power output is increased.
- 5 Thus, the load is maintained at constant rotational speed as the prime mover 60 accelerates to deliver more shaft power to the load. The constant rotational speed of the output shaft 82 may be defined as a target speed range, e.g. a defined deviation from a target speed, wherein the rotational speed is considered to be constant as long as it remains inside the target range. For
- 10 example, it could represent a target output frequency of the alternator, which is sensed by the controller 70 via an additional sensor input (not shown).
- The actuator mechanism 50 is arranged (e.g. by suitably programming the controller 70) to reduce the belt transmission reduction ratio progressively to transfer rotational energy from the flywheels 10, 20 to the output
- 15 shaft 82 of the primary transmission 80 to maintain the constant rotational speed of the output shaft 82 and the load 90 as the flywheels 10, 20 decelerate and the prime mover 60 accelerates from the first speed to the second speed. While reducing the belt transmission reduction ratio (from a higher reduction ratio to a lower reduction ratio) via the actuator mechanism 50, the controller 70 may
- 20 simultaneously adjust the ratio of the primary transmission 80 to match the increasing speed of the input 81 to the constant speed of the output shaft 82 as the prime mover 60 accelerates.
- The actuator mechanism 50 is further arranged, after the prime mover 60 (hence, also the input shaft 81) reaches the second speed, to increase
- 25 the belt transmission reduction ratio progressively to transfer rotational energy from the output shaft 82 of the primary transmission to accelerate the flywheels 10, 20 back to their normal operating speed. While increasing the belt transmission reduction ratio (from a lower reduction ratio to a higher reduction

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ratio) via the actuator mechanism 50, the controller 70 may maintain the primary transmission ratio substantially constant.

In this way, the alternator or other load 90 is maintained at its target rotational speed while the engine first accelerates to match its output power to the increased power demand of the load, and then afterwards accelerates the flywheels again up to their normal operating speed.

It will be noted that the continuously variable belt transmission ratio allows the flywheels 10, 20 to transmit power to the output shaft 82 while the flywheels are progressively decelerating, while maintaining the output shaft at a constant rotational speed.

In such arrangements, the continuously variable primary transmission 80 may be for example a hydraulic parallel path variable transmission, wherein input power is split between a hydro-mechanical variator and a planetary gear system.

Alternatively, other continuously variable primary transmission systems may be used as well known in the art.

Industrial Applicability

By arranging for at least a major proportion of the belt pressure forces F_s , F_d to act against the output axis X_1 of the output pulley 30 in mutual opposition, the novel apparatus allows the torque capacity of the flywheel belt transmission system to be selected independently of the side loading capacity of the engine crankshaft, primary transmission output shaft, or other system component which defines the axis of rotation X_1 of the output pulley.

Thus, the at least one endless belt 40 may be tensioned as necessary to apply sufficient belt pressure forces to transmit the desired torque T to match the mass and rotational speed of the flywheels 10, 20, which need not be limited by the side loading capacity of the output shaft bearings.

Moreover, by dividing the stored energy between at least first and second flywheels, the disclosure makes it possible to arrange a flywheel energy

recovery system in a more compact configuration wherein, ceteris paribus, each flywheel may have a smaller diameter than a single flywheel with the same energy storage capacity. Conversely, two flywheels suitable for use individually on a smaller engine may be paired to double the energy capacity of the system for use on a larger engine, reducing development and stockholding costs for the manufacturer.

The novel apparatus may be configured to supply a variable output power **P_{out}** to drive a load having a variable power demand **P_{demand}**, the apparatus further including a prime mover operable to supply a variable input power **P_{in}**, and the at least one endless belt being configured to transmit a maximum combined total momentary flywheel power **PF(max)** from all of the flywheels to drive the load, wherein (**P_{in} + PF(max) = P_{out}**).

Optionally in this case, the novel apparatus may further be configured to increase the input power **P_{in}** to match increasing power demand **P_{demand}** with a time lag causing a transient input power deficiency **δP_{in}**, wherein (**δP_{in} = P_{demand} - P_{in}**). The at least one endless belt may be configured to transmit the maximum combined total momentary flywheel power **PF(max)** when the transient input power deficiency **δP_{in}** is at a maximum designed value **δP_{in}(max)**, wherein (**PF(max) = δP_{in}(max)**). The at least one endless belt may be configured to transmit from each individual one of the flywheels a maximum individual momentary flywheel power **Pf(max)** to drive the load, wherein for each individual one of the flywheels, (**Pf(max) < δP_{in}(max)**). Thus, the individual flywheels may act together to supply the input power deficiency from the prime mover in a maximum designed transient load condition.

The at least one endless belt may provide a fixed belt transmission ratio between the at least one flywheel pulley and the at least one output pulley. In this case the flywheels will increase the inertia of the system and help to maintain the rotational speed of the output shaft when the torque reaction of the

load exceeds the available output torque of the engine. For example, when the engine is driving an alternator, increased inertia will help to maintain supply frequency within acceptable limits during transient spikes in the load, and when the transient load passes, the engine torque will accelerate the system back to the
5 target frequency.

Alternatively, the at least one endless belt may provide a variable belt transmission ratio between the at least one flywheel pulley and the at least one output pulley. In this case the belt transmission ratio may be controlled to transmit rotational energy selectively either to or from the flywheels, from or to
10 the load, the prime mover, or both the load and the prime mover. This can be arranged for example to increase the rate of acceleration of the prime mover under load, either to accelerate an output shaft driving the load or to maintain the speed of the output shaft under increasing load torque reaction.

Where the power output of the prime mover increases with speed
15 (for example, if the prime mover is an internal combustion engine), increasing the rate of acceleration of the prime mover under load may reduce output power lag during transient load spikes.

Conversely, after supplying rotational energy to the system, the flywheels can be accelerated by progressively changing the belt transmission
20 ratio to supply rotational energy at a sustainable rate from the prime mover to the flywheels.

Alternatively or additionally, if the flywheels are arranged as a regenerative braking or other energy recovery system, the belt transmission ratio can be controlled to transmit rotational energy from the load to the flywheels, for
25 example, to apply a controlled braking effort to the load. The load could be, for example, a vehicle moving on wheels wherein the apparatus is mounted on the vehicle to control rotation of the wheels, or a mass that moves relative to the apparatus.

In summary, a pair of flywheels drive a belt transmission system via respective flywheel pulleys which may be arranged, for example, in diametrically opposed relation on opposite sides of at least one output pulley. At least a major proportion of the belt pressure forces applied by the tensioned belt
5 towards the output axis of the at least one output pulley act in mutual opposition, so that the torque transmission capacity of the belt transmission is not limited by the side loading limit of the output pulley bearings. The belt transmission may provide a continuously variable ratio and may be arranged for example to improve the acceleration of a prime mover under load, or in conjunction with a
10 continuously variable primary transmission to maintain output shaft speed while the prime mover accelerates to match the increasing power demand of the load.

In the illustrated embodiments, a single endless belt is provided to couple two flywheel pulleys to a single output pulley. In alternative
embodiments, more than one endless belt and/or more than two flywheels and/or
15 more than one output pulley may be provided. For example, three, four, or more flywheels may be coupled via one or more endless belts to one, two or more output pulleys.

In such arrangements, it is possible for the belts and output pulleys to be arranged symmetrically on a common output shaft. For example, each of the
20 first and second flywheels may have a pair of flywheel pulleys, one on each side of the respective flywheel, each having an endless belt looped around a respective one of a corresponding pair of output pulleys. In such an arrangement, the output pulleys of the first flywheel may be arranged axially on a common output shaft, on either side of the output pulleys of the second flywheel, and the tension of all
25 four belts equalised so as to apply substantially no bending moment to the output shaft when considered at its two axial ends.

Conveniently, where two or more output pulleys are provided, all of the output pulleys may be arranged to rotate about a common axis, for example, on a common output shaft.

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However, in systems with more than one output pulley, it is conceivable for different output pulleys or different groups of output pulleys to rotate on different output shafts or about different output axes.

Many further adaptations are possible within the scope of the
5 claims.

In the claims, reference numerals and characters are provided in parentheses, purely for ease of reference, and are not to be construed as limiting features.

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Claims

1. An apparatus including:
 - at least one flywheel (10, 20) operatively connected to at least one
 - 5 flywheel pulley (11, 21) to drive the at least one flywheel pulley (11, 21) in rotation;
 - at least one output pulley (30) mounted for rotation about an output axis (X1); and
 - at least one endless belt (40) engaged with the at least one
 - 10 flywheel pulley (11, 21) and the at least one output pulley (30) to transmit rotational energy from the at least one flywheel (10, 20) via the at least one flywheel pulley (11, 21) to the at least one output pulley (30);
 - the at least one endless belt (40) being tensioned to apply belt pressure forces (Fs, Fd) acting against the at least one output pulley (30) towards
 - 15 the output axis (X1);
 - wherein the at least one flywheel (10, 20) includes:
 - a first flywheel (10), and
 - a second flywheel (20);
 - and the at least one flywheel pulley (11, 21) includes:
 - 20 at least one first flywheel pulley (11) driven by the first flywheel (10), and
 - at least one second flywheel pulley (21) driven by the second flywheel (20);
 - and the first and second flywheel pulleys (11, 21) are positioned in
 - 25 spaced relation to direct at least a major proportion of said belt pressure forces (Fs, Fd) to act against the at least one output pulley (30) in mutual opposition.

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- 2 An apparatus according to claim 1, wherein the first and second flywheel pulleys (11, 21) are arranged in diametrically opposed relation on opposite sides of the output axis (X1).
- 5 3 An apparatus according to claim 2, wherein the at least one endless belt (40) comprises at least a first endless belt (40) which is looped around respective ones of each of the first and second flywheel pulleys (11, 21) and the at least one output pulley (30).
- 10 4 An apparatus according to claim 1, wherein the at least one endless belt (40), the at least one output pulley (30), and the first and second flywheel pulleys (11, 21) are configured to provide a variable belt transmission ratio between each respective flywheel pulley (11, 21) and the at least one output pulley (30).
- 15 5 An apparatus according to claim 4, wherein the at least one endless belt (40) is arranged to engage a respective surface of rotation (13, 23, 31) of each of the first and second flywheel pulleys (11, 21) and the at least one output pulley (30), each respective surface of rotation (13, 23, 31) having a
- 20 respective diameter (D);
- and the apparatus includes an actuator mechanism (50) configured to adjust simultaneously the diameter (D) of the respective surface of rotation (13, 23, 31) of each of the first and second flywheel pulleys (11, 21) and the at least one output pulley (30) while maintaining equal the diameter (D) of the
- 25 respective surfaces of rotation (13, 23) of the first and second flywheel pulleys (11, 21).
- 6 An apparatus according to claim 4, wherein the apparatus includes a prime mover (60) having an output shaft (61), and the at least one

output pulley (30) is operatively connected to the output shaft (61) of the prime mover (60) to rotate in fixed relation to the output shaft (61) of the prime mover (60).

5 7 An apparatus according to claim 6, wherein the apparatus includes an actuator mechanism (50), and the belt transmission ratio is a reduction ratio from each respective flywheel pulley (11, 21) to the at least one output pulley (30), and the reduction ratio is continuously variable by the actuator mechanism (50), and the actuator mechanism (50) is arranged:

10 - to reduce the reduction ratio progressively to transfer rotational energy from the at least one flywheel (10, 20) to the output shaft (61) of the prime mover (60) as the prime mover (60) accelerates from a first speed to a second speed, and then

15 - after the prime mover (60) reaches the second speed, to increase the reduction ratio progressively to transfer rotational energy from the output shaft (61) of the prime mover (60) to accelerate the at least one flywheel (10, 20).

8 An apparatus according to claim 4, wherein the apparatus
includes a prime mover (60) and a primary transmission (80);
20 the primary transmission (80) having:
 an input (81),
 an output shaft (82), and
 a variable primary transmission ratio between the input
 (81) and the output shaft (82);
25 and the prime mover (60) is arranged to supply rotational energy
to the input (81) of the primary transmission (80) to drive a load (90) operatively
connected to the output shaft (82) of the primary transmission (80);
 and the at least one output pulley (30) is operatively connected to
the output shaft (82) of the primary transmission (80).

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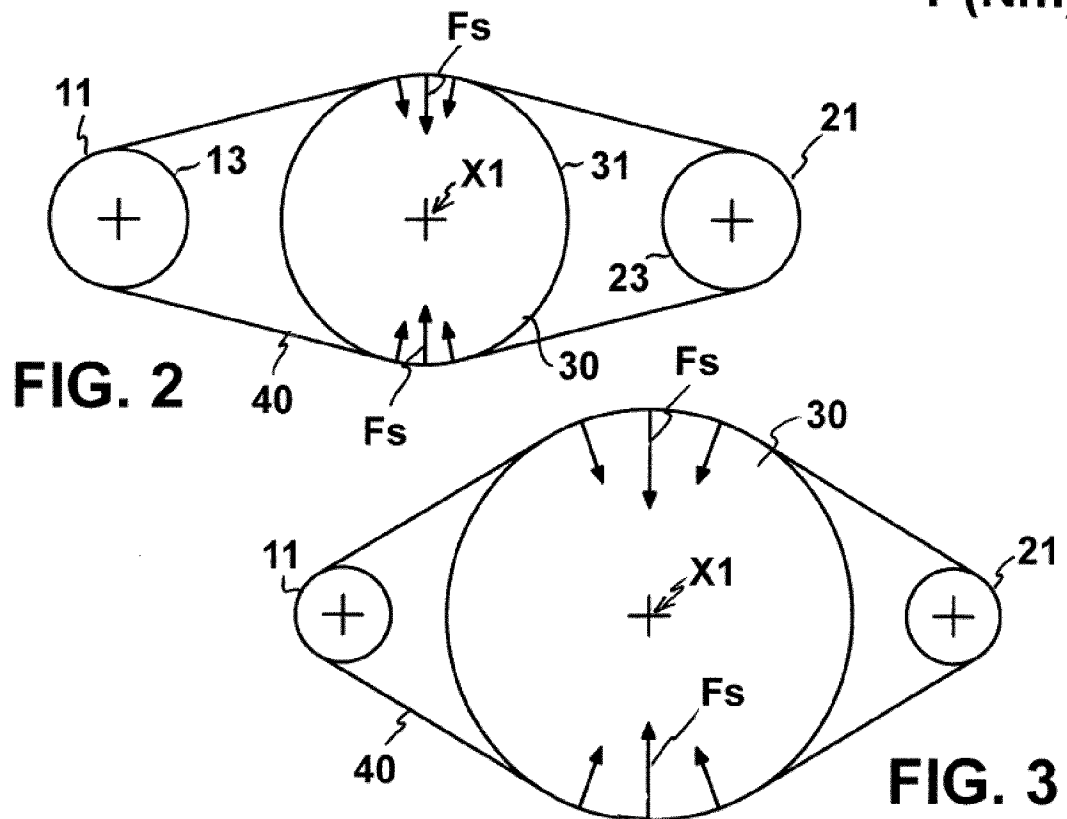
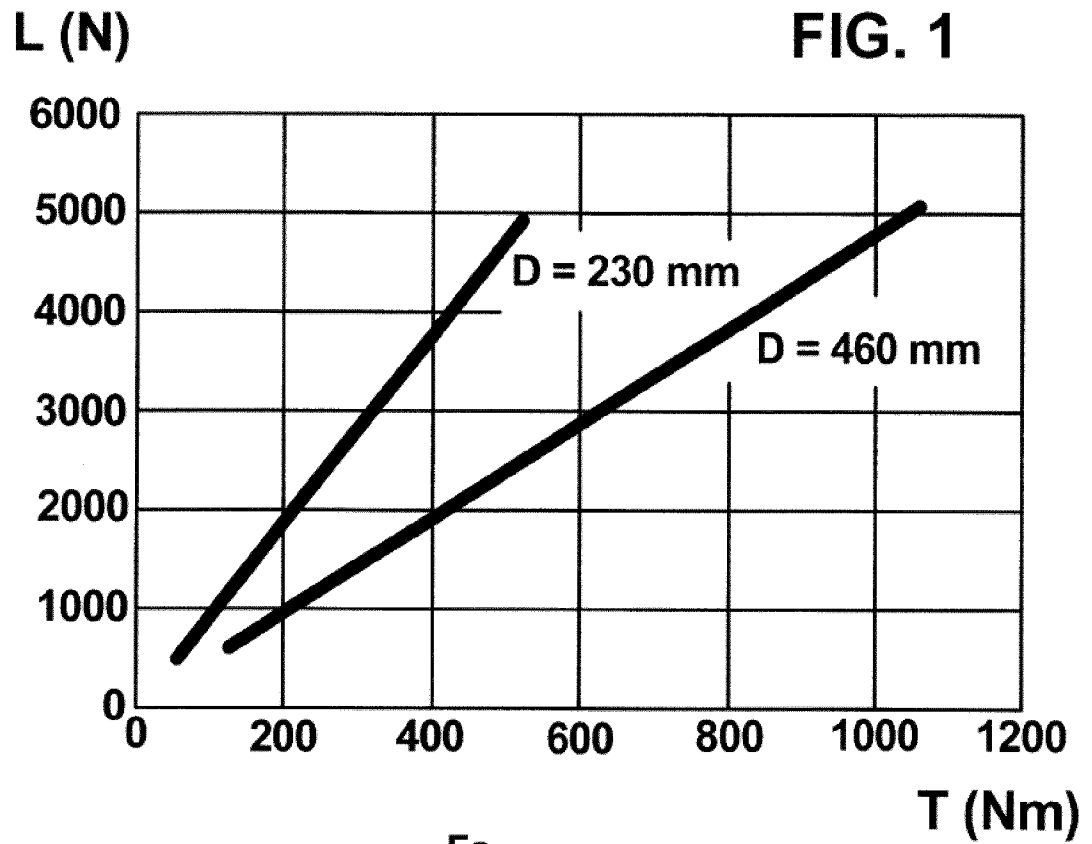
9 An apparatus according to claim 8, wherein:
the apparatus includes an actuator mechanism (50); and
the belt transmission ratio is a reduction ratio from each respective
flywheel pulley (11, 21) to the at least one output pulley (30), and the reduction
5 ratio is continuously variable by the actuator mechanism (50); and
the primary transmission ratio is continuously variable to maintain
a constant rotational speed of the output shaft (82) of the primary transmission
(80) as the prime mover (60) accelerates from a first speed to a second speed; and
the actuator mechanism (50) is arranged:
10 - to reduce the reduction ratio progressively to transfer
rotational energy from the at least one flywheel (10, 20) to the output
shaft (82) of the primary transmission (80) to maintain said constant
rotational speed of the output shaft (82) of the primary transmission (80)
as the at least one flywheel (10, 20) decelerates and the prime mover (60)
15 accelerates from the first speed to the second speed, and then
- after the prime mover (60) reaches the second speed, to
increase the reduction ratio progressively to transfer rotational energy
from the output shaft (82) of the primary transmission (80) to accelerate
the at least one flywheel (10, 20).

20

10. A method of storing and transmitting rotational energy
including:
operatively connecting at least one flywheel (10, 20) to at least
one flywheel pulley (11, 21) to drive the at least one flywheel pulley (11, 21) in
25 rotation;
mounting the at least one output pulley (30) for rotation about an
output axis (X1); and
engaging at least one endless belt (40) with the at least one
flywheel pulley (11, 21) and the at least one output pulley (30) to transmit

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- rotational energy from the at least one flywheel (10, 20) via the at least one flywheel pulley (11, 21) to the at least one output pulley (30);
- the at least one endless belt (40) being tensioned to apply belt pressure forces (F_s , F_d) acting against the at least one output pulley (30) towards
- 5 the output axis (X_1);
- and further including:
- configuring the at least one flywheel (10, 20) to include
- a first flywheel (10), and
- a second flywheel (20);
- 10 and configuring the at least one flywheel pulley (11, 21) to include:
- at least one first flywheel pulley (11) driven by the first flywheel (10), and
- at least one second flywheel pulley (21) driven by the second flywheel (20);
- 15 and positioning the first and second flywheel pulleys (11, 21) in spaced relation to direct at least a major proportion of said belt pressure forces (F_s , F_d) to act against the at least one output pulley (30) in mutual opposition.



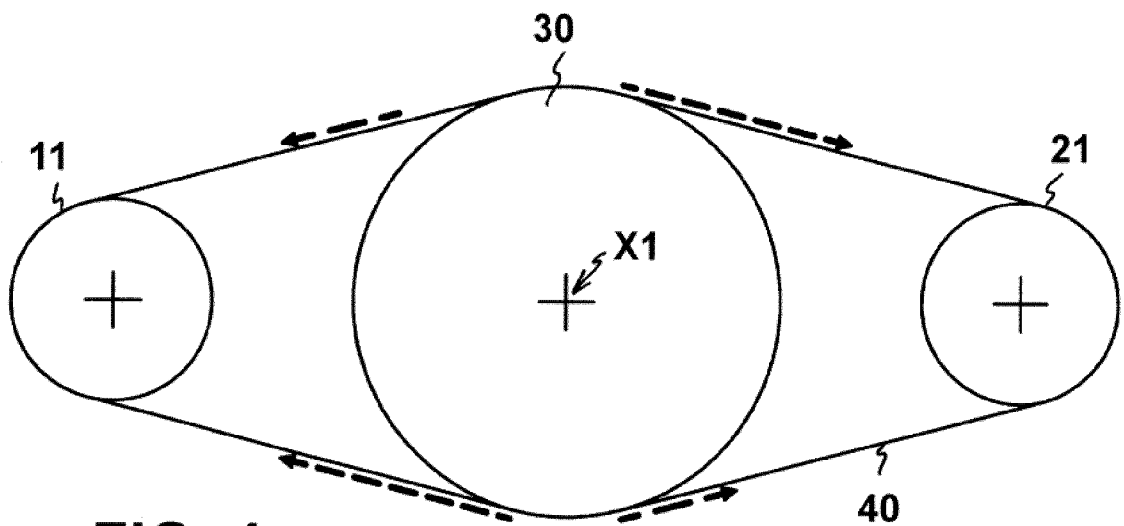


FIG. 4

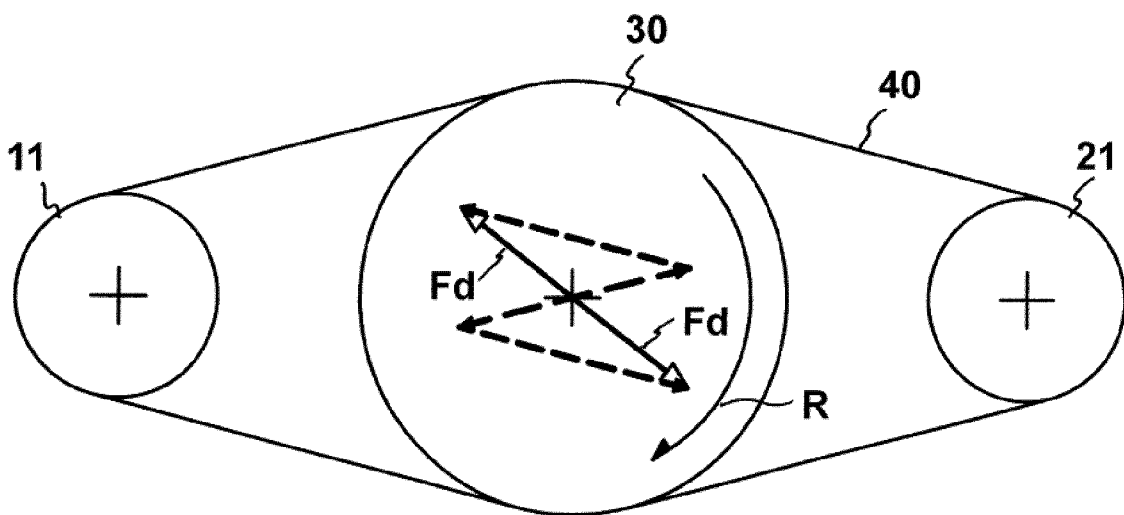
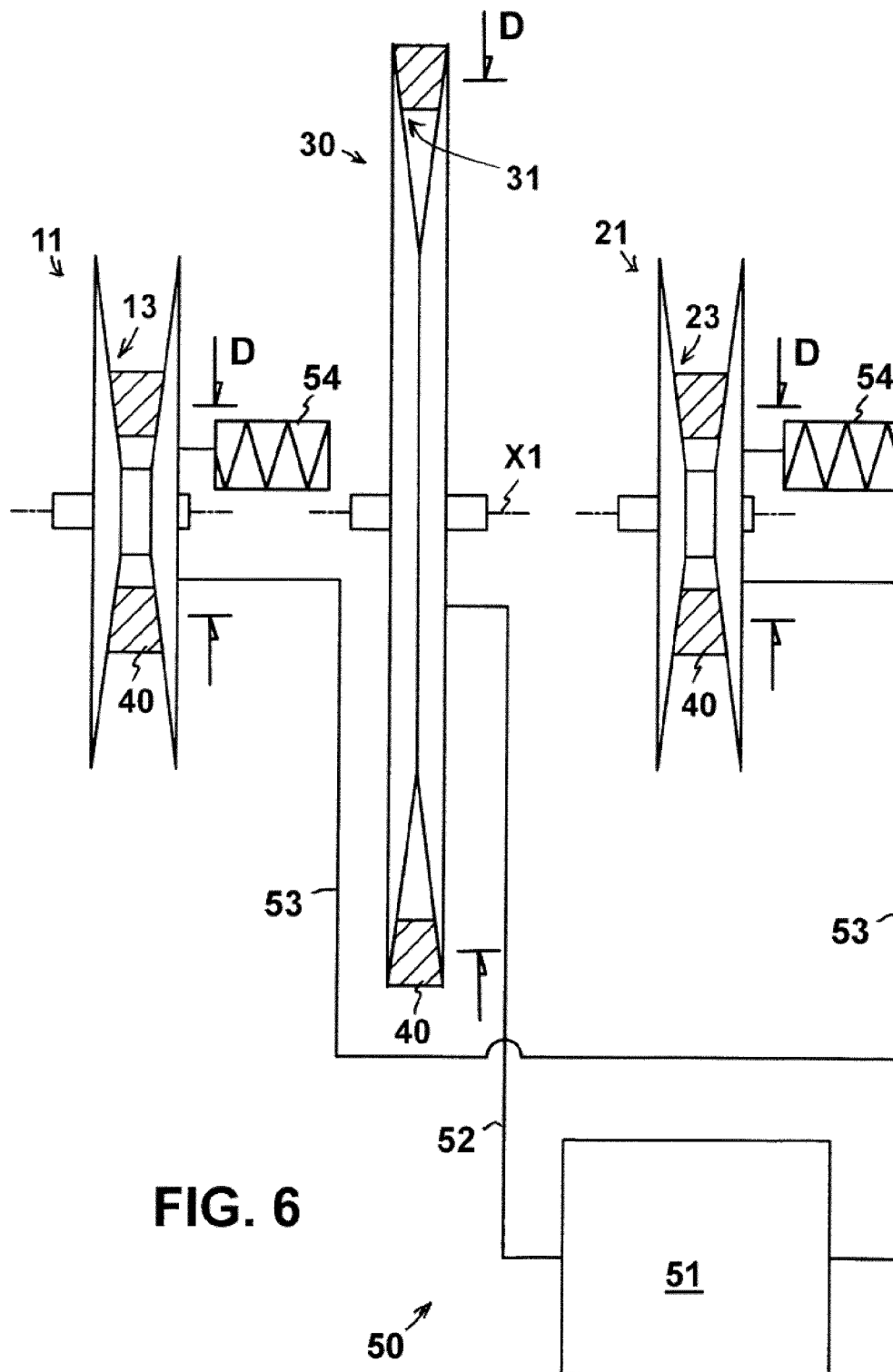
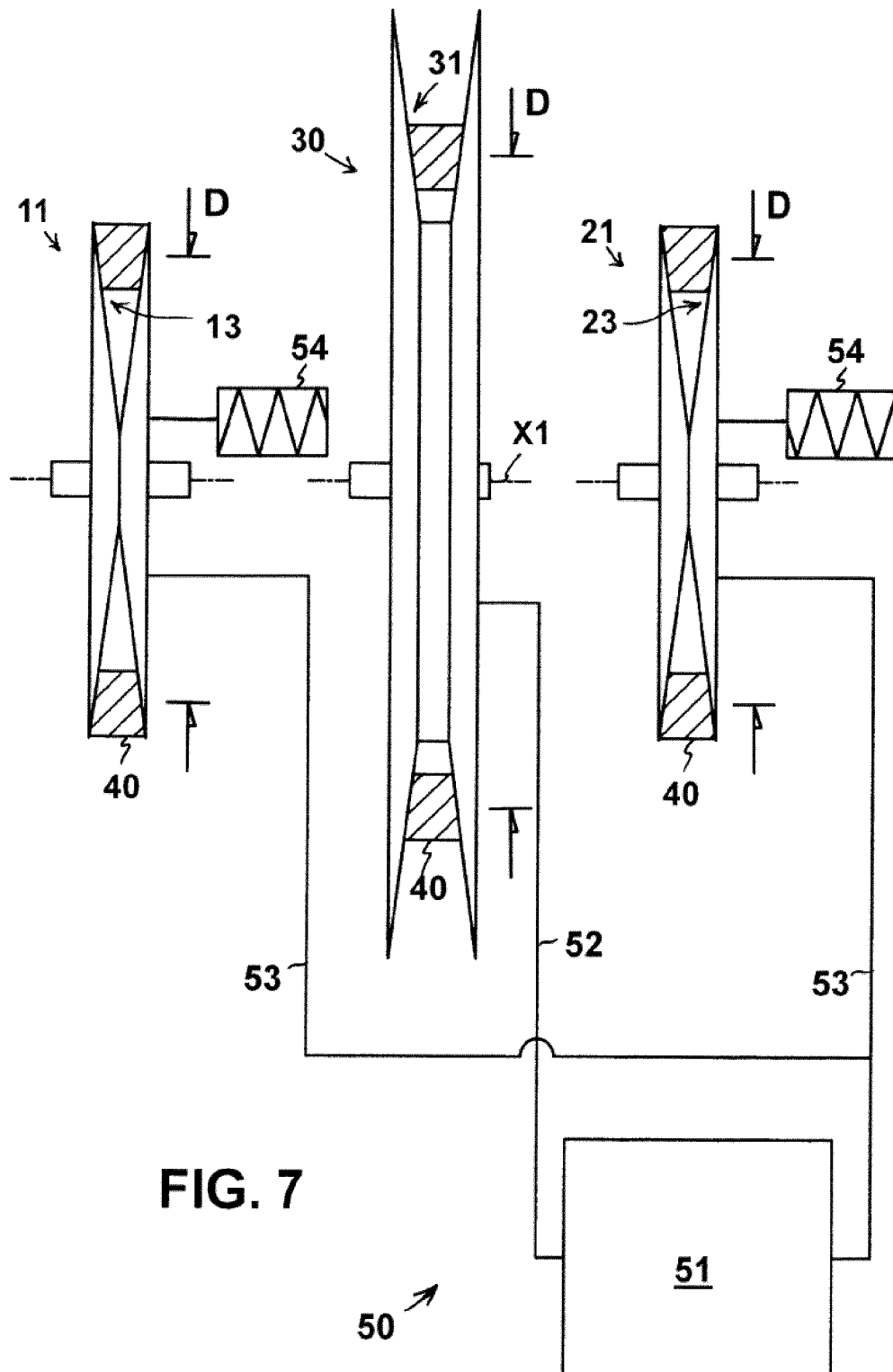
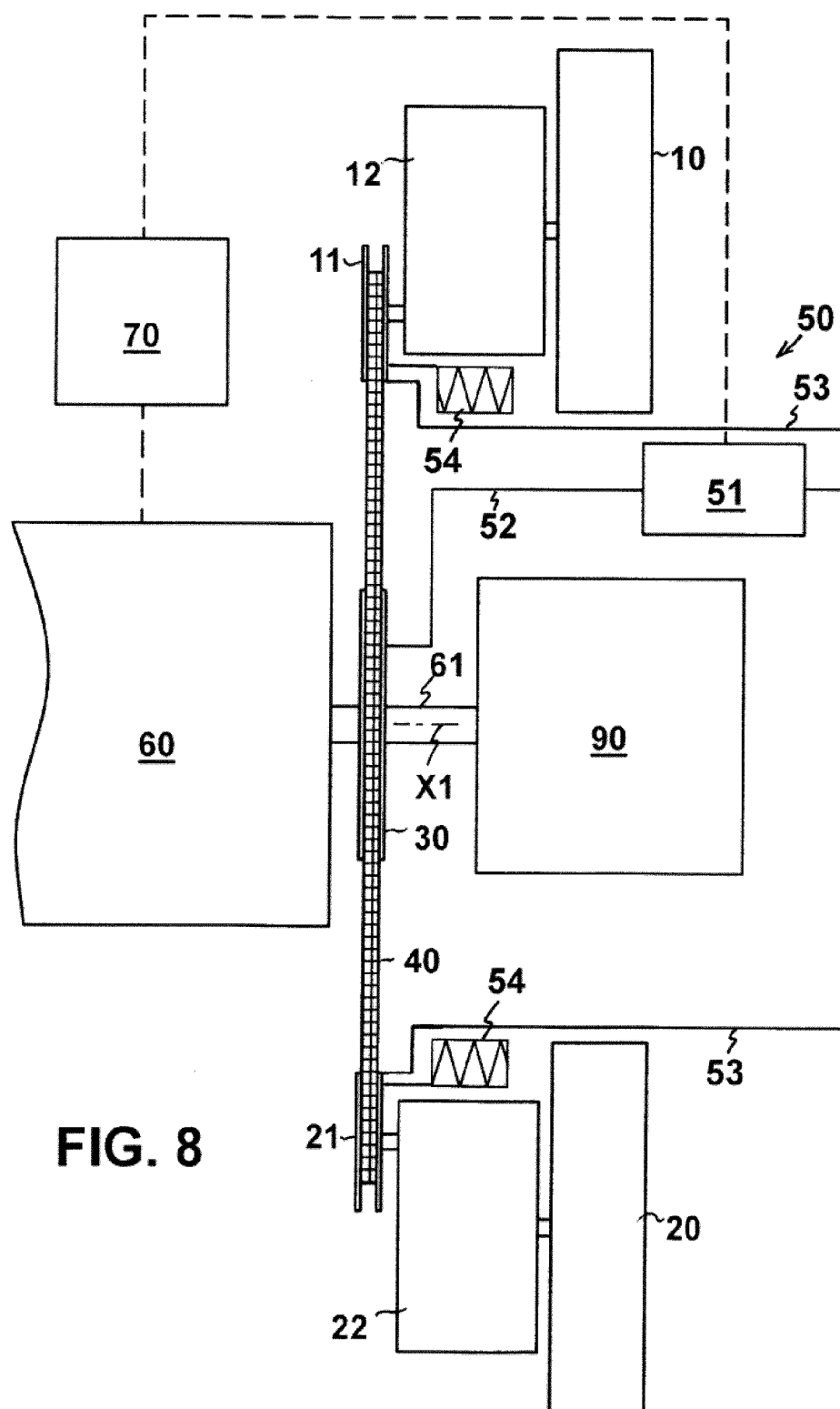


FIG. 5







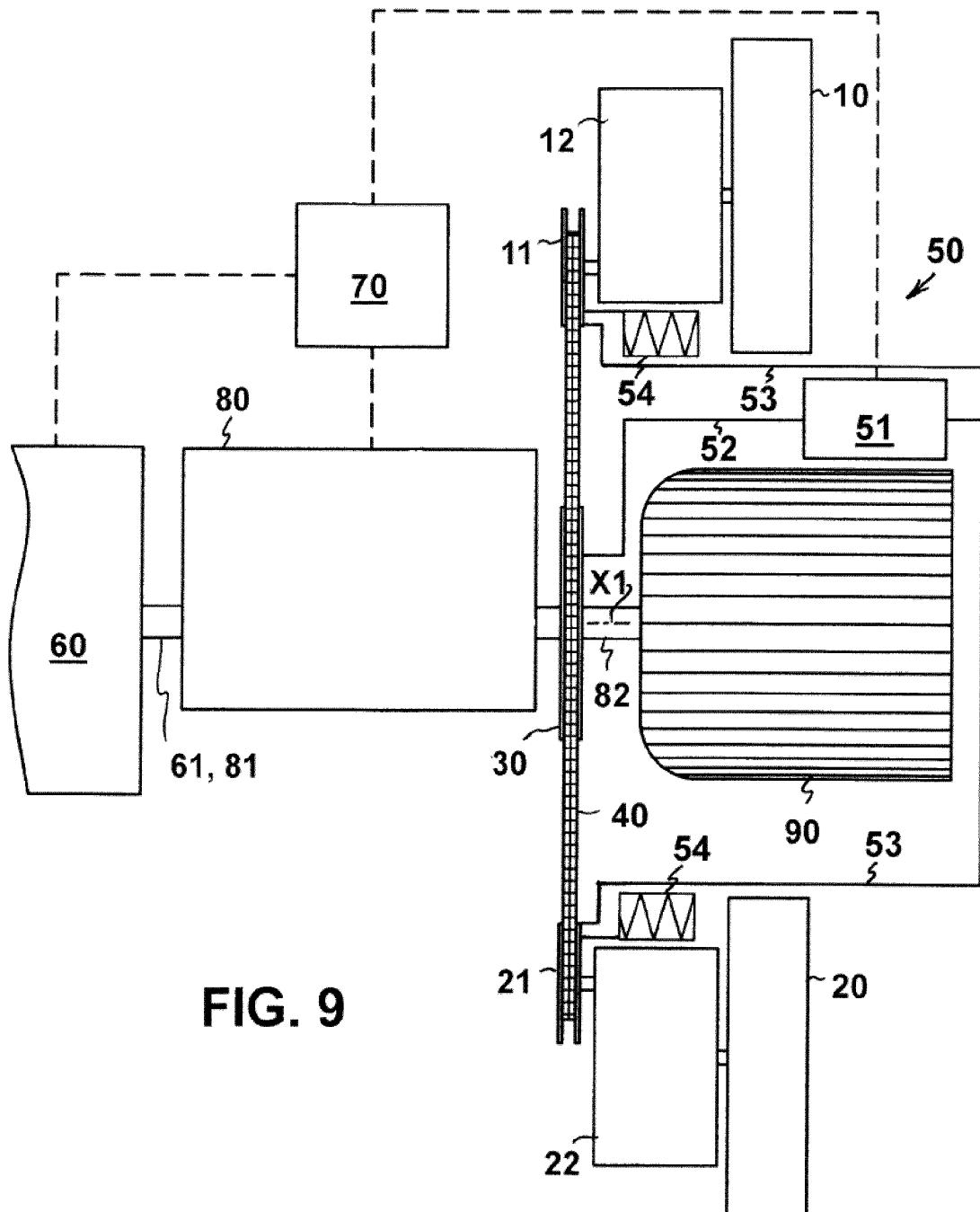


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/025456

A. CLASSIFICATION OF SUBJECT MATTER INV. F16H9/12 F16H7/02 B60K6/10 F16H33/02 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) F16H B60K		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP H03 33540 A (SHARP KK) 13 February 1991 (1991-02-13) figure 2	1-10
A	----- WO 2004/022324 A1 (BUEHLER AG [CH]; HANIMANN PHILIPP [CH] ET AL.) 18 March 2004 (2004-03-18) figure 4	1-10
A	----- FR 487 380 A (PERCY LEONARD WESTON [AU]) 28 June 1918 (1918-06-28) figure 4	1-10
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☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search	Date of mailing of the international search report	
16 April 2020	22/04/2020	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Belz, Thomas	

INTERNATIONAL SEARCH REPORT

International application No

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