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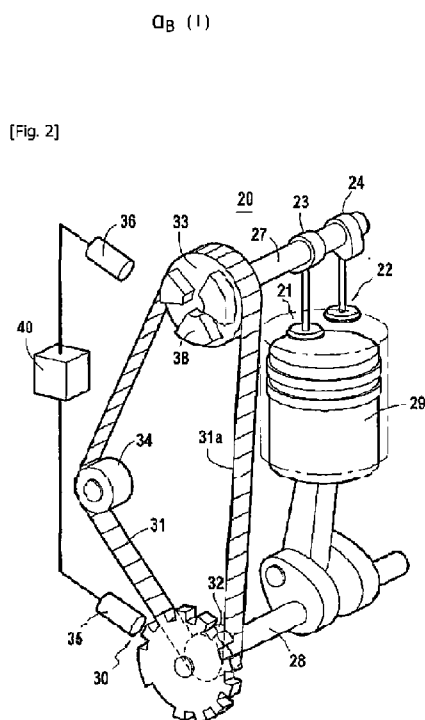
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(54) Title: WEAR MONITORING METHOD



(57) Abstract: The present invention concerns a method for monitoring wear of a transmission mechanism transmitting rotation (R) of a driving shaft to a camshaft (27) driving one or more cams (23, 24). The method comprises the steps of receiving a driving shaft angular position signal (V_2) according to a driving shaft angular position, receiving a camshaft angular position signal (V_1) according to a camshaft angular position, determining, based on the camshaft angular position signal (V_1), whether the camshaft angular position is within a range (formula (I)), narrower than a full rotation, wherein the one or more cams (23, 24) exert a torque (M_B) on the camshaft (27) in a retard direction opposite to a direction of the rotation (R) transmitted to the camshaft (27) by the transmission mechanism, and calculating a phase shift (Δt) between the driving shaft angular position signal (V_2) and the camshaft phase position signal (V_1).

WEAR MONITORING METHOD

TECHNICAL FIELD

5 The disclosure relates to the field of camshaft timing, and more specifically to a method for monitoring wear of a transmission mechanism transmitting rotation of a driving shaft to a camshaft driving one or more cams.

10 BACKGROUND

Ensuring accurate camshaft timing can be particularly important, in particular for the camshafts driving the gas exchange of internal combustion engines. An accurate synchronization of the one or more camshafts driving inlet and/or outlet valves of an internal combustion engine with a driving shaft, such as the crankshaft of the internal combustion engine, may contribute to optimum combustion conditions and, in so-called interference engines, prevent collision of the inlet and/or outlet valves with a piston.

When the camshaft is driven by the driving shaft over a transmission mechanism, such as a timing chain, belt or gear mechanism, wear in this transmission mechanism may increase a phase shift between the driving shaft and the camshaft beyond acceptable tolerances. In order to monitor such wear, monitoring methods are known comprising the steps of receiving a driving shaft angular position signal, receiving a camshaft angular position signal, calculating a phase shift between the driving shaft angular position signal and the camshaft phase position signal, and determining excessive wear of the transmission mechanism if the phase shift exceeds a predetermined threshold.

30 However, in certain angular position ranges the pressure of the cam
followers on the cam surface may push the camshaft in the direction of
rotation and thus transiently slacken the transmission mechanism. This
transient slack and consequent decrease in the phase shift may lead to an
35 underestimate of the wear of the transmission mechanism.

SUMMARY

A first object of the disclosure is that of increasing the accuracy of the determination of the wear in the transmission mechanism and preventing an underestimate.

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Accordingly, a first aspect of the disclosure relates to a method for monitoring wear of a transmission mechanism transmitting rotation of a driving shaft to a camshaft driving one or more cams, comprising the steps of receiving a driving shaft angular position signal according to a driving shaft angular position, receiving a camshaft angular position signal according to a camshaft angular position, determining, based on the camshaft angular position signal, whether the camshaft angular position is within a range, narrower than a full rotation, wherein the one or more cams exert a torque on the camshaft in a retard direction opposite to a direction of the rotation transmitted to the camshaft by the transmission mechanism, and calculating a phase shift between the driving shaft angular position signal and the camshaft phase position signal. The transmission mechanism may in particular comprise a timing chain. However, it may instead comprise a timing belt or gearings.

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Consequently, the phase shift may be taken into consideration for determining wear of the transmission mechanism only when the transmission mechanism is tautened by the torque exerted by the one or more cams on the camshaft in a direction opposite to the direction of the rotation transmitted to the camshaft by the transmission mechanism, and an underestimate of the wear due to the decreased phase shift when the transmission mechanism slackens outside of that angular position range.

The one or more cams may drive inlet and/or outlet valves of an internal combustion engine. Monitoring the wear of the transmission mechanism may thus ensure the accurate timing of the gas exchange of the internal combustion engine, and even prevent the collision of these valves with a piston. In this case, the driving shaft may in particular be a crankshaft of the internal combustion engine.

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The driving shaft angular position signal may be a pulse signal generated by the passage, near a driving shaft angular position sensor, of one or more beacons rotating with the driving shaft. Likewise, the camshaft angular position signal is a pulse signal generated by the passage, near a camshaft angular position sensor, of one or more beacons rotating with the camshaft. These beacons may be formed, for instance, by blocks of ferromagnetic material generating a response on induction sensors located in the vicinity of the corresponding shaft. However, alternative types of angular beacons, for instance optical beacons, may alternatively be considered.

A second aspect of this disclosure relates to an electronic monitoring device configured to carry out the abovementioned sensors.

A third aspect of this disclosure relates to an internal combustion engine comprising a camshaft with one or more cams for driving inlet and/or outlet valves of the internal combustion engine, a transmission mechanism for transmitting rotation from a driving shaft to the camshaft, one or more sensors for generating a driving shaft angular position signal and a camshaft angular position signal, and the abovementioned electronic monitoring device, connected to said one or more sensors, for monitoring the wear of the transmission mechanism.

The above summary of some example embodiments is not intended to describe each disclosed embodiment or every implementation of the invention. In particular, selected features of any illustrative embodiment within this specification may be incorporated into an additional embodiment unless clearly stated to the contrary.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be more completely understood in consideration of the following detailed description of an embodiment in connection with the accompanying drawings, in which :

- FIG. 1 is a schematic drawing of a motor vehicle ;
- FIG. 2 is a schematic drawing of a reciprocating internal combustion engine for driving the motor vehicle of FIG. 1;

- FIG. 3 illustrates pulsed driving shaft and camshaft angular position signals from the reciprocating internal combustion engine of FIG. 2;
- 5 – FIG. 4 is a flowchart illustrating a method of monitoring wear of a transmission mechanism for driving the camshaft of the reciprocating internal combustion engine of FIG. 2 based on the pulsed signals of FIG. 3;
- 10 – FIGS. 5A and 5B illustrate, respectively, the torque exerted on the camshaft by the cam follower before and after reaching the cam peak; and
- FIGS. 6A and 6B illustrate, respectively, the tautening and slackening of the transmission mechanism with the torques of FIGS. 5A and 5B.

15 While the invention is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit aspects of the invention to the particular embodiments described. On the contrary, the intention is to
20 cover all modifications, equivalents, and alternatives falling within the scope of the invention.

DETAILED DESCRIPTION

25 For the following defined terms, these definitions shall be applied, unless a different definition is given in the claims or elsewhere in this specification.

30 All numeric values are herein assumed to be preceded by the term “about”, whether or not explicitly indicated. The term “about” generally refers to a range of numbers that one of skill in the art would consider equivalent to the recited value (i.e. having the same function or result). In many instances, the term “about” may be indicative as including numbers that are rounded to the nearest significant figure.

Any recitation of numerical ranges by endpoints includes all numbers within that range (e.g., 1 to 5 includes a.o. 1, 4/3, 1.5, 2, e , 2.75, 3, π , 3.80, 4, and 5).

5 Although some suitable dimension ranges and/or values pertaining to various components, features and/or specifications are disclosed, one of skill in the art, incited by the present disclosure, would understand desired dimensions, ranges and/or values may deviate from those expressly disclosed.

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As used in this specification and the appended claims, the singular forms "a", "an", and "the" include plural referents unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term "or" is generally employed in its sense including "and/or" unless the content clearly dictates otherwise.

15

The following detailed description should be read with reference to the drawings in which similar elements in different drawings are numbered the same. The detailed description and the drawings, which are not necessarily to scale, depict illustrative embodiments and are not intended to limit the scope of the invention. The illustrative embodiments depicted are intended only as exemplary. Selected features of any illustrative embodiment may be incorporated into an additional embodiment unless clearly stated to the contrary.

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Fig. 1 illustrates schematically a vehicle 10 equipped with an internal combustion engine 20 for its propulsion. Although in the illustrated example the vehicle 10 is a wheeled road vehicle, it could also be an off-road vehicle, a tracked vehicle or even a boat or an aircraft. Similarly, although in the illustrated example the internal combustion engine 20 is a single-cylinder reciprocating internal combustion engine, it could be a multi-cylinder engine or even a single- or multi-rotor rotary engine.

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As seen in Fig. 2, the internal combustion engine 20 may comprise inlet and/or outlet valves 21,22 for driving its gas exchange. The internal combustion engine 2 may further comprise respective cams 23, 24 for

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driving the valves 21, 22 open, either directly or over respective valve rockers and/or pushrods, as well as respective return springs 25,26 for driving the valves 21, 22 closed against the cams 23, 24.

5 As also seen in Fig. 2, the internal combustion engine 20 may further comprise a camshaft 27 operatively connected to the cams 23, 24 for driving their rotation. In particular, the cams 23,24 may be integrally formed with the camshaft 27. Although in the illustrated example the internal combustion engine 2 comprises a single camshaft 27 for both the
10 inlet and outlet cams 23, 24, such an internal combustion engine may instead comprise multiple camshafts, for instance separate camshafts for the inlet and outlet valves and/or for different cylinders or banks of cylinders.

15 As in Fig. 2, the internal combustion engine 2 may further comprise a transmission mechanism 30 for driving the camshaft 27. More specifically, this transmission mechanism 30 may be configured to transmit rotation from a driving shaft to the camshaft 27. Typically, when the internal combustion engine 20 is a reciprocating internal combustion engine as in
20 the illustrated example, this driving shaft may be the crankshaft 28, so that the movement of the valves 21, 22 is synchronized with that of the corresponding piston 29. However, according to circumstances, a different driving shaft, such as for instance the output shaft of an electric motor synchronized with the crankshaft, may be chosen as the source of the
25 rotation transmitted to the camshaft 27.

 As in the illustrated example, the transmission mechanism 30 may be a timing chain mechanism comprising a timing chain 31, a driving sprocket 32, one or more driven sprockets 33, and a chain tensioner 34. Driving
30 sprocket 32 may be operatively connected to the driving shaft (crankshaft 28 in the illustrated example) and each driven sprocket 33 to a respective camshaft 27. Timing chain 31 may engage both the driving sprocket 32 and each driven sprocket 32, operatively connecting them to transmit the rotation of the driving sprocket 32 to each driven sprocket 33. In a four-
35 stroke internal combustion engine 20, each driven sprocket 33 may have twice the number of teeth of the driving sprocket 32, so as to rotate at

half the angular speed, and the chain tensioner 34 may press laterally against the timing chain 31 to maintain chain tension and thus chain length ℓ on the traction side 31a of the timing chain 31 from the driving sprocket 32 to each driven sprocket 33 and thus ensure synchronization between the driving shaft and the camshaft 27. Accurate synchronization is important not only to ensure combustion efficiency within the internal combustion engine 20, but also, in so-called interference engines, to prevent collision of one or more of valves 21, 22 against the corresponding piston.

However, wear in transmission mechanism 30 may affect the synchronization between the driving shaft and the one or more camshafts 27. In particular, in the illustrated example, the elongation of one or more of the links of timing chain 31 due to wear may shift the angular position of the one or more camshafts 27 with respect to the driving shaft. Although in the illustrated example the transmission mechanism is a timing chain mechanism, it may alternatively be a timing belt mechanism or a timing gear mechanism. In either case, accurate synchronization may also be affected by wear.

To address this, the internal combustion engine 20 may further comprise angular position sensors 35, 36 for detecting the angular position of, respectively, the driving shaft and the one or more camshafts 27, and an electronic monitoring device 40.

The angular position sensors 35, 36 may be configured to generate pulse signals in response to the nearby passage of one or more beacons rotating with, respectively, the driving shaft and the one or more camshafts 27. For example, as shown in Fig. 2, different-sized ferromagnetic blocks 38 fixed to the camshaft 27 may form the beacons for camshaft angular position sensor 36, which may be an inductive sensor. The driving shaft angular position sensor 36 may also be an inductive sensor, and the corresponding beacons may be formed by ferromagnetic teeth 39 fixed to the driving shaft, around its axis of rotation, wherein one of the teeth 39 may differ from the rest so as to index each full rotation of the driving shaft. In response to the rotation of

camshaft 27, angular position sensors 35, 36 may thus respectively generate camshaft angular position signal V_1 and driving shaft angular position signal V_2 , for instance as pulses in a voltage V over time t , as illustrated in Fig. 3.

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The electronic monitoring device 40 may be connected to the angular position sensors 35, 36 to monitor the wear of the transmission mechanism based on the camshaft angular position signal V_1 and driving shaft angular position signal V_2 . For this purpose, the electronic monitoring device 40 may be configured to carry out a monitoring method as illustrated by the flowchart of Fig. 4. In steps S100 and S110 of this method, the electronic monitoring device 40 may receive, respectively, camshaft angular position signal V_1 and driving shaft angular position signal V_2 . Consequently, in step S120, the electronic monitoring device 40 may determine, based on the camshaft angular position signal V_1 , whether the angular position of the camshaft 27 is within an angular position range α_B wherein the cams 23, 24 exert together a torque M_B on the camshaft 27 in a retard direction opposite to a direction of the rotation R transmitted to the camshaft 27 by the transmission mechanism.

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As shown in Figs. 5A and 5B, on each cam 23 or 24, the corresponding cam follower 50, directly or indirectly linked to the respective valve 21, 21, driven back by the respective return spring 25, 26, may exert a return force F_R on a cam surface which may comprise a valve opening part 60a, a valve closing part 60b and a cam peak 60c and cam back 60d interposed between the valve opening and closing parts 60a, 60b.. A radius r of the cam surface with respect to the rotation axis X of the cam 23, 24 may increase gradually over the valve opening part 60a from the cam back 60d towards the cam peak 60c, and decrease gradually again over the valve closing part 60b from the cam peak 60c to the cam back 60d, while remaining substantially constant over both the cam peak 60c and cam back 60d.

Even if the return force F_R is directly oriented towards the rotation axis X of the cam 23, 24, the contact force F_C between the cam follower 50 and the low-friction cam surface 60 may be essentially perpendicular to

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the cam surface 60, and thus have a component F_T with a lever arm a with respect to the rotation axis X , thus generating said torque M_B around the cam rotation axis X . On the valve opening part 60a of the cam surface, that is, before reaching cam peak 60c, this torque M_B may oppose
5 the rotation R of the cam 23,24, as shown on Fig. 5A, thus tautening the timing chain 31 on the traction side 31a of the respective driven sprocket 33, as shown on Fig. 6A. On the other hand, on the valve closing part 60b of the cam surface, that is, beyond cam peak 60c, the torque M_B may further promote the rotation R of the cam 23, 24, as shown on Fig. 5B,
10 thus slackening the timing chain 31 on the traction side 31a of the respective driven sprocket 33, as shown on Fig. 6B, and reducing the phase shift between the driving shaft and the camshaft 27.

While the torque M_B is illustrated in Figs. 5A and 5B for a single cam
15 23,24, the individual torques exerted by a plurality of cams 23,24 on each camshaft 27 may add and/or cancel each other at various angular positions over a full rotation of the camshaft 27, so that such a full rotation may comprise a plurality of angular position ranges where the total torque M_B exerted by the cams 23,24 on the camshaft 27 is opposed
20 to the direction of rotation R , and a plurality of angular position ranges where this total torque M_B exerted by the cams 23,24 on the camshaft 27 goes in the direction of rotation R .

When the timing chain 31 slackens on the traction side 31a between
25 the driven sprocket 33 and the driving sprocket 32, the phase shift Δt between the angular position of the driving shaft and that of the camshaft 27 may decrease and possibly lead to an underestimate of the wear of the transmission mechanism based on this phase shift. Going back to Fig. 3, the time intervals during which the transmission mechanism is tautened
30 by the torque exerted on the camshaft 27 by the cams 23, 24, are denoted by t_B . These time intervals correspond to angular position ranges α_B wherein the cams 23, 24 exert together a torque M_B on the camshaft 27 in a retard direction opposite to a direction of the rotation R transmitted to the camshaft 27 by the transmission mechanism.
35 Consequently, if the electronic monitoring device 40 determines, in step S120 of the method illustrated with the flowchart of Fig. 4, that the

angular position of the camshaft 27 is not within the angular position range α_B , the process may be ended and/or cycled back to the start. On the other hand, if the electronic monitoring device 40 determines in step S120 that the angular position of the camshaft 27 is within the angular position range α_B , the process advances to step S130, wherein the phase shift Δt may be calculated as a time lag between the start of a pulse p_1 in camshaft angular position signal V_1 and the start of a corresponding pulse p_2 in driving shaft angular position signal V_2 .

To determine excess wear of the transmission mechanism, a plurality of phase shifts Δt calculated over successive cycles of the method illustrated by the flowchart of Fig. 4 may be averaged, and the resulting average phase shift Δt_{ave} compared with a predetermined threshold Δt_{maxave} .

Consequently, the determination in step S120 of the method illustrated in Fig. 4 may prevent an underestimate of the wear of the transmission mechanism due to transient slackening of the timing chain 31 when the total torque M_B exerted by the cams 23,24 on the camshaft 27 is not opposed to the direction of rotation R , and ensure that the phase shift Δt is used to determine excess wear only when the timing chain 31 is taut on the traction side 31a.

Those skilled in the art will recognize that the present invention may be manifested in a variety of forms other than the specific embodiment described and contemplated herein. Accordingly, departure in form and detail may be made without departing from the scope of the present invention as described in the appended claims.

CLAIMS

1. Method for monitoring wear of a transmission mechanism transmitting rotation (R) of a driving shaft to a camshaft (27) driving one
5 or more cams (23,24), comprising the steps of:
receiving a driving shaft angular position signal (V_2) according to a driving shaft angular position;
receiving a camshaft angular position signal (V_1) according to a camshaft angular position;
10 determining, based on the camshaft angular position signal (V_1), whether the camshaft angular position is within a predetermined range, narrower than a full rotation, wherein the one or more cams (23,24) exert a torque (M_B) on the camshaft (27) in a retard direction opposite to a direction of the rotation (R) transmitted to the camshaft (27)
15 by the transmission mechanism; and
calculating a phase shift (Δt) between the driving shaft angular position signal (V_2) and the camshaft phase position signal (V_1).
2. Method according to any one of the previous claims, wherein
20 the transmission mechanism comprises a timing chain (31).
3. Method according to any one of the previous claims, wherein the one or more cams (23,24) drive inlet and/or outlet valves (21,22) of an internal combustion engine (20).
25
4. Method according to claim 3, wherein the driving shaft is a crankshaft (28) of the internal combustion engine (20).
5. Method according to any one of the previous claims, wherein
30 the driving shaft angular position signal (V_2) is a pulse signal generated by a passage, in a vicinity of a driving shaft angular position sensor (35), of one or more beacons rotating with the driving shaft.
6. Method according to any one of the previous claims, wherein
35 the camshaft angular position signal (V_1) is a pulse signal generated by a

passage, near a camshaft angular position sensor (36), of one or more beacons rotating with the camshaft (27).

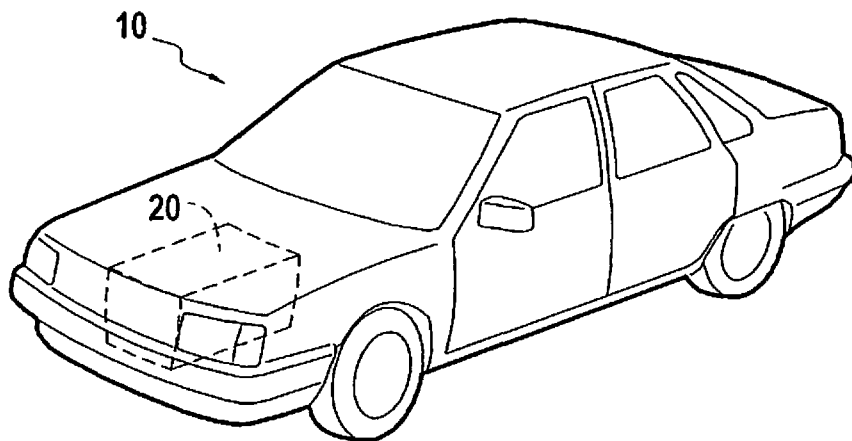
7. Electronic monitoring device (40) configured to carry out the
5 method according to any one of the previous claims.

8. Internal combustion engine (20) comprising:
a camshaft (27) with one or more cams (23,24) for driving inlet
and/or outlet valves (21,22) of the internal combustion engine (20);
10 a transmission mechanism for transmitting rotation from a
driving shaft to the camshaft (27);
one or more sensors (35,36) for generating a driving shaft
angular position signal (V_2) and a camshaft angular position signal (V_1);
and
15 the electronic monitoring device of claim 7, connected to said
one or more sensors (35,36), for monitoring the wear of the transmission
mechanism.

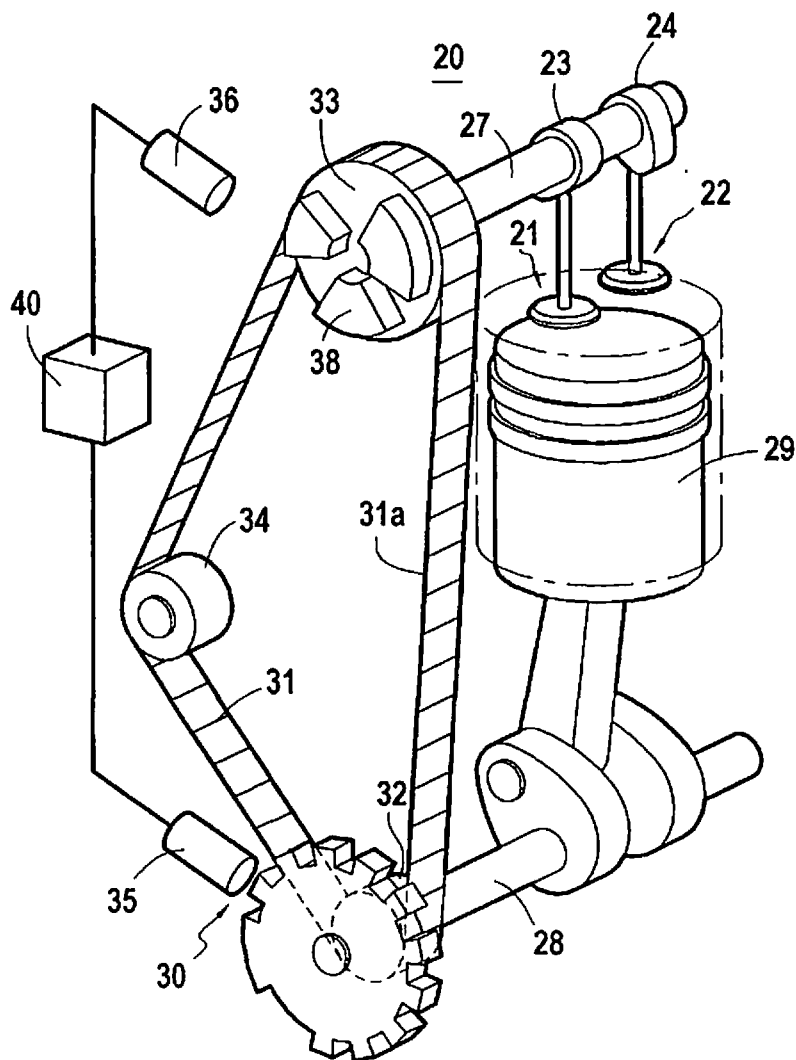
9. Vehicle (10) comprising an internal combustion engine (20)
20 according to claim 8.

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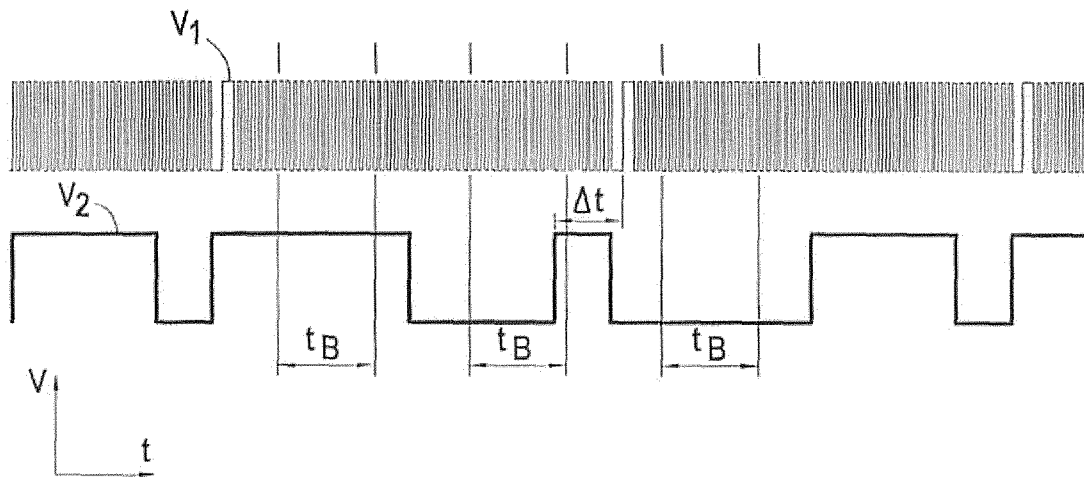
[Fig. 1]



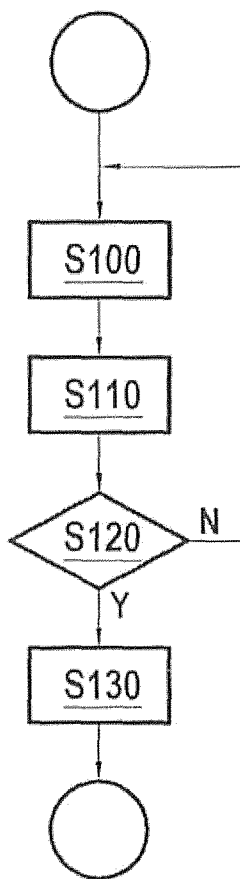
[Fig. 2]



[Fig. 3]



[Fig. 4]



[Fig. 5A-5B]

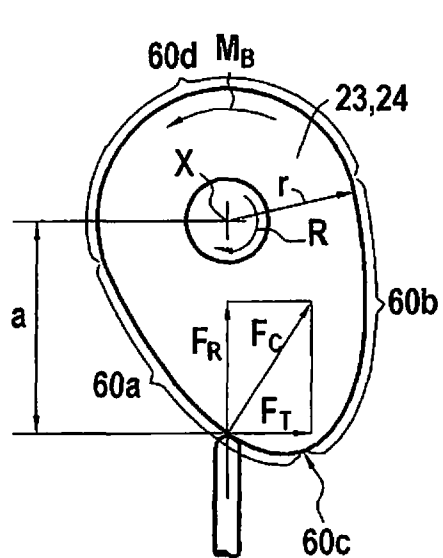


Fig. 5A

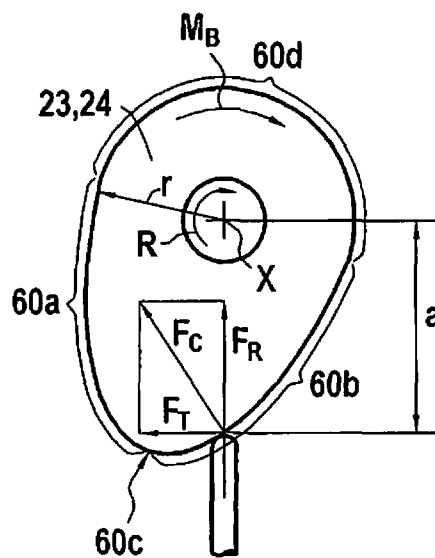


Fig. 5B

[Fig. 6A-6B]

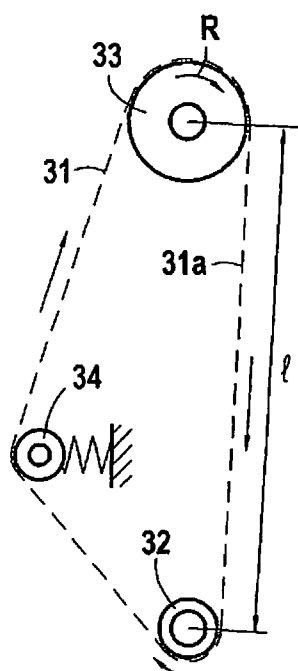


Fig. 6A

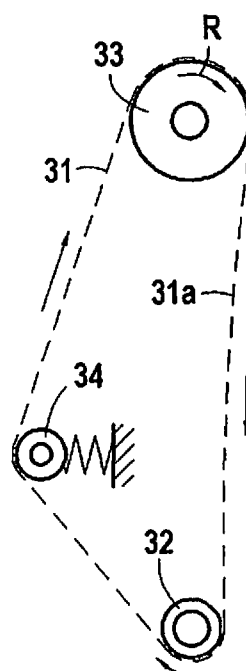


Fig. 6B

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/053418

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01M13/023 F01L1/02 F02B77/08 F16H7/00
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)
G01M F16H F01L F02B

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.
X	US 2009/139478 A1 (DELL HEIKO [DE] ET AL) 4 June 2009 (2009-06-04) abstract paragraphs [0006], [0007], [0009], [0036] figure 1	1-9
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Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

29 October 2019

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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