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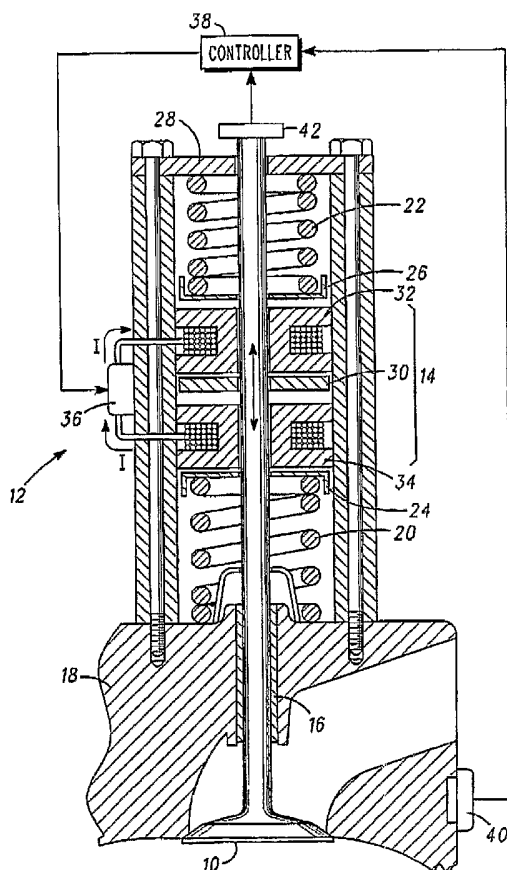
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[Continued on next page]

(54) Title: VALVE OPERATION IN AN INTERNAL COMBUSTION ENGINE



(57) Abstract: An apparatus and method for operating a plurality of valves in an engine uses valve actuators to move each valve. Accelerometers are used to detect acceleration of the valves and particularly the moment when they seat. A knock sensor detects an acoustic impulse made by the valves when they seat. A controller correlates signals from the sensor and accelerometers, wherein a signal from the sensor that correlates in time with a signal from an accelerometer indicates seating of the respective valve, which indicates a closure of the respective valve. The controller measures a magnitude of the acoustic impulse to be used as feedback in controlling the operation of the respective valve actuator, and provide softer landings of the valve.



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VALVE OPERATION IN AN INTERNAL COMBUSTION ENGINE

FIELD OF THE INVENTION

5 The present invention relates generally to operating valves on an internal combustion engine. More specifically, the invention relates to a technique for reducing valve noise during engine operation.

BACKGROUND OF THE DISCLOSURE

10

The trend in internal combustion engines is to increase efficiency. This has necessitated a move away from engines with fixed, cammed timing towards engines with variable timing, such as is available in camless engines. Instead of the mechanical or mechanical-hydraulic valve train systems of cammed engines, camless
15 engines can use an Electronic Valve Actuator (EVA) and Electro-Hydraulic Valve Actuator (EHA) to operate valves with almost any timing imaginable. However, such electrically dependant valve actuator systems present problems with closure detection and soft landing control. The use of EVA and EHA systems require control and diagnostics of the impact velocity and closure time of the valves. This is required for
20 valve durability, air flow control, and noise, vibration and harshness (NVH) performance.

Impediments to higher volume application of electrically driven (EVA) and electrically actuated and hydraulically driven (EHA) systems is its relatively high system cost. One of the factors causing this high cost is the requirement for closed
25 loop correction of the actuator and using one proximity sensor per actuator. In addition, the support systems for these individual sensors further increase cost because of the number of connectors, wiring, control blocks, integration, etc. required with this approach.

What is needed is lower cost approach for detecting valve closure and
30 operating EHA and EVA valve actuators. In particular, it would be of benefit to provide an apparatus and method of using indirect measurements of valve closure and

measuring movements of multiple actuators along with control and diagnostic methods using these measurements.

5

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the present invention, which are believed to be novel, are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may best be understood by making reference to the following description, taken in conjunction with the accompanying drawings, in the several figures of which like reference numerals identify identical elements, wherein:

FIG. 1 shows a cross-sectional view of a valve actuation apparatus, in accordance with the present invention;

FIG. 2 shows a schematic diagram of a circuit for controlling valves, in accordance with the present invention;

FIG. 3 shows a graphical representation of an first test of a V6 engine, in accordance with the present invention;

FIG. 4 shows a graphical representation of a second test of a V6 engine, in accordance with the present invention;

FIG. 5 shows a table of statistics for the graph of FIGs. 3 and 4;

FIG. 6 shows a table of statistics for a V8 engine, in accordance with the present invention; and

FIG. 7 is a flow chart showing a method, in accordance with the present invention.

25

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

The present invention describes an apparatus and method of using a single indirect measurement of closure for a plurality of valves, along with a low cost sensor per actuator to measure valve movement, along with control and diagnostic techniques

30

using these measurements. In this way, the present invention provides a lower cost approach for detecting valve closure and operating EHA and EVA valve actuators in a camless internal combustion engine.

5 In the example below an electrically driven valve actuator will be described, wherein an electromagnetic field is used for opening and closing a valve. Intake and exhaust valves are substantially identical in construction, and the present invention is applicable to both. In addition, multiple intake or exhaust valves can be accommodated per each cylinder.

10 Referring to FIG. 1, a valve 10 is shown coupled with a valve actuator 12. An electromagnetic solenoid 14 is provided in the valve actuator 12. The solenoid is operable to move the valve 10 in an upward or downward position, depending upon its polarity. The valve 10 is slip fit in a valve guide 16 installed in a cylinder head 18. The valve acts against two springs 20, 22 as it moves upward or downward, wherein the springs are always under some amount of compression. The valve 10 is shown in
15 the closed position wherein one spring 22 is under more compression than the other spring 20.

A lower spring retainer 22 is fixed to the valve 10 and is used to contain the first spring 20 against the cylinder head 18, wherein the spring provides a force to close the valve 10. An upper spring retainer 26 is fixed to the valve 10 and is used to
20 contain the second spring 22 against a cap 28 that is fixed in relation to the cylinder head 18, wherein the spring provides a force to open the valve 10.

The solenoid 14 has an armature 30 made of a high-magnetic-permeability material that is fixed to the valve 10. Fixed electromagnetic coils 32, 34 are positioned above and below the armature 30, and are used to drive the armature 30
25 therebetween. The electromagnetic coils 32, 34 have sufficient force to assist the springs 20, 22 in fully opening or closing the valve 10. A solenoid driver 36 can be used to supply power to the coils 32, 34, under control of a controller 38.

In operation, the controller 38 can signal the driver 36 to supply current to the coils 32, 34 to drive the armature 30, and subsequently the valve 10, in an upwards or
30 downwards motion. Preferably, the controller provides a variable signal such that the valve opens or closes in a controlled manner (i.e. at a controlled variable velocity). The signal can be an analog or digital signal for interpretation by the driver. The

electrical operation of the actuator 12 is known in the art and will not be presented here for the sake of brevity. In addition, the operation of an electro-hydraulic actuator is also known in the art, and can be used in a corresponding manner in the present invention.

5 Although the apparatus as shown is symmetrical there are instances when the opening force and closing force will be different, necessitating an asymmetrical actuator configuration. For example, an exhaust valve will require a very large opening force, which will change with engine conditions and timing, to open the valve against a large cylinder pressure after a combustion stroke, whereas the closing force
10 will be much less. An intake valve will generally have substantially equal opening and closing forces. Due to the variability in conditions and timing, there can be a problem with the valve seating against the head too harshly causing undesirable noise and vibration. In addition, the large forces involved in the engine, high currents driving the actuator, and the movement of components within the valve actuator,
15 cause an environment of high noise in the vicinity of the valve.

 The present invention solves this problem by providing redundant sensing means to detect valve closure and to adjust closure as needed to reduce noise and vibration. A sensor 40, such as an acoustic sensor, is used to detect the acoustic impulse made by the valve 10 upon seating (closure). In practice, the acoustic sensor
20 40 is an accelerometer mounted on the block or head 18 of an internal combustion engine to perform the measurement of the magnitude of the valve closing impact via measure of transmitted vibrations for EVA and EHA applications, in accordance with the present invention. Typically, these measurements are used as inputs for monitoring control for EVA and EHA systems by the controller 38. Preferably, a
25 common and relatively inexpensive accelerometer, such as the ones currently used for combustion knock detection, can be used for determining valve closing time and valve closing velocity, thereby saving an extra cost. In practice, to help discriminate from extraneous noise, the sensor 40 should be located in proximity to the engine valves and away from other noise sources. Therefore, in the example of a V8 engine, it may
30 be necessary to use two acoustic sensors, one for each bank of cylinders.

 An accelerometer 42 is disposed on each of the (EVA or EHA) actuators. For example, the accelerometer 42 can be coupled to the valve itself 12 (as shown),

springs 20,22, armature 30, or any available part of the valve actuator 12. Any of these are acceptable since these devices are mechanically coupled in motion. For best response it is preferable to mount the accelerometer 42 to the valve itself. However, there may be temperature, manufacturing, or assembly issues that might make this impractical. The accelerometer 42 is operable to detect movement of the valve 10, and in particular when the valve stops moving (valve closure). Although the valve also stops moving when the valve is fully open, this open position would not provide an acceleration signal as large as when the valve makes an abrupt stop upon closing. In addition, the knock sensor 40 would not detect an acoustic signal upon the valve opening, but only upon seating. The present invention takes advantage of this by correlating the signal from the knock sensor 40 and the accelerometer 42 in the controller 38 to confirm a valve closure, wherein a signal from the sensor 40 that correlates in time with a signal from the accelerometer 42 indicates a seating of the valve 10 associated with that particular accelerometer. Moreover, the use of multiple accelerometers with only one knock sensor is sufficient to detect closure of any valve. In addition, simultaneous closure of multiple valves can also be detected as will be detailed below.

Referring to FIG. 2, in a preferred embodiment, the apparatus further includes a timing detector 44 that is used to decide when correlation of the signals from the sensor 40 and any accelerometer 42 is performed. For example, the timing detector 44 can provide a timing window about a predetermined point when a particular valve is to seat. The timing detector can typically be a crankshaft position sensor, or can be generated by a controller 38. Timing of the engine is used to estimate a valve impact for windowing the measurements of the accelerometer(s) signals. In this way, a particular valve closure is only detected during the time when it can actually be measured, thereby reducing problems from false detections, due to extraneous noise for example. Using the indirect measurement of an accelerometer 42 for valve closure recognition, located at the correct timing position for closure from the timing detector 44, provides precise windows of detection to enable the measurement of the harshness of any particular valve closure by the acoustic sensor 40. In practice, the controller 38 can correlate the signals to confirm a true valve closure, obtain the magnitude of the acoustic impulse of the closure, and use the magnitude as feedback to modify the

valve actuation control to provide a softer closure (i.e. reduced impact velocity), thereby mitigating NVH problems.

In practice, the accelerometer(s) signals are windowed by a multiplexer 46, and can be filtered 48. Signal peaks are then determined in a peak detector 50. Any
5 signal peaks about a threshold, as determined by a comparator 52, are indicative of a valve closure that is too harsh. Alternatively, the controller 38 can compare the peak values to a threshold directly, without the need for a separate comparator 52. The peak values along with timing data 44 (e.g. crankshaft encoder data) are used to determine location (crankshaft angle) of valve impact. A combination of the
10 accelerometer(s) magnitude and signal energy is used to determine impact velocity. Impact velocity can be estimated and the requirements for subsequent soft landing can be determined by the controller 38. Thereafter, the controller can decrease the rate of movement (velocity) of the valve at the point of seating to reduce the magnitude of the acoustic impulse therefrom to below the threshold level.

15 Optionally, the controller can measure a characteristic frequency of the acoustic impulse to further discriminate a valve seating from extraneous noise. Further, where two valve closures overlap, either the energy (magnitude) of the signal will increase (compared to a single valve or due to a location relative to the accelerometer) or the frequency of the signals will be different, due to differences in
20 structure around the valve seat and differences in location relative to the sensor 40, which can be identified by the controller. The valve closing timing information would be an input to the valve actuation control algorithm in the controller 38 to control the next closing event and window for valve closure detection of the appropriate valve 10.

Since an energy of the valve closing signal can be measured, this energy can
25 be used as an input for soft landing control of the actuator. The magnitude of the valve closing signal measures how hard the valve landed for this closure event and can be used to precisely control the actuator current to optimize how hard the valve lands for next closure event. Further, this signal can be combined with an open loop speed/load function to provide a closed loop functionality. The information provided
30 by the above described techniques can also be used to perform diagnostics on the actuator/driver when the results do not meet expected criteria.

FIG. 2 shows a specific embodiment of the present invention to provide signal conditioning for the accelerometers and for determination of location of valve closure (CA_VC) and valve closing energy. One or more of the signal conditioning blocks 48, 50, 52 may be used depending upon the number of cylinders, number of valves, number of sensors, which sensors are mapped to which cylinder and possible overlap in time/crank angle of valve closing events.

The engine controller or valve controller 38 performs the close loop control and diagnostics of the individual EVA or EHA valve actuators. Based upon engine timing determined from the crank position sensor (timing detector 44), the controller 38 selects which valve(s) to be monitoring through Valve Select. There is a one-dimensional table used by the controller 38 to map the accelerometers 42 to the given valve 10. This table outputs the Valve Select to the multiplexer block 46 which selects the accelerometer (1, 2 ... N) for processing for that valve (1, 2 ... N). If more than one knock sensor 40 is used (not shown) then the table can include mapping information for which sensor is used for which valve.

The controller 38 also estimates the valve closing position of the valve(s) currently subject to monitoring by the processing blocks shown. This estimated valve closure position is based upon the drive commands to the valves, previously determined valve closure positions measured from these blocks, and the crankshaft position sensor, CPS (44). The CPS sensor is used to determine crankshaft angle position for measurement window generation 54 and interpolation in the peak detector 50. The window generation block 54 can generate multiple enable windows with individual programmable timing advances relative to estimated valve closure produced by the controller 38 and durations. The enable windows generated can be used to isolate the signal for peak detection; measure the energy of the signal during a period when a reference value can be determined for normalizing the signal; and to measure the energy of the signal during the impact of the valve, wherein the latter can be adapted in real-time based upon the peak location determined by the controller 38.

By adjusting the windows relative to an estimated valve closure, the window position can be narrowed and adapted to improve the signal to noise. Tests have confirmed that window durations of 5° and narrower can be used. The output of the multiplexer 46 is the multiplexed accelerometer signal. This output can optionally be

filtered 48 by an anti-aliasing filter to remove out-of-band signals to improve signal to noise. The multiplexed and filtered signal is then converted from an analog signal to a digital signal by an analog-to-digital converter which can be further processed by an infinite-impulse-response or finite-impulse-response filtering. For example,
5 determining the location and amplitude of the peak for valve closure can be enhanced by finite-impulse-response filtering, and determining the signal energy and a reference signal strength for normalization can be enhanced by either infinite-impulse-response or finite-impulse-response filtering

In particular, determining the location of valve closure can begin with a digital
10 filter that is preferably an FIR filter with linear phase delay and constant time delay to enable correction of the location of valve closure by the filter delay. After the digital filter, the signal is rectified. (Optionally, this rectification could be eliminated and the maximum and minimum location in the peak detection block be used. This may improve the determination of valve closure by examination of the sign and magnitude
15 of the peak as the valve closure should consistently provide, at a given condition, a repeatable signature of acceleration). The peak detector 50 has inputs of the conditioned accelerometer signal and window enable signal 54. The location and amplitude of the peak is then determined. The peak is the maximum of the input signal during the measurement window. Optionally, the peak can be normalized. The
20 location of the peak is determined by interpolation from the start and end of the window. The location of the valve closure can also be corrected for the signal processing delay (of which the filter is a major contributor), and output to the controller 38 for use in closed loop control of the valve.

The same filter 48 and peak detection 50 blocks can be used to process the
25 knock signal from the sensor 40. In this case, the filter 48 can isolate the signal due to the valve closure and remove extraneous noise sources such as vibration caused by combustion knock. The signal can be rectified (and optionally it can be squared) for processing. If linearization is desired, integration of the signal can also be done during two window periods to normalize the energy and peak signals. The
30 integration is averaged on a per sensor basis to remove event-to-event based variability in the reference measurement. Further, the output of the integration can be

normalized by a valve specific normalization value, which can then be used as an input to the closed loop control of the valve.

Alternatively or in conjunction with the above normalization, the signals maybe normalized or calibrated by activating the valves before the start of engine rotation or at low engine rotation speeds (such as cranking). The above outputs can be
5 used in conjunction with estimation and calculation techniques and timing detector as a diagnostic and or to improve the performance of the system when used in conjunction with the other indirect measurement techniques.

Multi-axis accelerometers maybe used to improve signal and separation
10 between valve generated signal and other sources of signal. Signals from the two or more axes may be processes as above or the signals may be combined and processed as a vector signal (magnitude and direction).

In operation, the processing for the location of valve closing and for the impact energy occur in parallel. Alternatively, the processing for the location of valve closing
15 could be performed first and then this location could be used to determine the window location. Buffering of the signal would then be used so that these calculations could be performed in series.

The present invention also includes a method for operating a plurality of valves in an engine driven by respective valve actuators. Referring to FIG. 7, the
20 method includes a first step 100 of detecting an acceleration of each of the respective plurality of valves. Preferably, this step includes multiplexing the acceleration signals onto a common signal line.

A next step 102 includes sensing an acoustic impulse made by the valves when they seat.

25 A next step 104 includes determining a timing for operation of the valves.

A next step 106 includes correlating signals from the detecting and sensing steps, wherein a signal from the sensor that correlates in time with a signal from an accelerometer indicates seating of the respective valve. In particular, the correlating step 106 provides correlation of the signals from the sensor and accelerometer during
30 a timing window about a predetermined timing point when the valve is to seat. This step can also include measuring a characteristic frequency of the acoustic impulse to further discriminate a valve seating from extraneous noise.

A next step 108 includes measuring a magnitude of the acoustic impulse from the sensing step to provide feedback. A magnitude of an acoustic impulse measured above a threshold level indicates an unacceptably harsh closure of the valve. A magnitude of an acoustic impulse measured above a second threshold level indicates an unacceptably harsh closures of at least two valves simultaneously.

A next step 110 includes actuating the respective valve actuator using the feedback from the measuring step in a way to reduce a magnitude of impact at valve seating. This step includes decreasing the rate of movement of the valve at seating to reduce seating impact.

A next step 112 includes repeating the above steps until the magnitude of the acoustic impulse at subsequent sensing steps is below a threshold level.

Example

Tests were conducted to determine the effect of the present invention using variable cam timing (VCT) V6 engine to obtain the data discussed below. The engine was firing during the data acquisition. Data was obtained from instrument grade accelerometers at a 200 KHz sample rate to provide a high fidelity signal. The results below were obtained by implementation of the basic peak detection algorithm as described herein.

For each engine and operating condition the occurrence of valve closing for the most recent event was continuously predicted and detected.

FIG. 3 shows the results for the V6 engine under full timing retard. The window for detection was 30-60° ATDC. The calculated peaks occur at about 47.1° ATDC. As can be seen, the present invention detected valve closure near 47° after top-dead-center (ATDC) a large majority of the time, with occasional noise detections at 46°. These results indicate that the present invention correctly determines the closing angle to 0.5° standard-deviations. The window start and stop positions (degrees), filter frequencies (Hz), accelerometer and valve used, valve closure mean and standard deviation (degrees) are listed in FIG. 5. As can be seen, appropriate filtering and/or windowing of +/- 1.0° would provide very accurate results. The intake valve closure was advanced by 30° and the test was repeated.

FIG. 4 shows the reported intake valve closing event from the peak detector. The window for detection was 0-30° ATDC. The calculated peaks occur at about 17.3° ATDC. As can be seen, the present invention detected valve closure near 17° after top-dead-center (ATDC) a large majority of the time, with only one noise
5 detected at 16°. The present invention was able to detect the 30° valve closure shift. These results indicate that the present invention again correctly determines the closing angle to 0.5° standard-deviations. The window start and stop positions (degrees), filter frequencies (Hz), accelerometer and valve used, valve closure mean and standard deviation (degrees) are listed in FIG. 5.

10 Similar results were obtained for both banks of cylinders. Tests were also conducted for a variable cam timing (VCT) V8 engine with significantly improved results. The window start and stop positions (degrees), filter frequencies (Hz), accelerometer and valve used, valve closure mean and standard deviation (degrees) are listed for the V8 engine in FIG. 6.

While the present invention has been particularly shown and described with reference to particular embodiments thereof, it will be understood by those skilled in the art that various changes may be made and equivalents substituted for elements thereof without departing from the broad scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed herein, but that the invention will include all embodiments falling within the scope of the appended claims.

CLAIMS:

What is claimed is:

1. An apparatus for detecting closure of a valve, the apparatus comprising:
5 a valve actuator operable to move the valve,
an accelerometer operable to detect movement of the valve;
a sensor operable to detect an acoustic impulse made by the valve when it seats;
and
a controller coupled to the accelerometer and sensor, the controller correlates
10 signals from the sensor and accelerometer, wherein a signal from the sensor
that correlates in time with a signal from the accelerometer indicating seating
of the valve.
2. The apparatus of claim 1, wherein the sensor is an existing knock sensor in an
15 engine incorporating the valve.
3. The apparatus of claim 1, wherein the accelerometer is disposed on one of the
valve, valve actuator, and valve actuator solenoid.
- 20 4. The apparatus of claim 1, further comprising a timing detector being coupled to
the controller, wherein the controller only provides correlation of the signals from the
sensor and accelerometer during a timing window about a predetermined point when
the valve is to seat.
- 25 5. The apparatus of claim 1, wherein the controller measures a characteristic
frequency of the acoustic impulse to further discriminate a valve seating from
extraneous noise.

6. The apparatus of claim 1, wherein the controller is coupled to control the valve actuator and the controller measures a magnitude of the acoustic impulse to be used as feedback in controlling the operation of the valve actuator.

5 7. The apparatus of claim 6, wherein the controller decreases the rate of movement of the valve at seating to reduce the magnitude of the acoustic impulse therefrom to below a threshold level.

8. An apparatus for operating a plurality of valves in an engine, the apparatus
10 comprising:
a plurality of valve actuators coupled to the plurality of valves, each valve actuator operable to move a respective valve,
a plurality of accelerometers operable to detect an acceleration of the respective plurality of valves;
15 a knock sensor operable to detect an acoustic impulse made by the valves when they seat; and
a controller coupled to the valve actuators, accelerometers and sensor, the controller correlates signals from the sensor and accelerometers, wherein a signal from the sensor that correlates in time with a signal from an
20 accelerometer indicates seating of the respective valve, which indicates a closure of the respective valve, and wherein the controller measures an magnitude of the acoustic impulse to be used as feedback in controlling the operation of the respective valve actuator.

25 9. The apparatus of claim 8, further comprising a timing detector being coupled to the controller, wherein the controller only provides correlation of the signals from the sensor and accelerometer during a timing window about a predetermined point when the valve is to seat.

10. The apparatus of claim 8, wherein the controller measures a characteristic frequency of the acoustic impulse to further discriminate a valve seating from extraneous noise.

5 11. The apparatus of claim 8, wherein the controller decreases the rate of movement of the valve at seating to reduce seating impact and subsequently the magnitude of the acoustic impulse therefrom to below a threshold level.

10 12. The apparatus of claim 8, wherein a magnitude of an acoustic impulse that is measured above a second threshold level indicates closures of at least two valves at substantially the same time.

15 13. The apparatus of claim 8, further comprising a signal line commonly coupled to at least two accelerometers, and a multiplexer coupled to the signal line, wherein the multiplexer multiplexes the signals from the at least two accelerometers to the controller.

14. A method for operating a plurality of valves in an engine driven by respective valve actuators, the method comprising the steps of:
20 detecting an acceleration of the respective plurality of valves;
 sensing an acoustic impulse made by the valves when they seat;
 correlating signals from the detecting and sensing steps, wherein a signal from the sensor that correlates in time with a signal from an accelerometer indicates seating of the respective valve;
25 measuring a magnitude of the acoustic impulse from the sensing step to provide feedback; and
 actuating the respective valve actuator using the feedback from the measuring step in a way to reduce a magnitude of impact at valve seating.

15. The method of claim 14, further comprising a step of determining a timing for operation of the valves, wherein the correlating step only provides correlation of the signals from the sensor and accelerometer during a timing window about a
5 predetermined timing point when the valve is to seat.

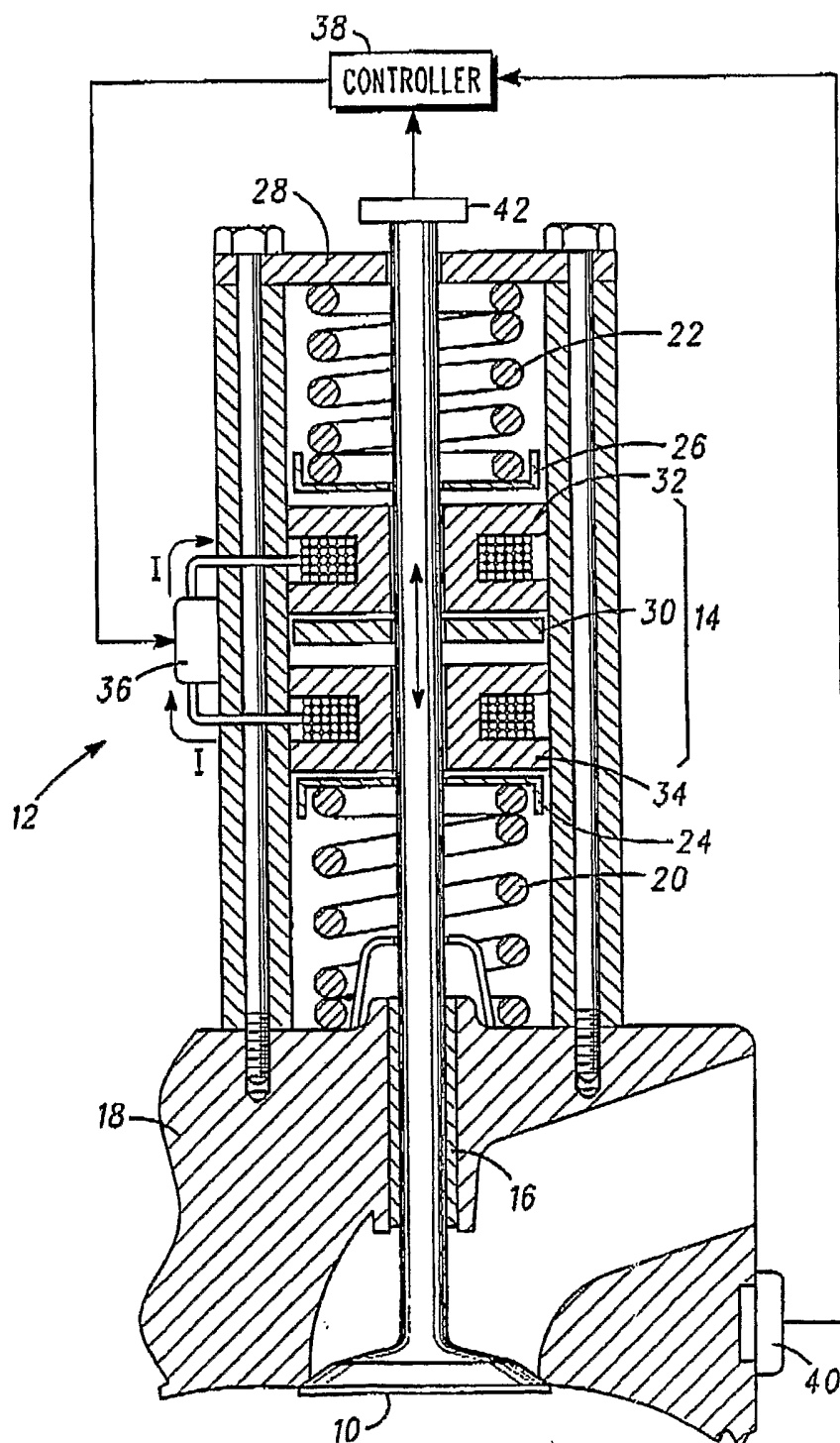
16. The method of claim 14, wherein the correlating step includes measuring a characteristic frequency of the acoustic impulse to further discriminate a valve seating from extraneous noise.
10

17. The method of claim 14, wherein the actuating step includes decreasing the rate of movement of the valve at seating to reduce seating impact, and further comprising the step of repeating the steps until the magnitude of the acoustic impulse at subsequent sensing steps is below a threshold level.
15

18. The method of claim 14, wherein, in the measuring step, a magnitude of an acoustic impulse measured above a second threshold level indicates closures of at least two valves.

20 19. The method of claim 14, wherein the detecting step includes multiplexing the acceleration signals onto a common signal line.

1/4

**FIG. 1**

SUBSTITUTE SHEET (RULE 26)

2/4

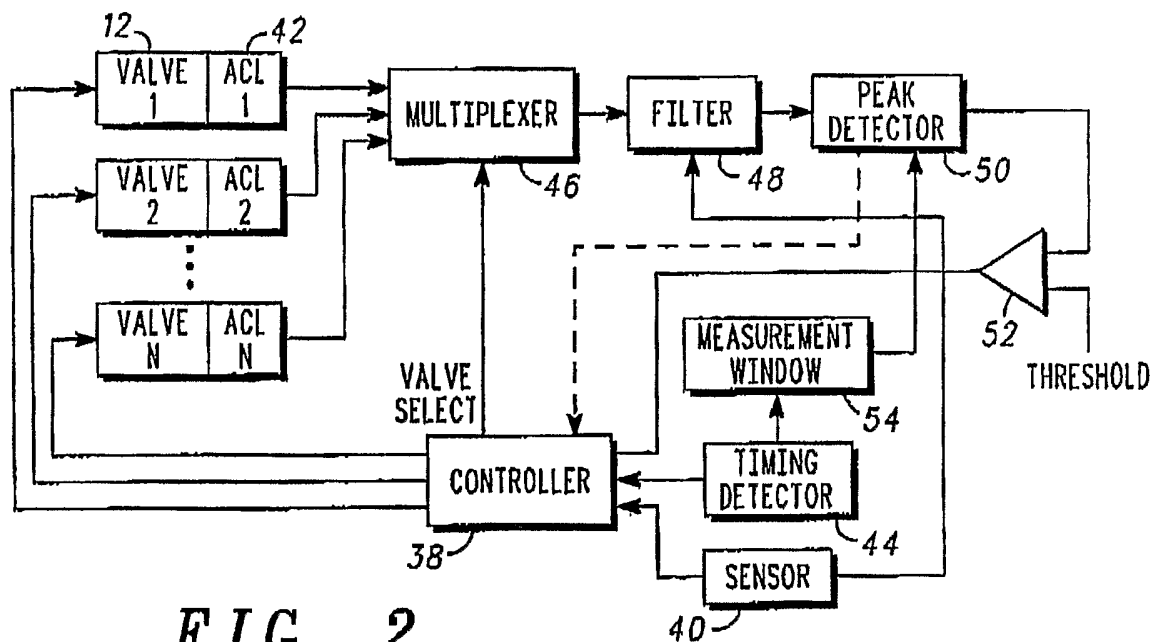


FIG. 2

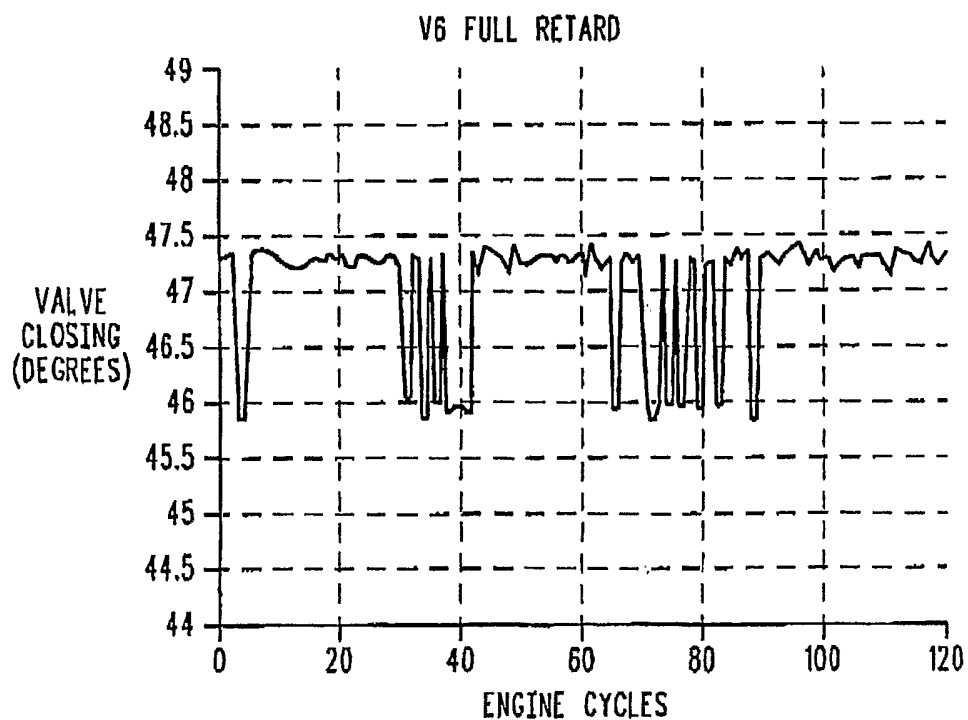
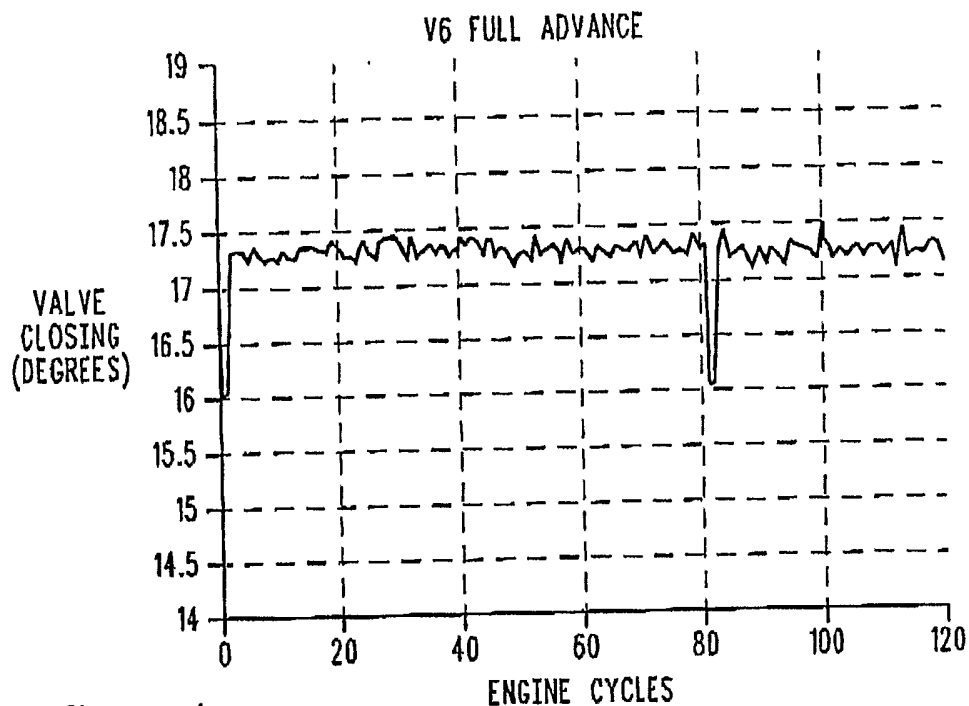


FIG. 3

SUBSTITUTE SHEET (RULE 26)

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**FIG. 4**

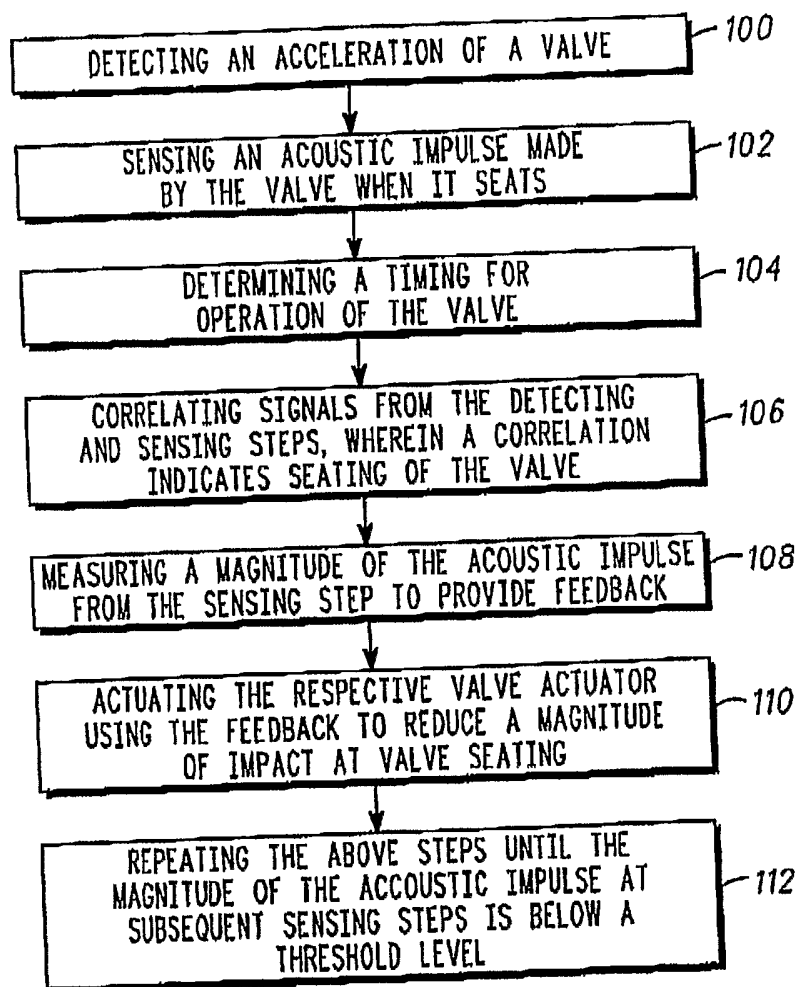
3.0L V6		
RUN No.	RET.	ADV.
WIN START	30	0
WIN STOP	60	30
HIGH PASS	500	500
LOW PASS	4000	4000
ACC No.	4	4
VALVE	INTAKE	INTAKE
CYL. 1 MEAN	47.0852	17.2845
CYL. 1 STD.	0.4722	0.1694

FIG. 5

4.6L V8		
RUN No.	RET.	ADV.
WIN START	80	70
WIN STOP	100	90
HIGH PASS	500	500
LOW PASS	4000	4000
ACC No.	5	5
VALVE	INTAKE	INTAKE
CYL. 1 MEAN	97	78
CYL. 2 MEAN	97	78
CYL. 3 MEAN	97	78
CYL. 4 MEAN	97	78
CYL. 5 MEAN	97	78
CYL. 6 MEAN	97	78
CYL. 7 MEAN	97	78
CYL. 8 MEAN	97	78
CYL. 1 STD.	0.11	0.1
CYL. 2 STD.	0.22	0.13
CYL. 3 STD.	0.14	0.11
CYL. 4 STD.	0.08	0.08
CYL. 5 STD.	0.14	0.14
CYL. 6 STD.	0.09	0.1
CYL. 7 STD.	0.07	0.1
CYL. 8 STD.	0.12	0.11

FIG. 6
SUBSTITUTE SHEET (RULE 26)

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*FIG. 7*

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US06/00711

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **F01L 9/04**(2006.01);**F16K 31/02**(2006.01)

USPC: 123/90.11

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)

U.S. : 251/129.01,129.15,129.16

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)

EAST sensor, valve, signal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6,349,685 B1 (Kolmanovsky et al.) 26 February 2002 (26.02.2002), see entire document.	1-11, 14-17
Y	US 6,167,852 B1 (Kamimaru et al.) 02 January 2001 (02.01.01), see entire document.	1-11, 14-17
A	US 6,374,813 B1 (Iida et al.) 23 April 2002 (23.04.2002), see entire document.	1-19

☐ 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	"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
"E" earlier application or patent published on or after the international filing date	"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
"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)	"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
"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	"&" document member of the same patent family

Date of the actual completion of the international search

11 April 2006 (11.04.2006)

Date of mailing of the international search report

24 MAY 2006

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