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(54) **Cylinder individual torque correction**

(57) It is described a method to cause the torques produced by each cylinder (10) of a multi-cylinder internal combustion engine to be substantially equal, said engine including a rotatable crankshaft (20) being driven by combustions in combustion chambers (12, 14) of said cylinders, wherein a pressure in each of said combustion chambers (12, 14) is measured and an amount of torque produced by each of said cylinders is determined based on the pressure measurements, wherein further the pressure is measured intermittently in sample steps (j), thus generating pressure sample value (p_j) for each sample step (j) determining a value (V'_j) of a change of the cylinder's combustion chamber volume for each sample step and a torque value (T) each cylinder produces during a certain rotation angle ($\Delta\alpha$) of the crankshaft (20) is calculated by multiplying each pressure sample value with the respective volume change value and by summing up all such obtained products and multiplying the result of the sum by $\Delta\alpha/4\pi$.

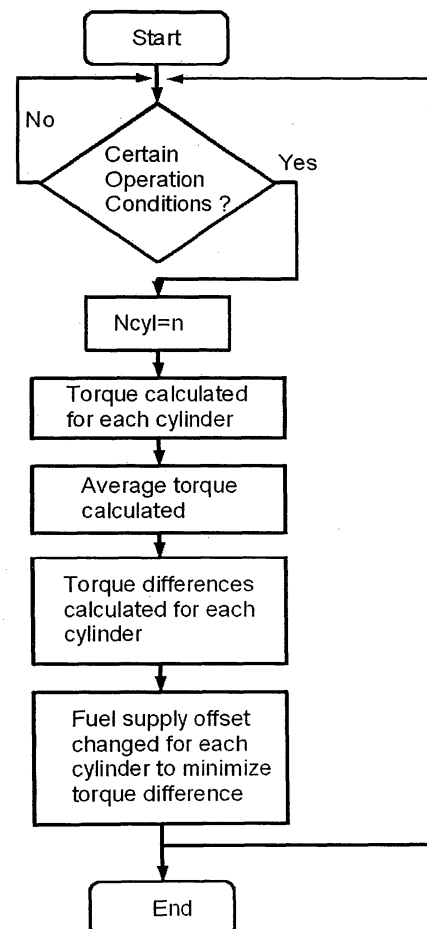


FIG. 2

Description

[0001] The invention relates to a method and an apparatus for balancing the cylinders of an multi-cylinder internal combustion engine to cause each cylinder to produce a substantially equal torque by determining the torque produced by each cylinder based on measurements of the pressure within the cylinders' combustion chambers.

[0002] Cylinders of internal combustion engines typically co-operatively and individually create a torque which is applied to a crankshaft and which e.g. causes an automobile to move. However, due to structural variances of each of the cylinders and variations in the fuel supply to the combustion chambers, the torque produced by each of the cylinders is generally not the same, which causes the cylinder to be "out of balance". Such unbalance causes or created an undesirable crankshaft oscillation and, in case of automotive engines, drive train resonances which not only reduce the operating live of the engine and any drive train but also an uncomfortable performance of the engine when installed in an automobile. Moreover, engines with unbalanced cylinders have an increased fuel consumption and are disadvantageous with respect to emissions created. It is therefore desirable to have the torque produced by each of the cylinders be substantially equal and to have the cylinders balanced, thus.

[0003] EP 1061242 A1 discloses a method and an apparatus for such cylinder balancing. According to this disclosure, the pressure within each combustion chamber is measured and the torque produced by each cylinder is calculated. However, the calculations proposed by this document require a substantial amount of computing power. With computing power in controllers of internal combustion engines are to be shared for several functions controlled within the engine, the approach of EP 1061246 A2 is disadvantageous.

[0004] Therefore, the invention aims at providing an improved method and apparatus for balancing the cylinders of a multi-cylinder internal combustion engine with reduced computing power.

[0005] According to the present invention, there is provided a method to cause the torques produced by each cylinder of a multi-cylinder internal combustion engine to be substantially equal, said engine including a rotatable crankshaft being driven by combustions in combustion chambers of said cylinders, wherein a pressure in each of said combustion chambers is measured and an amount of torque produced by each of said cylinders is determined based on the pressure measurements, wherein further the pressure is measured intermittently in sample steps, thus generating pressure sample value for each sample step determining a value of a change of the cylinder's combustion chamber volume for each sample step and a torque value each cylinder produces during a certain rotation angle of the crankshaft is calculated by multiplying each pressure sample value with the respec-

tive volume change value and by summing up all such obtained products and multiplying the result of the sum by $\Delta\alpha/4\pi$.

[0006] The torque thus provided by the method can be used to balance the cylinders easily by comparing the torque values and unifying the cylinders by adjusting the fuel supply system accordingly.

[0007] Further according to the invention there is provided an apparatus which controls an multi-cylinder internal combustion engine and performs the method above.

[0008] The invention uses intermittently measured pressure values to determine a measure for the torque each cylinder contributes to the overall torque generated by the engine. The pressure is sampled in steps with a pressure sample value being, thus, obtained for each sample step. For each sample step a corresponding combustion chamber volume change value is determined. This is done on basis of the crankshaft position, either by calculation of by accessing a suitable map which holds the combustion chamber volume change as a function of the crankshaft position change. For each sample step, the combustion chamber volume change value is multiplied with the pressure sample value. The products are added, and the result is a basis for computing a cylinder individual torque value.

[0009] As torque values of in the above described embodiments indicated mean pressure values/IMEP may be used. This IMEP values are torque values according to the understanding on which this description is based.

[0010] All determinations and computations can be done on-line during the pressure measurement. To ease the computation load on a controller it is, however, advantageous to first record the pressure data and the data on the crankshaft positions and to perform the determinations and computations later. This "off-line" approach results in a slower procedure. As variations in the cylinder balance occur only on a long term scale, such slower process is unproblematic in most applications.

[0011] The present invention will now be described further, by way of example, with reference to the accompanying drawings, in which:

- Fig. 1 is a fragmented and block diagrammatic view of an automobile two-cylinder internal combustion engine,
- Fig. 2 is a flow diagram of a method used to balance the cylinder of the engine according to figure 1, and
- Fig. 3 and 4 show charts representing the effects of cylinder balancing.

[0012] Referring now to Figure 1, there is shown an automobile engine 10 according to a preferred embodiment of the invention. As shown, engine 10 includes several combustion cylinders having combustion chambers 12, 14. In each cylinder a piston 16, 18 is displaceable and coupled by connecting rods 26, 28 to arms 22, 24 of

a rotatable crankshaft 20. While a two-cylinder engine is shown, it should be appreciated that additional and substantially identical cylinders may be included within a typical automobile engine and that the foregoing invention is equally and substantially identically applicable to a multi-cylinder internal combustion engine having any plurality of cylinders or cylinder arrangements.

[0013] As further shown in Figure 1, each chamber 12, 14 respectively communicates with a conventional and commercially available fuel injector assembly 30, 32. Particularly, each injector 30, 32 is communicatively and selectively coupled to a source of gasoline or fuel 34 and selectively and controllably receives and injects fuel into the respective cylinders 12, 14. The injected fuel is typically mixed with a certain amount of ambient air, selectively traversing through an intake manifold 35. In the combustion chambers, this mixture is combusted due to compression (in case of Diesel engines) or by use of a spark plug (in case of Otto engines) or other types of combustion assemblies (not shown), thereby creating a certain pressure within each of the combustion chambers 12, 14 before being exhausted into an exhaust manifold 33.

[0014] Particularly, this created combustion pressure causes the respective pistons 16, 18 to displace during a combustion cycle from a top dead center to a bottom dead center with the pistons 16, 18 respectively moving away from the injectors 30, 32 and cause the rods 26, 28 to create a torque which rotates the crankshaft 20 in the direction of an arrow 21. In automotive applications the rotating crankshaft 20, which is normally deployed within a crank case 23, transfers the created rotational torque or force to an automobile drive train 29, thereby allowing the automobile to be driven. Of course, the engine's use is not limited to automotive applications but it can also be installed at any other vehicle or even at a fixed site.

[0015] A piston movement cycle is completed when the pistons 16, 18 return to their upper dead center during an exhaust cycle, as it is known to the person skilled in the art of 4-stroke engines. The movement of the pistons within the cylinders changes the volume of the combustion chambers 12, 14 in periodic cycles corresponding to crankshaft rotation.

[0016] As further shown in Figure 1, the engine 10 includes a controller 36 which is operating under stored program control and which is controllably and communicatively coupled to the fuel injectors 30, 32, and which is effective to control the amount of fuel fed to each of the chambers 12, 14. The controller 36 may comprise a conventional and commercially available microprocessor and the communication between controller 36 and the fuel injectors 30, 32 may occur by use of a data bus 37. In the described embodiment, the controller 36 is adapted to receive signals corresponding to the instantaneous speed of the engine, such signals being available, by way of example and without limitation, by use of a conventional tachometer bus (not shown) which is typically

present within the engine when the latter is installed in an automobile. The controller 36 is further coupled, e.g. via the bus 47, to conventional and commercially available sensors 41, 43 which respectively measure and provide the controller 36 with the pressure within crankcase 23 and the crank angle which will be described later.

[0017] The engine 10 further includes pressure sensors 38, 40 which are respectively resident within each of the combustion chambers 12, 14 and which each sense the pressure respectively and combustably created in each of the chambers 12, 14 at substantially small and substantially regular sample steps or intervals. These sensors 38, 40 create and communicate respective signals, representative of the respectively sensed pressures, to the controller 36 by use of a data transmission channel, e.g. a bus 39. The sensors 38, 40 may comprise conventional and commercially available piezoelectric sensors or optical sensors. Non-limiting examples of such sensors 38, 40 include the sensor type described in US 5329809, sensor model number 6125 of Kistler Corporation and optical sensors available from Bookham Technologies, Inc.

[0018] In operation, the controller 36 calculates the total amount of torque produced by each of the cylinders 12, 14 during each engine cycle. Without limitation, this calculating of the total amount of the torque is now described regarding the first cylinder having combustion chamber 12. Of course, the same calculation equally applies to any further cylinder the multi-cylinder engine 10 may have.

[0019] The pressure sensor 38 within the combustion chamber 12 measures the pressure intermittently, i.e. provides one pressure value within a certain sample step designated herein by j . Thus, the pressure sensor 38 provides pressure sample value p_j to the controller 36. For each sample step j , the controller 36 calculates a corresponding change j of the volume of the combustion chamber 12, which change is due to the displacement of the piston 16. This change in volume can be calculated by means of the first derivative of the volume. Alternatively, a volume change value can be calculated by determining the volume at the beginning of the sample step and at the end of the sample step and computing the difference between these two volumes. In doing so, the controller 36 may evaluate the crankshaft position to determine the actual volume of the combustion chamber 12.

[0020] The controller 36 then computes the product of the pressure sample values and the volume change sample values V_j for each sample step. The respective results are added up for all sample steps which are within a certain segment of the cylinder's engine cycle. Usually, the segment is the combustion cycle. The sum thus obtained is then multiplied by the change $\Delta\alpha$ of crankshaft angle which occurs within this segment and divided by 4π . The total result of this calculation gives the torque T delivered by the cylinder within the segment defined through the change in crankshaft angle.

[0021] In other words, the controller 36 uses the fol-

lowing equation to calculate the amount of torque T produced by a single cylinder of the multi-cylinder engine:

$$T = \frac{\Delta\alpha}{4\pi} \sum_{j=1}^N P_j \bullet V'_j$$

[0022] In this equation $\Delta\alpha$ is the change of crankshaft angle, P_j is the pressure sample value, V'_j is the volume change sample value, j is the sample step index and N is the number of sample steps or periods which occur within the evaluated segment defined by the change of $\Delta\alpha$ of crankshaft angle.

[0023] To calculate the amount of torque T an cylinder generate during its respective working segment of the engine cycle, the change in crankshaft angle $\Delta\alpha$ is selected accordingly, i.e. the sample steps cover the combustion cycle for each cylinder individually.

[0024] The controller 36 performs calculation of the total amount of torque T produced by a respective cylinder for all cylinders of the multi-cylinder engine 10. This results in torque values T for each cylinder. Those torque values T are then compared to achieve cylinder balancing. For cylinder balancing, the controller 36 calculates an average value A from the cylinder individual torque values T. For each cylinder, a difference between the average value A and the torque value T is used in a feedback control controlling a cylinder individual offset used in controlling the injectors 30, 32. The controller 36 effects a change in fuel delivery to the individual cylinders to minimize the differences between the cylinder individual torque values T and the average torque value A.

[0025] The controller, thus, performs a method which is shown in Figure 2 in form of a flow diagram.

[0026] Figure 2 presents a flow diagram of the method for cylinder balancing performed by the apparatus described. After start of the engine 10, it is first checked, whether certain operation conditions are met, which are required or suitable to cylinder balancing. One condition may be, that the engine has reached a certain operation temperature. If the certain operation conditions are given, a number of cycles n is defined, for which the data is recorded and evaluated. Then, the combustion chamber pressure data and crankshaft angle data are recorded for $N_{cyl}=n$ cycles. At that time, n sampled sets of pressure values exist. These are averaged on basis of the sample index to obtain one set of sampled pressure values, in which the pressure sample values are averaged over n cycles.

[0027] In a next step, a torque T is calculated for each cylinder. Then, an average torque A produced by all cylinders of the multi-cylinder engine is computed.

[0028] The next step determines differences for each cylinder between the average torque A and the cylinder's individual torque T.

[0029] For cylinder balancing, the fuel supply offset is

then changed for each cylinder to minimize torque differences. That means, that the fuel control reduces fuel for a cylinder having a torque T above the average torque value A. The offset is raised, however, if the cylinder delivers a torque which is below average.

[0030] The procedure is then repeated.

[0031] Of course it is possible to activate the procedure only at certain time intervals or instances. Due to the fact that variations in the torque produced by each cylinder may be caused by wear or a built-up of soot at the cylinder's fuel injector 30, 32, variations in torque may occur relatively slowly. Hence, it may be sufficient to balance the cylinders only at certain time intervals or upon special requests, i.e. when the engine 10 is at a scheduled maintenance.

[0032] Referring to Figures 3 and 4, the result of the cylinder balancing is described. Figure 3 shows the torque produced by the individual cylinders of a internal combustion engine 10 having four cylinders. Figure 3 is a chart showing four curves 50, 51, 52 and 53 representing the change of the torque of the four cylinders over time. As the chart shows, the first cylinder, to which curve 50 is assigned, initially produces a torque which is significantly higher than the individual torque of the other cylinders. The forth cylinder, however, delivers a torque which is significantly lower than the torque of the other cylinders, as curve 53 shows. The second and third cylinders, to which curves 51 and 52 are assigned, produce a torque which is between the torques of the first and fourth cylinder.

[0033] As Figure 3 further shows, the method makes the torques delivered by the cylinders approximately equal after some seconds. This is due to the cylinder balancing performed by the controller and by means of the method described above.

[0034] Figure 4 shows in a chart the cylinder individual offsets adjusted during balancing. It will be no surprise to the person skilled in the art, that the first cylinder which initially having a higher torque according to curve 50 now receives fuel on basis of a negative offset. As the respective curve 54 shows, the offset is significantly reduced to below -0,3 mg per stroke in order to nullify the excess of torque this cylinder had generated. On the other hand, the third cylinder which had produced lesser torque according to curve 53 is supplied with extra fuel by use of an offset value which is significantly raised as curve 57 shows. The second and third cylinders to which curves 54 and 56 are assigned have offsets in the medium range according to their almost at average delivered torque according to curves 51 and 52.

[0035] The following modifications/additional features may be used in combination with embodiments of the invention:

[0036] The computing of the volume change sample value V'_j can be made as described above. Alternatively, a respective map can be used which may be stored in the controller 36 and gives the respective value as a function of the start and end of the respective sample steps.

Again the crankshaft position may be evaluated to obtain the volume change sample values.

[0037] Instead of the difference between the individual cylinder torques T and the average torque A , a different error function may be used, which, in particular, may use a non-linear function.

[0038] The number of cycles, over which the torque T is determined for the individual cylinders may, of course, also be equal 1.

[0039] Instead of the average torque A , a torque target value may be used, which may be received from a predetermined map which was obtained from a test bed run of an engine.

[0040] The controlling of the fuel supply system 34 must not rely on an offset value. However, any suitable action on the fuel supply system may be used which influences the torque individually for the cylinders.

[0041] The cylinder balancing can be performed at special operation conditions, i.e. at steady state operation points comprising a predetermined engine speed or load. Alternatively, the cylinder load balancing can be performed continuously, i.e. at almost every engine operating condition.

[0042] The averaging described above regarding the individual cylinder torque values can, of course, also be made on basis of the pressure signal. Then, the pressure signal is averaged first for several combustion cycles of the respective cylinder.

3. An internal combustion engine control apparatus for controlling an multi-cylinder internal combustion engine (10) to have all cylinders of the engine (10) producing a substantially equal torque, wherein the apparatus (36) performs the method of claim 1 or 2.

Claims

1. A method to cause the torques produced by each cylinder (10) of a multi-cylinder internal combustion engine to be substantially equal, said engine including a rotatable crankshaft (20) being driven by combustions in combustion chambers (12, 14) of said cylinders, wherein a pressure in each of said combustion chambers (12, 14) is measured and an amount of torque produced by each of said cylinders is determined based on the pressure measurements, wherein further the pressure is measured intermittently in sample steps (j), thus generating pressure sample value (p_j) for each sample step (j) determining a value (V'_j) of a change of the cylinder's combustion chamber volume for each sample step and a torque value (T) each cylinder produces during a certain rotation angle ($\Delta\alpha$) of the crankshaft (20) is calculated by multiplying each pressure sample value with the respective volume change value and by summing up all such obtained products and multiplying the result of the sum by $\Delta\alpha/4\pi$.
2. The method of claim 1, wherein the torque values (T) are compared for all cylinders and unified by adjusting a fuel parameter used in controlling a fuel supply system (34) feeding fuel to the cylinders.

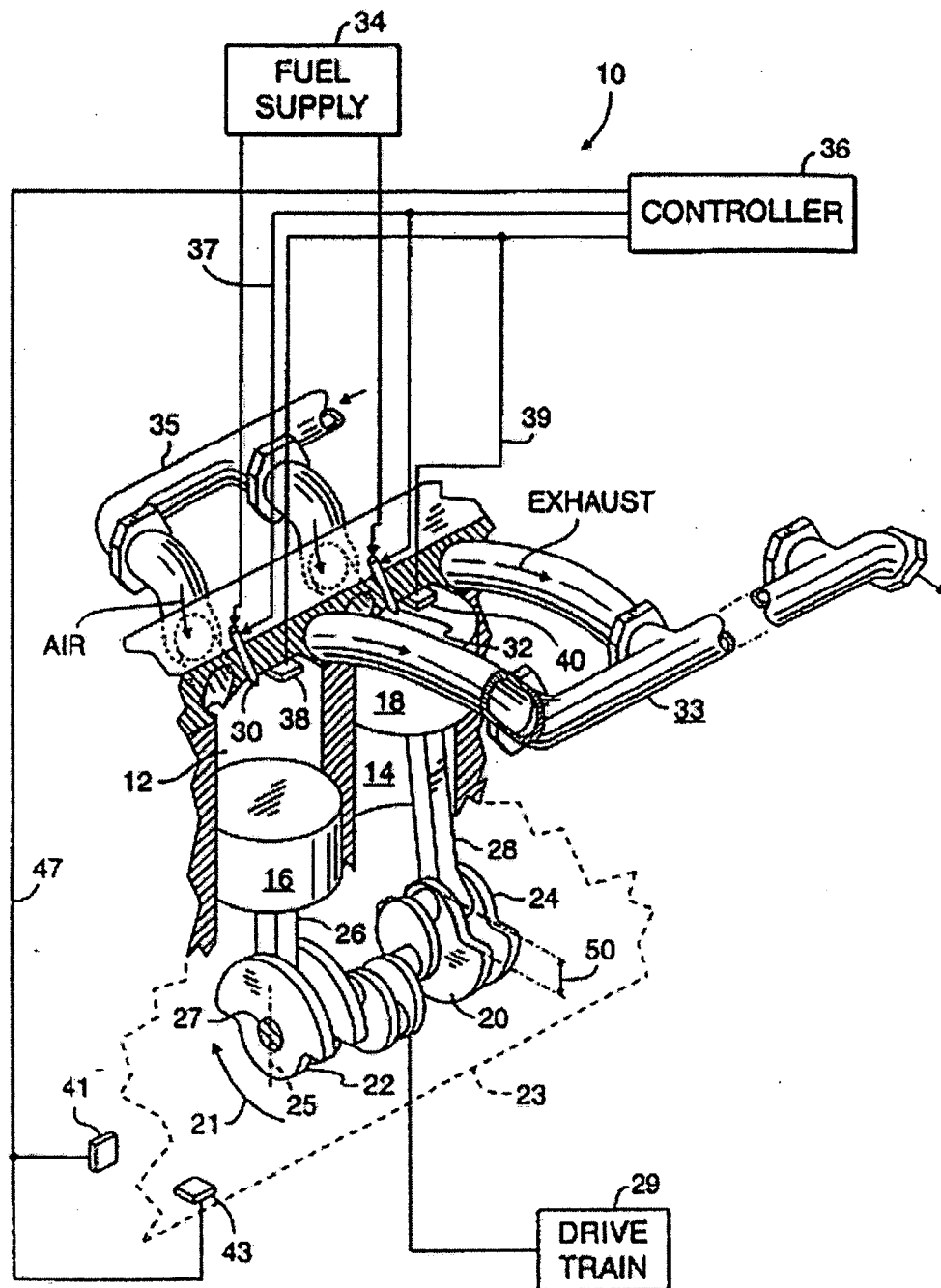


FIG. 1

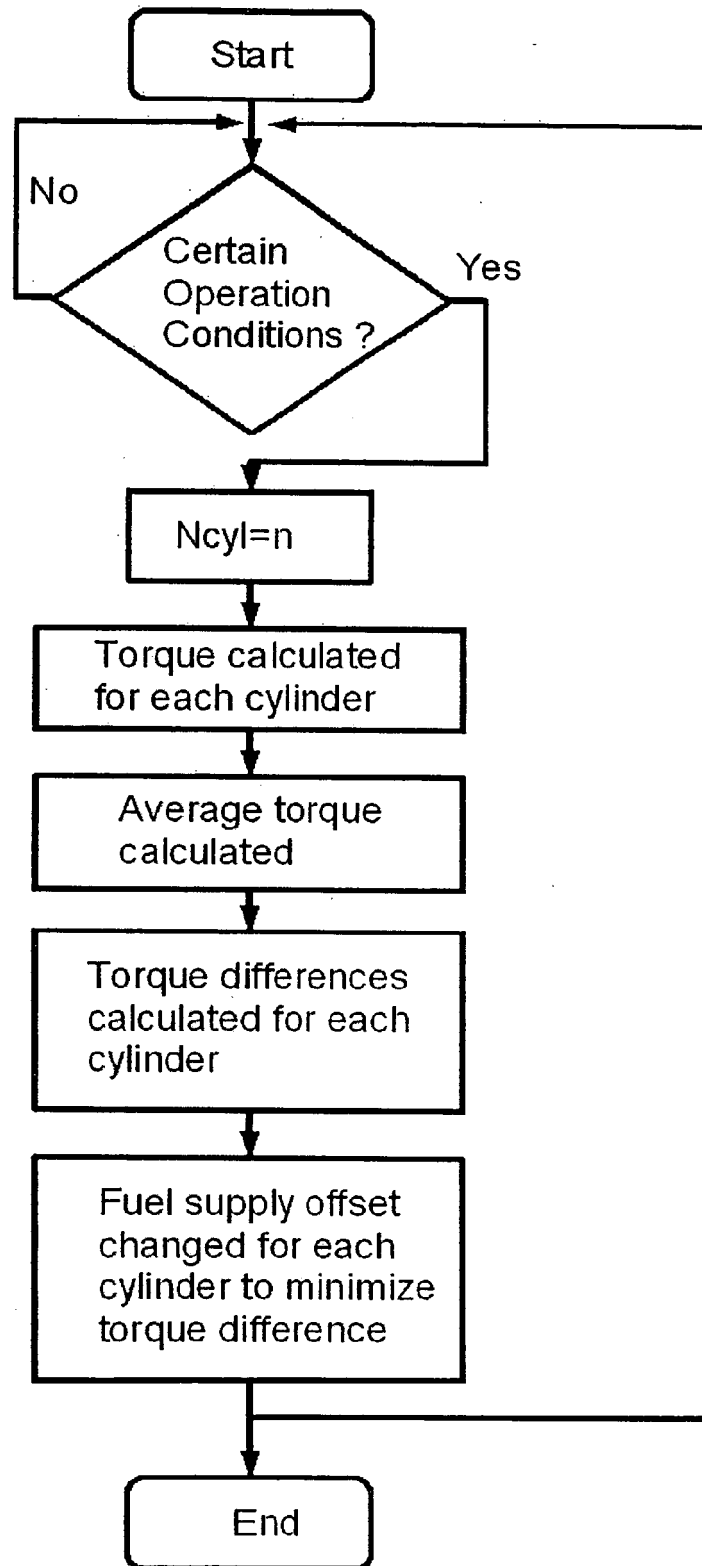


FIG. 2

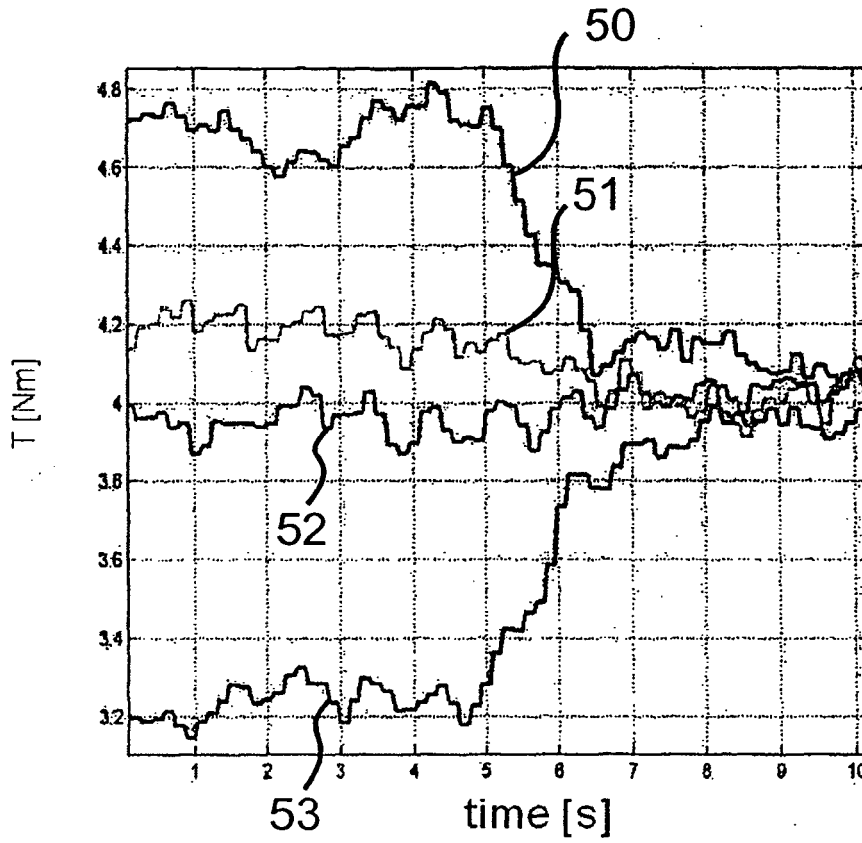


FIG. 3

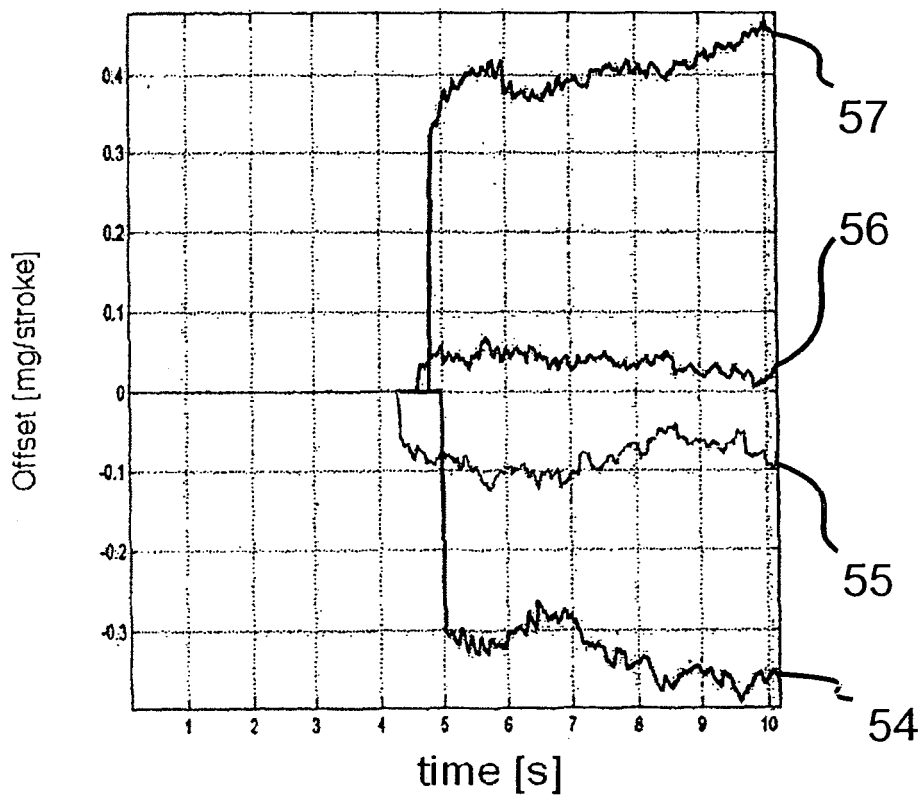


FIG. 4



EUROPEAN SEARCH REPORT

Application Number
EP 08 01 1165

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2004/048762 A (RICARDO CONSULTING ENG [GB]; CORNWELL RICHARD CHARLES ELLIO [GB]; WINS) 10 June 2004 (2004-06-10) * page 2, line 7 - page 3, line 9 * * page 6, line 1 - line 13 * * page 7, line 18 - page 8, line 16 * * page 10, line 1 - line 12 * -----	1-3	INV. F02D35/02 F02D41/14 F02D41/24
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			TECHNICAL FIELDS SEARCHED (IPC)
			F02D
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 5 December 2008	Examiner De Vita, Diego
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**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 08 01 1165

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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- EP 1061246 A2 [0003]
- US 5329809 A [0017]