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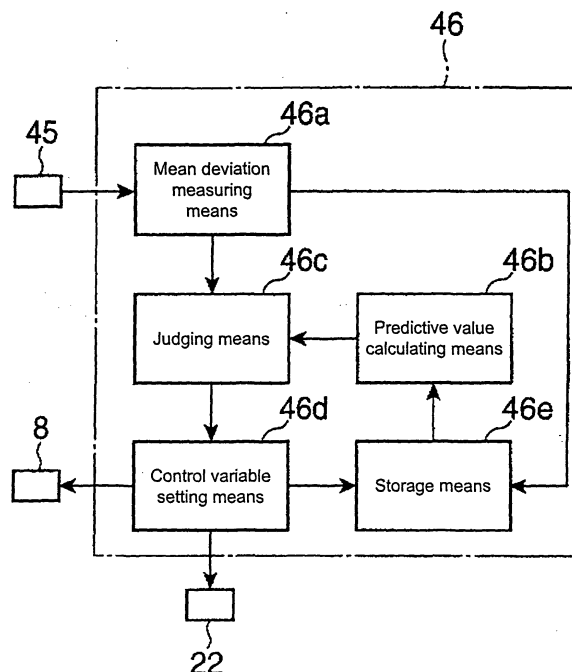
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(54) **Digital control apparatus for an engine and control method thereof**

(57) A control apparatus (40) for an engine (1) comprises roughness control means (46) which sets a control variable (IG; INJ; A/F) for the adjusting means (8, 28, 43, 44) including an injector (28) so as to maintain the combustion stability of the engine (1) within a certain range. The control apparatus (40) further includes: mean deviation measuring means (46a) is provided which measures a mean deviation (σ) of the fluctuation in angular velocity, for a plurality of control variables (IG; INJ; A/F) set by control variable setting means (46d) of the roughness control means (46) under the same operational condition of the engine (1); predictive value calculating means (46d) is provided which calculates a predictive value of the mean deviation (σ) in the case that a control variable (IG; INJ; A/F) for the adjusting means (8, 28, 43, 44) is changed, on the basis of the measured value of the mean deviation (σ) determined for the plural control variables (IG; INJ; A/F); and judging means (46c) is provided which judges of the engine (1) is in the proper combustion condition, from a difference (β) between the predictive value and the measured value of the mean deviation (σ) measured after the change in control variable (IG; INJ; A/F). Accordingly, the accurate determination can be made as to whether the engine (1) is in the stable combustion condition, without any erroneous determination.

FIG. 11



Description

[0001] The present invention relates to a control apparatus for an engine, to an engine, to a control method for an engine, to a computer-readable storage medium storing thereon a computer program, and to a computer program for performing an engine control method, when run on a suitable computer.

[0002] Conventionally, as disclosed in Japanese Unexamined Patent Publication H09-264183, a control apparatus for an engine has been known, which includes an angular velocity fluctuation detecting means for detecting the fluctuation in angular velocity of the engine rotation during a predetermined crank angle range between the crank angle at which combustion substantially completes in a cylinder immediately and the crank angle at which combustion starts in the following cylinder; a combustion condition determining means for determining a combustion condition from the fluctuation in angular velocity, which is determined based on the detected value by the angular velocity fluctuation detecting means; and an air-fuel ratio control means for controlling the fuel injection amount so as to adjust the air-fuel ratio in the engine in accordance with the detection of the combustion condition by the determining means. The control apparatus adjusts the air-fuel ratio to be approximately lean burn limit while maintaining the combustion stability, in accordance with the combustion condition determined based on the angular velocity or its fluctuation during the lean combustion mode of the engine.

[0003] In particular, firstly, an output signal from a crank angle sensor is used to sequentially detect the angular velocity of the engine rotation for determining a deviation between the detected value of the angular velocity at the present combustion and that at the previous combustion in the same cylinder. Then, the deviation is compared with a first reference value and a second reference value smaller than the first reference value by a predetermined amount, for determining the combustion condition of the engine. When the deviation becomes larger than the first reference value, the air-fuel ratio is adjusted to be richer for maintaining the combustion stability. When the deviation becomes smaller than the second reference value, the air-fuel ratio is adjusted to be approximately lean limit for improving fuel efficiency.

[0004] The above mentioned approach to the determination of the engine combustion condition based on the deviation between the detected value of the angular velocity at the present combustion and that at the previous combustion, can determine accurately to some extent on the basis of the deviation whether or not the combustion condition is approximate to the lean combustion limit, in an engine in which the fluctuation in engine rotation is relatively smaller during stable combustion condition, that is, in the engine which is configured so as to control the air-fuel ratio to be homogeneously lean in a region of intermediate speed and intermediate load except for idling condition.

[0005] However, a problem arises in an engine in which the engine rotation remarkably tends to fluctuate even in the stable combustion condition of the engine, or in an engine which executes a control of the lean combustion mode where the air-fuel ratio in combustion chambers is adjusted to be significantly lean of the stoichiometric air-fuel ratio and fuel is directly injected into the combustion chambers at predetermined timings so as to cause the resultant mixture, which has been stratified in the vicinity of spark plugs, to combust during low load and low speed condition. That is, in such type of engines, the reference values should include margins to accommodate significant fluctuation in engine rotation. Thus, the above mentioned determination may often cause erroneous recognition of the stable combustion condition of the engine, in spite that the engine is actually in the unstable combustion condition.

[0006] Additionally, as shown in FIG. 20 illustrating the relationship between a ignition timing and a fluctuation ratio in a target indicated mean effective pressure P_i in an engine which executes a control so as to operate on a stratified lean combustion mode, the smaller retard of the ignition timing causes the fluctuation P_i to be smaller, which provides a relatively stable combustion condition. However, when the retard amount of the ignition timing exceeds a certain value, the fluctuation in target indicated mean effective pressure P_i tends to abruptly increase.

[0007] Accordingly, the beforehand judgement of the tendency of the deteriorated combustion condition by comparing the deviation in angular velocity with reference values is remarkably difficult to make in the engine in which the engine rotation remarkably tends to fluctuate in the stable combustion region of the engine. Thus, in the case that the roughness control as described in the patent publication above is executed to sequentially retard the ignition timing while determining the engine combustion condition from the amount of the deviation between the angular velocity at the present combustion and that at the previous combustion, the engine is inevitably deteriorated in its combustion stability because the ignition timing enters the misfire region as shown in FIG. 21.

[0008] In view of the problem above, an object of the present invention is to accurately determine whether or not the engine is in the stable combustion condition without any erroneous determination.

[0009] The object is solved according to the invention by a control apparatus for an engine according to claim 1, by an engine according to claim 10, by a control method according to claim 13, by a computer-readable storage medium according to claim 14, and by a computer program according to claim 15. Preferred embodiments of the present invention are subject of the dependent claims.

[0010] Thus, the present invention accurately judges as to whether the engine is in the stable combustion condition without any erroneous determination.

[0011] In accordance with the present invention, there is provided a control apparatus for an engine comprising: angular velocity fluctuation detecting means; adjusting means; roughness control means; mean deviation measuring means; predictive value calculating means; and judging means. The angular velocity fluctuation detecting means detects the fluctuation in angular velocity of engine rotation. The adjusting means adjusts a combustion condition of the engine. The roughness control means sets or determines a control variable for the adjusting means so as to maintain the proper combustion stability of the engine. The mean deviation measuring means measures a mean deviation of the fluctuation in angular velocity or rotational cycle, for each of a plurality of control variables set by the roughness control means under the same operational condition of the engine. The predictive value calculating means calculates a predictive value of the mean deviation in the case that a control variable for the adjusting means is changed, on the basis of the measured value of the mean deviation determined for each of the plural control variables. The judging means judges if the engine is in the proper combustion condition, from a difference between the predictive value and the measured value of the mean deviation measured after the change in control variable.

[0012] Accordingly, in an engine in which the engine rotation remarkably tends to fluctuate even when the engine is in the stable combustion region, the judgement can be accurately made without any erroneous determination as to whether the engine is in the stable combustion condition, on the basis of the difference between the predictive value of the mean deviation and the measured value of the mean deviation measured after the change in control variable.

[0013] Preferably, the control apparatus may further comprise control variable setting means which sets or determines a control variable for the engine according to the judgement by the judging means. Then, the judging means judges if a difference between the predictive value of the mean deviation predicted in a previous control and the measured value of the mean deviation measured after a change in control variable is within a specified (predetermined or predeterminable) allowable range, and the control variable setting means sets or determines a control variable for the adjusting means so as to improve the combustion stability of the engine, if the judging means judges that the difference between the predictive value and the measured value of the mean deviation is out of the allowable range.

[0014] Accordingly, in the case that the engine is judged to be in the stable combustion condition from the difference between the predictive value of the mean deviation and the measured value of the mean deviation measured after the change in control variable, the control variable is set or determined so as to improve the combustion stability of the engine, thereby effectively preventing the deterioration in the combustion stability

of the engine, in which the engine rotation remarkably tends to fluctuate even when the engine is in the stable combustion region.

[0015] In accordance with the preferred embodiment of the present invention, the predictive value calculating means may calculate the predicted value of the mean deviation on the basis of the least squared method using the latest plural measured values which are measured by the mean deviation measuring means.

[0016] Accordingly, the predicted value of the mean deviation in the case that the control variable is changed can be easily and accurately determined from the measured value of the mean deviation measured by the mean deviation measuring means.

[0017] Alternatively, the predictive value calculating means may calculate the predicted value of the mean deviation on the basis of the successive approximation using the latest plural measured values which are measured by the mean deviation measuring means.

[0018] Accordingly, the predicted value of the mean deviation in the case that the control variable is changed can be more accurately determined from the measured value of the mean deviation measured by the mean deviation measuring means.

[0019] Preferably, the control apparatus may further comprise storage means which stores the mean deviation of a fluctuation in angular velocity, and/or operational region determining means which determines an operational segment of an operational region in which the engine is operating, the operational segments being divided with respect to engine rotational speed and engine load. Then, the mean deviation measuring means preferably stores the mean deviation of a fluctuation in angular velocity measured for each of plural control variables in the storage means correspondingly to the operational segments, and the control variable setting means preferably reads the mean deviation for the operational segment from the storage means and uses the mean deviation to control the adjusting means, when the engine has shifted to another operational segment.

[0020] Accordingly, a meticulous roughness control of the engine is provided for each of operational segments which are divided with respect to engine rotational speed and engine load, thereby effectively improving fuel efficiency while maintaining the preferable combustion stability of the engine.

[0021] More preferably, the control variable setting means may reflect data corresponding to the operational segment with a sufficient number of stored data of the mean deviation and a sufficient number of the shift in control variable towards the stable combustion limit, to control the adjusting means in an operational segment with an insufficient amount of stored data of the mean deviation.

[0022] Accordingly, the control variable is more quickly optimized for the adjusting means, than the case with the roughness control for each of operational segments which are divided with respect to engine rotational

speed and engine load.

[0023] Further preferably, the control variable setting means may determine the number of the judgement by the judging means that the measured value of the mean deviation is out of the allowable range, and reduce an incremental amount of the control variable for the more number of the judgements, when shifting the control variable for the adjusting means towards the stable combustion limit.

[0024] Accordingly, the deterioration in combustion stability caused by the roughness control is effectively prevented while the optimum control variable is more quickly determined for the adjusting means.

[0025] Still further preferably, the control apparatus may further comprise air-fuel ratio control means which, in accordance with the engine operational condition, changes the operational mode between the lean combustion mode with a larger air-fuel ratio than the stoichiometric air-fuel ratio in a combustion chamber of the engine and the rich combustion mode with an air-fuel ratio equal to or more than the stoichiometric air-fuel ratio in the combustion chamber, and/or target load setting means which sets or determines a target load to be used for engine control in shifting to the rich combustion mode, on the basis of a control variable set by the roughness control means during the lean combustion mode.

[0026] Accordingly, a torque shock is effectively prevented in the changing from the lean combustion mode to the rich combustion mode.

[0027] Still further preferably, the control variable setting means may set control variables for the adjusting means for each of the operational segments in the operational region of the lean combustion mode, and determine a mean control variable for the overall lean combustion mode on the basis of the control variables. Further, the target load setting means may set the target load to be used when the operational mode shifts to the rich combustion mode, on the basis of the mean control variable determined by the control variable setting means.

[0028] Accordingly, even when the aging of the engine causes the control variable, such as the amount of ignition retard to vary, the target load to be used for the engine control can be properly set based on the mean control variable for overall lean combustion mode.

[0029] In accordance with the present invention, there is further provided an engine equipped with the control apparatus in accordance with the present invention or the preferred embodiments thereof.

[0030] Particularly, the control apparatus is advantageously combined with a direct-injection spark-ignition engine which controls an injector of the engine to inject fuel directly into the combustion chamber during the compression stroke so as to stratify mixture in the vicinity of the spark plug of the engine at an ignition timing. This is because direct-injection spark-ignition engines have the tendency that the engine rotation remarkably fluctuates even in the stable combustion region of the

engine. More advantageously, the control apparatus may be combined with the direct-injection spark-ignition engine which produces tumble flow in a combustion chamber of the engine during the compression stroke, and controls an injector to inject fuel directly into the combustion chamber in the substantially opposite direction against the tumble flow so as to stratify mixture in the vicinity of a spark plug of the engine at an ignition timing, as a result of the collision of the tumble flow and the injected fuel.

[0031] In accordance with the present invention, there is still further provided a control method for an engine, in particular according to the present invention or a preferred embodiment thereof, including angular velocity fluctuation detecting means for detecting the fluctuation in angular velocity of engine rotation, adjusting means for adjusting a combustion condition of the engine, and roughness control means which sets or determines a control variable for the adjusting means so as to maintain the proper combustion stability of the engine. The control method comprises the following steps of: measuring a mean deviation of the fluctuation in angular velocity, for each of a plurality of control variables set by the roughness control means under the same operational condition of the engine; calculating a predictive value of the mean deviation in the case that a control variable for the adjusting means is changed, on the basis of the measured value of the mean deviation determined for each of the plural control variables; and judging if the engine is in the proper combustion condition, from a difference between the predictive value and the measured value of the mean deviation measured after the change in control variable.

[0032] In accordance with the present invention, there is further provided computer-readable storage medium having stored thereon a computer program, which, when loaded onto a computer, carries out the engine control method for an engine according to the present invention or the preferred embodiments thereof.

[0033] In accordance with the present invention, there is further provided control program which, when loaded onto a computer, carries out the engine control method for an engine according to the present invention or the preferred embodiments thereof.

[0034] Other features, aspects, and advantages of the present invention will become apparent from the following description of the invention which refer to the accompanying drawings. It should be understood that even though embodiments are separately described, single features thereof may be combined to additional embodiments.

[0035] FIG. 1 is a schematic diagram of an engine equipped with a control apparatus in accordance with a preferred embodiment of the present invention.

[0036] FIG. 2 is a functional block diagram of a control unit.

[0037] FIG. 3 is a functional block diagram illustrating particular configuration of a target load detecting

means.

[0038] FIG. 4 is a map or table or relationship of operational segments used for an air-fuel ratio control.

[0039] FIG. 5 is a schematic diagram illustrating the arrangement of a detectable plate and a crank angle sensor.

[0040] FIG. 6 is a graph chart showing strokes of each cylinder, and change in torque and angular velocity with respect to crank angle.

[0041] FIG. 7 is a graph chart showing the correlation between combustion pressure and the fluctuation in angular velocity.

[0042] FIG. 8 is a graph chart showing the fluctuation in angular velocity with noise factors.

[0043] FIG. 9 is a graph chart showing data of angular velocity from which the frequency components of rotational order of 0.5 and its integral multiplies of the engine rotation are removed.

[0044] FIG. 10 is a graph chart showing data obtained by removing a frequency band of rotational orders less than 0.5 from the data shown in FIG. 9 by a bypass filter operation.

[0045] FIG. 11 is a functional block diagram illustrating particular configuration of a roughness control means.

[0046] FIG. 12 is a diagram showing the relationship between the stable combustion region, and the timings of ignition and fuel injection.

[0047] FIG. 13 is a flow chart showing the main control routine for setting ignition timing and fuel injection timing.

[0048] FIG. 14 is a flow chart showing the main control routine of the roughness control.

[0049] FIG. 15 is a flow chart showing the control routine for complementing control data.

[0050] FIG. 16 is a flow chart showing the control routine for setting an ignition timing and an injection timing in the main control routine of the roughness control

[0051] FIG. 17 is a flow chart showing the control routine for measuring the mean deviation σ .

[0052] FIG. 18 is a graph chart showing the change in mean deviation while the roughness control is being performed.

[0053] FIG. 19 is a timing chart showing the change in ignition timing in accordance with the present invention.

[0054] FIG. 20 is a graph chart showing the relationship between ignition timing and target load.

[0055] FIG. 21 is a timing chart showing the change in ignition timing in accordance with a conventional approach.

[0056] FIG. 1 schematically shows an engine which incorporates or represents a preferred embodiment of the present invention. The engine is a four-cycle gasoline engine, comprising an engine main body 1 provided with four cylinders arranged in line and corresponding intake and exhaust systems. In each of the cylinders of the engine main body 1, a combustion chamber 3 is de-

finer substantially above a piston 2. An intake port 4 and an exhaust port 5 open to the combustion chamber 3, and an intake valve 6 and an exhaust valve 7 is provided in the ports 4, 5. At least one spark plug 8 is fitted to the engine main body 1 so as to front or at least partly project into the combustion chamber 3. The spark plug 8 is to be electrically connected to an ignition circuit 9 which includes an igniter or other devices operative to electrically control ignition timings.

[0057] At an end portion of a crank shaft in the engine main body 1, a detectable plate 11 is attached, which is formed with projections 12 at predetermined positions of the periphery of the plate 11. Facing the periphery of the detectable plate 11, a crank angle sensor 13 is disposed. The crank angle sensor 13 comprises a preferably electromagnetic pickup and/or other components. Thus, while the engine is operating with the detectable plate 11 rotated together with the crank shaft, the crank angle sensor 13 outputs pulse signals in response to the approach of projections 12 to the crank angle sensor 13. The engine main body 1 is also provided with a coolant temperature sensor 14 operative to detect the coolant temperature.

[0058] The intake system of the engine comprises an intake-air passage 16 for introducing intake air filtered through an air filter 15 into the engine main body 1. The intake-air passage 16 comprises a common intake-air passage 17 on the upstream side thereof, a surge tank 18 on the downstream side thereof, and individual intake-air passages 19 connecting the surge tank 18 with each of the intake ports 4 for respective cylinders. In the common intake-air passage 17, an air-flow sensor 21 operative to detect the amount of intake air, an electrically-controlled throttle valve 22 operative to adjust the amount of intake air, an ISC (Idle Speed Control) passage 23 which bypasses the electrically-controlled throttle valve 22, and an ISC valve 24 operative to open and close the passage 23, are provided. In the intake-air passage 16, an intake-air temperature sensor 25 operative to detect the intake-air temperature, an idle switch 26 operative to detect the fully closed state of the throttle valve 22, and other devices, are fitted or provided.

[0059] At the preferably upper peripheral portion of the combustion chamber 3, an injector 28 is provided for injecting fuel. The injector 28 injects fuel, supplied through a fuel supply passage from a low-pressure fuel pump and a high-pressure fuel pump not shown, directly into the combustion chamber 3. Particularly, the injector 28 operates in accordance with signals (e.g. injection pulses) from an ECU 40 described later so as to open its valve during a time period equivalent to a injection pulse width at the injection timing set in association with an ignition timing. While the engine is operating on the lean combustion mode as described later, fuel is injected in the latter half of the compression stroke against a tumble flow generated in the combustion chamber 3, so that the mixture resulting from the collision of the tumble flow and the fuel spray is stratified and maintained in the

proximity of the spark plug 8 at the ignition timing.

[0060] In order to generate the tumble flow sufficient in strength in the combustion chamber 3 in the latter half of the compression stroke, the individual intake-air passage 19 for each cylinder preferably branches out into two passages. On the downstream side of the pair of passages, two intake ports 4 open to the combustion chamber 3. On the upstream side of the pair of the passages, a pair of intake shutter valve 29 is correspondingly provided. In the lean combustion mode of the engine, the intake shutter valve 29 is closed to increase the intake-air velocity, thereby generating strong tumble flow in the combustion chamber 3.

[0061] On the other hand, the exhaust system of the engine comprises an exhaust-air passage 31 which communicates with exhaust ports 5 for respective cylinders. The exhaust-air passage 31 is provided with a three-way catalyst on the upstream side thereof, and/or a lean NOx catalyst (for absorbing or storing NOx and reducing it) on the downstream side thereof. The lean NOx catalyst is capable of purifying NOx even in the lean combustion condition.

[0062] Identified by 40 is a control unit for controlling the engine (referred to as ECU hereinafter), which includes a microcomputer. The control unit 40 receives detected signals from the crank angle sensor 13, coolant temperature sensor 14, air-flow sensor 21, intake-air temperature sensor 25, idle switch 26, acceleration-pedal position or operation sensor, and/or other sensors. The ECU 40 sends the signal for controlling the ignition timing to the ignition circuit 9, and the signal for controlling the fuel injection to the injector 28.

[0063] The control unit 40, as shown in FIG. 2, includes a target load setting means 41; a operational region determining means 42; a fuel injection control means 43; an ignition timing control means 44; an angular velocity fluctuation detecting means 45; a roughness control means 46; and/or an air-fuel ratio control means 47. The target load setting means 41 is provided for setting or computing or determining a value equivalent to a target load of the engine. The operational region determining means 42 is provided for determining the operational region of the engine. The fuel injection control means 43 is provided for controlling the timing of the fuel injection to be performed by the injector 28. The ignition timing control means 44 is provided for controlling the timing at which the spark plug 8 ignites the mixture. The angular velocity fluctuation detecting means 45 is provided for detecting the fluctuation in angular velocity of the engine rotation. The roughness control means 46 is provided for performing a roughness control of correcting the adjustment of an adjusting means consisting of the spark plug 8 and the injector 28, as will be described later. Finally, the air-fuel ratio control means 47 is provided for controlling the air-fuel ratio A/F in the combustion chamber 3 in accordance with the engine operational condition.

[0064] The target load setting means 41, as shown in

FIG. 3 by way of example, includes: a volumetric efficiency setting means 41a; a charging efficiency calculating means 41b; and a Pi calculating means 41c. The volumetric efficiency setting means 41a is provided for setting a hypothetical volumetric efficiency, on the basis of engine rotational speed n_e determined from the output signal sent from the crank angle sensor 13 and acceleration-pedal position (or operational amount of the acceleration pedal) ac detected by the acceleration-pedal position sensor 20, with reference to a prescribed map or table or relationship. The charging efficiency calculating means 41b is provided for calculating a hypothetical charging efficiency on the basis of the volumetric efficiency set as above and atmospheric pressure at detected by an atmospheric pressure not shown. Finally, the Pi calculating means 41c is provided for calculating a target indicated mean effective pressure corresponding to the target load on the basis of the charging efficiency calculated as above.

[0065] The Pi calculating means 41c, in the lean combustion mode of the engine, sets or determines a target indicated mean effective pressure preferably in the following manner:

Firstly, the Pi calculating means 41c calculates a mean control variable for the entire region of the lean combustion mode on the basis of the control variables for the adjusting means (or the amount of ignition retard) in each of plural operational segments divided with respect to engine rotational speed and engine load.

Then the Pi calculating means 41c sets or determines the target indicated mean effective pressure corresponding to the target load to be used when the engine shifts from the lean combustion mode to the rich combustion mode, on the basis of the mean control variable calculated as above. That is, in the lean combustion mode of the engine, the increased amount of the engine torque caused by the correction of retarding the ignition timing by the roughness control means 46 is calculated based on the mean control variable, and the control map or table or relationship for setting the target indicated mean effective pressure (equivalent to target load) is corrected based on the increased amount of the engine torque. As a result, a torque shock is avoided in shifting from the lean combustion mode to the rich combustion mode of the engine.

[0066] The operational region determining means 42 determines the engine operational mode in the following manner: Firstly, the operational region determining means 42 uses the target indicated mean effective pressure corresponding to the target load set by the target load setting means 41 and the detected value of the engine rotational speed n_e , to determine the operational region. Then, the combustion mode of the engine is set based on the operational region determined as above. In the operational region in which the target load and the engine rotational speed are smaller than predetermined values, or in the operational region of lower load and lower engine rotational speed defined by bold lines in

FIG. 4 for example, the engine operates on the lean combustion mode. In the operational region outside of the above, the engine operates on the rich combustion mode. The operational region of the lean combustion mode is divided into a plurality of segments with respect to target load and engine operational speed as indicated by broken lines in the drawing. In the 1st segment (1) to the 12th segment (12) excluding highly low rotational speed region and in an idling segment (I), the roughness control means 46 executes the roughness control.

[0067] The injection timing control means 43, in accordance with the determination of the operational region by the operational region determining means 42, sets or determines a fundamental or basic injection timing in a predetermined period during the intake stroke while the engine is in the operational region of the rich combustion mode, and sets or determines a fundamental or basic injection timing in a specified (predetermined or predeterminable) period during the compression stroke while the engine is in the operational region of the lean combustion mode. If required, the injection timing control means 43 can correct the fundamental injection timing. Particularly, in the operational region of the lean combustion mode, the injection timing is set at a timing a predetermined period before the ignition timing set by the ignition timing control means 44 described later.

[0068] The ignition timing control means 44 sets or determines a fundamental or basic ignition timing for mixture on the basis of the target load of the engine set by the target load setting means 41 and the detected value of the engine rotational speed for each of the operational segments determined by the operational region determining means 42, with reference to a map or table or relationship. Additionally, in the operational region of the lean combustion mode, the ignition timing is corrected based on the control variable (or the amount of ignition retard) set by the roughness control means 46 as will be described later.

[0069] The angular velocity fluctuation detecting means 45, using the signal from the crank angle sensor 13, detects the angular velocity of the engine rotation preferably in the form of intervals of the signal outputs of the crank angle sensor 13. In addition, the angular velocity fluctuation detecting means 45, using the detected value of the angular velocity, detects the difference between the angular velocity at the previous combustion and that at the present combustion in the same cylinder. The angular velocity is detected within the predetermined crank angle range between the crank angle at which the combustion substantially completes in a cylinder and the crank angle at which combustion starts in the following cylinder (preferably in a middle stage of the expansion stroke).

[0070] In accordance with a preferred embodiment, the crank angle sensor 13 is configured so as to detect the angular velocity preferably within the range between ATDC 85° and 130° during the expansion stroke. For

example, as shown in FIG. 5, the projections 12 of the detectable plate 11 and the crank angle sensor 13 are arranged so as to detect ATDC 85° CA and ATDC 130° CA. The interval of 45° between the two detection points is used to determine the angular velocity. ATDC stands for after top dead center; and CA for crank angle.

[0071] FIG. 6 shows the variation in engine torque and angular velocity (rad/sec) with respect to the crank angle in an in-line four-cylinder four-cycle gasoline engine. As shown, the combustion occurs in the order of cylinder number 4, cylinder number 2, cylinder number 1, and cylinder number 3. The combustions cause the gas pressure torque to vary, and the piston movements cause the inertia torque to vary, so that the resultant torque of the combusted-gas torque and the inertia torque varies as indicated by a bold line. Then, the angular velocity varies depending on a difference between the resultant torque and the required torque for maintaining the angular velocity. As a result, the angular velocity varies as indicated by a solid line A in the case of the normal combustion. On the other hand, in the case of misfire in cylinder number 1, the angular velocity varies as indicated by a broken line B because of the torque loss due to the misfire in cylinder number 1.

[0072] That is, during the normal combustion of the engine, an increase in combustion pressure after ignition causes the angular velocity to rise, and the completion of the combustion causes the angular velocity to decrease. On the other hand, in the case of misfire, though a rate of the increase in angular velocity lessens, the angular velocity is not so greatly different from that in the normal combustion because the angular velocity is relatively small in the early stage of the combustion stroke even during the normal combustion. Then, after the middle stage of the stroke, the angular velocity remarkably reduces with the decrease in combustion pressure, and increasingly differs from the angular velocity in the normal combustion. In the cylinder following the misfiring cylinder (or in cylinder number 3 in the case of the misfire in cylinder number 1), though the angular velocity is relatively small under the influence of the misfire in the preceding cylinder, the required torque for maintaining the angular velocity is reduced with the decrease in angular velocity, so that the angular velocity increases under the same torque. As a result, the angular velocity becomes approximate to that in the normal condition as the stroke proceeds.

[0073] FIG. 7 shows the correlation between the combustion pressure and the fluctuation in angular velocity. Its horizontal axis indicates the crank angle from the top dead center of the compression stroke of a cylinder, which is defined as 0° CA; its vertical axis indicates the correlation coefficient. The correlation coefficient refers to the level of the effect on the angular velocity by the combustion condition (e.g. combustion pressure) in the present cylinder. Positive values of this coefficient mean the intimate correlation between the fluctuation in combustion pressure in the cylinder (or the decrease in com-

bustion pressure with misfire) and the fluctuation in angular velocity (or the decrease in angular velocity). On the other hand, negative values of the coefficient mean that the fluctuation in combustion pressure in the preceding cylinder affects the fluctuation in angular velocity more greatly than that in the present cylinder.

[0074] As apparent from FIG. 6 and FIG. 7, before the elapse of the primary combustion period after ignition (approximately TDC to ATDC 20° CA) and the delay time necessary for the torque increase caused by the combustion to be reflected on the angular velocity (approximately 20° CA), the combustion condition in the preceding cylinder more greatly affects the fluctuation in angular velocity. In the meantime, after the timing of elapse of those periods (equivalent to the timing of the combustion completion) before the start of the combustion in the following cylinder, the intimate correlation is seen between the fluctuation in combustion pressure in the present cylinder and the fluctuation in angular velocity. Accordingly, it was recognised that a sufficiently accurate determination of the combustion condition can be made by determining the fluctuation in angular velocity (or difference between the angular velocity at the previous combustion and that at previous combustion) on the basis of the angular velocity within the crank angle range between the crank angle at which combustion substantially completes (approximately ATDC 40°) and the crank angle at which combustion starts in the following cylinder (approximately ATDC 200°).

[0075] The angular velocity detecting means 45 determines the fluctuation in angular velocity on the basis of the data of angular velocity (or detected data of angular velocity) as described above. In order to remove noise components unfavorable to the determination of the combustion condition, the angular velocity detecting means 45 preferably conducts a noise reduction of filtering process or a process for removing the frequency components of rotational order of 0.5 and its integral multiples of the engine rotation and the frequency components of rotational order less than 0.5 of the engine rotation, in determining the fluctuation in angular velocity from the angular velocity data.

[0076] That is, besides the fluctuation in combustion condition, noise components which may cause angular velocity to fluctuate include: the fluctuation in angular velocity due to the resonance originating from the combustion as the vibration source; the fluctuation in angular velocity occurring during the rotation of wheel due to the unbalanced wheels and drivetrains; and/or the fluctuation in angular velocity due to the vibration transmitted from road surface to wheels. As shown in FIG. 8, noise components resulting from explosive rotation due to the resonance occur in a frequency of rotational orders of 0.5 and its integral multiples of the engine rotation, and noise components due to the rotation of unbalanced wheels and road surface conditions occur in a frequency band of rotational orders less than 0.5.

[0077] Therefore, the angular velocity detecting

means 45 firstly removes the signal with the frequency of rotational orders of 0.5 and its integral multiples of the engine rotation from the detected data of angular velocity. Particularly, by determining a difference between the angular velocity in the present cycle and that in the previous cycle, or a difference $d\omega$ between the present detected value of angular velocity $\omega[i]$ and the previous detected value $\omega[i - 4]$ detected four strokes before, the data of the fluctuation in angular velocity are determined, from which the frequency components of rotational orders of 0.5 and its integral multiples of the engine rotation are excluded, as shown in FIG. 9.

[0078] Moreover, the angular velocity detecting means 45, as described above, removes the noise components of the frequency of rotational orders less than 0.5 of the engine rotation. Particularly, an operation as a highpass filter, like a rotationally synchronized FIR digital filter for example, is performed to reduce the a frequency band of rotational orders less than 0.5, as shown in FIG. 10. Therefore, such operations as above remove the frequency components of rotational order of 0.5 and its integral multiples of the engine rotation and the frequency components of rotational order less than 0.5 of the engine rotation, so as to provide the precise data of the fluctuation in angular velocity indicative of the fluctuation in combustion condition.

[0079] As shown in FIG. 11, the roughness control means 46 preferably includes: a mean deviation measuring means 46a; a predictive value calculating means 46b; a judging means 46c; a control variable setting means 46d; and/or a storage means 46e. The mean deviation measuring means 46a is provided for measuring or determining a mean deviation of the angular velocity fluctuation using the detected data of the fluctuation in angular velocity detected by the angular velocity fluctuation detecting means 45. The predictive value calculating means 46b is provided for calculating a predictive value of the mean deviation in the case of change in control variables (or the amount of ignition retard) for the adjusting means comprising the spark plug 8. The judging means 46c is provided for judging if the engine is in the proper combustion condition or not from the measured value and the predictive value of the mean deviation. The control variable setting means 46d is provided for setting a control variable in accordance with the judgement of the judging means 46c. The storage means 46e is provided for at least temporarily storing the control variable set by the control variable setting means 46d, the measured value of the mean deviation by the mean deviation measuring means 46a, and the like.

[0080] The mean deviation measuring means 46a measures the mean deviation in the following manner: While the engine is operating on the lean combustion mode with the constant operational condition, or during the normal operational condition where an operational condition equivalent to one of the 1st segment (1) to 12th segment (12) is maintained over a certain time period

for example, the mean deviation measuring means 46a calculates a difference between the angular velocity of the engine rotational speed at the present combustion and the angular velocity of the engine rotational speed at the previous combustion detected by the angular velocity detecting means 45 over four seconds for example, to collect the data for approximately 200 cycles.

Then, the mean deviation measuring means 46a uses a mean value of the data collected as above and the difference in angular velocity to determine the mean deviation, which are outputted to the judging means 46c and stored in the storage means 46e.

[0081] The predictive value calculating means 46c determines a predictive value of the mean deviation varying depending on the correction of the ignition timing, using the control variable set by the control variable setting means 46d. The determination is made preferably on the basis of the least squared method using a plurality of the latest measured values which are measured by the mean deviation measuring means 46a. For example, when the control variable setting means 46d corrects the ignition timing so as to sequentially retard the ignition timing, the four mean deviations stored in the storage means 46e (or four measured values of the mean deviation calculated and stored at every timing of ignition retard) are read. Using the four values, the predictive value calculating means 46b predicts the variation in mean deviation with further ignition retard, preferably on the basis of the least squared method.

[0082] Immediately after engine start or in other conditions with no measured value by the mean deviation measuring means 46b, reference data (or standard data predetermined) in the storage means 46e are used to predict the predictive value of the mean deviation on the basis of the least squared method. In the case that no measured value exists for the present operational segment, or in the case that the insufficient number of measured value exists for the present operational segment but the considerable number of measured values exists for another operational segment, measured values are read from the operational segment with the considerable number of the values, adapted for the variation in measured values stored for the present operational segment, and used in the roughness control.

[0083] The judging means 46c, in the operational region of the lean combustion mode, judges if the engine is in the proper combustion condition, from a difference between the predictive value of the mean deviation predicted by the predictive value calculating means 46b and the measured value actually determined by the mean deviation measuring means 46a when the control variable setting means 46d performs the control for varying the control variable.

[0084] That is, while the control is sequentially retarding or advancing the ignition timing, the judging means 46c judges if a difference between a predictive value of the mean deviation predicted at the timing of the previous control (before the retard or advance of the ignition)

and a measured value of the mean deviation determined at the timing of the present control (after the retard or advance of the ignition) is in a specified (predetermined or predeterminable) allowable range. When the difference between the predictive value and the measured value of the mean deviation is confirmed to be in the allowable range, the engine is judged to be in the proper combustion condition, then the signal indicative of the proper condition is transmitted to the control variable setting means 46d. On the other hand, the difference is confirmed to be out of the allowable range, the engine is judged to be in the improper combustion condition, then the signal indicative of the improper condition is transmitted to the control variable setting means 46d.

[0085] The control variable setting means 46d, when the judging means 46c judges that the difference between the predictive value and the measured value of the mean deviation is out of the allowable range, sets or determines a control variable which corrects the ignition timing to be advanced for improving the combustion stability of the engine. On the other hand, when the judging means 46c judges that the difference between the predictive value and the measured value of the mean deviation is in the allowable range, or when the control is initiated immediately after engine start for example, the control variable setting means 46d sets or determines a control variable which corrects the ignition timing to be retarded for improving the fuel efficiency of the engine. Then, the control variable is transmitted to the ignition timing control means 44.

[0086] Additionally, in the operational condition of the lean combustion mode, a control variable for correcting a fuel injection timing preferably is calculated or determined based on the control variable set by the control variable setting means 46d (or the amount of ignition retard). This variable causes the fuel injection to occur a predetermined period before the ignition timing. That is, a stable combustion region in the operational condition of the lean combustion mode, in which the mixture is stratified in the proximity of the spark plug 8 and ignited, tends to narrow as the ignition is retarded as shown in FIG. 12. In addition, a certain correlation is seen between the stable combustion region and the fuel injection timing in the case that ignition is retarded. Thus, the setting of the amount of the ignition retard to a certain amount will automatically provide the proper fuel injection timing for maintaining combustion stability.

[0087] The air-fuel ratio control means 47, shown in FIG. 2, controls the air-fuel ratio A/F by adjusting the amount of fuel to be injected into the combustion chamber 4 from the injector 28 and the amount of the valve travel of the electrically-controlled throttle valve 22, in accordance with the output signals from the sensors such as air-flow meter 21 and coolant temperature sensor 14, the target indicated mean effective pressure corresponding to the target load and set by the target load setting means 41, a detected value of engine load, and the operational region determined by the operational re-

gion determining means 42. Particularly, the air-fuel ratio control means 47 performs a control for changing the combustion mode by adjusting the air-fuel ratio A/F in accordance with the engine operational condition. More particularly, the air-fuel ratio control means 47 adjusts the air-fuel ratio A/F to be lean as predetermined for providing the lean combustion mode in the operational region up to intermediate speed and intermediate load, and adjusts the air-fuel ratio A/F to be equal to or less than the stoichiometric air-fuel ratio A/F for providing the rich combustion mode in the operational region of higher engine speed and higher load, as shown in FIG. 4 in warmed-up state of the engine.

[0088] Moreover, in the lean combustion mode, the target load setting means 41 sets or determines the target indicated mean effective pressure corresponding to the target load to be used when the combustion mode shifts to the rich combustion mode, on the basis of the control variable for the spark plug 8 set by the roughness control means 46, that is, the amount of the ignition retard. Then, using the target indicated mean effective pressure set as above, the air-fuel ratio control means 47 sets or determines an air-fuel ratio A/F in the shifting of the combustion mode.

[0089] The apparatus in accordance with a preferred embodiment of the present invention acts as will be described with reference to the flow charts shown in FIG. 13 through FIG. 17. FIG. 13 shows a main control routine for setting a fuel injection timing and an ignition timing for mixture. After the control routine starts, firstly, the target load setting means 41 sets or determines a volumetric efficiency of intake air corresponding to the engine rotational speed and the acceleration pedal travel with reference to a map or table or relationship (at step S1). The value of the volumetric efficiency and the value of the atmospheric pressure are used to determine a charging efficiency of intake air (at step S2), then, based on the charging efficiency, a target indicated mean effective pressure P_i corresponding to a target load of the engine is determined (at step S3).

[0090] Next, the operational condition determining means 42 judges whether or not the engine is operating on the lean combustion mode (at step S4). If NO, that is, the engine is confirmed to be operating on the rich combustion mode, an ignition timing IG for the mixture is set or determined from a fundamental or basic ignition timing read out with reference to a map or table or relationship based on the target indicated mean effective pressure P_i (at step S5), and a fuel injection timing INJ is set or determined from a fundamental or basic injection timing read out with reference to a map or table or relationship based on the target indicated mean effective pressure P_i (at step S6).

[0091] If YES at step S4, that is, the engine is confirmed to be operating on the lean combustion mode, a judgement is made as to whether the roughness control means 46 had performed a correction of ignition retard (at step S7). If YES at step S7, and data for the rough-

ness control are available, the roughness control is performed (at step S8) as will be described.

[0092] If NO at step S7, that is, the data for the roughness control is not available because the present condition is immediately after engine start, an ignition timing IG for mixture is set or determined from the fundamental ignition timing read out with reference to a map or table or relationship based on the target indicated mean effective pressure P_i (at step S9), and the roughness control is performed at step S8. Then, an ignition control signal and an injection control signal corresponding to the ignition timing IG, which had been set by the roughness control or set at steps S5 and S6, are transmitted to respective actuators, i.e. the signal is output for controlling the ignition and the injection timings (at steps S10 and S11).

[0093] A main control routine performed at step S8 will now be described with reference to a flow chart shown in FIG. 14. After the control routine starts, data of engine rotational speed n_e and the target indicated mean effective pressure P_i are acquired (at step S21). Based on the acquired data, a segment corresponding to the present operational condition is selected from the 1st to 12th segments shown in FIG. 3 (at step S22), then a complementary control for control data is performed as will be described (at step S23).

[0094] Next, a judgement is made as to whether the engine operational segment at the present control is different from that at the previous control (at step S24). If NO, that is, the operational segment of the engine has not changed, a judgement is made as to whether a timer has counted a sampling time predetermined e.g. as approximately four seconds (at step S25). If YES at step S25, that is, the timer is confirmed to have counted the sampling time, a control for setting an ignition timing and an injection timing is performed (at step S26). Then, the timer is reset to zero (at step S27), and the routine returns.

[0095] If NO at step S25, that is, the timer is confirmed not to have counted the sampling time, the timer is incremented (at step S29), and the routine returns. If step S24 judges YES, that is, the step confirms that the operational segment has changed to the other before the timer completes the count of the sampling time, control data for the other segment, to which the operational segment has changed, that is, control variable indicative of the amount of ignition retard and a measured value of the mean deviation for the following segment, are read from the storage means 46e (at step S28). Then, the routine proceeds to step S27 and resets the timer.

[0096] The complementary control routine performed at step S23 will now be described with reference to the flow chart shown in FIG. 15. After the control routine starts, firstly, a mean ignition-retard amount (or a mean control variable) for the overall region of the lean combustion mode is calculated based on control data stored for each of the plural divided segments in the region of the lean combustion mode (at step S31). Based on the

value calculated as above, an increment or the increased amount of the target indicated means effective pressure P_i is calculated (at step S32).

[0097] Then, a control map or table or relationship, which provides the target load (or target indicated means effective pressure) to be used for engine control when the operational mode shifts from the lean combustion mode to the rich combustion mode, is corrected based on the increment of the target indicated mean effective pressure P_i corresponding to the ignition retard control (at step S33), and a segment with the maximum amount of ignition retard and the amount of the maximum retard R_{max} are read (at step S34).

[0098] Next, a judgement is made as to whether the roughness control has been performed in the present segment (at step S35). If YES, a judgement is made as to whether the amount of ignition retard R_α in the present segment is less than half of the amount of the maximum retard R_{max} (at step S36). If NO at step S36 and a predetermined number of control data have been accumulated and available in the present segment, the routine returns as it is and uses the accumulated data to control for setting an ignition timing and an injection timing as will be described.

[0099] If NO at step S35, that is, the roughness control has not been performed in the present segment, or if YES at step S36, that is, the amount of ignition retard R_α in the present segment is less than e.g. half of the amount of the maximum retard R_{max} , control data in the present segment is complemented based on the amount of the maximum retard R_{max} of the segment read at step S34 or the segment with the maximum amount of ignition retard (at step S38). Particularly, if the roughness control has not performed many times in the present segment, control data in the present segment (or the amount of ignition retard) is set preferably based on the amount of the maximum retard R_{max} . Additionally, data determined from the measured value of the mean deviation, which has been obtained for the segment with the maximum amount of ignition retard, is stored in the storage means 46e as a measured value of the mean deviation in the present segment.

[0100] Described next is the control routine for setting an ignition timing and an injection timing performed at step S26 in the main control routine of the roughness control.

[0101] Referring to FIG. 16, after the control routine starts, a counter not shown counts and recognizes the number of the executions A_d of the advance control in the present segment, that is, the number of the settings of a control variable which improves the combustion stability, in accordance with the judgement by the judging means 46c as will be described (at step S41).

[0102] If the number of the executions of the advance control is confirmed to be zero or relatively small at step S41, a nominal value α_n is set to 1° (at step S42). The nominal value α_n indicates an incremental ignition retard amount by which the ignition timing in the previous

control is to be retarded for providing the ignition timing in the present control. If the number of the executions of the advance control is confirmed to be medium, the nominal value α_n is set to 0.5° (at step S43). If the number of the execution of the advance control is confirmed to be large, the nominal value α_n is set to 0.25° (at step S44).

[0103] Then, a measured value of the mean deviation σ , which has been obtained in a control for measuring the mean deviation as described later, is read (at step S45), a difference β between a predictive value of the mean deviation σ calculated in the previous control and the measured value of the mean deviation σ is calculated (at step S46), and a judgement is made as to whether the difference β is in a specified (predetermined or predetermined) allowable range (at step S47).

[0104] If YES at step S47, that is, the difference β is in the allowable range, an incremental ignition retard amount α to be used for the present control is set to the nominal value α_n which has been determined either at steps S41, S42, or S43 (at step S48). Then, a predictive value of the mean deviation σ in the case that an ignition timing control is performed based on the incremental ignition retard amount α , is calculated on the basis of the least squared method, using the values of the mean deviation σ in the storage means 46e. The values of the mean deviation σ are, the latest four measured values actually acquired in the control for measuring the mean deviation σ , or data determined by step S37 in the complementary control for control data shown in FIG. 15 (at step S49).

[0105] Immediately after engine start or other condition with no measured values being measured by the mean deviation measuring means 46b, four reference data in the storage means 46e are used to calculate the predictive value of the mean deviation σ on the basis of the least squared method. The reference data are standard data, which have been predetermined so as to be equivalent to the measured values of the mean deviation σ in the case that ignition timing is sequentially retarded by 1° from the timing which is advanced by 4° from an initial timing (or a fundamental ignition timing). The initial timing is set so as to be unlikely to impair the combustion stability.

[0106] If NO at step S47, that is, the difference the difference β is out of the predetermined allowable range, the incremental ignition retard amount α for the following control is set to -1° (at step S50). Then, the counter for counting the number of the executions of the advance control is incremented by 1 (at step S51), and at step S49, the predictive value of the mean deviation σ in the case of the advance of the ignition timing is calculated on the basis of the least squared method using the measured values of the mean deviation σ stored in the storage means 46e.

[0107] Next, the ignition timing IG is updated ($IG = IG - \alpha$) based on the incremental ignition retard amount α set by step S48 or step S50 to determine a final retard

amount (control variables for the adjusting means) for correcting the fundamental ignition timing (at step S52), and the injection timing INJ is updated ($INJ = INJ - \alpha$) based on the retard amount α (at step S53), so as to provide the injection timing INJ a certain period earlier than the ignition timing IG.

[0108] A control routine for measuring the mean deviation σ will now be described with reference to the flow chart shown in FIG. 17. The control routine for measuring the mean deviation σ runs separately from the roughness control described above. After the control routine for measuring the mean deviation σ starts, firstly, the angular velocity fluctuation detecting means 45 detects fluctuation data indicative of the fluctuation in angular velocity (at step S61). Then, noise components are preferably removed or filtered from the fluctuation data (at step S62), and the fluctuation data preferably substantially without noise components is stored in the storage means 46e (at step S63).

[0109] Next, a judgement is made as to whether a timer has counted a certain (predetermined or predeterminable) period of time, during which a certain number of the fluctuation data are collected (at step S64). At the time when the step judges YES, the mean deviation measuring means 46a calculates the mean deviation σ of the fluctuation in angular velocity in accordance with the following formula (at step S65), and the routine returns.

$$\sigma = \sum |d\omega[i] - d\omega_f| / N \quad (i = 1 \text{ to } N)$$

Where, $d\omega[i]$ is a deviation data measured during the predetermined sampling time, from which noise components are removed;

$d\omega_f$ is a mean value of each fluctuation data above; and N is the number of the counts of the deviation data.

[0110] As described above, there is provided a control apparatus for an engine comprising, angular velocity fluctuation detecting means 45 for detecting the fluctuation in angular velocity of engine rotation, adjusting means including an injector 28 for adjusting a combustion condition of the engine, and/or roughness control means 46 which sets or determines a control variable for the adjusting means (or the amount of ignition retard) so as to maintain the combustion stability of the engine within a certain range, wherein, a judgement is made as to whether the engine is in the stable combustion condition by judging means 46c based on a difference between a measured value of the mean deviation σ of the fluctuation in angular velocity actually measured by mean deviation measuring means 46a and a predictive value of the mean deviation σ calculated by predictive value calculating means 46b. Accordingly, the determination is accurately made as to whether the engine is in the stable combustion condition without any erroneous

determination, even in the engine in which the engine rotation remarkably tends to fluctuate, or in an engine which executes a lean combustion mode where the air-fuel ratio A/F in combustion chambers is adjusted to be significantly lean of the stoichiometric air-fuel ratio A/F during low load and low speed condition and fuel is directly injected into the combustion chambers at predetermined timings so as to cause the resultant mixture, which has been stratified in the vicinity of spark plugs, to combust.

[0111] FIG. 18 is a graph chart showing the change in mean deviation σ , when the roughness control is performed which gradually retards ignition timing from the initial timing at which the combustion stability is not impaired in the engine described above. A solid line indicates the change in measured value; a broken line indicates the change in predictive value. This data proves that, even while the combustion is stable, the fluctuation (or increase and/or decrease) in measured value of the mean deviation σ is enlarged as the amount of ignition retard increases, and the fluctuation in measured value becomes more remarkable while the difference between the measured value of the mean deviation σ and the predictive value of the mean deviation σ increases as the amount of ignition retard approaches the misfire region after exceeding a certain amount. Accordingly, a determination can be made as to whether the ignition timing has closely approached the misfire region, in accordance with the judgement made by the judging means 46c as to whether the difference between the measured value of the mean deviation σ and the predictive value of the mean deviation σ is in the predetermined allowable (predetermined or predeterminable) range k with its center being the predictive value.

[0112] If the judging means 46c judges that the difference between the measured value of the mean deviation σ and the predictive value of the mean deviation σ is out of the allowable range k , the control variable indicative of the amount of ignition retard is set so as to improve the combustion stability of the engine and the fuel injection timing is correspondingly corrected, so that the ignition timing is reliably prevented from entering the misfire region while improving fuel efficiency by retarding as much as possible within the stable combustion limit, as shown in FIG. 19.

[0113] Moreover, in accordance with a preferred embodiment described above, the predicted value of the mean deviation σ , in the case that the control variables indicative of the amount of ignition retard are changed, are determined preferably on the basis of the least squared method using the latest plural measured values which are measured by the mean deviation measuring means 46b. Accordingly, the predictive value of the mean deviation σ is easily and accurately determined.

[0114] Alternatively, the predicted value of the mean deviation σ may be determined on the basis of the other method, such as the successive approximation, successive over relaxation method, or steepest descent meth-

od using the latest plural measured values which are measured by the mean deviation measuring means 46b. Especially, the successive approximation advantageously provides an accurate calculation for the predictive value of the mean deviation σ .

[0115] Further, in accordance with the preferred embodiment described above, the mean deviation σ of the fluctuation in angular velocity measured for each of plural control variables by the mean deviation measuring means 46a are stored in the storage means 46e separately by the operational segments divided with respect to engine rotational speed and engine load, and, when the engine shifts to another operational segment, the mean deviation σ for the operational segment is read from the storage means 46e and is used to control the adjusting means including the injector 28. Accordingly, a meticulous roughness control for each segment is provided for the engine, thereby effectively improving fuel efficiency while maintaining the preferable combustion stability of the engine.

[0116] Especially, as shown in the preferred embodiment, data for the operational segment with a sufficient number of stored data of a mean deviation σ and a sufficient number of the shift in control variable towards the stable combustion limit (for more amount of retard) are reflected on or diverted to the control of the adjusting means including the injector 28 in an operational segment with an insufficient number of stored data of a mean deviation σ . Accordingly, the optimized ignition timing can be determined more quickly than the case with the control of gradually retarding the ignition timing from the initial timing for each operational segment.

[0117] Moreover, in accordance with the preferred embodiment, when the control variable for the adjusting means shifts towards the stable combustion limit (for more amount of retard), the number of the judgements made by the judging means 46c that the measured value of the mean deviation σ is out of the allowable range k is determined. Then, the incremental amount of the control variable, or an incremental ignition retard amount is reduced for the larger number of the judgements. Accordingly, the deterioration in combustion stability caused by the roughness control is effectively prevented while the optimum control variable is more quickly determined for the adjusting means.

[0118] For example, in an operational segment where the ignition retard is likely to deteriorate the combustion stability under the influence of some factor, a considerable amount of ignition retard may possibly cause misfire in the engine. This drawback can be avoided, or the deterioration in combustion stability is prevented in the engine, by preferably setting or determining the incremental amount of the control variable to relatively small as described above. On the other hand, in the other operational segment, the ignition timing can be quickly retarded to the optimum, by setting the incremental amount of the control variable to relatively large.

[0119] Further, in accordance with the preferred em-

bodiment, in an engine comprising an air-fuel ratio control means 47 which, in accordance with the engine operational condition, changes the operational mode between the lean combustion mode with a larger air-fuel ratio A/F than the stoichiometric air-fuel ratio in the combustion chamber 4 and the rich combustion mode with an air-fuel ratio A/F equal to or more than the stoichiometric air-fuel ratio in the combustion chamber 4, the target load setting means 41 is provided which sets or determines a target load (or target indicated mean effective pressure) to be used for engine control in shifting to the rich combustion mode, on the basis of a control variable (or the amount of ignition retard) set by the roughness control means 46 during the lean combustion mode. Accordingly, a torque shock is advantageously prevented in the changing of the combustion mode.

[0120] Particularly, the increased amount of the engine torque due to the ignition retard to the optimum timing by the roughness control means 46 is calculated based on the control variable by the target load setting means 41, and the control map or table or relationship for setting or determining the target indicated mean effective pressure (or target load) is corrected based on the increased amount of the engine torque. As a result, a torque shock is effectively avoided in the shifting from the lean combustion mode to the rich combustion mode of the engine.

[0121] Especially, in accordance with the preferred embodiment, the target load at the timing when the operational mode shifts to the rich combustion mode is set in the following manner:

Firstly, control variables for the adjusting means for each of operational segments divided with respect to engine rotational speed and engine load in the operational region of the lean combustion mode are set, a mean control variable for the overall lean combustion mode is determined based on the control variables, and the target load to be used when the operational mode shifts to the rich combustion mode is set based on the mean control variable.

Accordingly, a torque shock is easily and effectively avoided in any case of the shifting from whichever operational segments of lean combustion mode to the rich combustion mode of the engine. Further, though the aging of the engine causes the mean control variable for overall lean combustion mode to vary, the air-fuel ratio control described above can accommodate the aging of the engine by setting the target load on the basis of the mean control variable.

[0122] It should be appreciated that the control apparatus for an engine in accordance with the present invention is not limited to the preferred embodiment described above, but can be modified in various ways. For example, the angular velocity detecting means 45 may detect the equivalent to angular velocity, such as rotational cycle, in place of angular velocity. The control variable for adjusting means which maintains the engine combustion stability within a certain range may be an

air-fuel ratio A/F in the combustion chamber, in place of the ignition timing and the fuel injection timing.

[0123] Additionally, the roughness control in the preferred embodiment described above removes the frequency components of rotational order of 0.5 and its integral multiplies of the engine rotation and the low frequency components of rotational order less than 0.5 of the engine rotation in determining the fluctuation in angular velocity from the angular velocity data, in a constant manner. However, the frequency components of rotational order of 0.5 and its integral multiplies of the engine rotation may be preferably removed when the engine operates at relatively high rotational speed, because the effect of resonance caused by the combustion increases for the higher rotational speed of the engine.

[0124] As described above, in accordance with a preferred embodiment of the present invention, there is provided a control apparatus for an engine comprising, angular velocity fluctuation detecting means 45 for detecting the fluctuation in angular velocity of engine rotation, adjusting means 8; 28; 43; 44 for adjusting a combustion condition of the engine 1, and roughness control means which sets or determines a control variable for the adjusting means 8; 28; 43; 44 so as to maintain the combustion stability of the engine 1 within a certain (predetermined or predeterminable) range, wherein, mean deviation measuring means is provided which measures or determines a mean deviation σ of the fluctuation in angular velocity, for a plurality of control variables (IG, INJ and/or A/F) set by the roughness control means 46 under the same operational condition of the engine 1, predictive value calculating means 46b is provided which calculates a predictive value in the case that a control variable for the adjusting means 8; 28; 43; 44 is changed, on the basis of the measured value of the mean deviation σ determined for the plural control variables (IG, INJ and/or A/F), and judging means 46c is provided which judges of the engine 1 is in the proper combustion condition, from a difference between the predictive value and the measured value of the mean deviation σ measured after the change in control variable (IG, INJ and/or A/F). Accordingly, in an engine 1 in which the engine rotation remarkably tends to fluctuate even when the engine 1 is in the stable combustion region, the judgement can be accurately made without any erroneous determination as to whether the engine 1 is brought to the stable combustion condition by the execution of the roughness control for effectively preventing the misfire condition of the engine, while improving fuel efficiency by setting ignition timing close to the stable combustion limit.

Claims

1. A control apparatus (40) for an engine (1) comprising,

angular velocity fluctuation detecting means (45) for detecting the fluctuation in angular velocity of engine rotation,

adjusting means (8, 28, 43, 44) for adjusting a combustion condition of the engine (1),

roughness control means (46) which sets a control variable (IG; INJ; A/F) for the adjusting means (8, 28, 43, 44) so as to maintain the proper combustion stability of the engine (1), mean deviation measuring means (46a) which measures a mean deviation (σ) of the fluctuation in angular velocity, for each of a plurality of control variables (IG; INJ; A/F) set by the roughness control means (46) under the same operational condition of the engine (1),

predictive value calculating means (46b) which calculates a predictive value of the mean deviation (σ) in the case that a control variable (IG; INJ; A/F) for the adjusting means (8, 28, 43, 44) is changed, on the basis of the measured value of the mean deviation (σ) determined for each of the plural control variables (IG; INJ; A/F), and judging means (46c) which judges if the engine (1) is in the proper combustion condition, from a difference (β) between the predictive value and the measured value of the mean deviation (σ) measured after the change in control variable (IG; INJ; A/F).

2. The control apparatus (40) for an engine (1) as defined in claim 1, further comprising,

control variable setting means (46d) which sets a control variable (IG; INJ; A/F) for the engine (1) according to the judgement by said judging means (46c),

wherein, said judging means (46c) judges if a difference (β) between the predictive value of the mean deviation (σ) predicted in a previous control and the measured value of the mean deviation (σ) measured after a change in control variable (IG; INJ; A/F) is within a specified allowable range (k), and

said control variable setting means sets a control variable (IG; INJ; A/F) for the adjusting means (8, 28, 43, 44) so as to improve the combustion stability of the engine (1), if said judging means (46c) judges that the difference (β) between the predictive value and the measured value of the mean deviation (σ) is out of the allowable range (k).

3. The control apparatus (40) for an engine (1) as defined in any one of the preceding claims,

wherein, said predictive value calculating means (46b) calculates the predicted value of the mean deviation (σ) on the basis of the least squared method using the latest plural measured values

which are measured by said mean deviation measuring means (46a).

4. The control apparatus for an engine as defined in claim 1 or 2,

wherein, said predictive value calculating means (46b) calculates the predicted value of the mean deviation (σ) on the basis of the successive approximation using the latest plural measured values which are measured by said mean deviation measuring means (46a).

5. The control apparatus (40) for an engine (1) as defined in any one of the preceding claims, further comprising,

storage means (46e) which at least temporarily stores the mean deviation (σ) of a fluctuation in angular velocity, and/or
operational region determining means (42) which determines an operational segment of an operational region in which the engine (1) is operating, the operational segments being divided with respect to engine rotational speed and engine load,

wherein, said mean deviation measuring means (46a) preferably stores the mean deviation (σ) of a fluctuation in angular velocity measured for each of plural control variables (IG; INJ; A/F) in said storage means (46e) correspondingly to the operational segments, and

said control variable setting means (46d) preferably reads the mean deviation (σ) for the operational segment from said storage means (46e) and uses the mean deviation (σ) to control the adjusting means (8, 28, 43, 44), when the engine (1) has shifted to another operational segment.

6. The control apparatus (40) for an engine (1) as defined in claim 5,

wherein, said control variable setting means (46d) reflects data corresponding to the operational segment with a sufficient number of stored data of the mean deviation (σ) and a sufficient number of the shift in control variable (IG; INJ; A/F) towards the stable combustion limit, to control the adjusting means (8, 28, 43, 44) in an operational segment with an insufficient amount of stored data of the mean deviation (σ).

7. The control apparatus (40) for an engine (1) as defined in any one of the preceding claims,

wherein, said control variable setting means (46d) determines the number of the judgement by the judging means (46c) that the measured value of the mean deviation (σ) is out of the allowable range (k) and reduces an incremental amount (α)

of the control variable (IG; INJ; A/F) for the more number of the judgements, when shifting the control variable (IG; INJ; A/F) for the adjusting means (8, 28, 43, 44) towards the stable combustion limit.

8. The control apparatus (40) for an engine (1) as defined in any one of the preceding claims, further comprising,

air-fuel ratio control means (47) which, in accordance with the engine operational condition, changes the operational mode between the lean combustion mode with a larger air-fuel ratio than the stoichiometric air-fuel ratio in a combustion chamber (3) of the engine (1) and the rich combustion mode with an air-fuel ratio equal to or more than the stoichiometric air-fuel ratio in the combustion chamber (3), and target load setting means (41) which sets a target load to be used for engine control in shifting to the rich combustion mode, on the basis of a control variable (IG; INJ; A/F) set by the roughness control means (46) during the lean combustion mode.

9. The control apparatus (40) for an engine (1) as defined in claim 8, wherein,

said control variable setting means (46d) sets control variables (IG; INJ; A/F) for the adjusting means (8, 28, 43, 44) for each of the operational segments in the operational region of the lean combustion mode, and determines a mean control variable for the overall lean combustion mode on the basis of the control variables (IG; INJ; A/F), and

said target load setting means (41) sets the target load to be used when the operational mode shifts to the rich combustion mode, on the basis of the mean control variable determined by said control variable setting means (46d).

10. An engine (1) equipped with the control apparatus (40) as defined in any one of the preceding claims.

11. The engine (1) as defined in claim 10,

wherein the engine (1) controls an injector (28) of the engine (1) to inject fuel directly into the combustion chamber (3) during the compression stroke so as to stratify mixture in the vicinity of the spark plug (8) of the engine (1) at an ignition timing.

12. The engine (1) as defined in claim 10,

wherein the engine (1) produces tumble flow in a combustion chamber (3) of the engine (1) during the compression stroke, and controls an injector (28) of the engine (1) to inject fuel directly into the combustion chamber (3) in the substantially opposite direction against the tumble flow so as to stratify mixture in the vicinity of a spark plug (8) of the en-

gine (1) at an ignition timing, as a result of the collision of the tumble flow and the injected fuel.

13. A control method for an engine (1), the engine (1) including angular velocity fluctuation detecting means (45) for detecting the fluctuation in angular velocity of engine rotation, adjusting means (8, 28, 43, 44) for adjusting a combustion condition of the engine (1), and roughness control means (46) which sets a control variable (IG; INJ; A/F) for the adjusting means (8, 28, 43, 44) so as to maintain proper the combustion stability of the engine (1), comprising the following steps of:

measuring a mean deviation (σ) of the fluctuation in angular velocity, for each of a plurality of control variables (IG; INJ; A/F) set by the roughness control means (46) under the same operational condition of the engine (1),
calculating a predictive value of the mean deviation (σ) in the case that a control variable (IG; INJ; A/F) for the adjusting means (8, 28, 43, 44) is changed, on the basis of the measured value of the mean deviation (σ) determined for each of the plural control variables (IG; INJ; A/F), and
judging if the engine (1) is in the proper combustion condition, from a difference (β) between the predictive value and the measured value of the mean deviation (σ) measured after the change in control variable (IG; INJ; A/F).

14. A computer-readable storage medium having stored thereon a computer program, which, when loaded onto a computer, carries out the engine control method for an engine (1) as defined in claim 13.

15. A computer program, which, when loaded onto a computer, carries out the engine control method for an engine (1) as defined in claim 13.

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FIG. 1

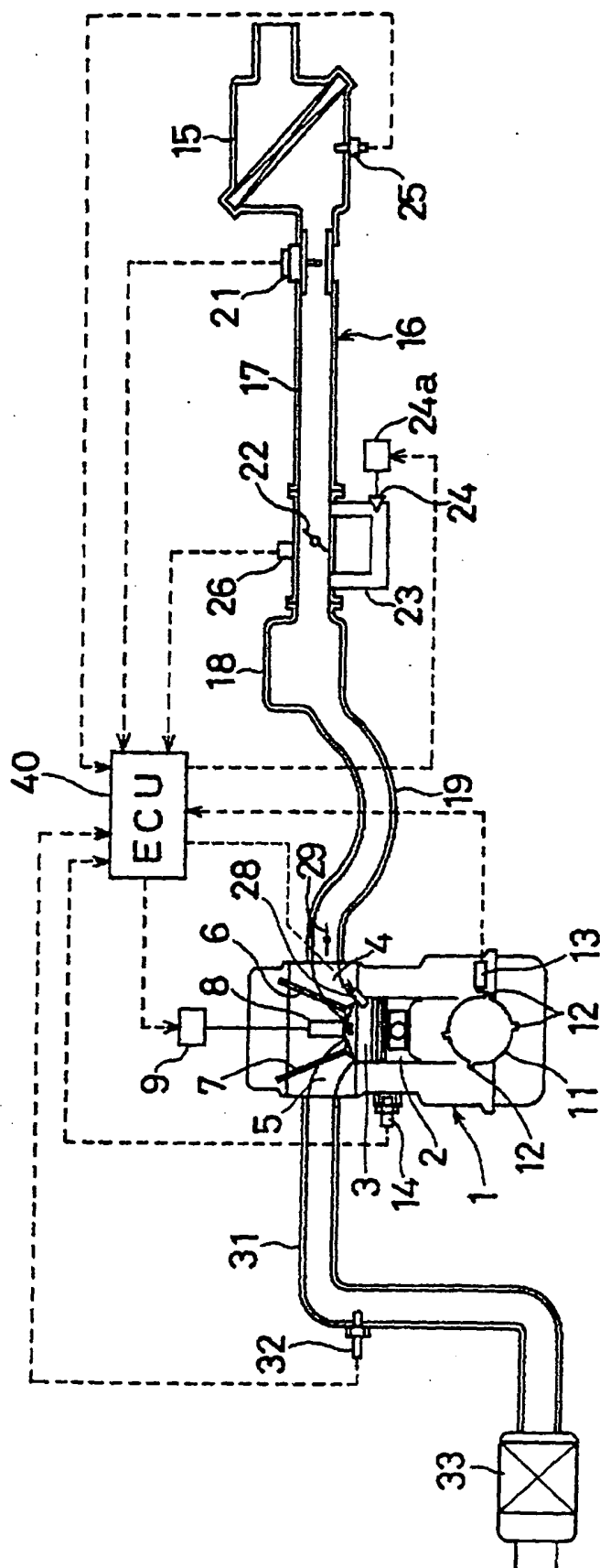


FIG. 2

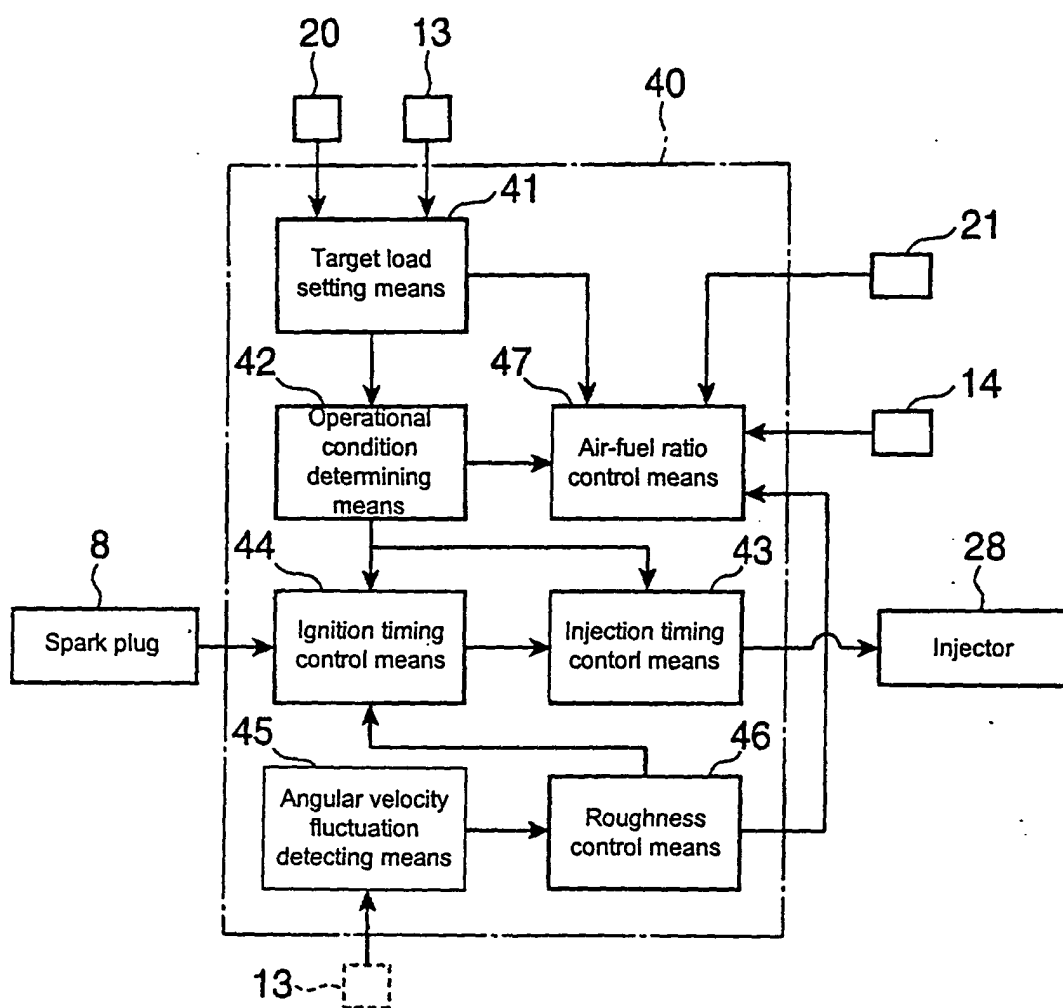


FIG. 3

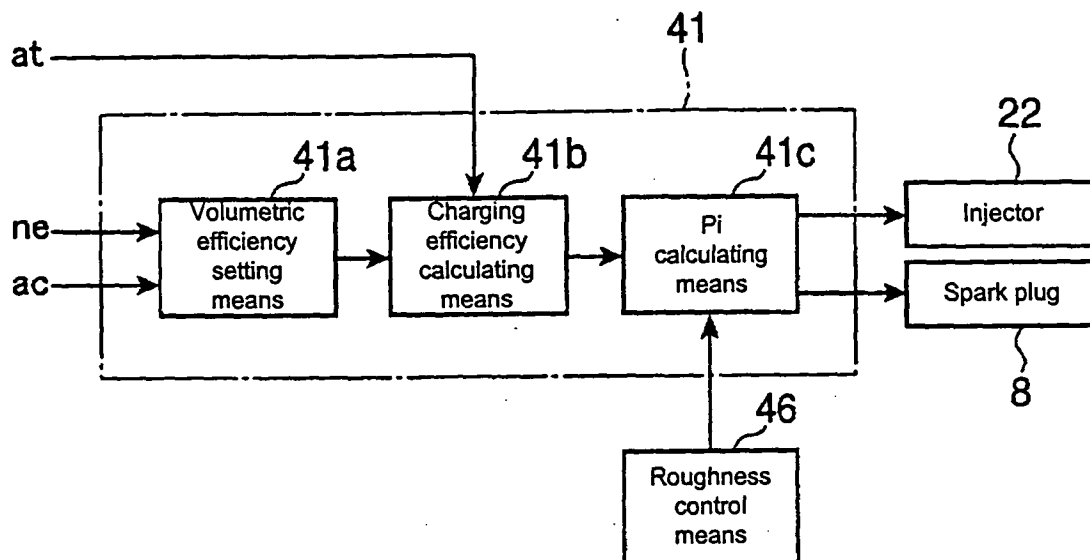


FIG. 4

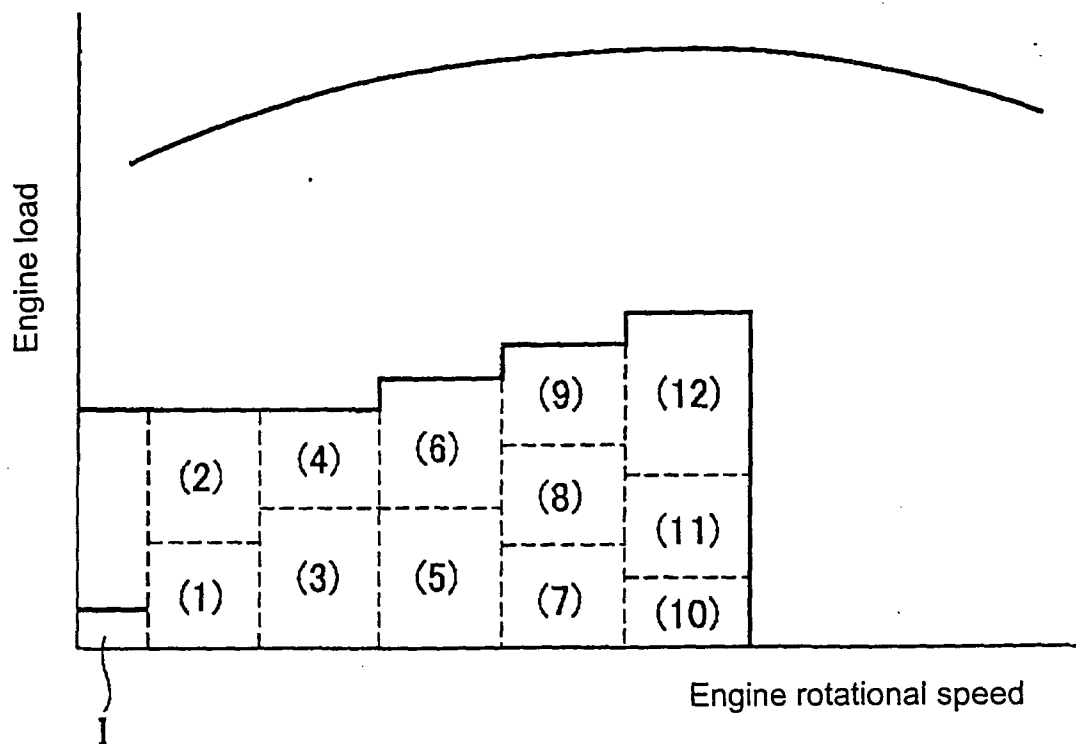


FIG. 5

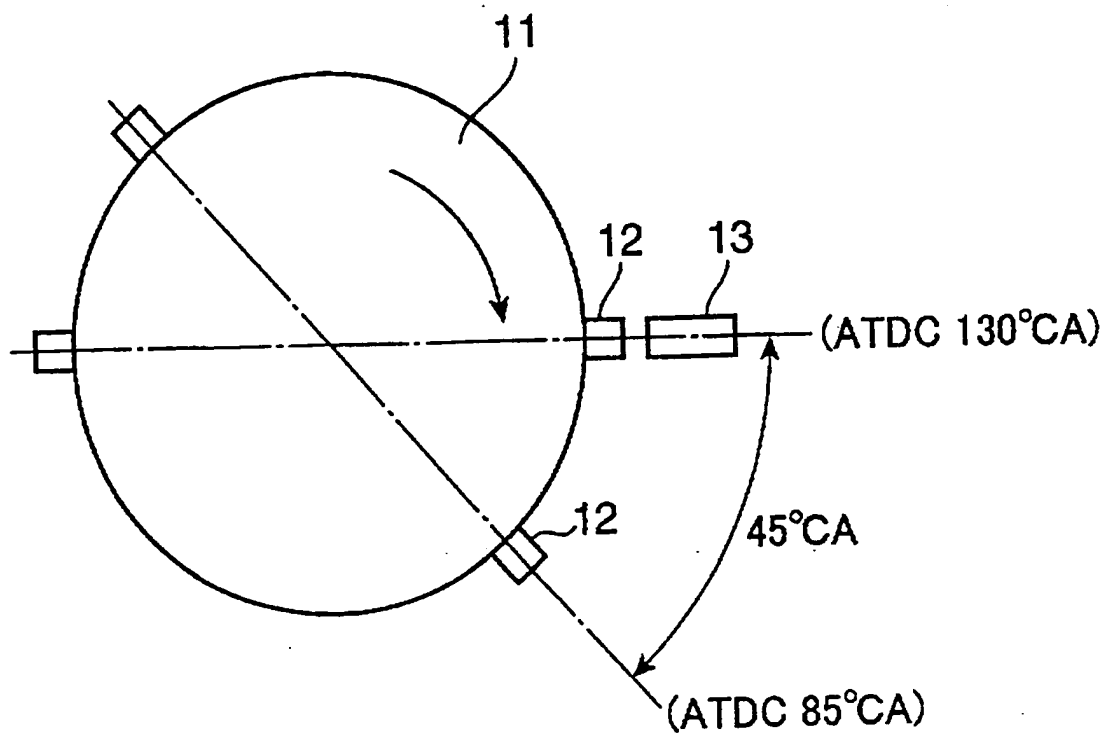


FIG. 6

No.1 Cyl	Intake	Compression	Expansion	Exhaust
No.2 Cyl	Compression	Expansion	Exhaust	Intake
No.3 Cyl	Exhaust	Intake	Compression	Expansion
No.4 Cyl	Expansion	Exhaust	Intake	Compression

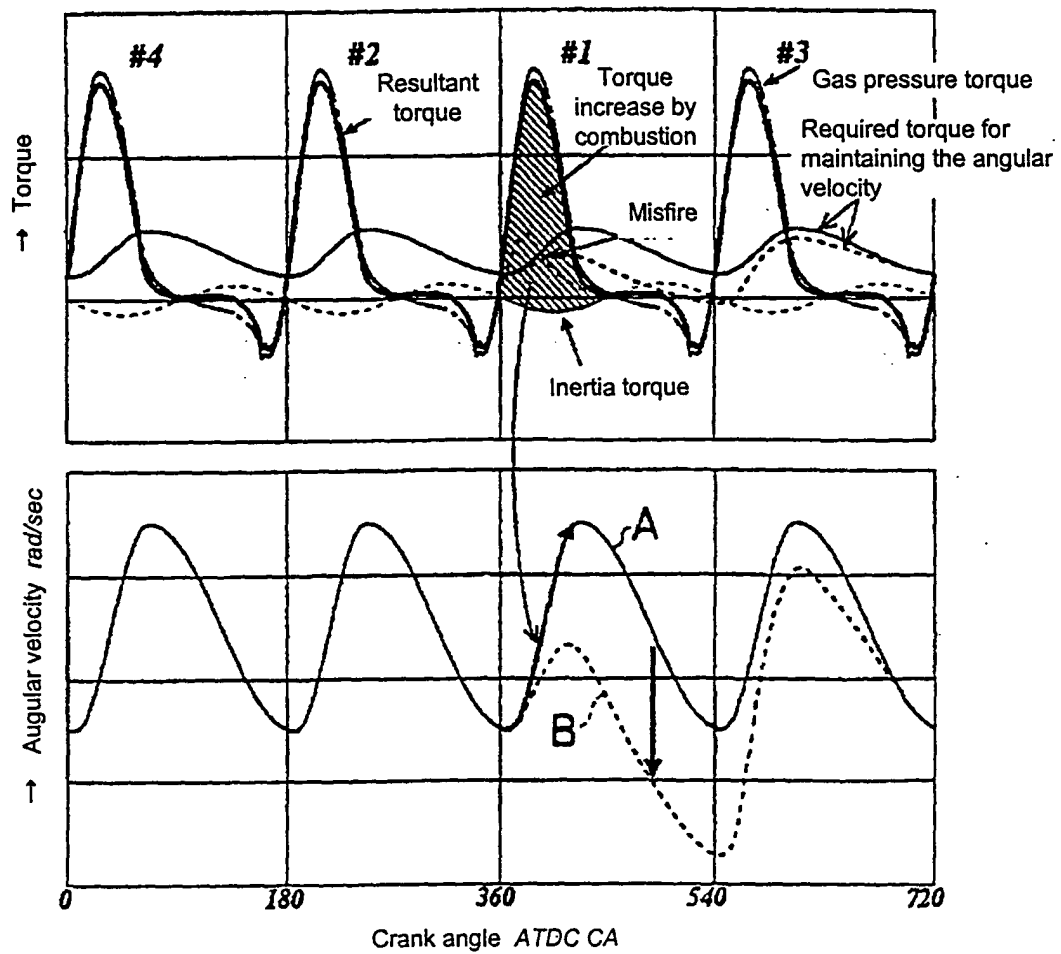


FIG. 7

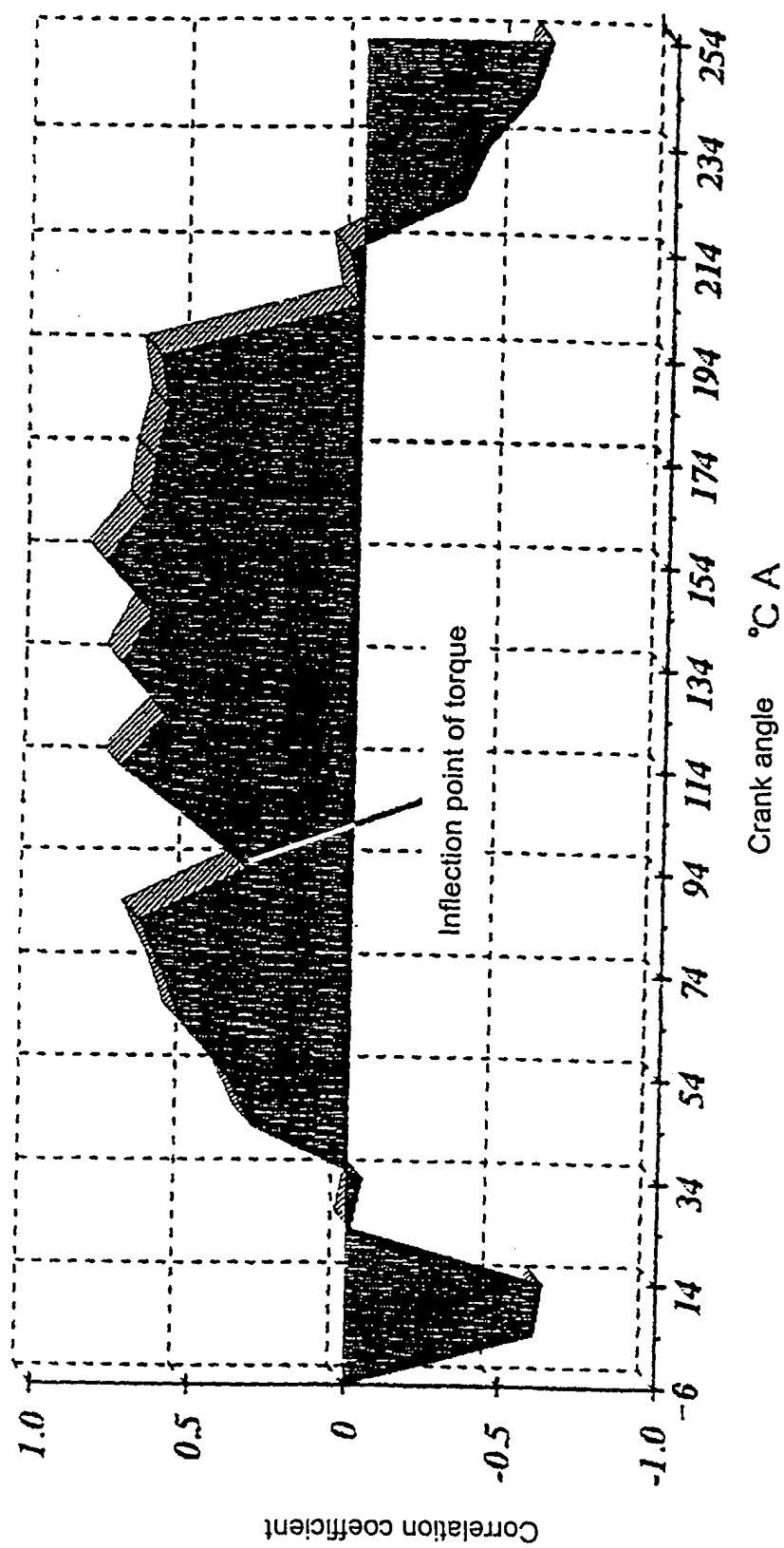


FIG. 8

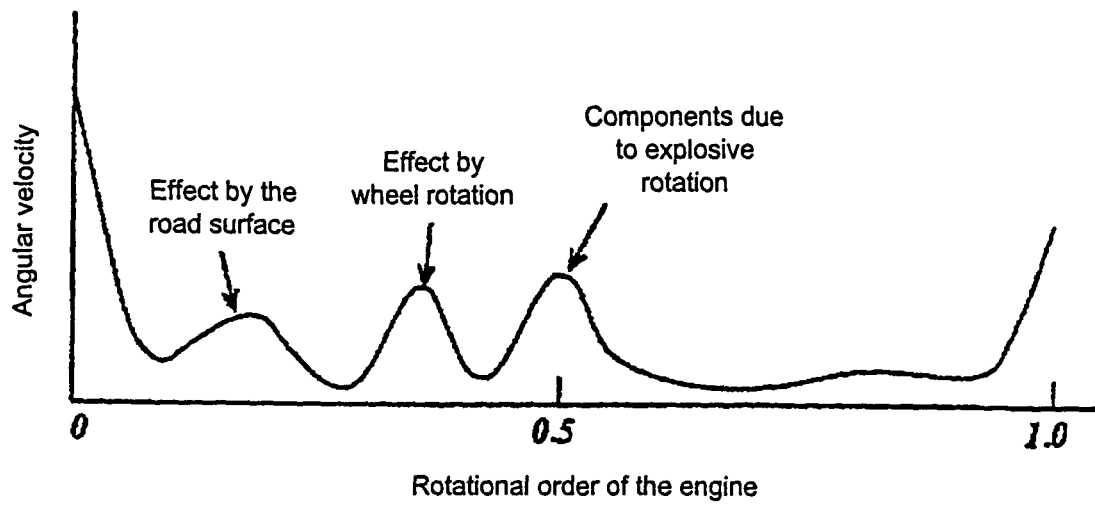


FIG. 9

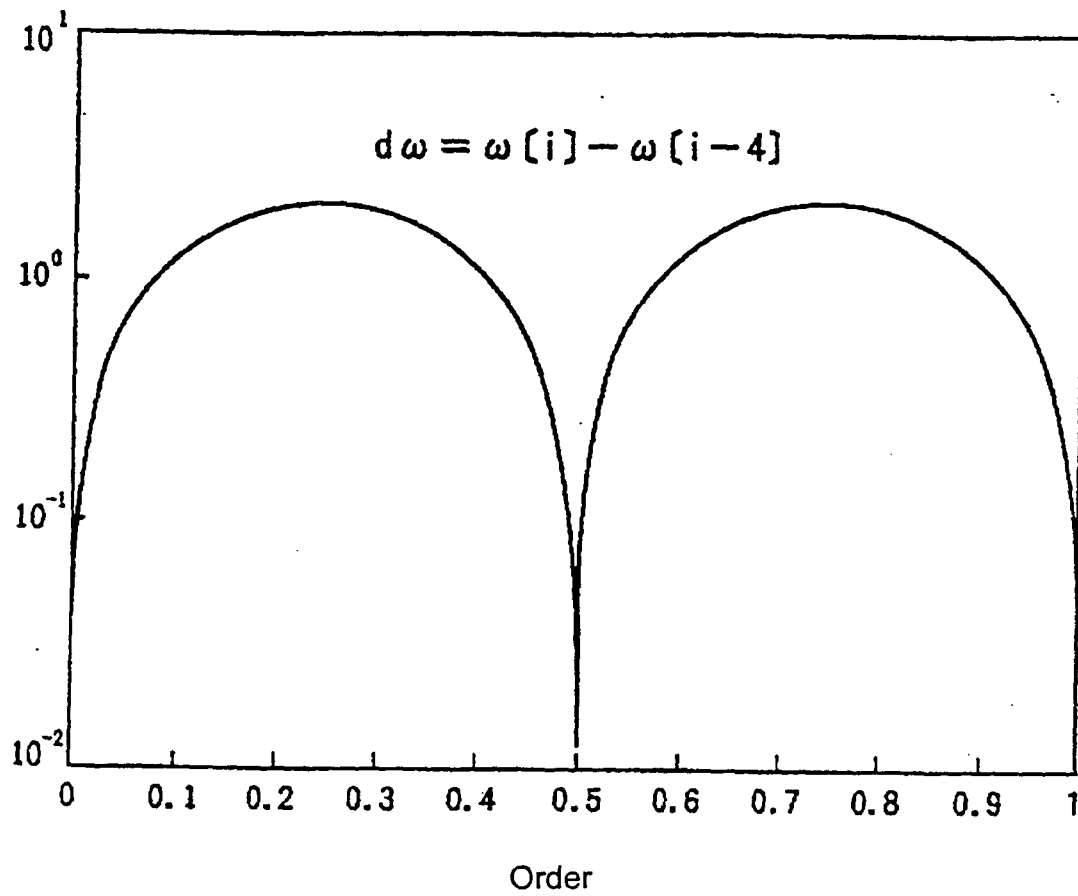


FIG. 10

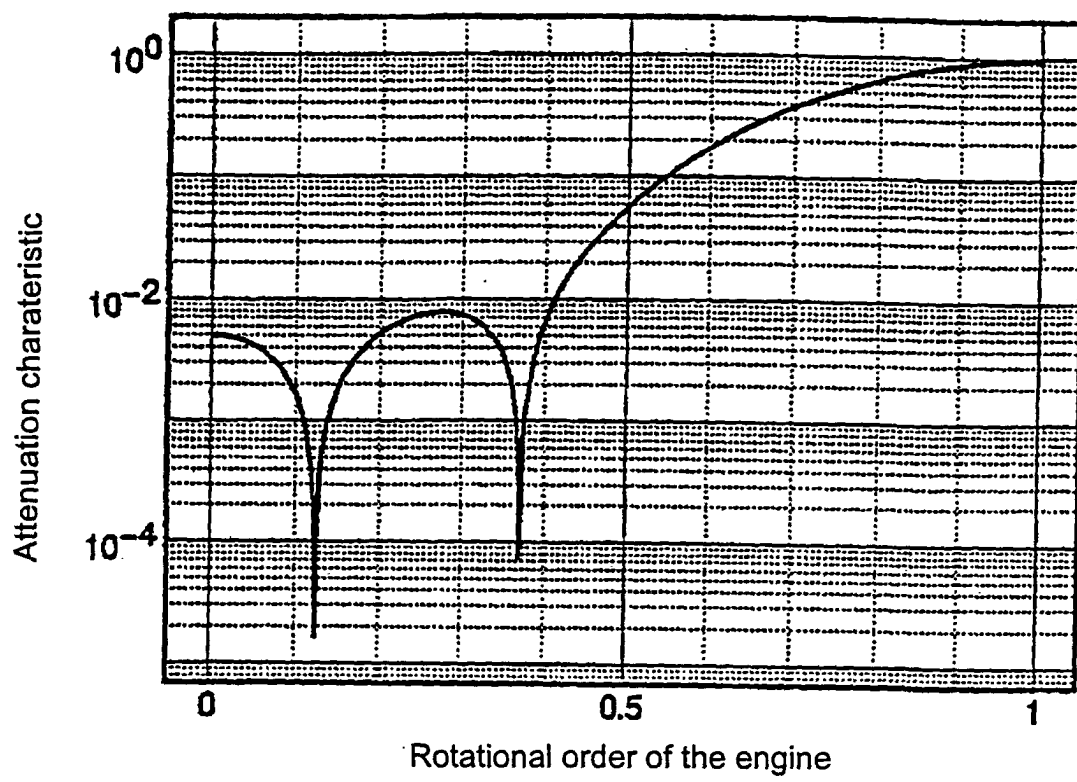


FIG. 11

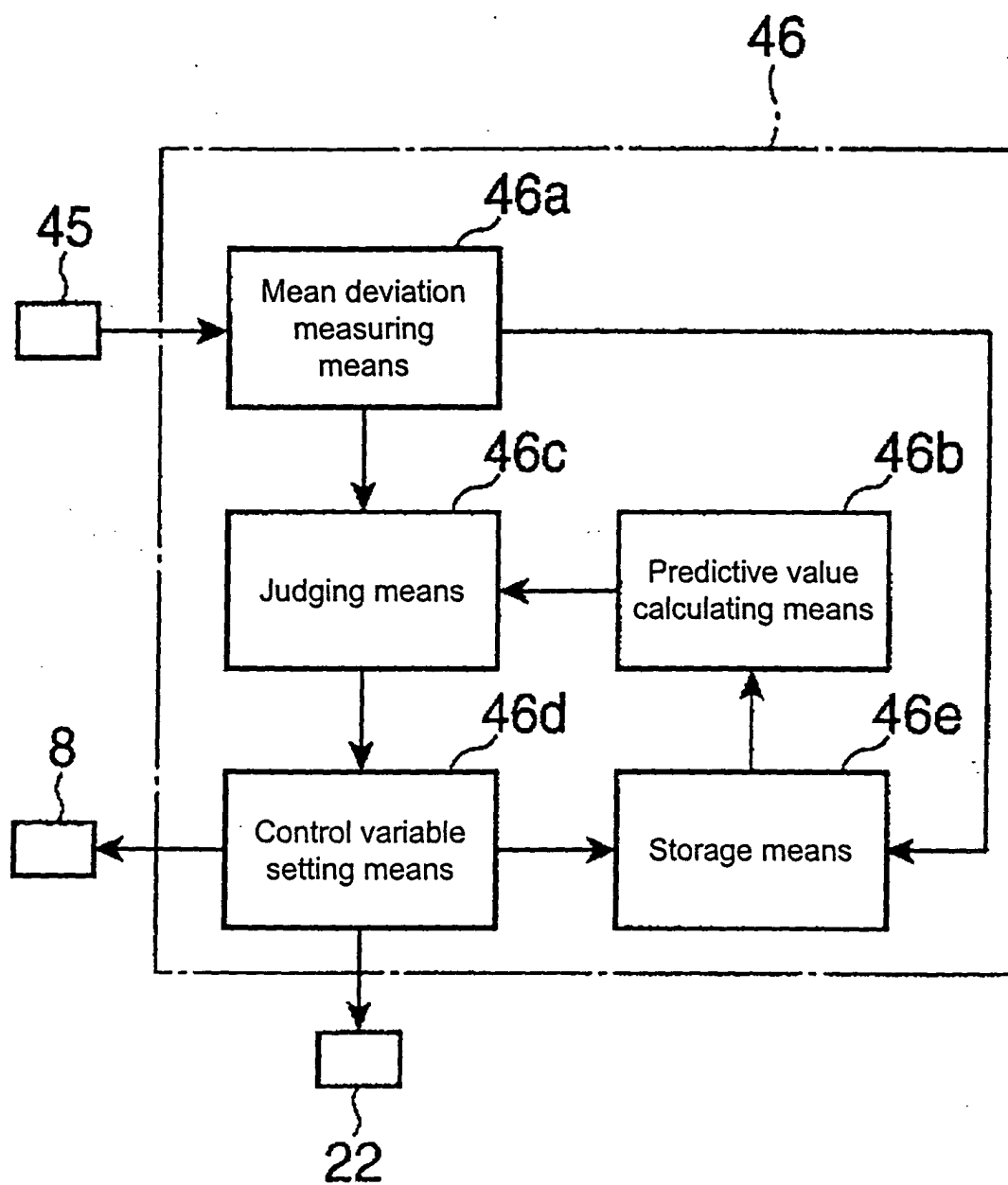


FIG. 12

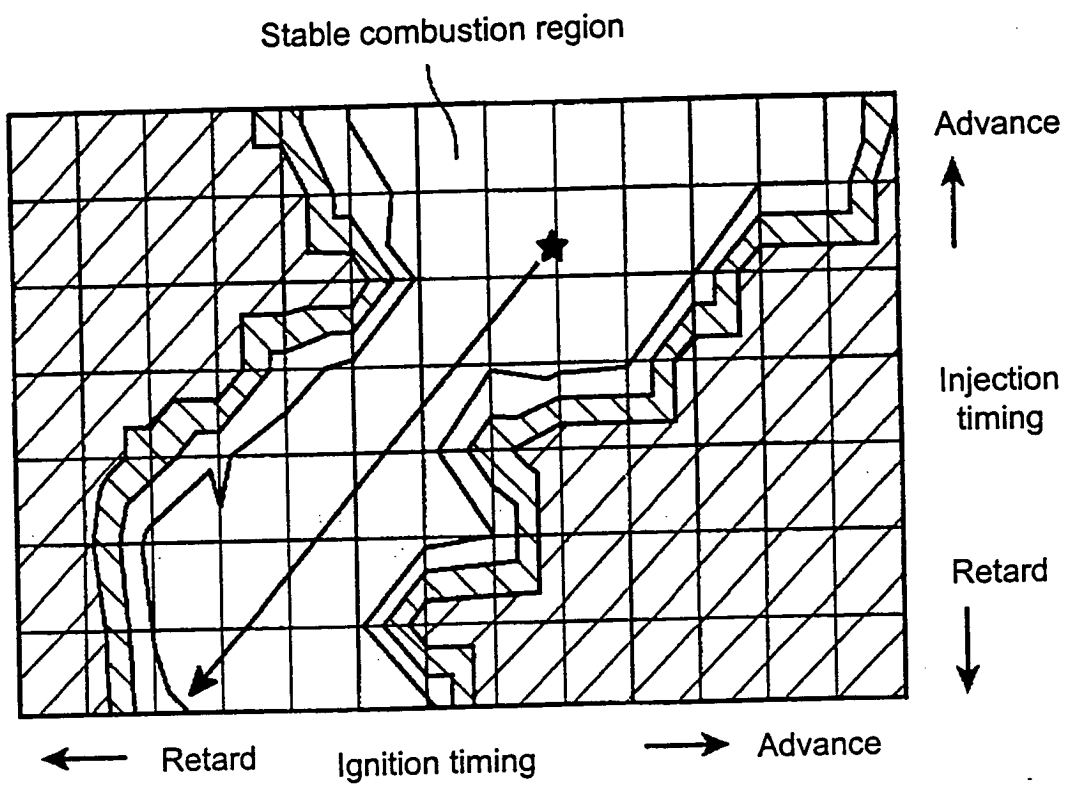


FIG. 13

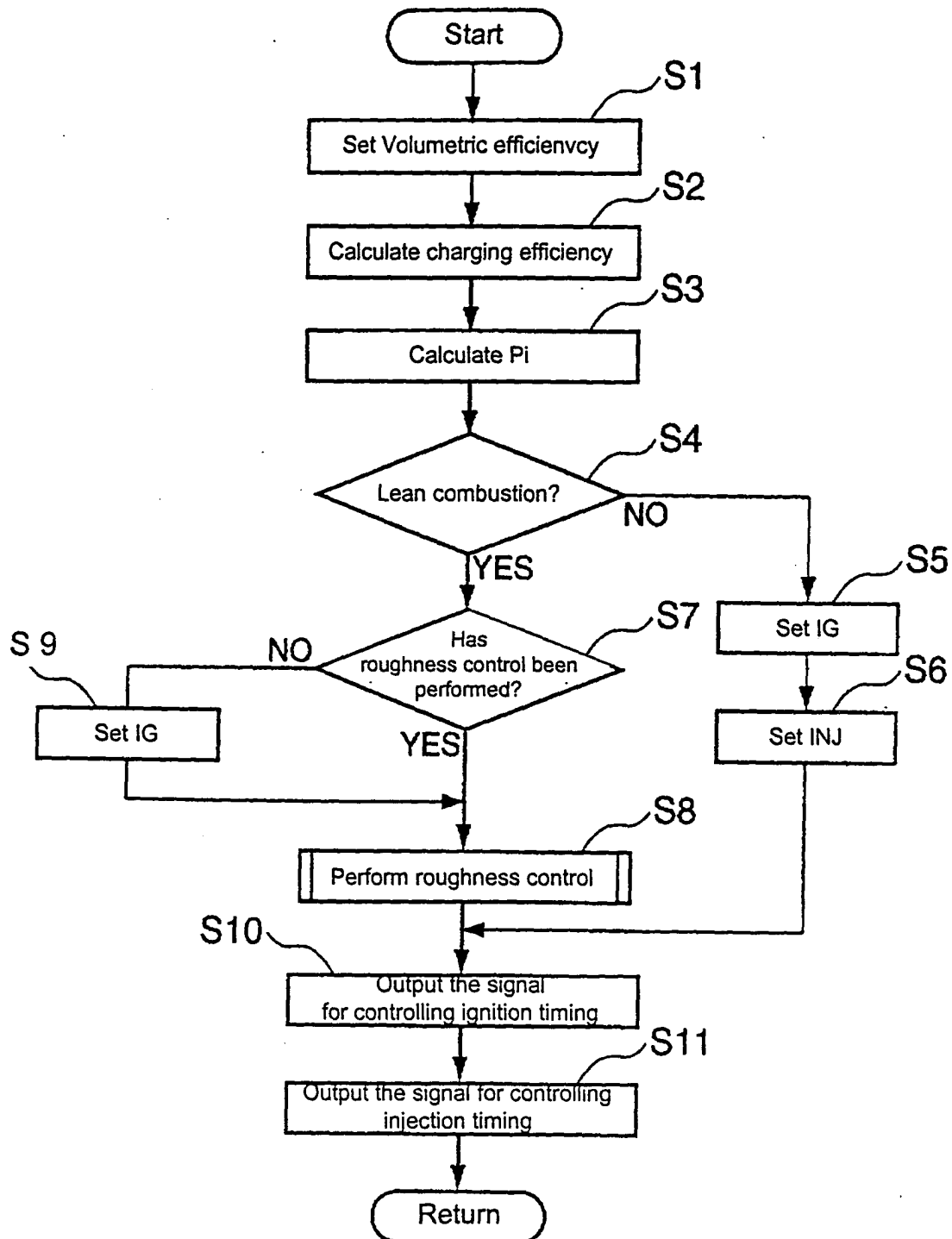


FIG. 14

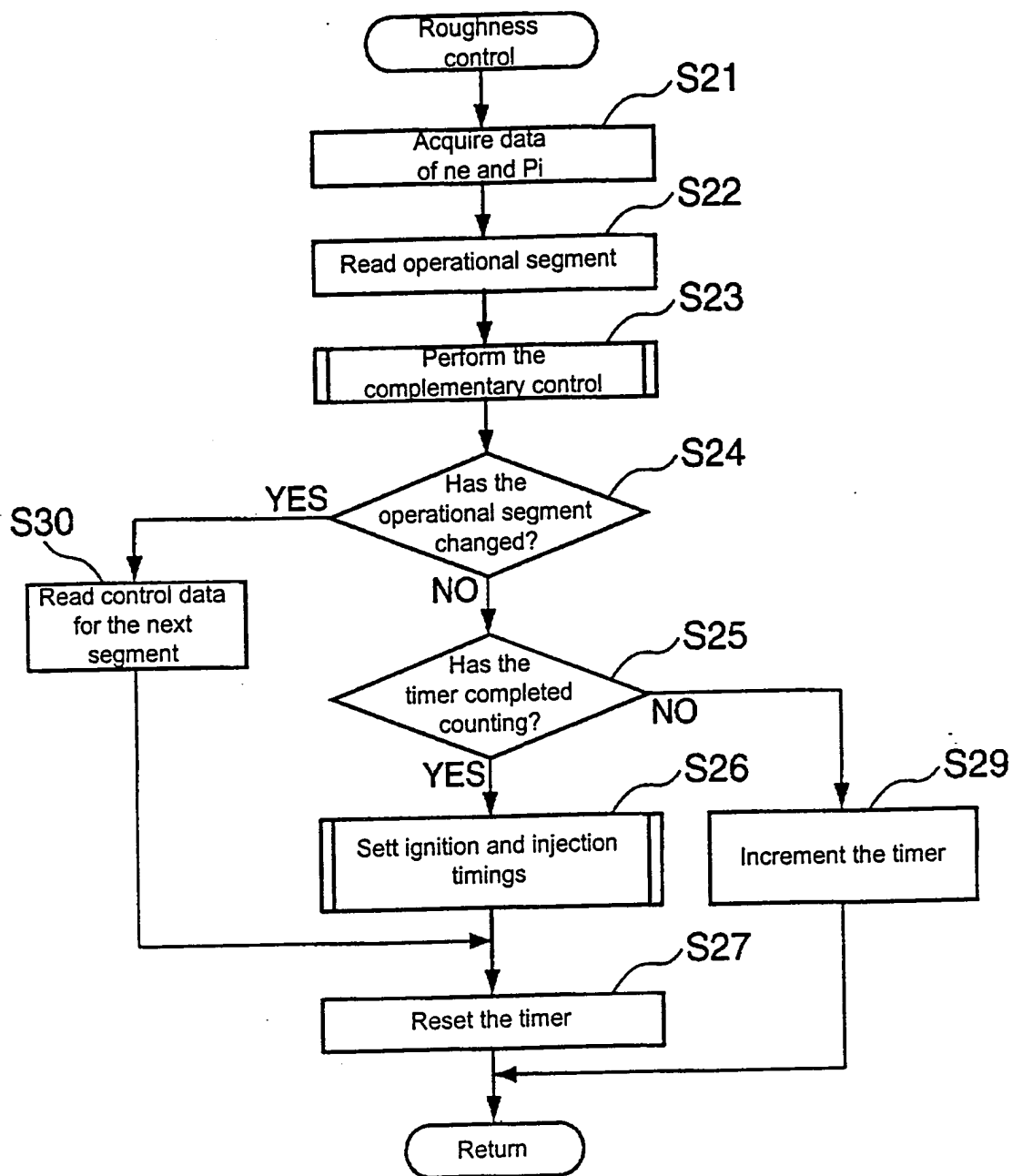


FIG. 15

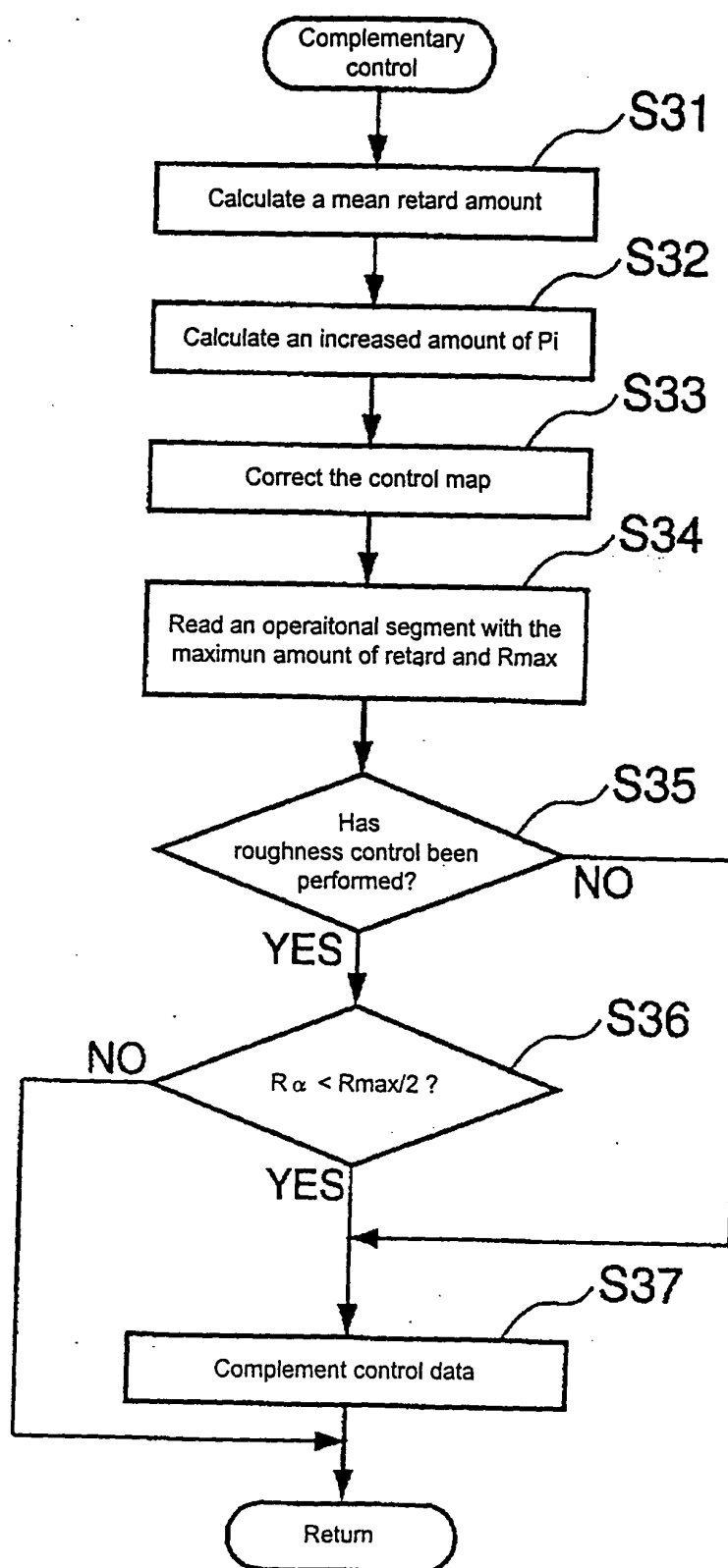


FIG. 16

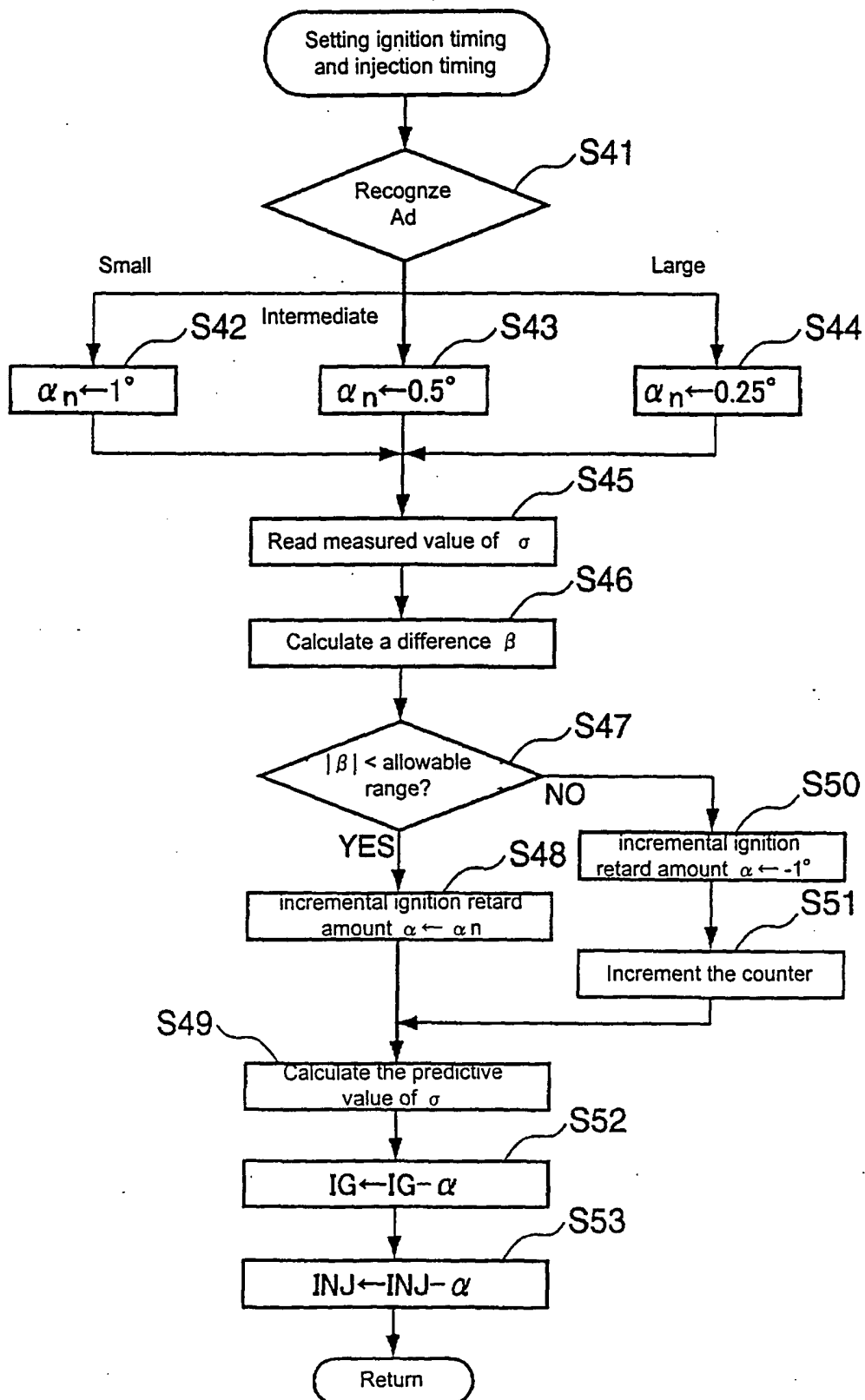


FIG. 17

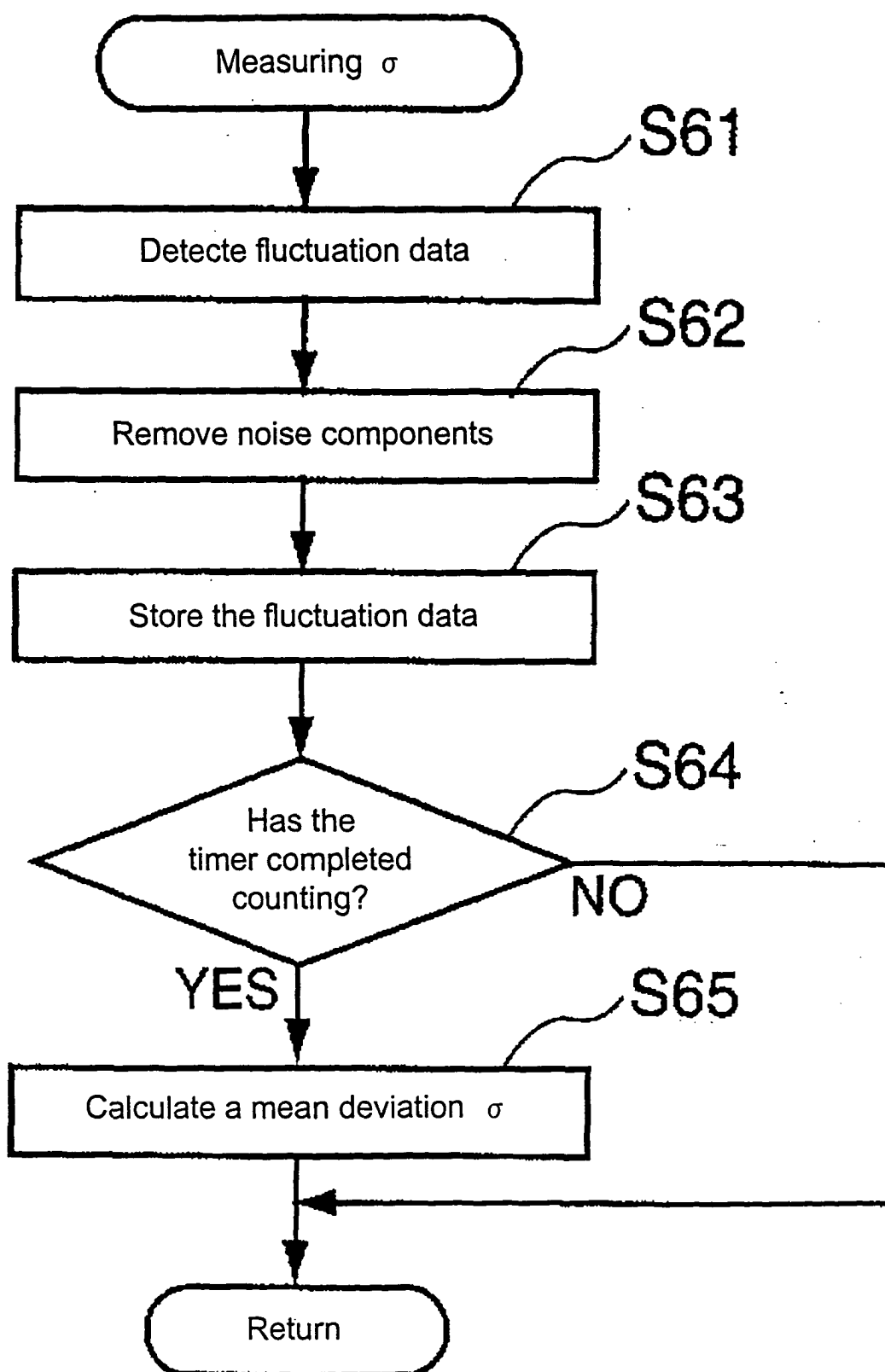


FIG. 18

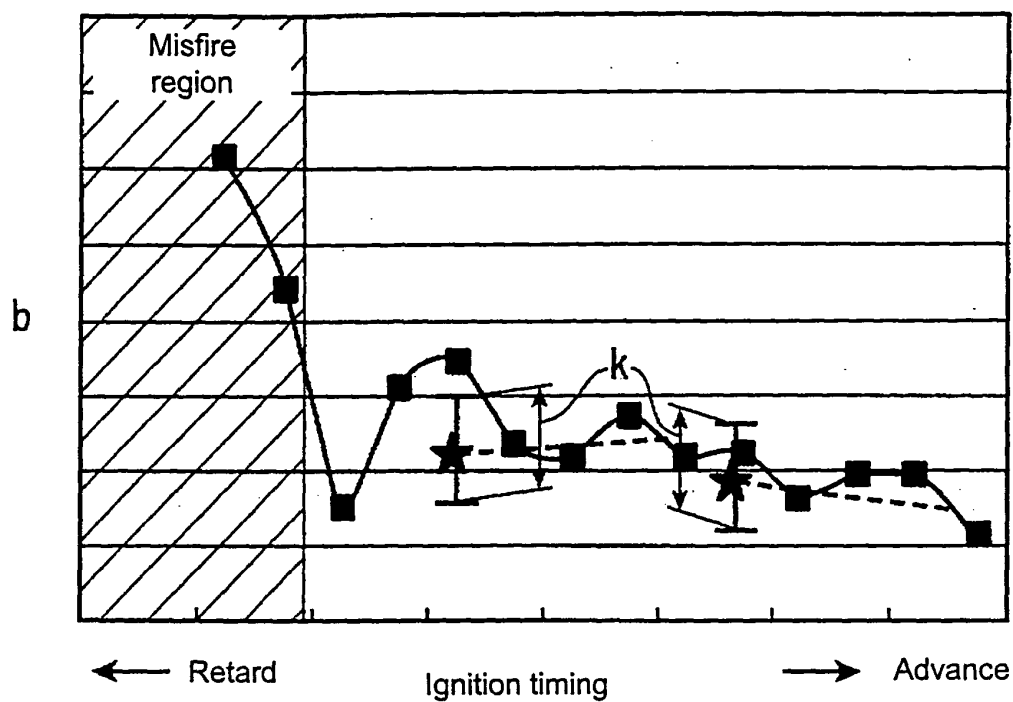


FIG. 19

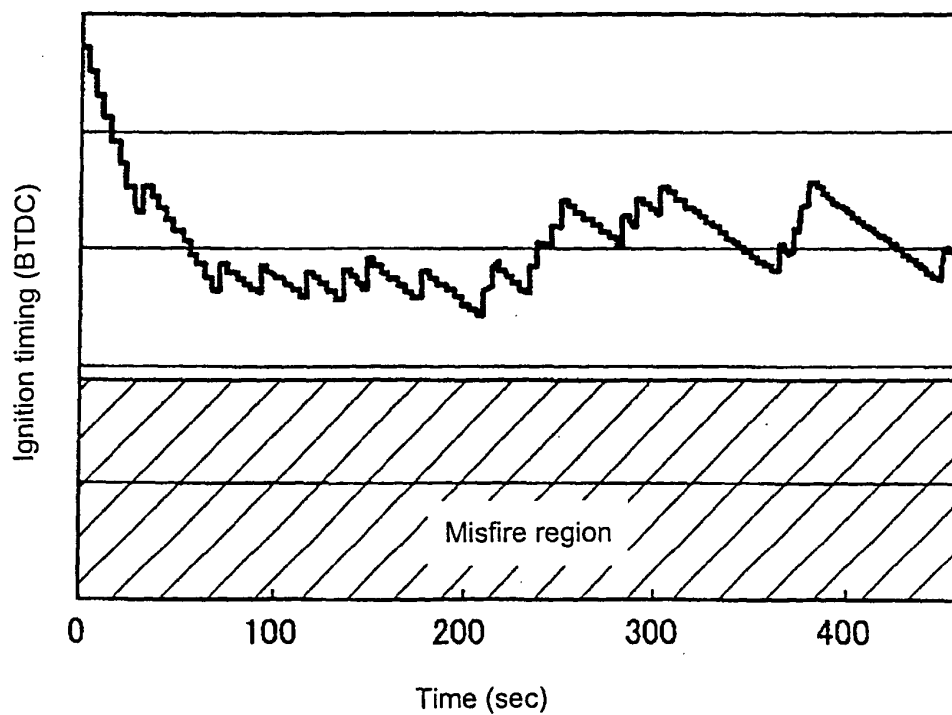


FIG. 20

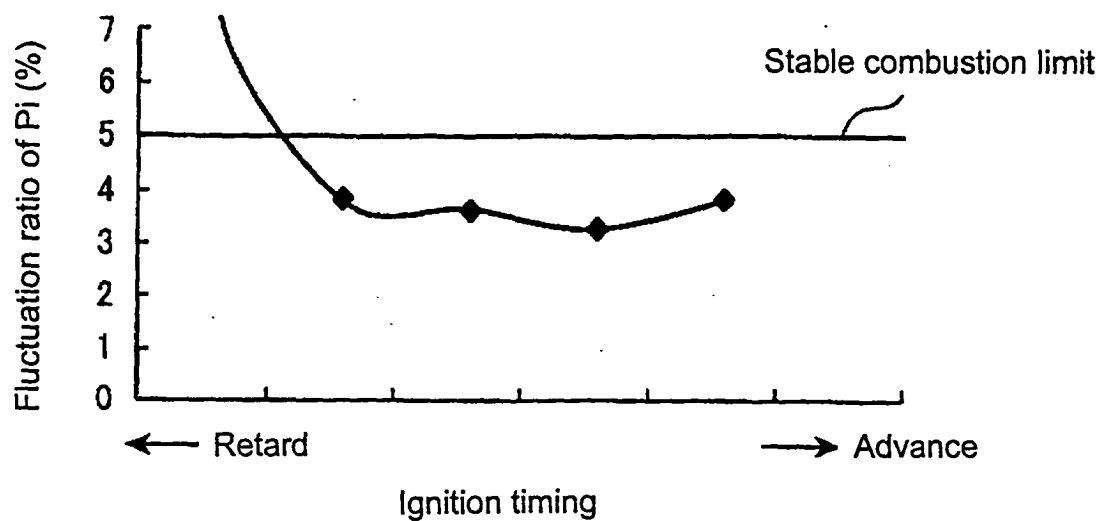
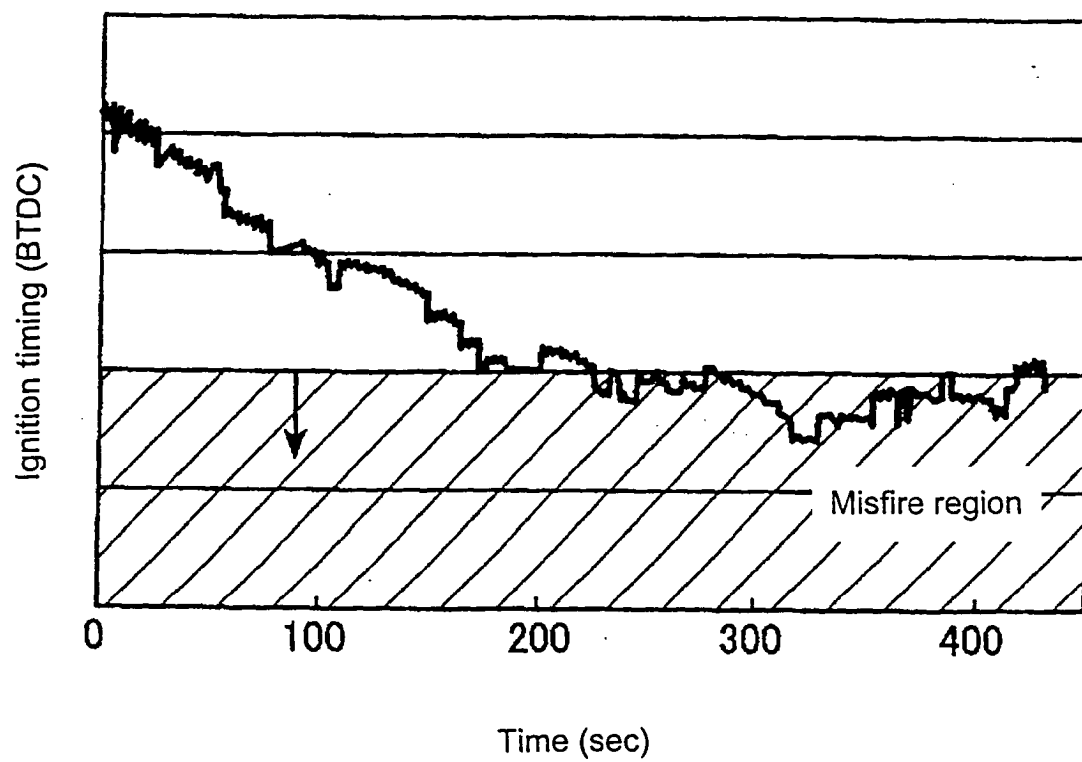


FIG. 21





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EUROPEAN SEARCH REPORT

Application Number
EP 03 00 6712

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The present search report has been drawn up for all claims			
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CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 03 00 6712

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The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
Place of search THE HAGUE		Date of completion of the search 12 August 2003	Examiner Lapeyronnie, P
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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