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(54) **Intake system for an internal combustion engine with at least two cylinders**

(57) An internal combustion engine has throttle valves installed, each of its air intake passages connecting a surge tank with each of the cylinders. An inter-cylindrical connecting passage is formed near the air intake valves between adjacent air intake passages. An auxiliary air intake passage branches from the surge tank to bypass the throttle valve and connects to the inter-cylindrical connecting passage. An idle speed control valve is installed in the auxiliary air intake passage. Thus, stabilized combustion of the air/fuel mixture even during the low to mid-load operating ranges can be obtained to improve fuel economy and reduce NO_X emissions. The invention is of particular advantage in engines using exhaust gas recirculation.

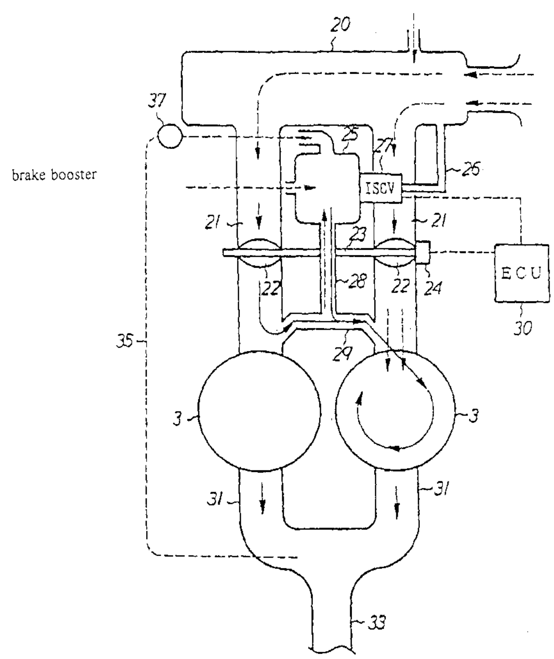

FIGURE 3

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Description

[0001] The present invention relates to an internal combustion engine, preferably a four-cycle, multi-cylinder engine.

[0002] Internal combustion engines using swirling or tumbling action of the air/fuel mixture in each cylinder in order to stabilize combustion are generally known from the prior art.

[0003] However, the intake air volume is relatively low when the engine is running in a low-load operating range. Moreover, adequately strong swirling cannot be generated inside of the cylinders of the engine in the low to mid-load operating range.

[0004] Thus, adequate improvements in fuel economy and reduced NO_X emissions are difficult to obtain when stabilizing the air/fuel mixture combustion and, in particular, when increasing the use of EGR gases (exhaust gas recirculation).

[0005] Further, in internal combustion engines that use fuel injectors to spray fuel into the various intake passages, variations occur in the amounts of fuel injected into the respective intake passages.

[0006] The present invention was developed to address the afore-mentioned technical problems. It has as its objective the provision of an internal combustion engine that provides stable combustion of the air/fuel mixture at low to mid-load operating ranges, and which shows improved fuel economy and reduced NO_X emissions.

[0007] The afore-mentioned technical problem is solved by an internal combustion engine comprising a first intake passage branching off from a surge tank and leading to a first cylinder, at least a second intake passage branching off from said surge tank and leading to another cylinder, at least one throttle valve in the intake system, an inter-cylindrical connecting passage connecting said intake passages downstream the at least one throttle valve, an auxiliary intake passage connecting said surge tank and said inter-cylindrical connecting passage, and a control valve for opening and closing said auxiliary intake passage to control the flow therethrough.

[0008] By the engine according to claim 1, intake air may flow through the auxiliary air intake passages to the cylinders respectively thereby allowing the creation of a strong swirling or tumbling action of the air/fuel mixture to stabilize combustion particularly during the low to mid-load operating range. Preferably, exhaust gas recirculation is used in the engine in order to further improve fuel economy and to further reduce NO_X emissions. It is immediately apparent that the invention is particularly advantageous to engines using said exhaust gas recirculation as the increase of swirling or tumbling action during the low to mid-load operating range because the amount of recirculated exhaust gas can be increased. It should be noted that exhaust gas recirculation can be obtained not only by a recirculation pipe connecting the exhaust passage and air intake passage but also via the cylinder by increasing the overlap of the opening and closing timing of intake and exhaust valves of the engine.

[0009] Further, the inter-cylindrical connecting passage allows residual fuel or air/fuel mixtures remaining in the respective other cylinder or cylinders to be drawn into one cylinder during its intake stroke to serve as auxiliary fuel thereby eliminating any variations in the amount of fuel injection among the cylinders.

[0010] It should be noted that the invention is not limited to a two-cylinder engine but applicable to any multi-cylinder engine. Inter-cylindrical connecting passages may be provided between neighbouring intake passages or may connect more or even all intake passages of the engine.

[0011] According to a preferred embodiment, the volume of the auxiliary surge tank is roughly equal to or greater than the displacement of the respective cylinders. Thus, it is possible to remove the pumping loss that takes place in the partial load range (low-load to mid-load range) that results from an increase air intake volume from the auxiliary air intake passage. Further, it is also possible to diminish any air intake pulses.

[0012] Preferably, the auxiliary surge tank is connected with an exhaust passage to allow exhaust gas recirculation via said auxiliary surge tank. Preferably during the low to mid-load operating ranges both air and the EGR gases are drawn into each cylinder from the auxiliary surge tank thereby further improving fuel economy and reducing NO_X emissions.

[0013] According to another embodiment, a variable valve timing apparatus is installed for varying the opening and closing timing for the intake valves of the engine thereby allowing to increase the EGR gas content to improve fuel economy and reduce NO_X emissions.

[0014] Preferably, the inter-cylinder connecting passage open into the air intake passages, preferably in the vicinity of the intake valves, the openings of said intake passages being directed toward the combustion chamber of each cylinder, respectively. By this, an even stronger swirl or tumble is generated inside the cylinders to even further stabilize the combustion of the air/fuel mixture.

[0015] Further advantageous embodiments are laid down in the further subclaims.

[0016] The invention will be described hereinafter in further detail by the examples shown in the drawings, wherein:

[0017] **Figure 1** is a vertical sectional view of a first embodiment of a four-cycle, twin cylinder engine according to this invention.

[0018] **Figure 2** is a top sectional view of a first embodiment of a four-cycle, twin cylinder engine according to this invention.

[0019] **Figure 3** is a component diagram of a first embodiment of a four-cycle, twin cylinder engine according to this invention.

[0020] **Figure 4** is a graph of the relationship between accelerator aperture and air intake volume for of a first embodiment of a four-cycle, twin cylinder engine according to this invention.

[0021] **Figure 5** is a diagram showing the placement of the intercylinder connecting passage of a five-valve engine.

[0022] **Figure 6** is a graph showing the relationship between the throttle aperture and the air intake volume for another embodiment of a four-cycle, twin cylinder engine according to this invention.

[0023] **Figure 7** is a vertical sectional view of a second embodiment of a four-cycle, twin cylinder engine according to this invention.

[0024] **Figure 8** is a top sectional view of a second embodiment of a four-cycle, twin cylinder engine according to this invention.

[0025] **Figure 9** is a component diagram of a second embodiment of a four-cycle, twin cylinder engine according to this invention.

[0026] **Figure 10** is a graph showing the timing for the opening and closing of the intake and exhaust valves for an embodiment of a four-cycle, twin cylinder engine according to this invention.

[0027] Figures 1 through 4 show a first embodiment.

[0028] In the present embodiment, the four-cycle, twin cylinder engine 1 has two cylinders 3 installed in the cylinder body, and pistons 4 are slidably inserted into each of the cylinders 3 and connected by piston pins 4 and connecting rods 5 to the crankshaft 6.

[0029] A cylinder head 7 is attached atop the foregoing cylinder bodies 3, and two air intake passages 8 and two exhaust passages 9 are formed for each cylinder. The air intake passages 8 and the exhaust passages 9 each converge into one air intake passage 8 and one exhaust passage 9.

[0030] Further, there are air intake ports 8a and exhaust ports 9a (see Figure 2) for the air intake passages and exhaust passages which open into the combustion chambers S; these ports are opened and closed at the requisite timing by air intake valves 11 and exhaust valves 12 to provide the required gas change for the cylinders 3.

[0031] To wit, the foregoing air intake valves 11 and the exhaust valves 12 are biased by the valve springs 13, 14 into the normally closed position. The air intake cams 15a and the exhaust cams 16a are integrally formed on the air intake camshaft 15 and the exhaust camshaft 16 to open the valves at the requisite timing.

[0032] As is shown in Figure 2, sprockets 17 and 18 are attached to the end of the foregoing air intake camshaft 15 and exhaust camshaft 16. These sprockets 17, 18 are engaged by an endless cam chain 19 that also engages a sprocket (not shown) affixed to the crankshaft (see Fig. 1) which causes the air intake camshaft 15 and the exhaust camshaft to be driven through the sprockets 17 and 18 at ½ the speed of the crankshaft 6 to open and close the above described air intake valves 11 and exhaust valves 12 at an appropriate timing.

[0033] On the other hand, as is shown in Figure 1, a surge tank 20 is located above the cylinder head 7. Two air intake passages 21 leave from this surge tank and bend into a sideways "U" configuration. The ends of these passages are connected to each cylinder at the foregoing air intake passages 8 that are formed in the cylinder head 7. A throttle valve 22 is installed in the horizontal sections of each of the two air intake passages 21, and both throttle valves 22 are connected integrally through a valve shaft 23. A servo motor or other actuator 24 (see Figure 3) synchronously opens and closes the throttle valves.

[0034] Further, there is an auxiliary surge tank 25 formed in the sideways "U" bend, inside the two air intake passages 21. This auxiliary surge tank 25 connects to an idle speed control valve (called "ISCV" below) through auxiliary air intake passages 26 that branch downstream of the foregoing surge tank 20. An auxiliary air intake passage 28 connects from the bottom of the auxiliary surge tank, and said auxiliary air intake passage 28 is bent at a right angle to extend approximately horizontally toward the cylinder head. The volume of the auxiliary surge tank is approximately equivalent or slightly more than the displacement of the cylinders.

[0035] On the other hand, as shown in Figures 2 and 3, there is an intercylindrical connection passage that connects the adjacent two air intake passages 8 in the vicinity of the air intake valve. Said intercylindrical connection passage 29 is fitted with openings into the air intake passages 8 that are directed toward the combustion chambers of each cylinder (see Figure 1). The foregoing auxiliary air intake passage 28 also connects to this intercylindrical connection passage 29.

[0036] Thus, as shown by the diagram in Figure 3, the auxiliary air intake passages 26, 28 bypass the throttle valve 22 and are connected to the intercylindrical connection passage 29. Located midway are the auxiliary surge tank 25 and ISCV 27. The combination of ISCV 27 and actuator 24 is connected to an engine control unit 30 (called "ECU" below) and is driven by control signals from that ECU 30.

[0037] Also, as shown in Figures 1 and 2, exhaust pipes 31 are connected to each of the exhaust passages 9 formed in the cylinder head 7, and each exhaust pipe is connected to a catalytic converter 32 which in turn is connected to a tail pipe 33 that opens into the atmosphere. In the figures, 34 is an exhaust temperature sensor.

[0038] One of the exhaust pipes leads to the EGR pipe 35, and said EGR pipe connects to the foregoing auxiliary surge tank 25, with an EGR valve 37 being installed midway between them. As shown by Figure 3, the auxiliary surge tank 25 is also connected to a brake booster (not shown).

[0039] Next, the operation of the four-cycle, twin cylinder engine 1 of this embodiment will be explained.

[0040] Figure 4 shows the flow/volume relationship between ISCV 27 and an accelerator angle or aperture (amount of accelerator movement) controlling the throttle aperture α. When the engine 1 is started, the accelerator aperture a value as shown in the figure is α_1; thereafter, in low load operating ranges, the ECU 30 exerts control to leave only the ISCV 27 open while keeping the throttle valves 22 fully closed.

[0041] Accordingly, in low-load operating ranges, intake air that is drawn into the surge tank bypasses the throttle valves 22 and flows into the auxiliary air intake passage 26 before passing the ISCV 27 and being introduced into the auxiliary surge tank 25. At the same time, a part of the exhaust gases generated during the previous cycle is moved through the EGR pipe 35 and the EGR valve into the auxiliary surge tank 25.

[0042] Also, the intake air from the auxiliary surge tank 25 and the EGR gases pass through the auxiliary air intake passage 28 and through the intercylindrical connection passage 29, and then into the cylinder during its air intake stroke (see the right cylinder in Figure 3). In this process, the required amount of fuel is injected from the injectors 10 into the air intake passages 8, and this fuel is mixed with the intake air to form the requisite ratio of an air/fuel mixture.

[0043] In addition, the openings from the intercylindrical connection passage 29 into the air intake passages 8 are directed toward the combustion chambers S of the respective cylinders to generate a strong swirl, such as shown by the arrows in Figure 3, inside the cylinder undergoing the air intake stroke. This feature stabilizes the combustion of the air/fuel mixture. As a result it is possible to increase the amount of EGR gases to improve fuel economy and reduce NO_X emissions. Also, the residual fuel or air/fuel mixture in the air intake passage 8 of the other cylinder is also drawn-in during the same intake stroke as an intercylindrical supplementary fuel source, and this intake eliminates any variations in the amount of fuel injected from the injectors 10 among the cylinders. Also, a part of the exhaust gases generated by the combustion of the air/fuel mixture in the combustion chamber S passes through the EGR pipe 35 and EGR valve 37 and is then introduced into the auxiliary surge tank 25.

[0044] When the accelerator aperture α exceeds the α_1 aperture shown in Figure 4 to reach a mid-range load operating range, the ECU 30 will drive the actuator 24 and gradually opens the throttle valve 22. The intake air drawn into the surge tank flows into the air intake passage of the cylinder undergoing the intake stroke, and the subsequent fuel/air mixture is drawn into that cylinder from both the intercylindrical connection passage 29 and the air intake passage 21. Accordingly, since the intercylindrical connection passage 29 remains directed toward the combustion chamber in this mid-load operating range, the introduction of the air-fuel mixture into the cylinder 3 produces a swirl in same that stabilizes the combustion of this air/fuel mixture. This feature makes it possible to increase the utilization of EGR gases, thus improving fuel economy and reducing NO_X emissions.

[0045] Then, when the accelerator aperture α reaches α_2 as shown in Figure 4, because the ISCV 27 is closed, there is a higher load operating range than would otherwise be the case from an accelerator aperture α of α_2, wherein all of the intake air drawn into the surge tank flows through the air intake passage 21 and into the cylinder during the intake stroke, while at the same time, the air/fuel mixture for combustion is introduced into the cylinder 3 from both of the air intake passages 21 and 8.

[0046] Then, during high load operations when large amounts of intake air are flowing through the air intake passages 21, 8, the flow of the intake air is higher than it was for the low and mid-range load operations, and accordingly, the air/fuel mixture is introduced into the cylinders at a high velocity. Thus, a uniform air/fuel mixture is provided inside the cylinders, making possible stable combustion of the air/fuel mixture in the combustion chambers S. Since the valve 37 is fully closed while the engine is operating in the high load range, the exhaust gases generated by the combustion of the air/fuel mixture are not introduced into the auxiliary surge tank 25; all of the exhaust gases pass through the exhaust pipes 31, through the catalytic converter 32 to be cleaned, and then through the tail pipe 33 to be released into the atmosphere.

[0047] The above describes a four valve engine equipped with two air intake valves and two exhaust valves per cylinder, but in engines having 3 intake valves and 2 exhaust valves, as shown in Figure 5, the intercylindrical connecting passage 29 must have its openings at the end of the air intake passage directed toward the combustion chambers. In Figure 5, 9 represents an exhaust passage, 8a an air intake port, and 9a an exhaust port.

[0048] Further, the example included using throttle valves 22 that were electrically controlled by an ECU 30, but in engines having a wire connection linking the accelerator with the throttle valves, as shown in Figure 6, the ISCV valve may be opened only during idling so that the intake air bypasses the throttle valve and flows through the auxiliary surge tank, then the auxiliary air intake passage and the intercylindrical connection passages to each cylinder where it creates a swirling or tumbling action. In Figure 6, the horizontal axis shows the throttle aperture (accelerator pedal aperture).

[0049] A second embodiment will be explained with reference to Figures 7 through 10. Figure 7 is a vertical sectional view of the four-cycle, twin cylinder engine of this embodiment; Figure 8 is a top sectional view of the same engine; Figure 9 is a diagram of the engine components; and Figure 10 is a graph showing the timing for the opening and closing of the intake and exhaust valves. In these figures, parts corresponding to those shown in Figures 1 through 3 bear the same reference numbers, and further explanation of them will be omitted.

[0050] The basic structure of the four-cycle, twin cylinder engine 1 of this embodiment is the same as that of the previous first embodiment, but in this embodiment, a variable valve timing apparatus 36 that can vary the timing of the opening and closing of the air intake valves 11 has been installed on the end of the camshaft 15. Also, the EGR pipe 35 and EGR valve 37 (see Figures 2 and 3) used in the previous first embodiment were not installed.

[0051] The basic operation of the engine 1 of this embodiment is the same as that of the engine 1 of the previous embodiment, but during the low to mid-load operating ranges, the foregoing variable valve timing apparatus 36 is driven (ON) so as to control the opening and closing timing of the intake valves 11 at the advance angle shown in Figure 10(a), thereby increasing the overlap $\Delta\alpha_1$ between the intake and exhaust valves 11, 12 to make it possible to increase the volume of residual gases in each cylinder and to increase the internal amount of EGR to improve fuel economy and reduce NO_X emissions, while at the same time eliminating the need for the EGR valve 35 that was used in the first embodiment.

[0052] Then, while in the high load operating range, the variable valve timing apparatus 36 is shut down (OFF) to reduce the overlap $\Delta\alpha_2$ between the intake and exhaust valves 11, 12 as shown in Figure 10(b). In Figure 10, the horizontal axis shows the crank angle and "TDC" is the top dead center.

Claims

1. Internal combustion engine comprising:

   a first intake passage (21) branching off from a surge tank (20) and leading to a first cylinder,
   at least a second intake passage (21) branching off from said surge tank (20) and leading to another cylinder,
   at least one throttle valve in the intake system,
   an inter-cylindrical connecting passage (29) connecting said intake passages (21) downstream the at least one throttle valve (22),
   an auxiliary intake passage (26,28) connecting said surge tank (20) and said inter-cylindrical connecting passage (21,21), and
   a control valve (27) for opening and closing said auxiliary intake passage (26,28) to control the flow therethrough.

2. Internal combustion engine according to claim 1, **characterized in that** an auxiliary surge tank (25) is arranged in said auxiliary intake passage (26,28) downstream said control valve (27).

3. Internal combustion engine according to claim 1 or 2, **characterized in that** the volume of the auxiliary surge tank (25) is roughly equal to or greater than the displacement of the respective cylinders.

4. Internal combustion engine according to one of claims 1 to 3, **characterized in that** the control valve (27) is an idle speed control valve which is open under low load conditions while under these conditions the throttle valves (22) are kept closed.

5. Internal combustion engine according to one of claims 1 to 4, **characterized in that** in the mid load operating range the control valve (27) is kept open while the throttle valves are being opened gradually.

6. Intemal combustion engine according to one of claims 1 to 5, **characterized in that** at a higher load operating range the control valve (27) is kept closed.

7. Internal combustion engine according to one of claims 1 to 6, **characterized in that** the inter-cylinder connecting passages (29) open into the air intake passages (21), their openings being directed toward the combustion chamber of each cylinder.

8. Internal combustion engine according to one of claims 1 to 7, **characterized in that** the auxiliary surge tank (25) is connected with the exhaust passage to allow exhaust gas re-circulation via said auxiliary surge tank (25).

9. Internal combustion engine according to one of claims 1 to 7, **characterized in that** a variable valve timing apparatus (36) is installed for varying the opening and closing timing for the intake valves (11) of the engine.

10. Internal combustion engine according to claim 9, **characterized in that** said variable valve timing apparatus (36) is adapted to control the opening and closing timing of the intake valves (11) at an advance angle to thereby increase an overlap between the intake and exhaust valves (11, 12) of the engine during low- load and/or mid-load operating ranges.

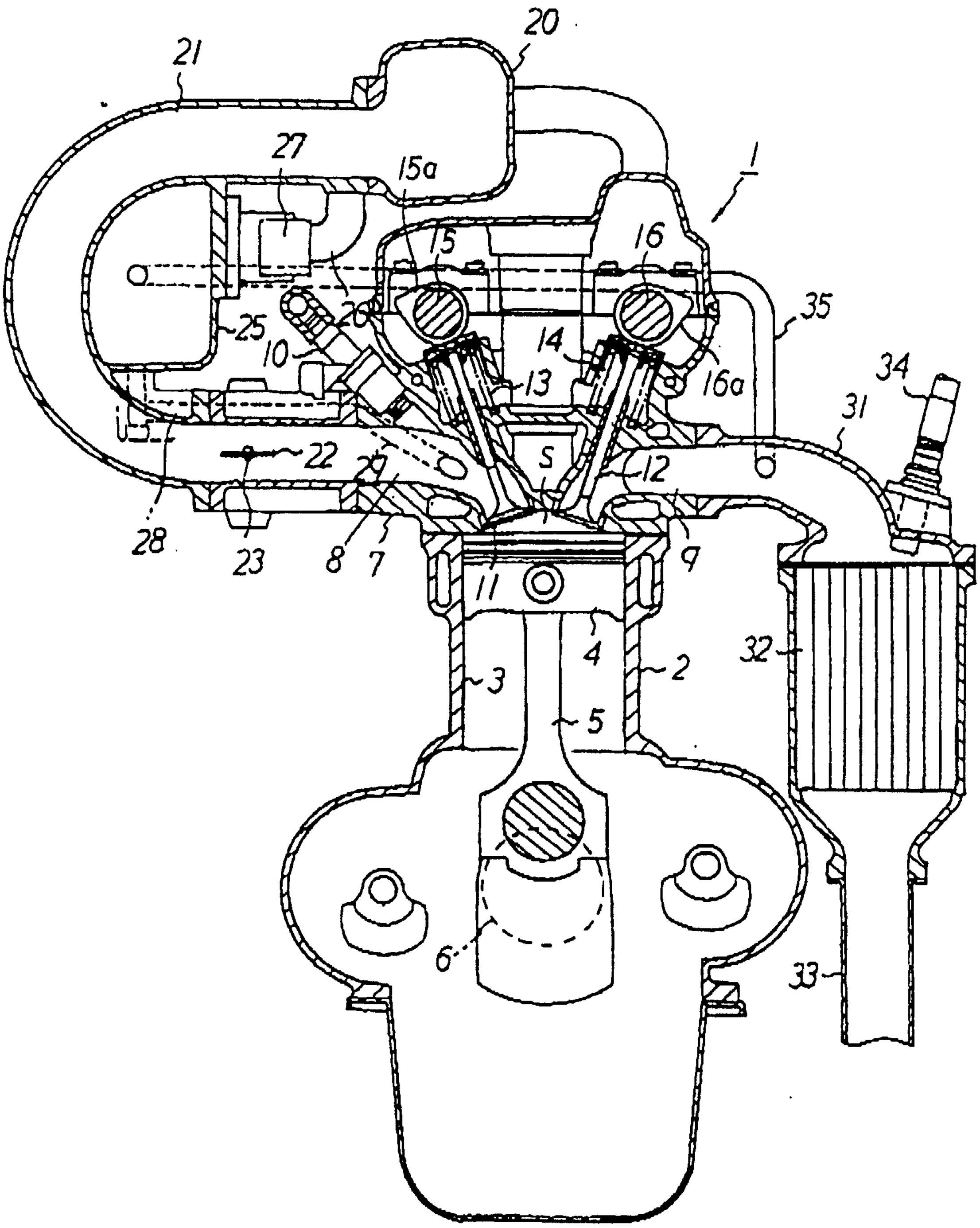
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FIGURE 1

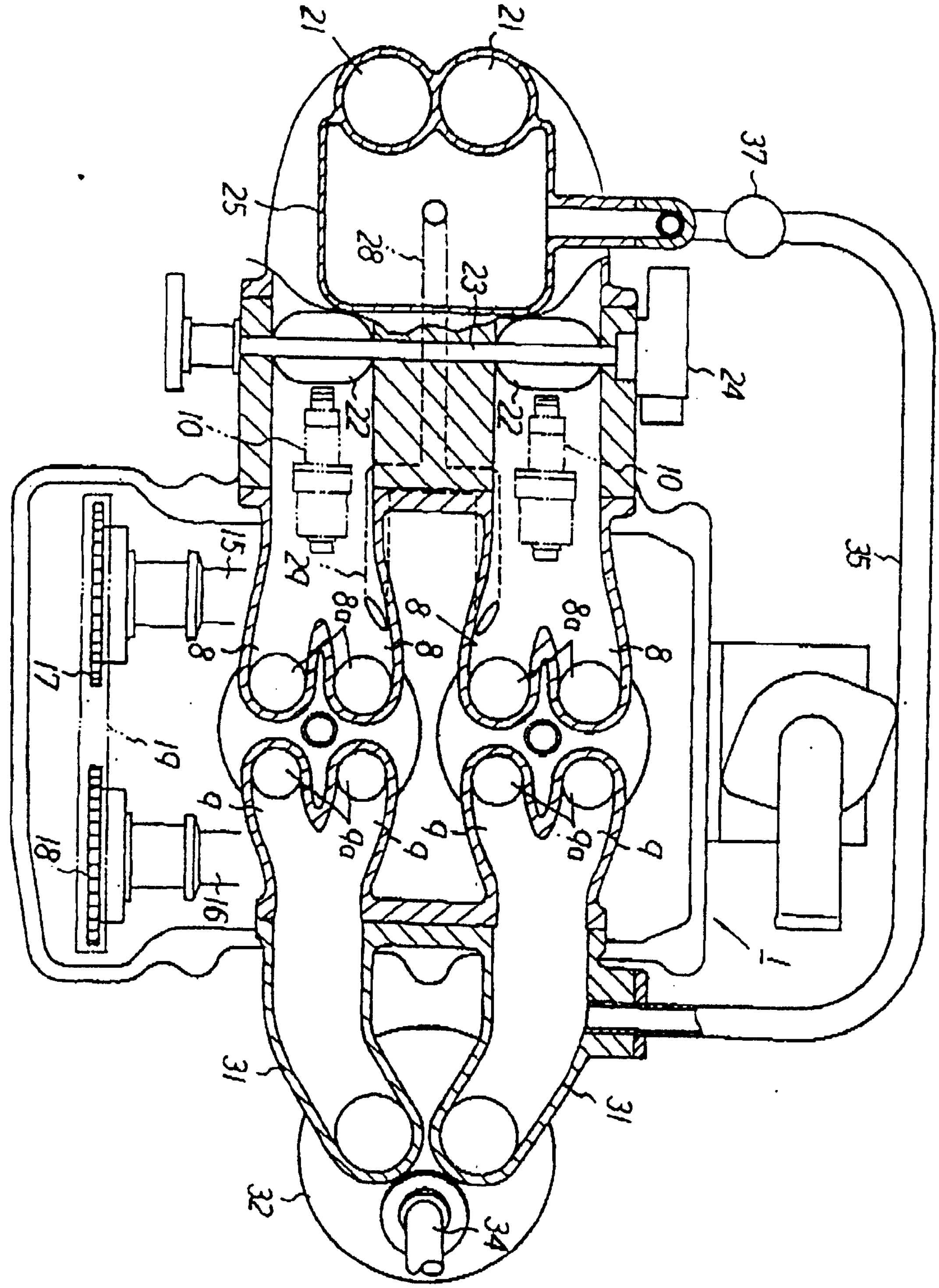
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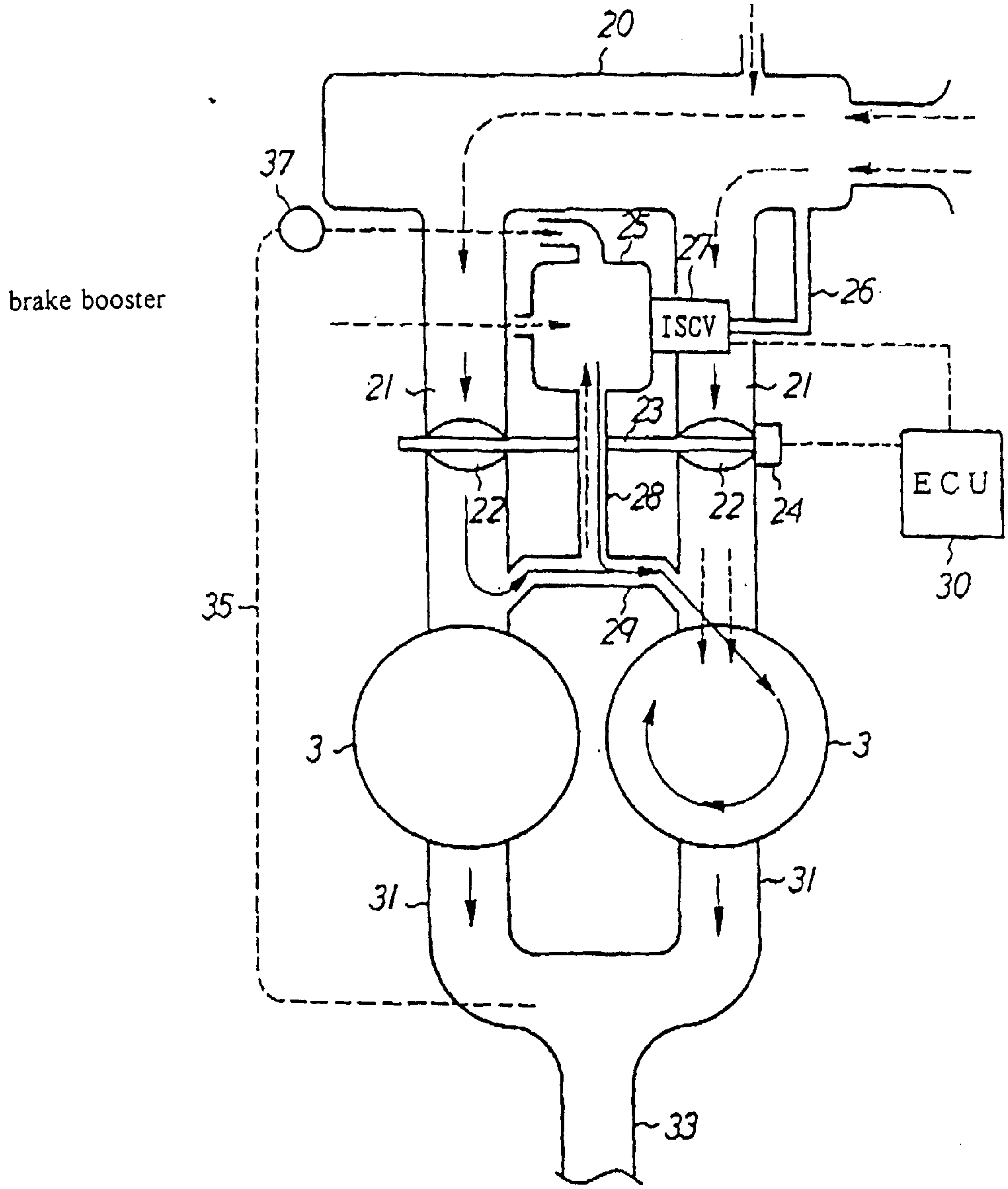
FIGURE 2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37
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26
brake booster
ISCV
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ECU
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3
3
31
31
33

FIGURE 3

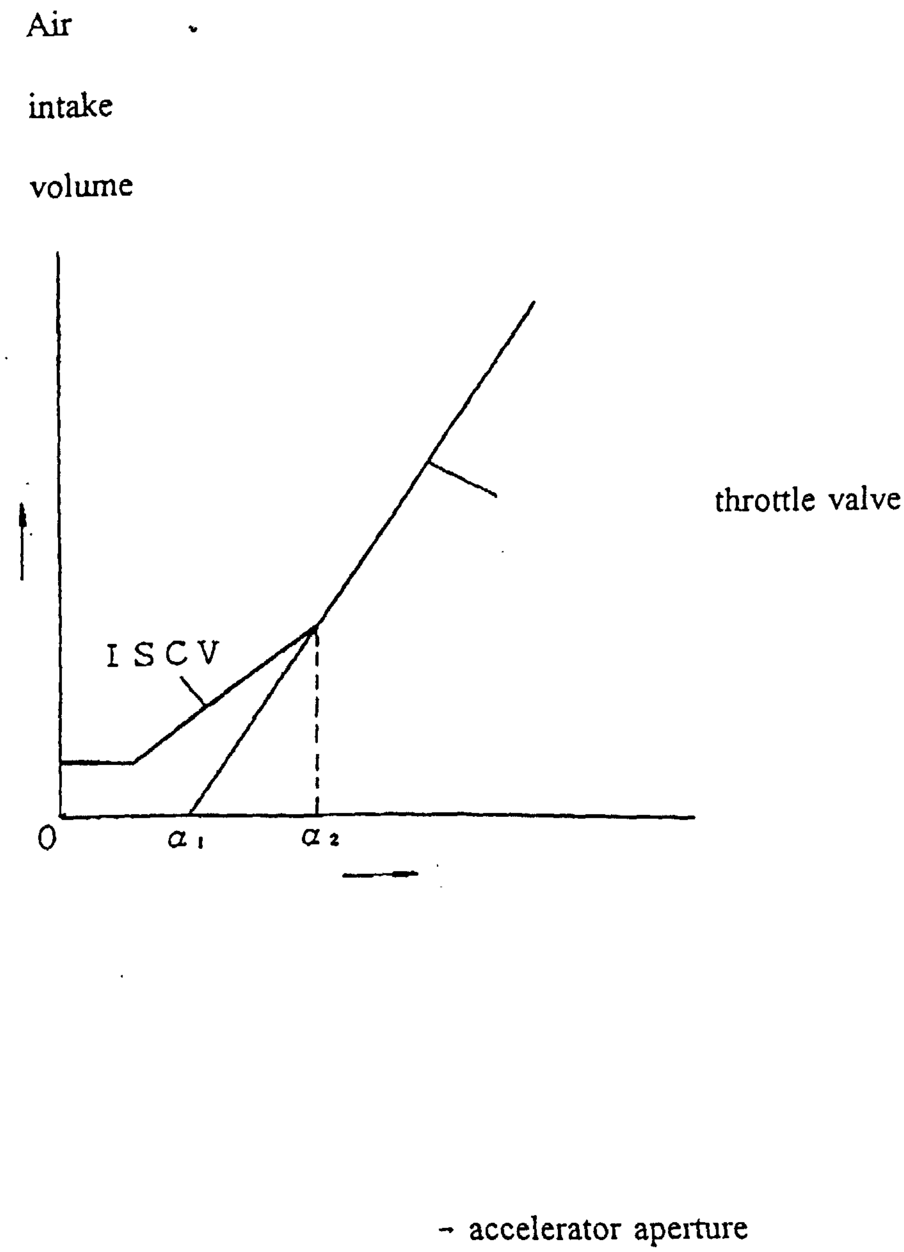

Air
intake
volume
throttle valve
ISCV
0
α_1
α_2
→ accelerator aperture

FIGURE 4

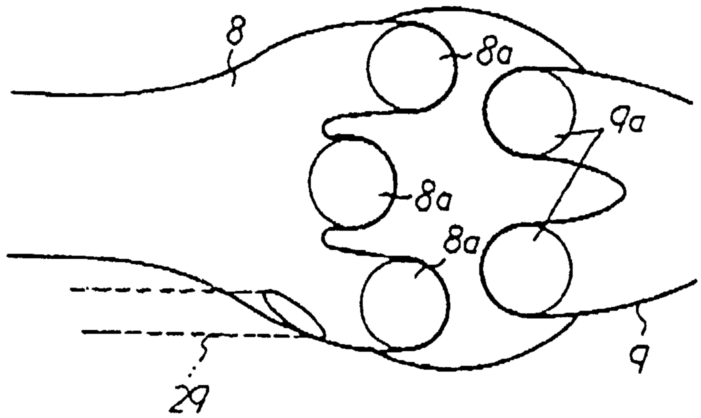


FIGURE 5

(key for inside the graph, top to bottom: total air intake flow volume; throttle valve; idling)

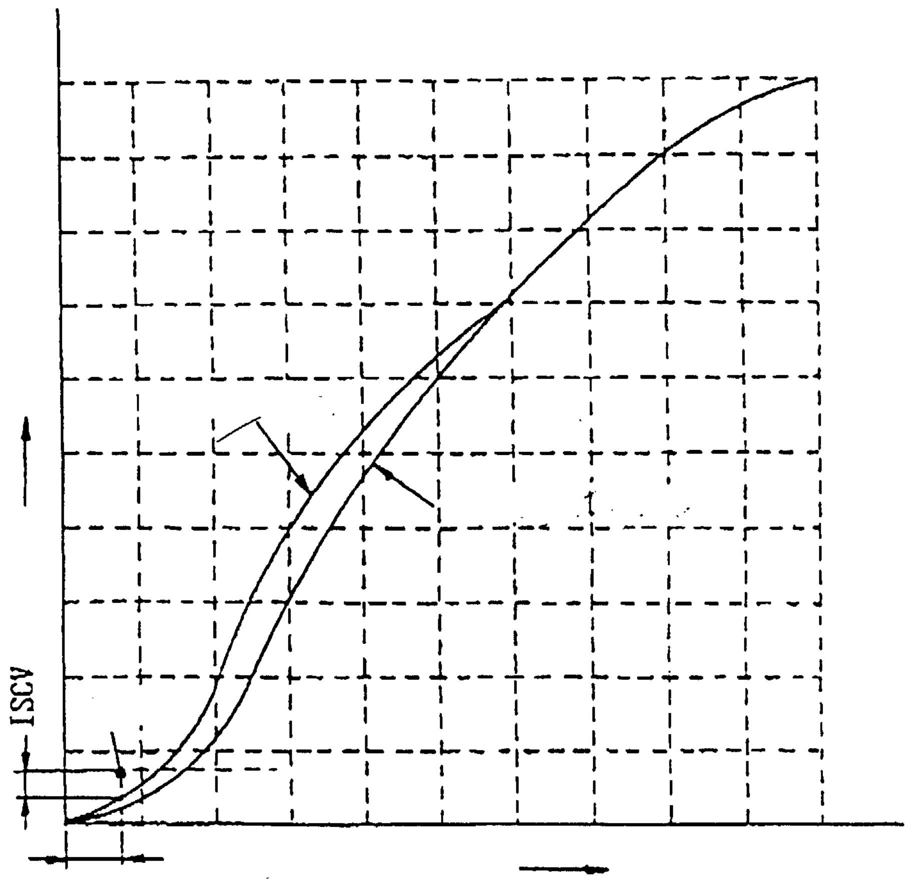
Air

intake

flow

Volume

↑



Idle adjustment tolerance

→Throttle aperture

FIGURE 6

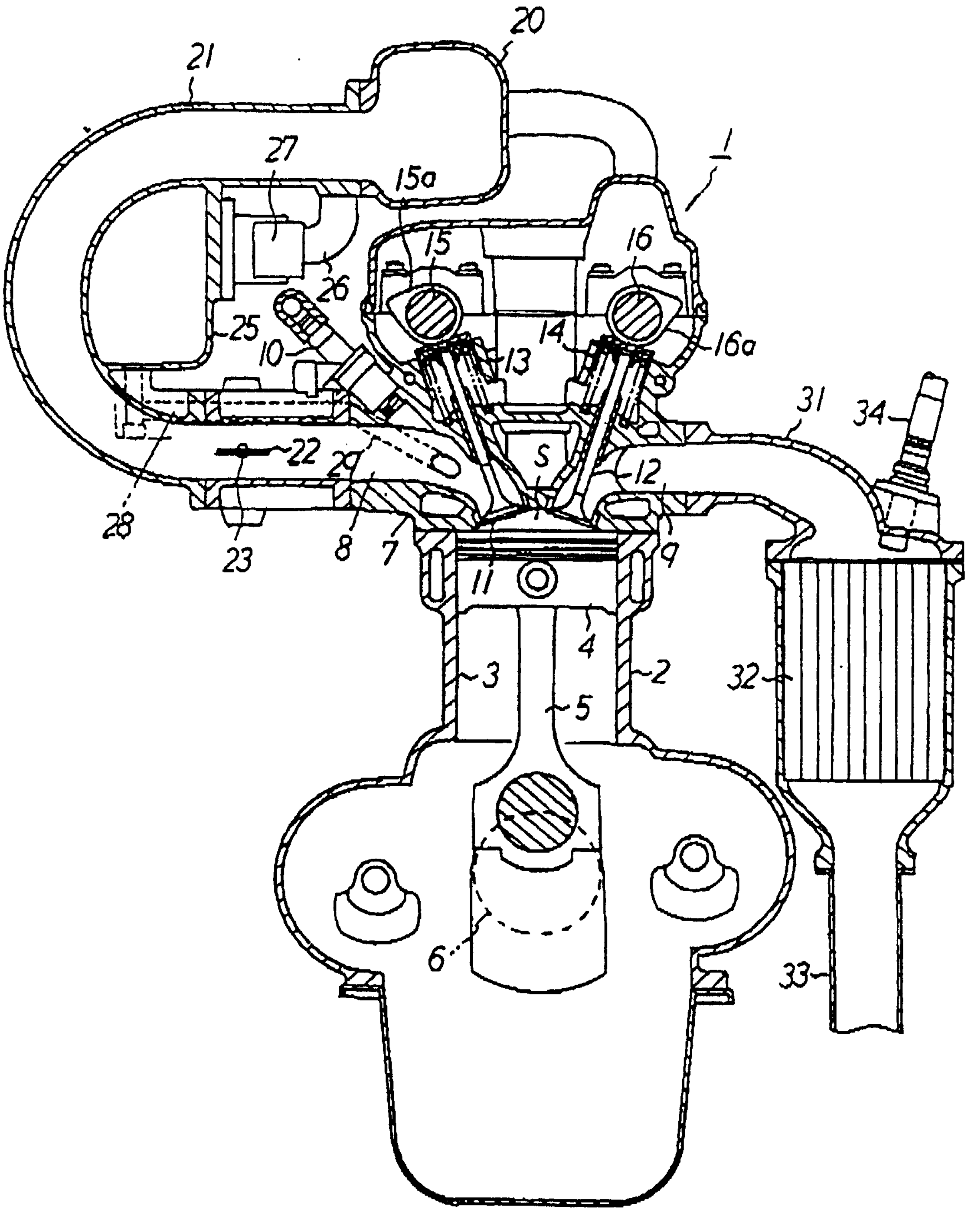

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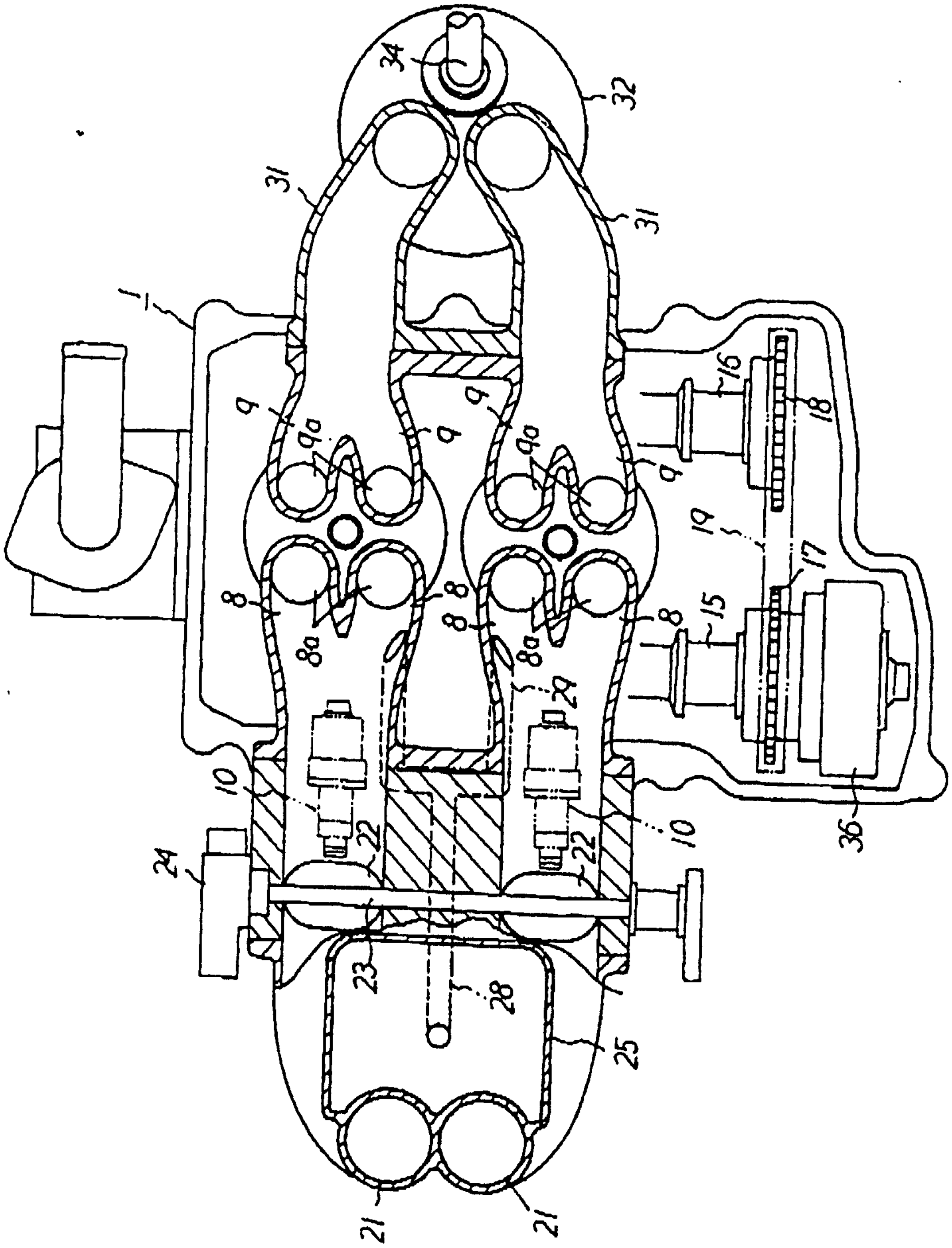
FIGURE 7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36
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FIGURE 8

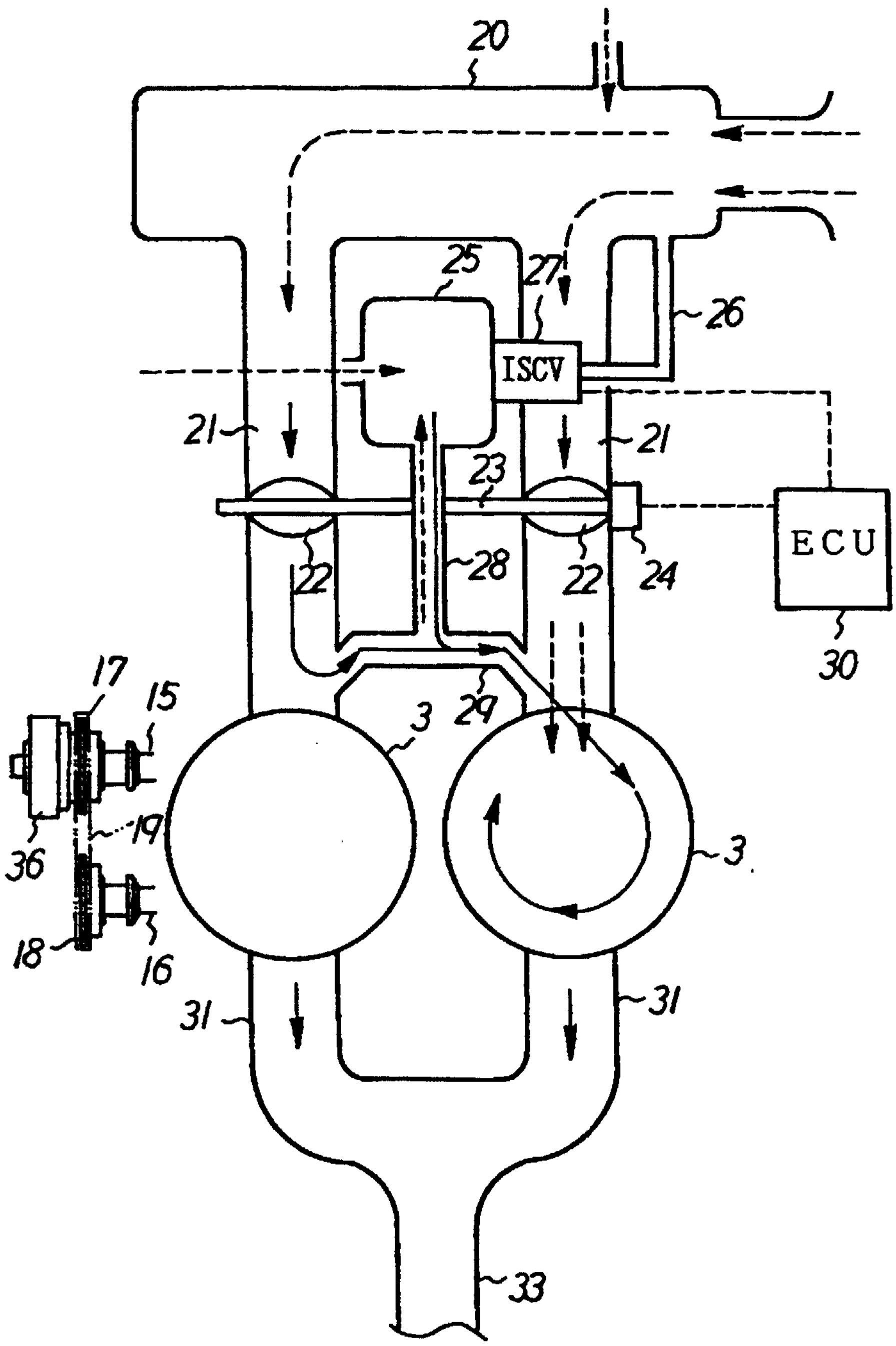
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FIGURE 9

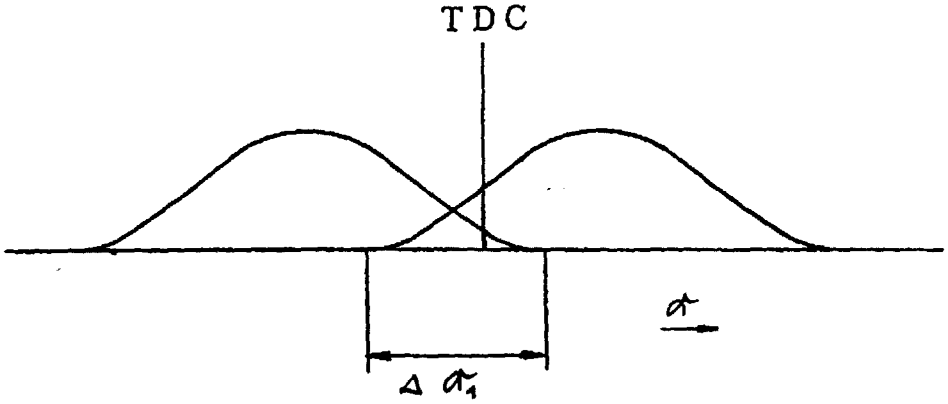

FIGURE 10 (a)

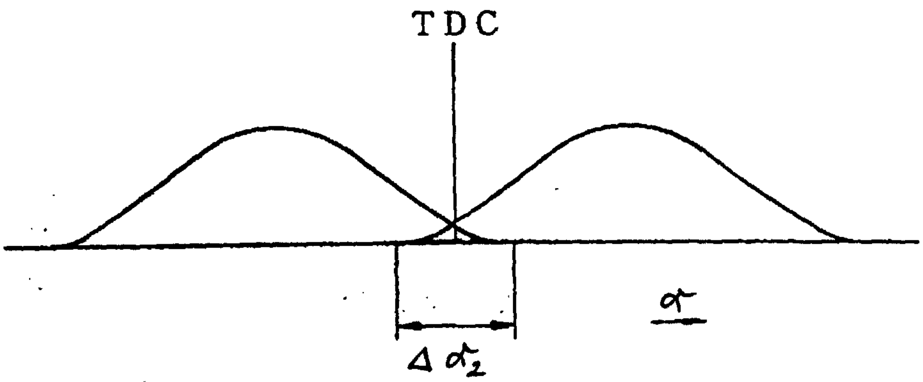

FIGURE 10 (b)