(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 881 378 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
02.12.1998 Bulletin 1998/49

(51) Int. Cl.[6]: **F02M 25/07**

(21) Application number: **98109895.7**

(22) Date of filing: **29.05.1998**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **30.05.1997 JP 142381/97**

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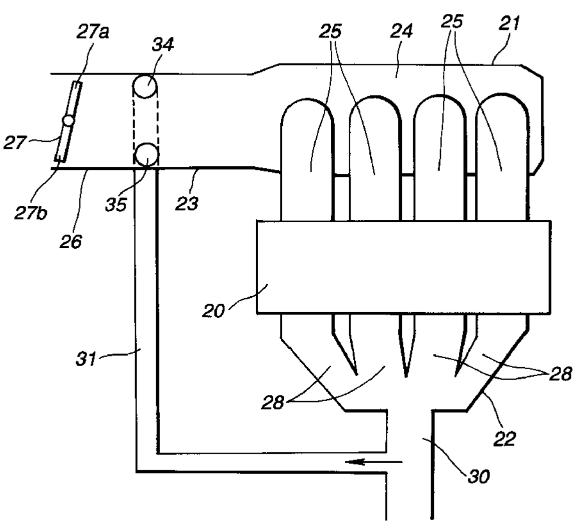
(54) Exhaust gas recirculation system for engine

(57) An exhaust gas recirculation system for returning part of exhaust gas of an engine to an intake system has first and second gas introduction ports for directing the EGR gas into an intake air passage downstream of a throttle valve. The first and second introduction ports are opened, respectively, to first and second mixing points downstream of first and second swing ends of the throttle valve, aimed in opposite directions, and inclined downstream with respect to the longitudinal direction of the intake passage in a manner as to mix the EGR gas efficiently with the fresh intake air and to prevent deposits.

FIG.1



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Description

The contents of a Japanese Patent Application No. 9-142381 with a filing date of 30 May 1997 are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

The present invention relates to an exhaust gas recirculation (EGR) system for returning part of exhaust gas of an engine to an intake system to improve the fuel efficiency and exhaust performance.

In order to improve fuel consumption for less CO_2 and to reduce NOx in compliance with growing environmental concerns, there have been proposed a variety of EGR systems for recirculating a controlled amount of exhaust gas to the intake system in a normal operation not requiring higher output power.

Japanese Utility Model *Kokai* Publication No. 3(1991)-114563 shows a first conventional EGR system having a horizontally confronting pair of openings for introducing EGR gas into an intake pipe. Japanese Utility Model *Kokai* Publication No. 3(1991)-114564 shows a second conventional EGR system having an annular EGR gas passage around an intake pipe and a plurality of holes for introducing the EGR gas from the annular passage into the intake pipe. Both systems are aimed to reduce the cylinder to cylinder nonuniformity in the EGR rate.

Japanese Patent *Kokai* Publication No. 8(1996)-218949 discloses a third conventional EGR system having an EGR passage opening to a second surge tank provided downstream of a first surge tank in an intake passage. This system introduces the EGR gas at a remote position from a throttle valve, to prevent adhesion to the throttle valve, of harmful components (deposits) of the exhaust gas mixture.

SUMMARY OF THE INVENTION

However, the conventional EGR systems are not completely sufficient for mixing the EGR gas with the intake air and for uniformly distributing the EGR gas to the engine cylinders. In the second system, conditions of fresh intake air streams through the throttle valve exert large influence on the mixing of the EGR gas and adhesion of deposits to the throttle valve. Insufficient blend of the EGR gas with the intake air is causative of uneven distribution of the EGR rate among the cylinders, unstable engine performance, increase of emission and poor fuel economy. Deposits on a throttle valve decrease the accuracy of intake air quantity control.

It is therefore an object of the present invention to provide an exhaust gas recirculation type engine system for uniformizing the EGR distribution among engine cylinders and protect a throttle valve against deposits.

According to the present invention, an exhaust gas recirculation system for an engine comprises an exhaust system, an intake system and an EGR system. The intake system comprises a pipe arrangement or pipe system and a throttle valve. The pipe arrangement is a single member or an assembly (such as an assembly of an intake manifold and a throttle body) for defining passages for distributing intake air to cylinders of the engine. The pipe arrangement comprises a collector section, a plurality of branches leading from the collector section, respectively, to the cylinders of the engine, and an intake passage section for introducing the intake air into the collector section. The throttle valve is disposed in the intake passage section at an intermediate position so that the intake passage section is divided into an upstream intake passage subsection on an upstream side of the throttle valve and a downstream intake passage subsection extending from the throttle valve to the collector section.

The EGR system is arranged to return part of the exhaust gas as EGR gas from the exhaust system into the downstream passage subsection of the intake system. The EGR system comprises at least one EGR gas introduction port having an EGR gas introduction opening for directing an inflow EGR gas stream into the downstream passage subsection. The EGR gas introduction opening is located downstream of a first free end of the throttle valve in a closed position. The EGR gas introduction port extends along a tangential direction tangential to a curved inside wall surface of the downstream passage subsection. An inflow direction of the EGR gas introduction port is inclined downstream so as to form a predetermined angle with respect to a direction of a fresh intake air stream in the downstream intake passage subsection.

The EGR port is thus directed to produce a screw-like spiral flow advancing downstream along the inside surface of the intake passage subsection. An intake air stream is induced into the spiral flow and well mixed with the EGR gas. The spiral flow promotes mixing of the EGR gas with the intake air, and prevents deposits by keeping the EGR gas outside a back flow region behind the throttle valve.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view showing an engine system having EGR introduction ports according to a first embodiment of the present invention.

Fig. 2 is a view showing an arrangement of the EGR ports according to the first embodiment.

Fig. 3 is a view showing the arrangement of the EGR ports according to the first embodiment.

Fig. 4 is a graph showing an EGR region.

Figs. 5 and 6 are views for illustrating streams on the downstream side of a throttle valve.

Fig. 7 is a graph showing a relation between a throttle opening and a back flow region.

Figs. 8 and 9 are views for illustrating extents of a back flow region under low load condition and high load condition.

Figs. 10 ~ 14 are views for illustrating EGR gas diffusion from various introduction positions.

Figs. 15, 16 and 17 are views for illustrating a spiral flow produced by the EGR introduction ports according to the first embodiment of the invention.

Fig. 18 is a view showing a travel distance of the EGR gas along a spiral path according to the first embodiment of the invention.

Fig. 19 is a graph for illustrating improvement in cylinder to cylinder EGR distribution by the spiral EGR path shown in Fig. 18.

Figs. 20A and 20B are schematic views for illustrating the EGR introductions positions according to the first embodiment.

Fig. 21 is a graph for illustrating improvement in deposit prevention by the EGR introduction positions according to the first embodiment.

Fig. 22 is a schematic view showing gas introduction ports of an EGR system according to a second embodiment of the present invention.

Fig. 23 is a schematic view showing the arrangement of the introduction ports according to the second embodiment.

Fig. 24 is a schematic view showing the arrangement of the introduction ports according to the second embodiment.

Fig. 25 is a schematic view showing gas introduction ports of an EGR system according to a third embodiment of the present invention.

Fig. 26 is a schematic view showing the arrangement of the introduction ports according to the third embodiment.

Fig. 27 is a schematic view showing gas introduction ports of an EGR system according to a fourth embodiment of the present invention.

Fig. 28 is a schematic view showing an EGR introduction point according to a fifth embodiment of the present invention.

Fig. 29 is a graph showing factors to determine gas introduction ports of an EGR system according to a sixth embodiment of the present invention.

Figs. 30 and 31 are views for illustrating effect of the gas introduction ports according to the sixth embodiment.

Fig. 32 is a schematic view showing introduction ports of an EGR system according to a seventh embodiment of the present invention.

Fig. 33 is a graph for illustrating EGR introduction points according to the seventh embodiment.

DETAILED DESCRIPTION OF THE INVENTION

Figs. 1 ~ 3 show an engine system according to a first embodiment of the present invention.

The engine system shown in Fig. 1 comprises an engine 20, an intake system, an exhaust system, and an EGR system for returning part of the exhaust gas as EGR gas from the exhaust system to the intake system.

The intake system comprises a piping (or pipe arrangement or pipe system) for distributing intake air to cylinders of the engine 20. The intake piping of this example includes an intake manifold 21 and a throttle body 26 for defining an intake passage system for distributing the intake air to the engine cylinders. The exhaust system comprises an exhaust manifold 22 for carrying exhaust gas away from the cylinders of the engine 20.

The intake manifold 21 of this example includes an inlet pipe section 23, a collector section 24 of a predetermined volume extending from the inlet pipe section 23, and a set of branches 25 extending from the collector section 24 to the cylinders of the engine 20, respectively.

The throttle body 26 is connected with the intake manifold 21 on the upstream side of the inlet pipe section 23. The throttle body 26 and the inlet section 23 define an intake air passage for introducing the intake air to the collector section 24 of the intake manifold 21. The throttle body 26 has a throttle valve 27 therein. The throttle valve 27 is disposed in the intake air passage. On the downstream side of the throttle valve 27, a downstream passage section of the intake passage extends to the collector section 24.

The exhaust manifold 22 comprises a set of branches 28 extending respectively from the engine cylinders, and an exhaust pipe section 30 to which the branches 28 converge.

The EGR system comprises an EGR passage 31 for exhaust gas recirculation. The EGR passage 31 branches off from the exhaust pipe section 30. As shown in Fig. 3, the EGR passage 31 of this example bifurcates into first and second branch passages 32 and 33 leading to the inlet pipe section 23 of the intake manifold 21 between the throttle valve 27 and the collector section 24. The EGR gas from the exhaust system flows into the intake flow in the intake air passage at a confluence point located in the downstream passage section downstream of the throttle valve 27 and upstream of the collector section 24.

The first branch passage 32 has a first introduction port 34 having a first EGR gas introduction opening which opens into the inlet pipe section 23 at a first EGR introduction position located in the rear of a downstream side free end 27a of the throttle valve 27 in a closed position. The second branch passage 33 has a second introduction port 35 having a second EGR gas introduction opening which opens in the intake pipe section 23 at a second EGR introduction position located in the rear of the position of an upstream side free end 27b of the throttle valve 27 in the closed position.

The inlet pipe section 23 of this example has a circular cross section as shown in Fig. 3. As viewed in Fig. 3, each of the first and second introduction ports 34 and 35 extends along a line tangent to the circle of the cross section of the inlet pipe section 23. The first and second introduction ports 34 and 35 are so arranged that the two inflow directions of the first and second introduction ports 34 and 35 are opposite to each other as shown in Fig. 3. The first and second introduction ports 34 and 35 are opened in a cross-flow manner (or counter flow manner) in the opposite directions. As shown in Fig. 2, each of the introduction ports 34 and 35 is inclined downstream so as to form a predetermined angle θ (lead angle) with respect to a fresh intake air flow direction in the inlet pipe section 23.

It is optional to arrange the introduction ports 34 and 35 so that the ports 34 and 35 extend from the opposite directions, respectively. In this case, the introduction port 34 extends from the left side of Fig. 3, and the introduction port 35 extends from the right.

Fig. 4 shows a normal engine operating region and an EGR region in terms of the engine speed and the throttle opening degree. In the normal operating region, the region in which EGR is utilized is a region formed by excluding a high load region near full throttle and a low load region near idle condition.

Figs. 5 and 6 schematically show streams in the inlet pipe section 23 on the downstream side of the throttle valve 27, as viewed from a direction perpendicular to the axis of the throttle valve 27 and a direction parallel to the axis of the throttle valve 27. Through an open area between the throttle valve 27 and the inside wall surface of the inlet pipe section 23, main streams flow downstream toward the collector section 24. Behind the throttle valve 27, there appears a back flow region. The size of the back flow region varies in dependence on the opening degree of the throttle valve 27, as shown in Fig. 7. Figs. 8 and 9 show forms of back flow streams in the high load operating region and the low load region. The back flow region grows larger when the opening degree of the throttle valve 27 is small.

The position of the EGR gas introduction point A exerts influence on streams in the inlet pipe section 23 as shown in Figs. 10 ~ 15.

In the example of Fig. 10, the EGR gas is introduced horizontally at a position downstream of the back flow region behind the throttle valve 27. In this case, the EGR gas is caught between upper main stream and lower main stream, respectively, from the free ends 27a and 27b of the throttle valve 27. Therefore, the EGR gas is carried away toward the collector section 24 quickly before diffusing enough. The EGR confluence position of Fig. 10 is advantageous to prevention of deposit but disadvantageous to mixing with fresh intake air.

In the example of Fig. 11, the EGR gas is introduced horizontally into the back flow region near the throttle valve 27. The EGR gas is pushed backward by back flow streams and strikes directly against the throttle valve 27, causing undesired deposition.

In the example of Fig. 12, the EGR gas is introduced horizontally at a position near the downstream end of the back flow region. Variation in the engine load condition caused by variation in the throttle opening exerts strong influence, and the mixing of the EGR gas with the fresh intake air and prevention of deposit are both unstable. The instability is increased especially when the amount of EGR is increased.

In the examples of Figs. 13 and 14, the EGR gas is introduced vertically. The back flow region influences the performance in mixing of the EGR gas with the fresh intake air and the prevention of deposit in the same manner as in the examples of Figs. 10 and 11. In the example of Fig. 13, the EGR gas forms a drift stream segregated from fresh intake air streams coming from the free ends of the throttle valve 27, without mingling with the fresh air streams. In the example of Fig. 14, the performance is affected by the flow speed of the EGR gas. When the EGR gas streams are fast and strong, the EGR streams vertically traverse the main streams, and increase undesired deposition. When the EGR gas streams are weak, the EGR gas forms segregated streams detrimental to the gas mixing.

Fig. 7 shows how the back flow region affects the mixing of the EGR gas with the fresh intake air and the formation of deposit.

From the above, the requirements for promoting the mixing of the EGR gas with the fresh intake air and preventing deposit are: i) to avoid the back flow region, ii) to increase a stay time of the EGR gas, iii) to mix the EGR gas into main streams of the fresh intake air from both free ends of the throttle valve 27.

To meet these requirements, the EGR system according to the present invention employs at least one EGR gas introduction port directed to produce a spiral flow mixing with fresh main streams (upper main stream and lower main stream) from the free ends 27a and 27b of the throttle valve 27.

In the illustrated example, the first EGR gas confluence of the first introduction port 34 is located just in the rear of the downstream side free end 27a of the throttle valve 27 in the closed valve position, and the second EGR gas confluence of the second introduction port 35 is located just in the rear of the upstream side free end 27b of the throttle valve 27 in the closed valve position. Each introduction port 34 or 35 extends along a line tangent to the circular cross section of the inlet pipe section 23, and each introduction port 34 or 35 is inclined downstream so as to form a predetermined angle θ (lead angle) with respect to a fresh intake air flow direction in the inlet pipe section 23. Furthermore, the first and second introduction ports 34 and 35 are opened in a cross-flow manner (or counter flow manner) in the opposite directions. Therefore, The EGR gas is mixed with the fresh intake air outside the back flow region at a mixing position where the velocity of the fresh main stream is highest, and the EGR gas and the intake air form a spiral flow flowing helically on and near the cylindrical inside wall surface of the inlet pipe section 23 toward the collector section 24.

Therefore, the EGR gas stays very long as compared with the conventional design. The main fresh intake air streams are involved into the spiral flow of the EGR gas, and the EGR gas diffuses from the outside toward the center of the inlet pipe section 23 in the process of the spiral flow. The EGR gas stays outside the back flow region, without causing deposit. The EGR system of this embodiment can mix the EGR gas with the intake air sufficiently, distribute the EGR gas uniformly among the cylinders, and prevent deposits efficiently.

As shown in Fig 18, the distance L2 traveled by the EGR gas along the spiral flow path (corresponding to the stay time) to the inlet of the most upstream branch 25 is much longer than the distance L1 of the conventional straight path. As shown in Fig. 19, the degree of nonuniformity or irregularity in the EGR gas distribution among the cylinders is decreased by the increase in the EGR gas travel distance.

As shown in Figs. 20 and 21, the upper and lower EGR introduction positions according to this embodiment can prevent the formation of deposits sufficiently as compared with the center EGR introduction position.

The engine system according to the first embodiment of the present invention can make the EGR rates of the cylinders uniform even when the amount of EGR is great, and thereby improve the fuel consumption and exhaust performance. Furthermore, the engine system according to this embodiment can ensure the accurate control of the intake air quantity by preventing deposits.

Figs. 22 ~ 24 show an EGR system according to a second embodiment of the present invention. Each of the EGR introduction ports 34 and 35 comprises a guide case 40 defining the EGR introduction opening. In this example, the guide case 40 of each introduction port is cylindrical, and projects into the inlet pipe section 23. In the example shown in Fig. 24, each introduction port has the EGR introduction opening in an imaginary plane containing the axis of the inlet pipe section 23. The axis of the throttle valve 27 is perpendicular to this plane.

The guide case 40 of each introduction port 34 or 35 is oriented to produce a spiral flow advancing downstream as in the first embodiment, and opened at the position to drag the upper or lower main intake stream into the spiral flow. The outside cylindrical surface of each guide case 40 exposed in the inside of the inlet pipe section 23 serves as a deflector for inducing and guiding the fresh intake air stream (upper main stream or lower main stream) to the direction of the spiral flow.

By using the inside and outside wall surfaces of the guide cases 40 for strengthening the spiral flow, the EGR system of the second embodiment can mix the EGR gas with the intake air sufficiently, distribute the EGR gas uniformly among the cylinders, and prevent deposits by causing the EGR gas to stay away from the back flow region.

Figs. 25 and 26 show an EGR system according to a third embodiment of the present invention. In this embodiment, the gas introduction opening of each of introduction ports 45 and 46 is in the form of an elongated circle. The cross sectional shape of each of the introduction ports 45 and 46 is elongated along the longitudinal direction of the inlet pipe section 23, as shown in Fig. 25. In this example, the cross sectional size of the opening of the second introduction port 46 in the rear of the upstream side end 27b of the throttle valve 27 is greater than the cross sectional opening size of the first introduction port 45 in the rear of the downstream side valve end 27a.

The elongated openings of the first and second introduction ports 45 and 46 make it possible to decrease the distance between the throttle valve 27 and the EGR gas introduction position, and to increase the distance to the collector section 24 to the advantage of mixing of the EGR gas with the fresh intake air. The first EGR gas introduction port 45 is located on the side on which the region of the main fresh intake air stream is relatively narrow, and the second EGR gas introduction port 46 is located on the side on which the region of the main fresh intake air stream is relatively large. Therefore, the smaller introduction port 45 and the larger introduction port 46 can introduce the EGR gas efficiently, and keep the EGR gas outside of the back flow region.

Fig. 27 shows an EGR system according to a fourth embodiment of the present invention. In this embodiment, the EGR gas is introduced from an introduction port 51 located downstream of the upstream end 27b of the throttle valve 27 whereas an auxiliary air is introduced from an introduction port 50 downstream of the downstream end 27a of the throttle valve 27. The introduction ports 50 and 51 are directed and opened as in the preceding embodiments. In this embodiment, therefore, the introduction port 51 is connected with the exhaust system, and the introduction port 50 is connected with the intake system at a position upstream of the throttle valve 27. In this example, the introduction port 50 is connected with an air cleaner on the upstream side of the throttle valve 27.

The EGR system of this example can increase the strength of the spiral flow and mix the EGR gas uniformly. In this example, the introduction port 50 for the auxiliary air is located on the side on which the region of the main intake air stream is narrow. Therefore, this EGR system can prevent the EGR gas from entering the back flow region more efficiently, and prevent deposits from being produced.

Fig. 28 shows an EGR system according to a fifth embodiment. The downstream inclination angle θ (lead angle) (as shown in Fig. 2) of each EGR gas introduction port is so determined that the distance from the EGR gas introduction position to the inlet of the most upstream branch 25 of the intake manifold 21 along the longitudinal center line of the inlet pipe section 23 is longer than one pitch (lead) of a helix defined by the angle θ, on the inside cylindrical surface of the inlet pipe section 23.

Therefore, this design makes sufficiently long the travel distance of the EGR gas along the spiral path from the EGR gas confluence to the inlet of the most upstream branch 25, and ensures the proper mixing of the EGR gas with the intake air.

Fig. 29 is a graph for illustrating a sixth embodiment of the present invention. In this embodiment, the opening size (or opening area) of each of first and second EGR introduction ports 55 and 56 is determined in accordance with the maximum speed of the fresh intake air passing through the throttle valve 27, the distance between the axis of the throttle valve 27 and the openings of the gas introduction ports 55 and 56, and the EGR gas discharge speed (the speed of the EGR gas flowing into the inlet pipe section 23) modified by the shapes of the openings of the introduction ports 55 and 56.

As shown in Fig. 29, the speed of a fresh main stream decreases as the distance from the throttle valve 27 in the downstream direction increases. The opening sizes and shapes of the introduction ports 55 and 56 are so determined as to hold the discharge speed of the EGR gas from each introduction port 55 or 56 always high as compared with the speed of the main stream near the opening of the introduction port. The setting of the EGR inflow speed is higher than the fresh main stream speed, as shown in Fig. 29.

Therefore, each of the introduction ports 55 and 56 flows the EGR gas into the inlet pipe section 23 at such a sufficient velocity to produce a strong spiral flow as shown in Fig. 30, instead of losing its speed by collision with the main stream as shown in Fig. 31. The EGR gas flows along the spiral path without turning inside toward the center of the inlet pipe section 23, and stays away from the back flow region without causing deposits. The higher speed EGR flow of Fig. 30 can prevent deposits and mix the EGR gas efficiently.

Fig. 32 shows a part of an engine system according to a seventh embodiment of the present invention. The intake passage defined by the inlet pipe section 23 and the throttle body 26 is inclined with respect to the longitudinal direction of the collector section 24 to form a bend 62 of an angle α in an imaginary plane to which the axis of the throttle valve 27 is perpendicular. In this embodiment, the positions of the openings of first and second introduction ports 60 and 61 are adjusted in accordance with the bend angle α.

In the example shown in Fig. 32, the longitudinal center line of the intake air passage is bend downward with respect to the longitudinal direction of the collector section 24, so that the upstream side end 27b of the throttle valve 27 is located on the inner side of the bend 62. In this case, the gas introduction position of the introduction port 61 located downstream of the upstream free end 27b of the throttle valve on the inner side of the bend 62 is shifted downstream slightly, and the gas introduction position of the introduction port 60 located downstream of the downstream free end 27a of the throttle valve on the outer side of the bend 62 is shifted downstream to a greater extent in accordance with the downward bend angle. As a result, the longitudinal distance along the longitudinal direction of the inlet pipe section 23 from the axis of the throttle valve 27 to the confluence point of the port 60 on the outer side of the bend 62 is greater than the longitudinal distance from the axis of the throttle valve 27 to the confluence point of the port 61 on the inner side of the bend 62.

When the longitudinal center line of the intake air passage is bend upward with respect to the longitudinal direction along which the collector section 24 extends, so that the downstream side end 27a of the throttle valve 27 is located on the inner side of a bend, then the EGR introduction confluence position of the introduction port 60 located downstream of the downstream free end 27a of the throttle valve on the inner side of the bend is shifted upstream in accordance with the upward bend angle, and the confluence position of the introduction port 61 located downstream of the upstream free end 27b of the throttle valve 27 on the outer side of the bend 62 is shifted upstream to a smaller extent as shown in Fig. 33.

When the inlet pipe section 32 has a downward bend as shown in Fig. 32, the back flow region tends to shift toward the outer side of the bend. Therefore, the EGR introduction confluence positions of the ports 60 and 61 are shifted downstream so that the confluence point of the port 60 is shifted away from the back flow region. When the inlet pipe section has an upward bend, the back flow region shifts toward the center of the inlet pipe section 23. In this case, the confluence positions of the ports 60 and 61 are shifted upstream to increase the travel distance of the EGR gas.

The introduction ports 60 and 61 are thus opened at optimum positions in conformity with the form of the back flow region. Therefore, the design of this embodiment can mix the EGR gas efficiently, and prevent deposits.

As shown in Fig. 3, the swing axis of the throttle valve 27 according to each of the illustrated embodiments of the present invention extends in an imaginary first center plane C1. An imaginary second center plane C2 intersects the first center plane C1 at right angles along the center line of the cylindrical inlet pipe section 23. The inlet pipe section 23 in the illustrated examples is straight, and in the form of a hollow right circular cylinder. First and second imaginary tangent planes T1 and T2 are parallel to the first center plane C1, and tangent to the cylindrical inside wall surface of the inlet pipe section 23 on opposite sides of the first center plane C1. Third and fourth imaginary tangent planes T3 and T4 are parallel to the second center plane C2, and tangent to the cylindrical inside wall surface of the inlet pipe section 23 on opposite sides of the second center plane C2. In Fig. 2, an imaginary cross sectional plane S is a plane to which the center line of the inlet pipe section 23 is perpendicular, and the axis of the throttle valve 27 is parallel.

In the example shown in Figs. 2 and 3, the first introduction port 34 extends alongside the first tangent plane T1 from a first side (right side) of the second center plane C2, and opens toward the fourth tangent plane T4. The second introduction port 33 extends alongside the second tangent plane T2 from a second side (left side) of the second center plane C2, and opens toward the third tangent plane T3.

Each of the first and second introduction ports 34 and 35 of this example is circular in cross section. The cylindrical inside wall surface of the first introduction port 34 contains one straight line which lies on the first tangent plane T1 and which is tangent to the cylindrical inside wall surface of the inlet pipe section 23 at a point shown at M1 in Fig. 3. The cylindrical inside wall surface of the second introduction port 35 contains one straight line which lies on the second tangent plane T2 and which is tangent to the cylindrical inside wall surface of the inlet pipe section 23 at a point shown at M2 in Fig. 3. The longitudinal direction of each introduction port 34 and 35 forms the angle θ with the cross sectional plane S as shown in Fig. 2. The first and second introduction ports 34 and 35 are inclined from the cross sectional plane S in a such a direction as to produce a spiral flow advancing downstream toward the collector section 24. The spiral flow direction produced by the, first introduction port 34 is the same as that of the second introduction port 35. In the example of Fig. 3, the spiral flow is in the counterclockwise direction.

Claims

1. An exhaust gas recirculation system for an engine, comprising:

   an exhaust system for carrying exhaust gas away from the engine;
   an intake system comprising a pipe arrangement for distributing intake air to cylinders of the engine, the pipe arrangement comprising a collector section, a plurality of branches leading from the collector section, respectively, to the cylinders of the engine, and an intake passage section for introducing the intake air into the collector section, the intake system further comprising a throttle valve disposed in the intake passage section at an intermediate position dividing the intake passage section into an upstream intake passage subsection on an upstream side of the throttle valve and a downstream intake passage subsection extending from the throttle valve to the collector section; and
   an EGR system for returning part of the exhaust gas as EGR gas from the exhaust system into the downstream passage subsection of the intake system, the EGR system comprising an EGR gas introduction port having an EGR gas introduction opening for directing an inflow EGR gas stream into the downstream passage subsection, the EGR gas introduction opening being located downstream of a first free end of the throttle valve in a closed position, the EGR gas introduction port extending along a tangential direction tangential to a curved inside wall surface of the downstream passage subsection, an inflow direction of the EGR gas introduction port being inclined downstream so as to form a predetermined angle with respect to a direction of a fresh intake air stream in the downstream passage subsection.

2. The exhaust gas recirculation system as claimed in Claim 1 wherein the EGR introduction port comprises a guide case projecting into the downstream passage subsection.

3. The exhaust gas recirculation system as claimed in Claim 1 wherein the EGR introduction port is elongated in cross section.

4. The exhaust gas recirculation system as claimed in Claim 1 wherein the EGR introduction port extends along a predetermined tangent line tangent to an imaginary helix on the curved inside wall surface of the downstream passage subsection, and a lead of the helix is smaller than a distance between the EGR introduction opening and an inlet of any of the branches of the pipe arrangement.

5. The exhaust gas recirculation system as claimed in Claim 1 wherein an opening area of the EGR gas introduction opening is determined in accordance with a maximum speed of a fresh intake air stream passing through the throttle valve, a distance from an axis of the throttle valve and the EGR gas introduction opening and a speed of an EGR gas inflow stream modified by an opening shape of the EGR gas introduction opening.

6. The exhaust gas recirculation system as claimed in Claim 1 wherein the EGR system further comprises a complementary introduction port having a complementary introduction opening for directing an inflow gas stream into the downstream intake passage subsection between the throttle valve and the collector section, the complementary introduction opening being located downstream of a second free end of the throttle valve in the closed position, the complementary introduction port extending along a tangential direction tangential to the curved inside wall surface of the downstream intake passage subsection, an inflow direction of the complementary introduction port being inclined downstream so as to form a predetermined angle

with respect to a direction of a fresh air stream in the downstream intake passage subsection, the EGR gas introduction port and the complementary introduction port extending from opposite directions so that the inflow direction of each of the EGR and complementary introduction ports is opposite to the inflow direction of the other.

7. The exhaust gas recirculation system as claimed in Claim 6 wherein a cross sectional size of the EGR gas introduction opening located downstream of the first free end of the throttle valve is greater than a cross sectional size of the complementary introduction opening located downstream of the second free end of the throttle opening, and the first free end of the throttle valve is located upstream of the second free end when the throttle valve is in the closed position.

8. The exhaust gas recirculation system as claimed in Claim 6 wherein the EGR introduction port and the complementary introduction port are both connected with the exhaust system to introduce the EGR gas into the downstream intake passage subsection through both introduction ports.

9. The exhaust gas recirculation system as claimed in Claim 6 wherein the complementary introduction port is connected with the intake system to introduce fresh air into the downstream intake passage subsection through the complementary introduction port whereas the EGR introduction port is connected with the exhaust system, the second free end of the throttle valve being located downstream of the first free end when the throttle valve is in the closed position.

10. The exhaust gas recirculation system as claimed in Claim 6 wherein the intake passage section has a bend with respect to the collector section along a plane perpendicular to an axis of the throttle valve, and positions of the EGR introduction opening and the complementary introduction opening are modified in accordance with a bent angle between the intake passage section and the collector section.

11. An engine system comprising:

an engine comprising a plurality of engine cylinders;
an exhaust system for carrying exhaust gas away from the engine;
an intake system comprising a pipe system comprising a collector section, a plurality of branches each extending from the collector section to one of the engine cylinders for distributing intake air to the engine cylinders of the engine, and an intake passage section for introducing the intake air into the collector section, the intake system further comprising a throttle valve disposed in the intake passage section, the intake passage section comprising an upstream intake passage subsection on an upstream side of the throttle valve and a downstream intake passage subsection extending from the throttle valve to the collector section on a downstream side of the throttle valve; and
an EGR system for returning part of the exhaust gas as EGR gas from the exhaust system to the downstream intake passage subsection of the intake system, the EGR system comprising a first gas introduction port for directing an inflow gas stream into the downstream intake passage subsection, the first introduction port being inclined in a direction to produce a spiral flow along a curved inside wall surface of the downstream intake passage subsection toward the collector section, the first introduction port opening into the downstream intake passage subsection at such a position downstream of a first swing end of the throttle valve as to cause the inflow stream from the first introduction port to flow into a fresh air stream coming through a gap between the first swing end of the throttle valve in a closed position and the inside wall surface of the intake passage section.

12. The engine system as claimed in Claim 11 wherein the first introduction port extends along an inclined line which is inclined from an imaginary sectional plane of the downstream intake passage subsection in such a direction as to form a spiral flow advancing downstream toward the collector section along the inside wall surface of the downstream intake passage subsection.

13. The engine system as claimed in Claim 12 wherein the first introduction port lies between an imaginary first center plane containing a swing axis on which the throttle valve swings and a center line of the downstream intake passage subsection, and a first imaginary tangent plane which is parallel to the first center plane and tangent to the inside wall surface of the downstream intake passage subsection which is a cylindrical surface, and the first introduction port extends along the first tangent plane and opening to a first mixing point lying on an imaginary second center plane intersecting the first center plane at right angles along the center line of the downstream intake passage subsection.

14. The engine system as claimed in Claim 13 wherein the first introduction port has a cylindrical inside wall surface contiguous with the first tangent plane along an imaginary first inclined tangent straight

line lying on the first tangent plane and forming a predetermined lead angle with the imaginary sectional plane to which the center line of the downstream intake passage subsection is perpendicular, and the first introduction port extends along the inclined tangent straight line and terminates at a point at which the first inclined line intersects the second center plane.

15. The engine system as claimed in Claim 14 wherein the EGR system further comprises a second gas introduction port for directing an inflow gas stream into the downstream intake passage subsection of the intake system, the second introduction port opening into the downstream intake passage subsection at such a position downstream of a second swing end of the throttle valve as to cause the inflow stream from the second introduction port to flow into a fresh air stream coming through a gap between the second swing end of the throttle valve in the closed position and,the inside wall surface of the intake passage section, the first and second introduction ports being located on opposite sides of the first imaginary center plane, the first and second introduction ports being located, respectively, on first and second sides of the second imaginary center plane, the first introduction port extending from the first side of the second center plane and opening toward the second side of the second center plane, the second introduction port extending from the second side of the second center plane and opening toward the first side of the second center plane, each of the first and second introduction ports being inclined from the imaginary sectional plane.

16. The engine system as claimed in Claim 15 wherein each of the first and second introduction ports terminates in the second center plane.

17. The engine system as claimed in Claim 15 wherein each of the first and second introduction ports is elongated along the center line of the downstream intake passage subsection.

18. The engine system as claimed in Claim 15 wherein the first introduction port has a first introduction opening located downstream of the first swing end of the throttle valve in the closed position, the second introduction port has a second introduction opening located downstream of the second swing end of the throttle valve in the closed position, the first swing end is located on a downstream side of the swing axis of the throttle valve, the second swing end of the throttle valve is located on a upstream side of the swing axis of the throttle valve, the first introduction opening is smaller in size than the second introduction opening.

19. The engine system as claimed in Claim 15 wherein the downstream intake passage subsection and the collector section are connected end to end so as to form a bend forming an angle in the second center plane so that the longitudinal center line of the downstream intake passage subsection intersects a longitudinal line along which the collector section extends at an intersection point in the second center plane, one of the first and second introduction ports is an outside introduction port located on an outer side of the bend, the other of the first and second introduction ports is an inside introduction port located on an inner side of the bend, and a distance of an open end of the inside outside introduction port from the swing axis of the throttle valve along the center line of the downstream intake passage section is greater than a distance of an open end of the inside introduction port from the swing axis of the throttle valve along the center line of the downstream intake passage subsection.

20. An engine system comprising:

an engine comprising a plurality of engine cylinders;

an exhaust system for carrying exhaust gas away from the engine;

an intake system comprising a pipe arrangement comprising a collector section, a plurality of branches each extending from the collector section to one of the engine cylinders for distributing intake air to the engine cylinders of the engine, and an intake passage section for introducing the intake air into the collector section, the intake system further comprising a throttle valve disposed in the intake passage section, the intake passage section comprising an upstream intake passage subsection on an upstream side of the throttle valve and a downstream intake passage subsection extending from the throttle valve to the collector section on a downstream side of the throttle valve, the downstream intake passage section having a cylindrical inside wall surface extending along and around an imaginary straight center line perpendicular to an imaginary sectional plane of the downstream intake passage subsection; and

an EGR system for returning part of the exhaust gas as EGR gas from the exhaust system to the downstream intake passage subsection of the intake system, the EGR system comprising first and second gas introduction ports for directing first and second inflow gas streams into the downstream intake passage subsection, the first introduction port opening to a first mixing point so that the first inflow stream from the first introduction port meets a main intake air stream in the downstream intake passage subsection at the first mixing point, the second introduction port opening to a second mixing point so that the second inflow stream from the second introduction port meets a main intake air stream in the downstream intake passage subsection at the second mixing point, the first mixing point being located on a first side of an imaginary first center plane containing a swing axis of the throttle valve and the center line of the downstream intake passage subsection, the second mixing point being located on a second side of the first center plane, both of the first and second mixing points lying on an imaginary second center plane intersecting the first center plane at right angles along the center line of the downstream intake passage subsection, the first introduction port extending toward the second center plane from a first side of the second center plane, the second introduction port extending toward the second center plane from a second side of the second center plane, the first and second introduction ports being inclined with respect to the sectional plane of the downstream intake passage subsection in such a direction to produce a spiral flow along the cylindrical inside wall surface of the downstream intake passage subsection toward the collector section.

FIG.1

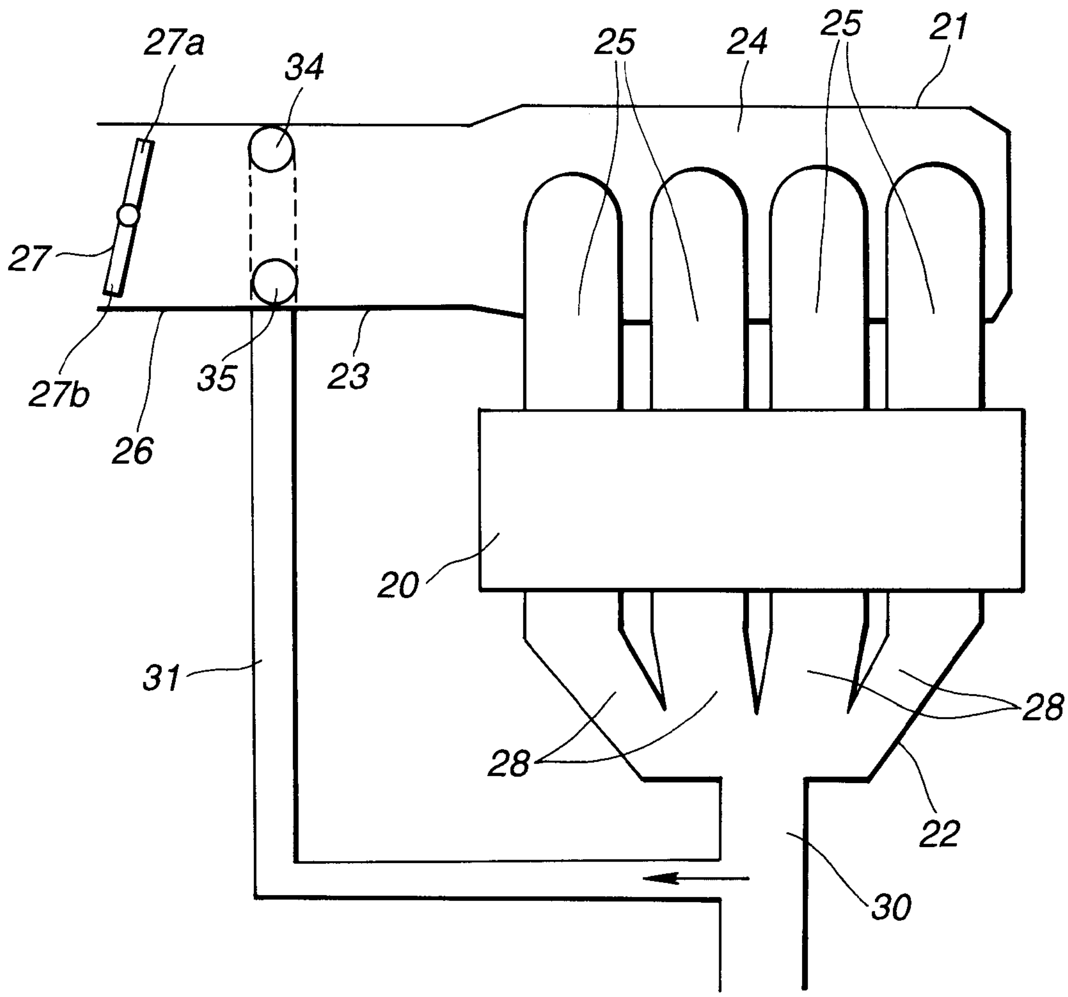


FIG.2

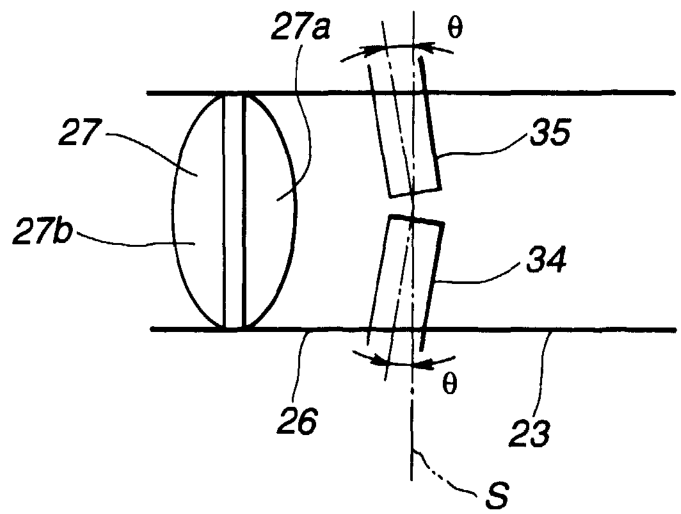


FIG.3

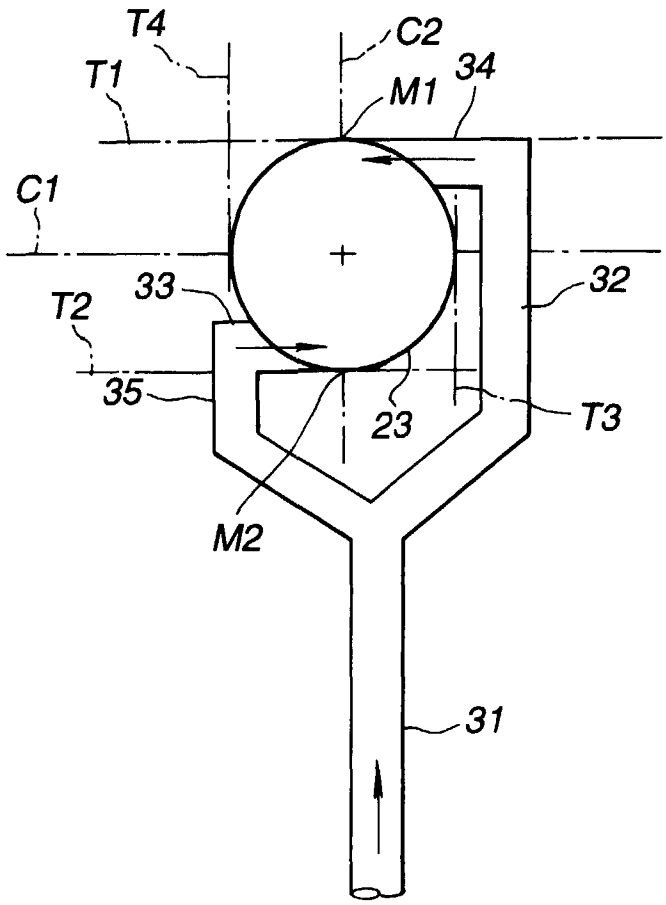


FIG.4

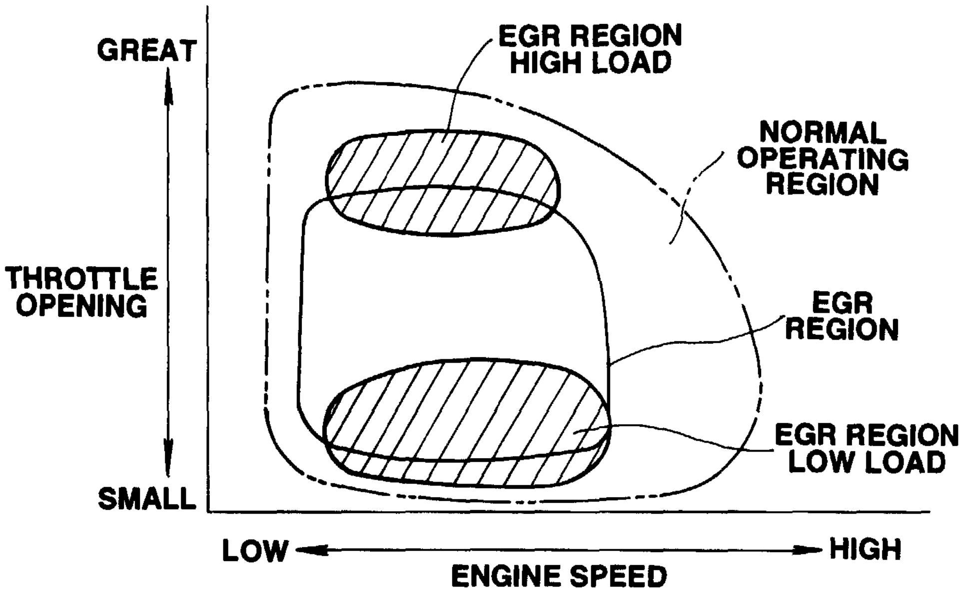

GREAT
EGR REGION
HIGH LOAD
NORMAL
OPERATING
REGION
THROTTLE
OPENING
EGR
REGION
EGR REGION
LOW LOAD
SMALL
LOW
HIGH
ENGINE SPEED

FIG.5

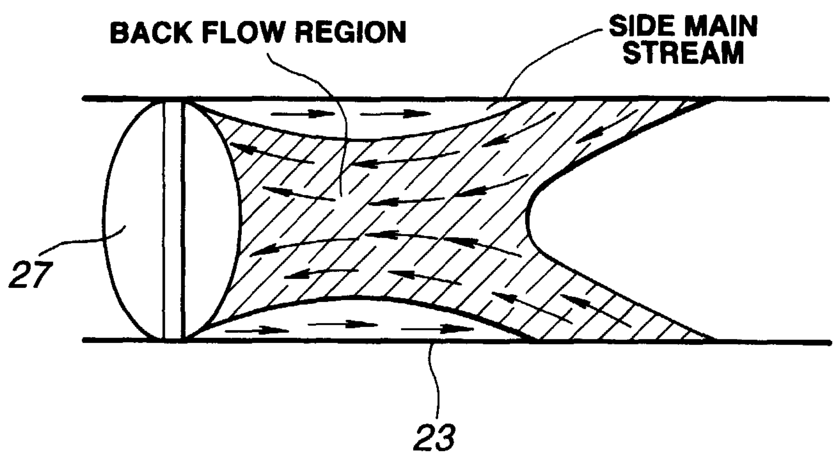

BACK FLOW REGION
SIDE MAIN
STREAM
27
23

FIG.6

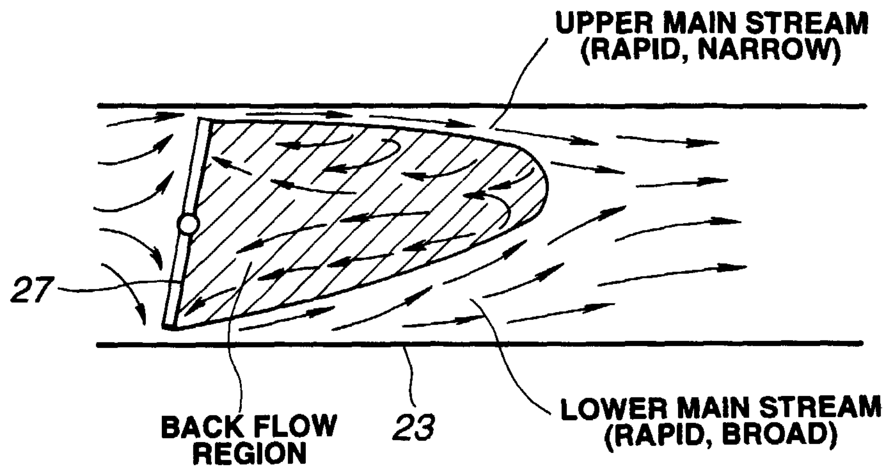

UPPER MAIN STREAM
(RAPID, NARROW)
27
BACK FLOW
REGION
23
LOWER MAIN STREAM
(RAPID, BROAD)

FIG.7

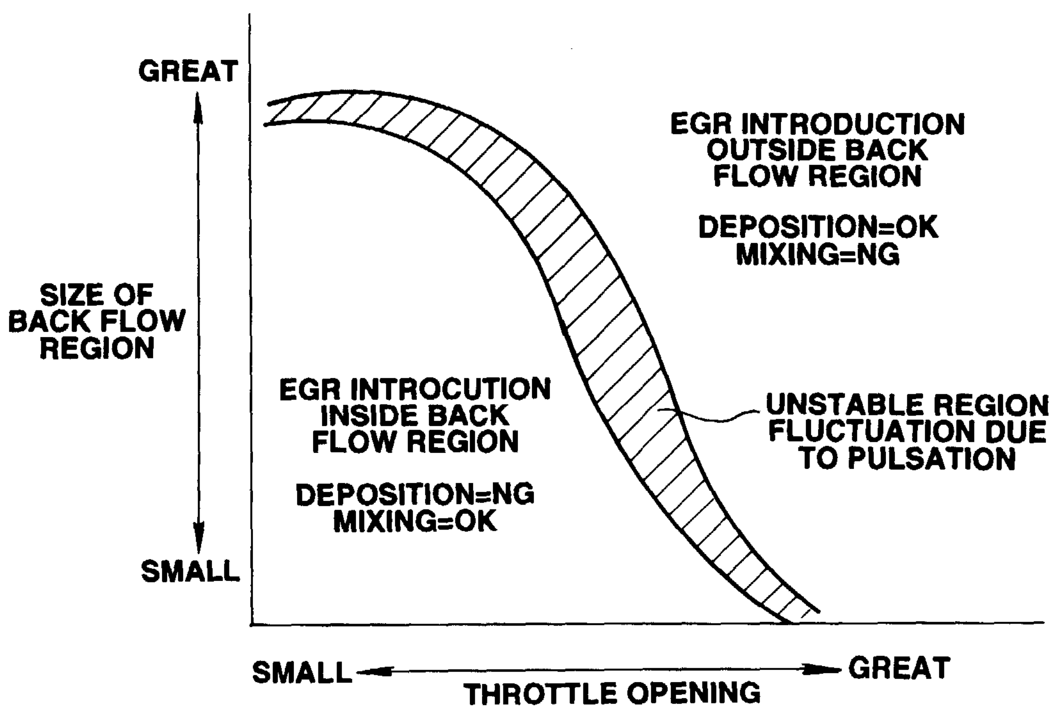

GREAT
SIZE OF
BACK FLOW
REGION
SMALL
EGR INTRODUCTION
OUTSIDE BACK
FLOW REGION
DEPOSITION=OK
MIXING=NG
EGR INTROCUTION
INSIDE BACK
FLOW REGION
DEPOSITION=NG
MIXING=OK
UNSTABLE REGION
FLUCTUATION DUE
TO PULSATION
SMALL
THROTTLE OPENING
GREAT

FIG.8

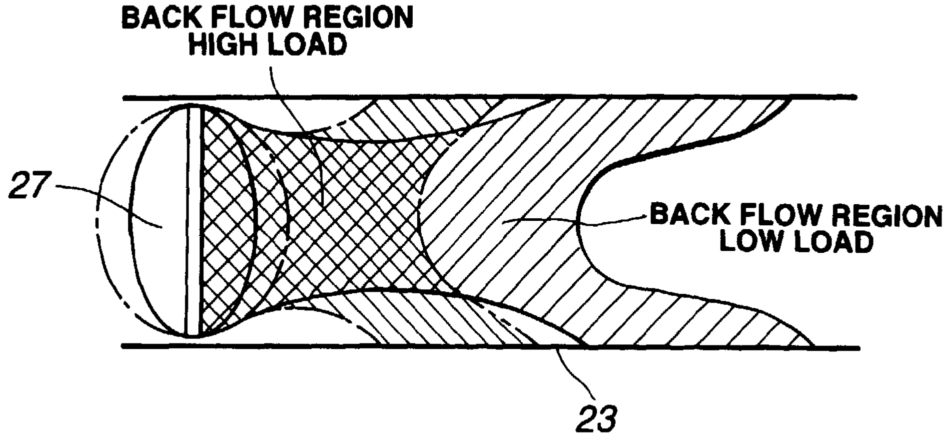


FIG.9

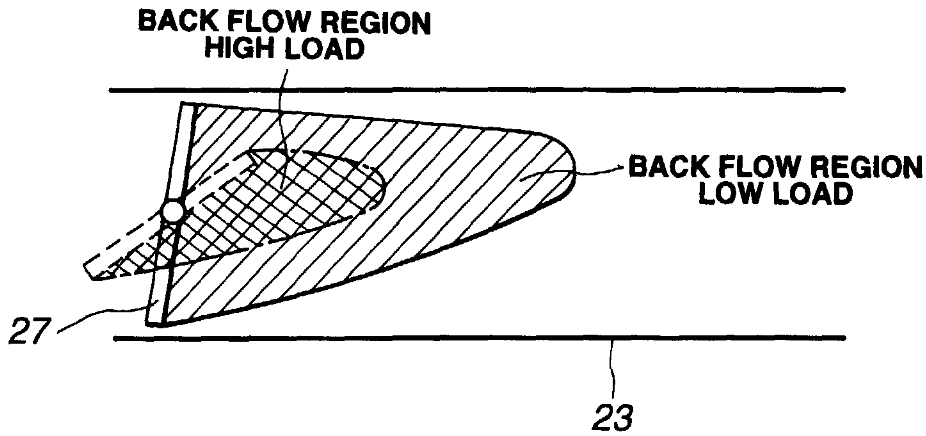


FIG.10

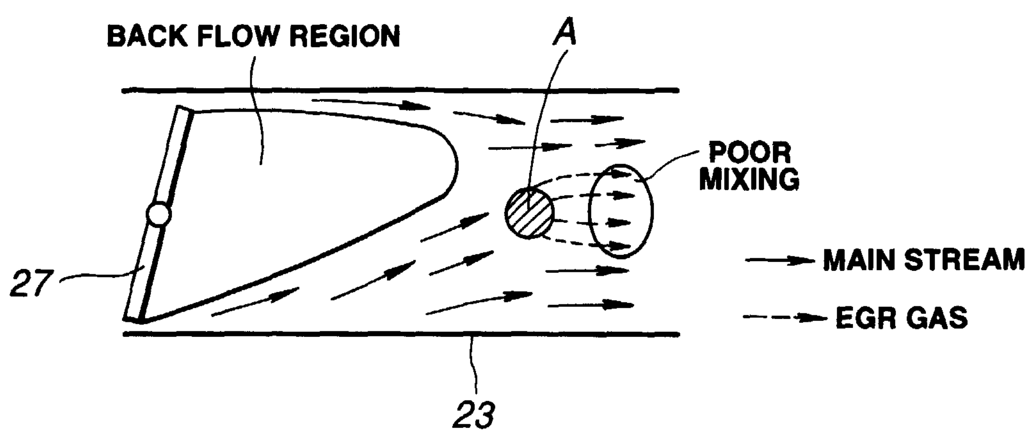


FIG.11

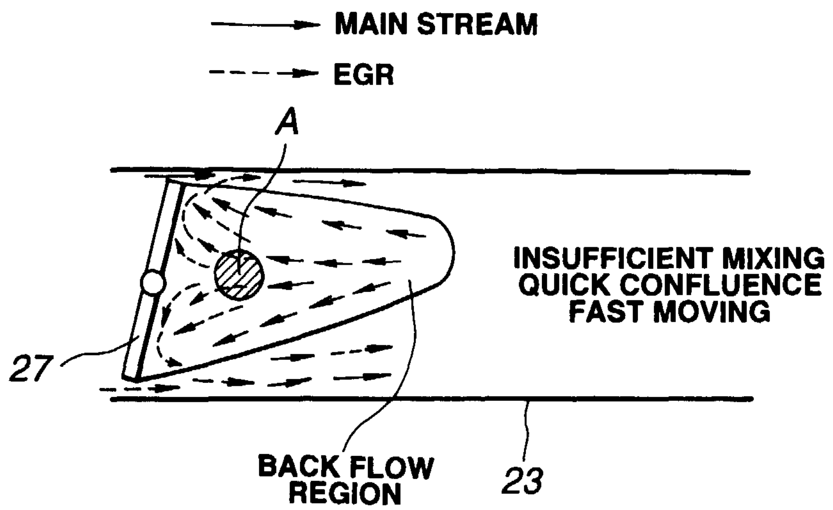

MAIN STREAM
EGR
A
INSUFFICIENT MIXING
QUICK CONFLUENCE
FAST MOVING
27
BACK FLOW
REGION
23

FIG.12

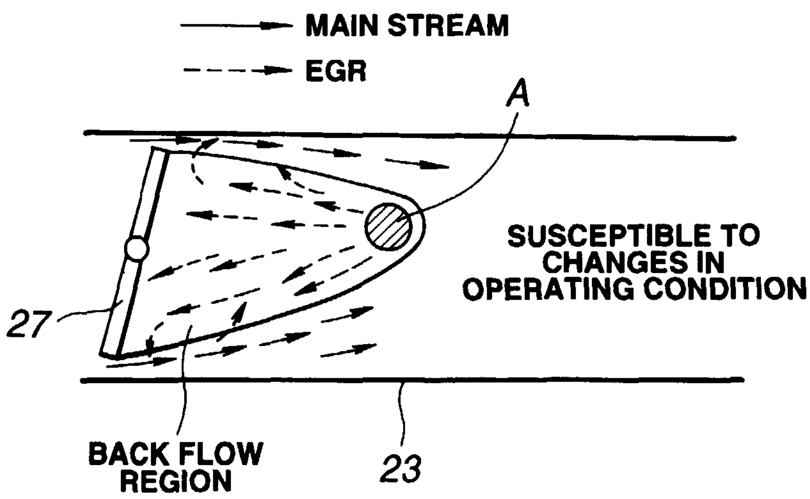

MAIN STREAM
EGR
A
SUSCEPTIBLE TO
CHANGES IN
OPERATING CONDITION
27
BACK FLOW
REGION
23

FIG.13

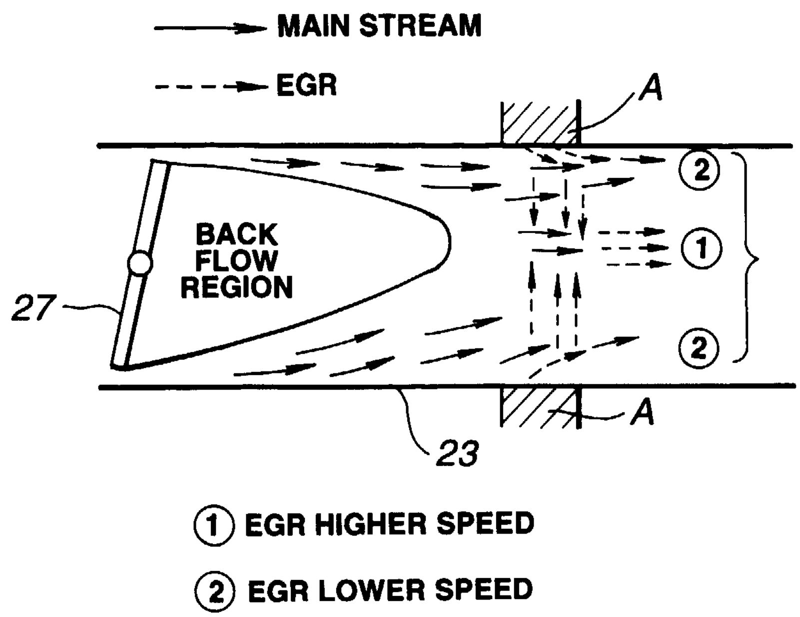

MAIN STREAM
EGR
A
BACK
FLOW
REGION
27
2
1
2
A
23
1 EGR HIGHER SPEED
2 EGR LOWER SPEED

FIG.14

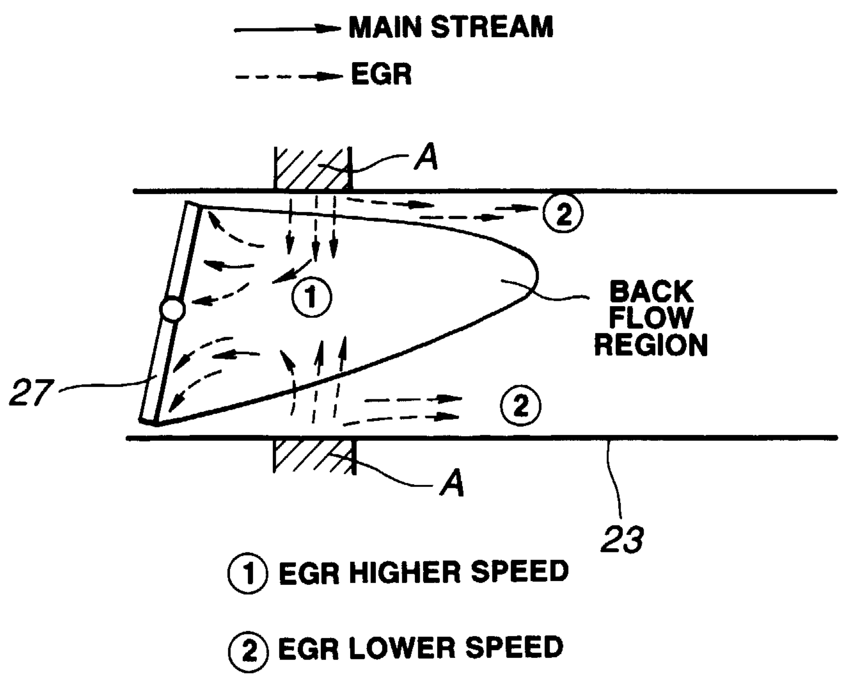

MAIN STREAM
EGR
A
2
1
BACK
FLOW
REGION
27
2
A
23
1 EGR HIGHER SPEED
2 EGR LOWER SPEED

FIG.15

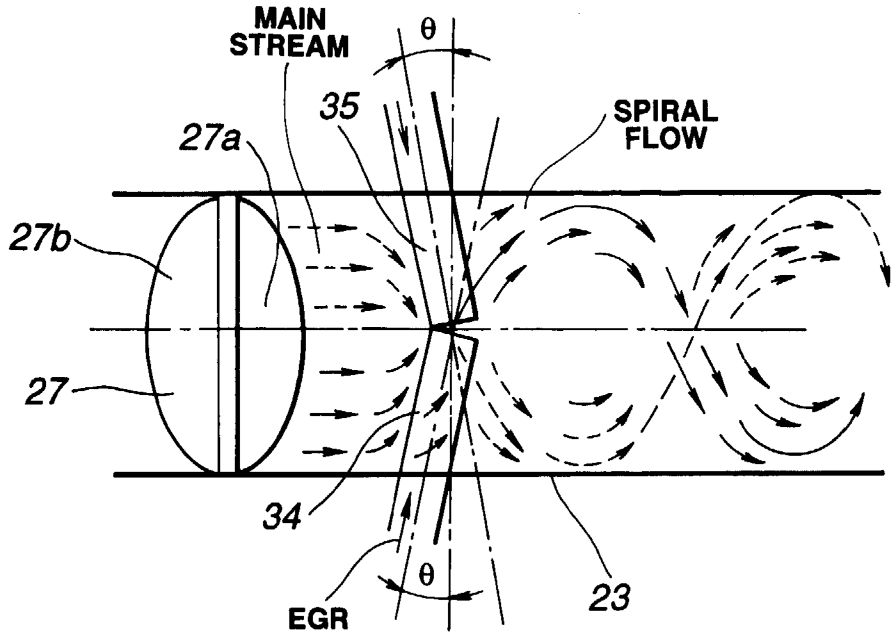

MAIN STREAM
θ
35
27a
SPIRAL FLOW
27b
27
34
EGR
θ
23

FIG.16

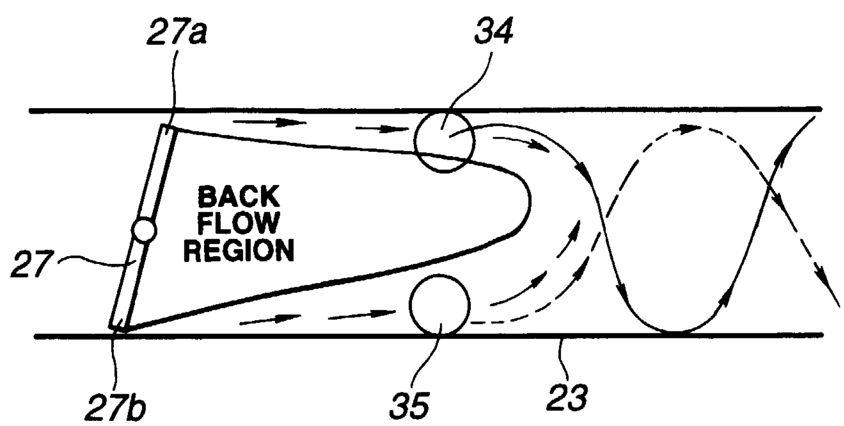

27a
34
BACK FLOW REGION
27
27b
35
23

FIG.17

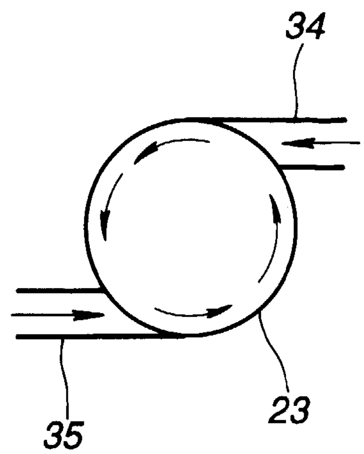

34
35
23

FIG.18

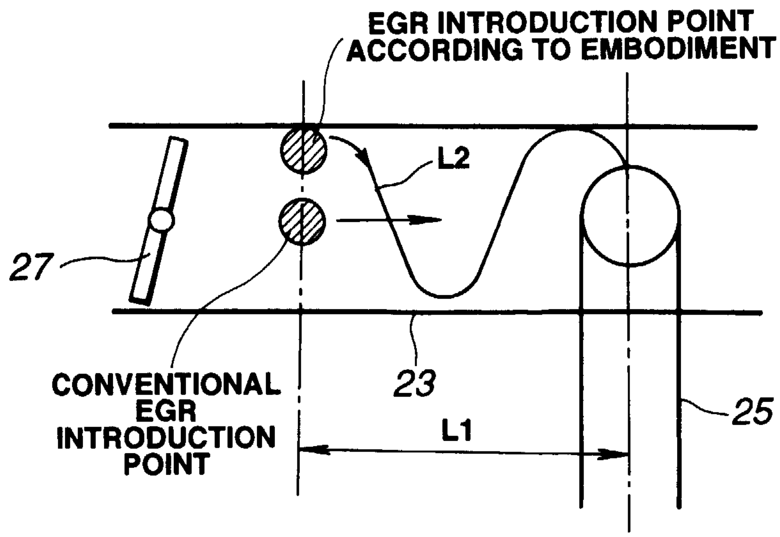

EGR INTRODUCTION POINT ACCORDING TO EMBODIMENT
L2
27
CONVENTIONAL EGR INTRODUCTION POINT
23
L1
25

FIG.19

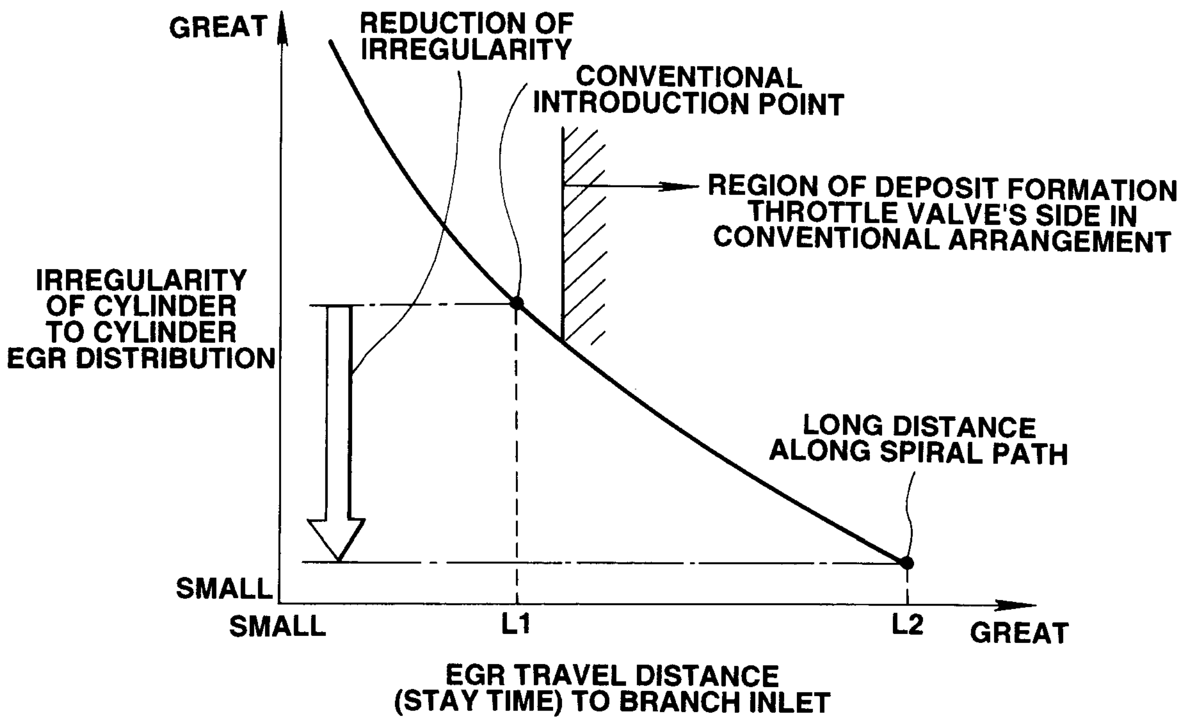


FIG.20A

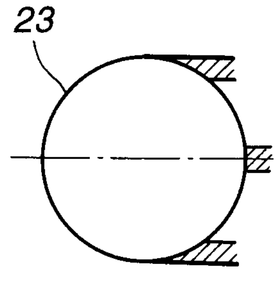


FIG.20B

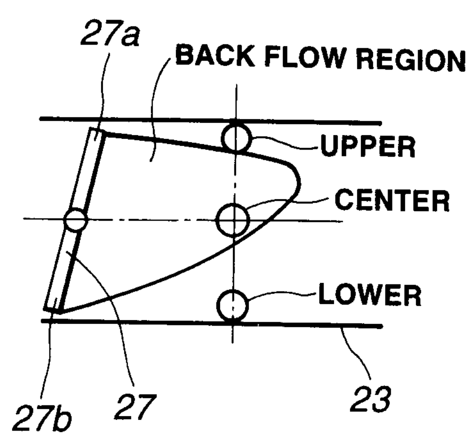


FIG.21

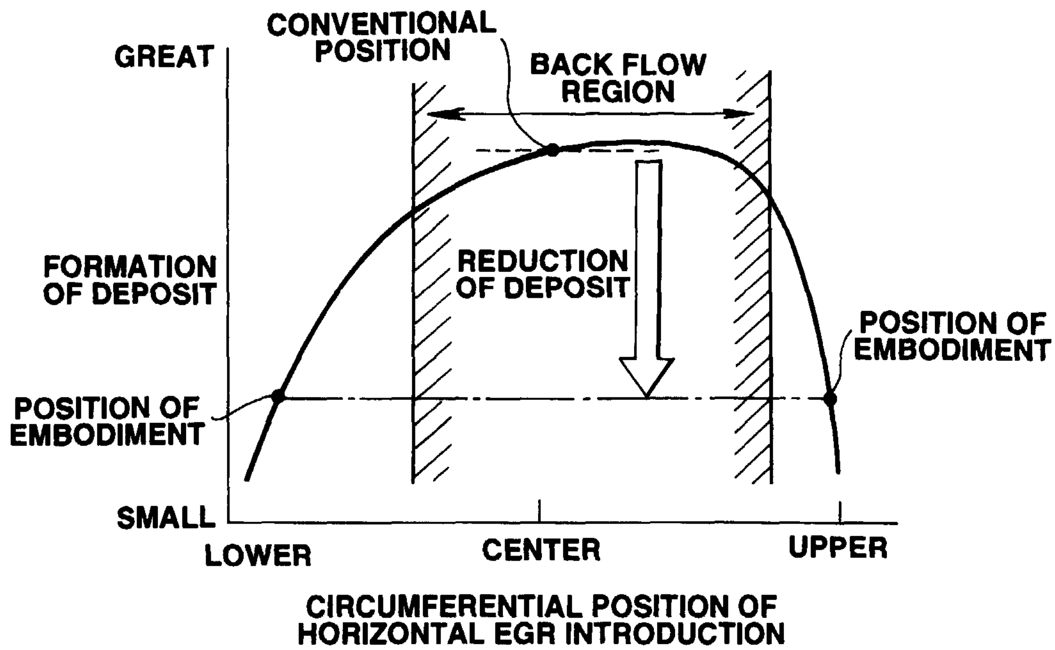

CONVENTIONAL
POSITION
GREAT
BACK FLOW
REGION
FORMATION
OF DEPOSIT
REDUCTION
OF DEPOSIT
POSITION OF
EMBODIMENT
POSITION OF
EMBODIMENT
SMALL
LOWER
CENTER
UPPER
CIRCUMFERENTIAL POSITION OF
HORIZONTAL EGR INTRODUCTION

FIG.22

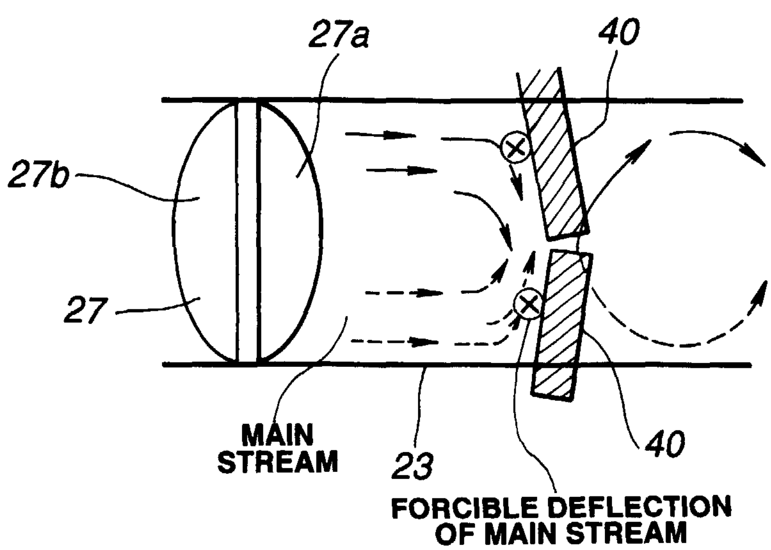

27a
40
27b
27
MAIN
STREAM
23
40
FORCIBLE DEFLECTION
OF MAIN STREAM

FIG.23

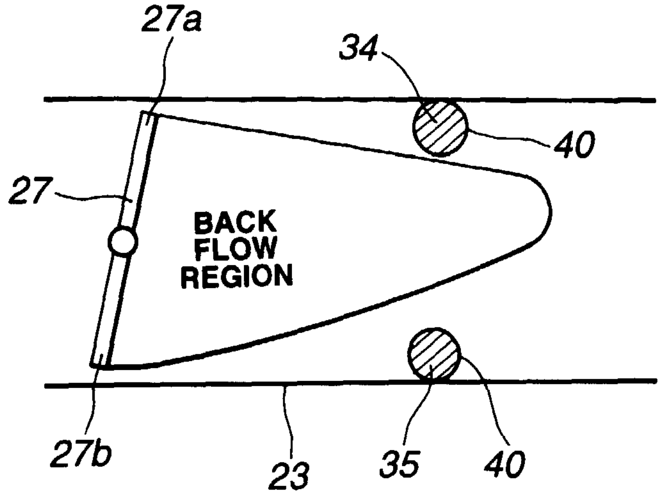


FIG.24

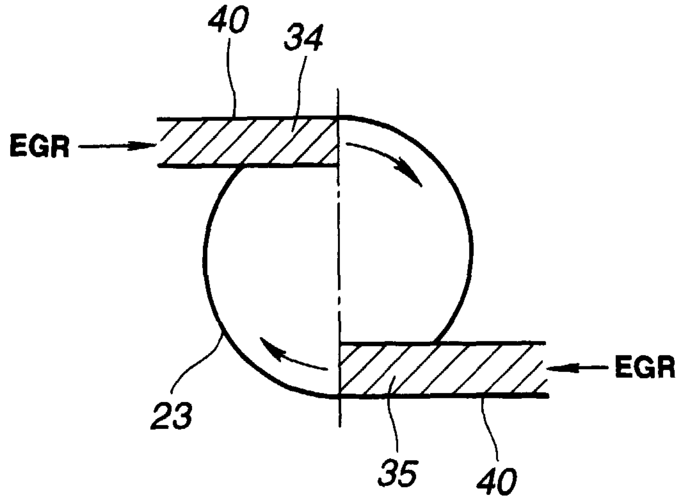


FIG.25

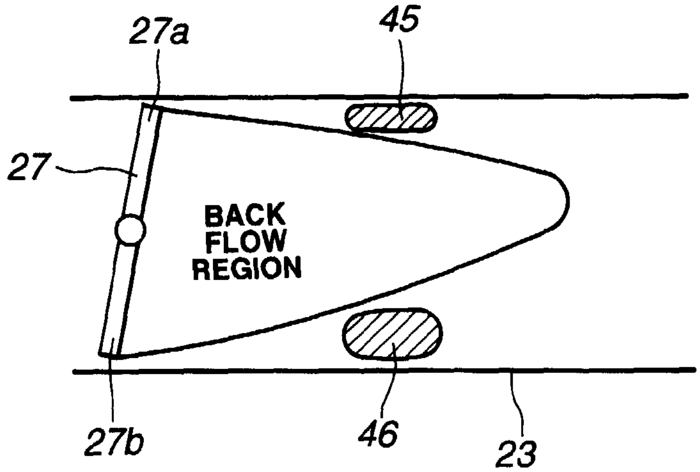


FIG.26

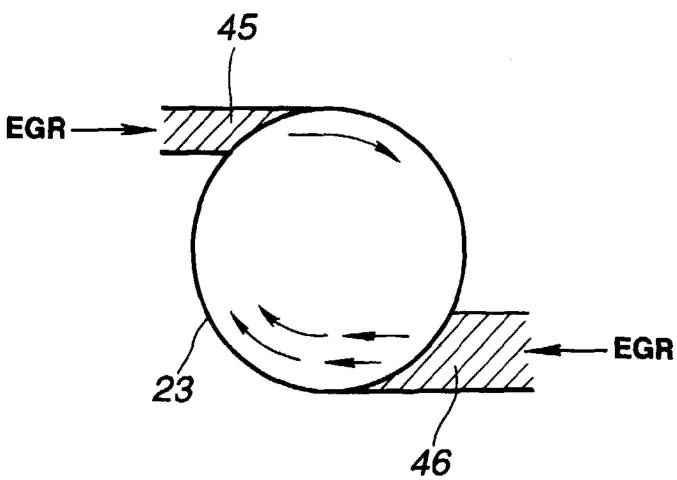


FIG.27

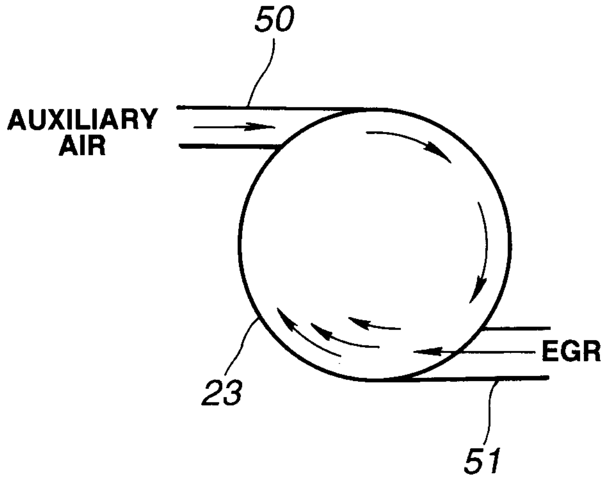

50
AUXILIARY AIR
EGR
23
51

FIG.28

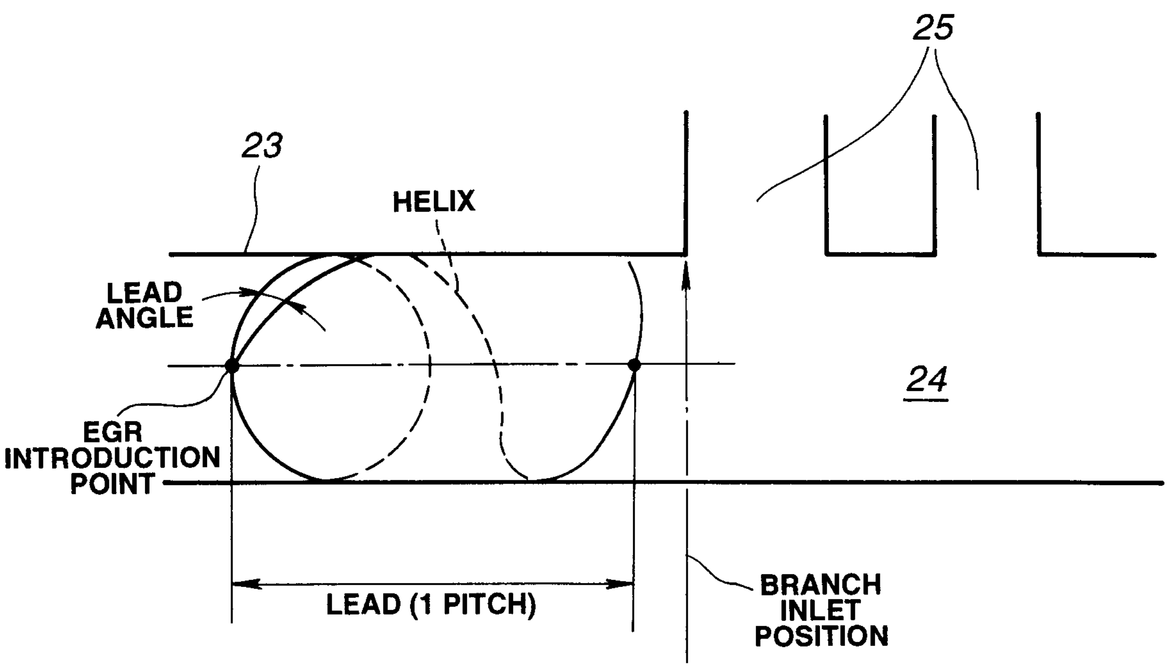

25
23
HELIX
LEAD ANGLE
24
EGR INTRODUCTION POINT
LEAD (1 PITCH)
BRANCH INLET POSITION

FIG.29

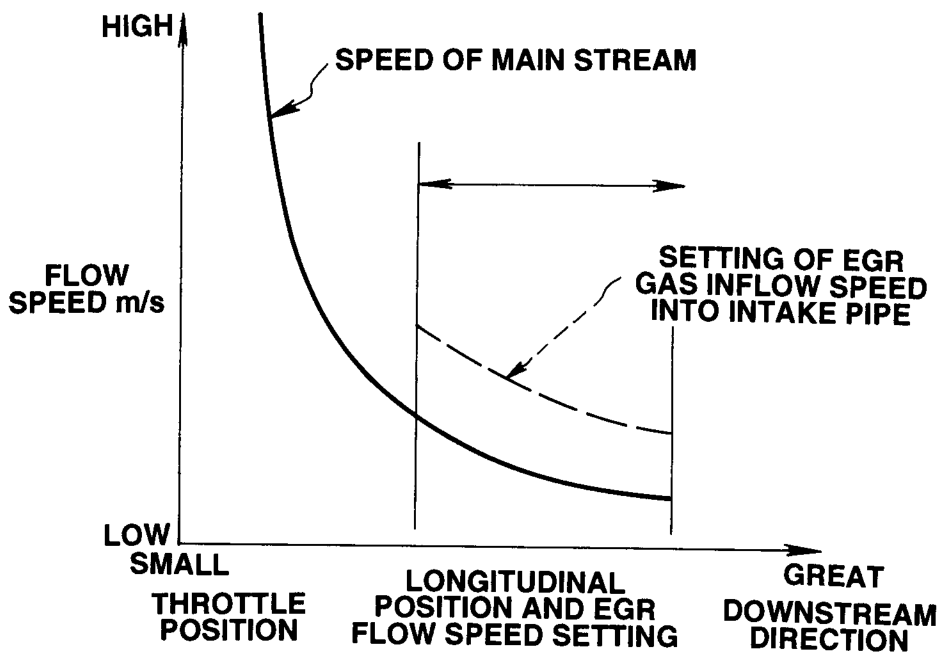

HIGH
SPEED OF MAIN STREAM
FLOW SPEED m/s
SETTING OF EGR GAS INFLOW SPEED INTO INTAKE PIPE
LOW
SMALL
THROTTLE POSITION
LONGITUDINAL POSITION AND EGR FLOW SPEED SETTING
GREAT
DOWNSTREAM DIRECTION

FIG.30

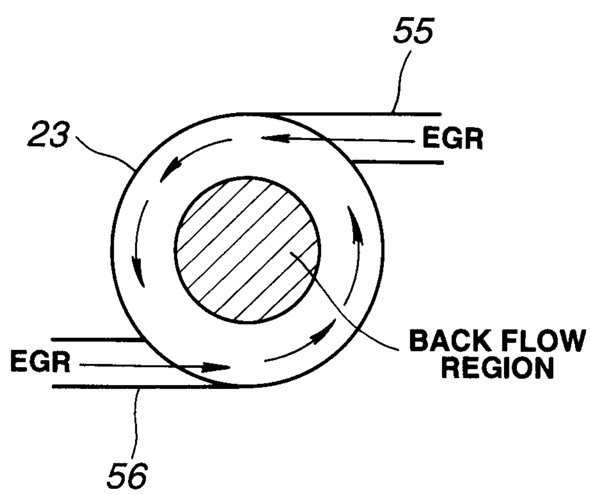

55
23
EGR
EGR
BACK FLOW REGION
56

FIG.31

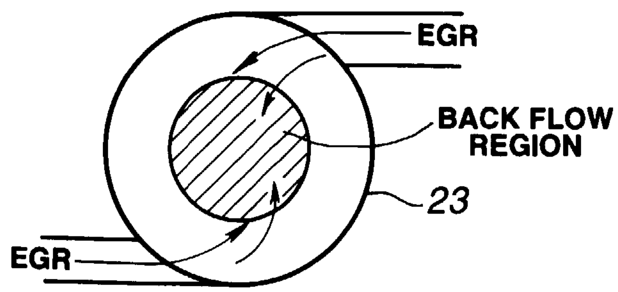


FIG.32

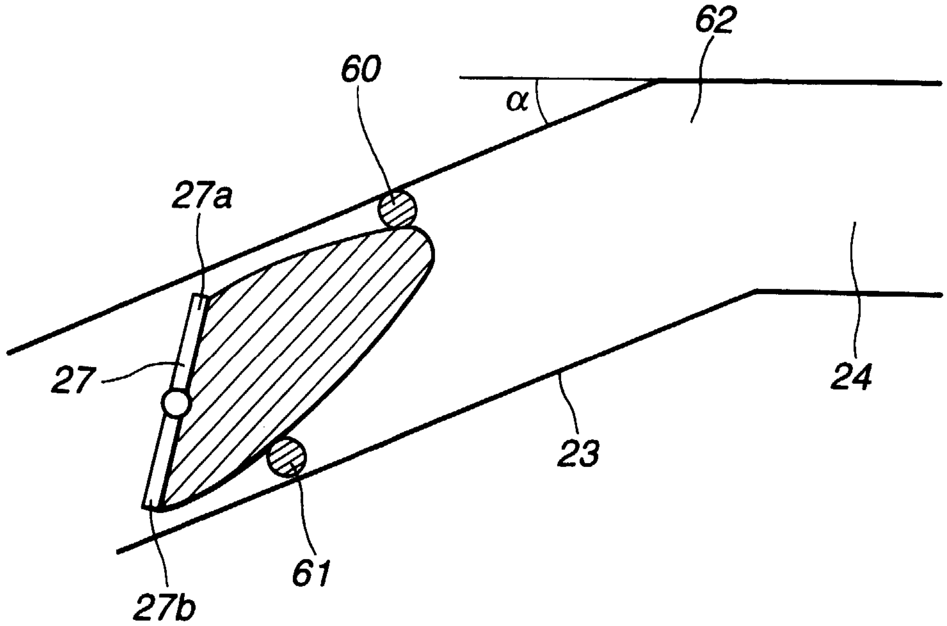
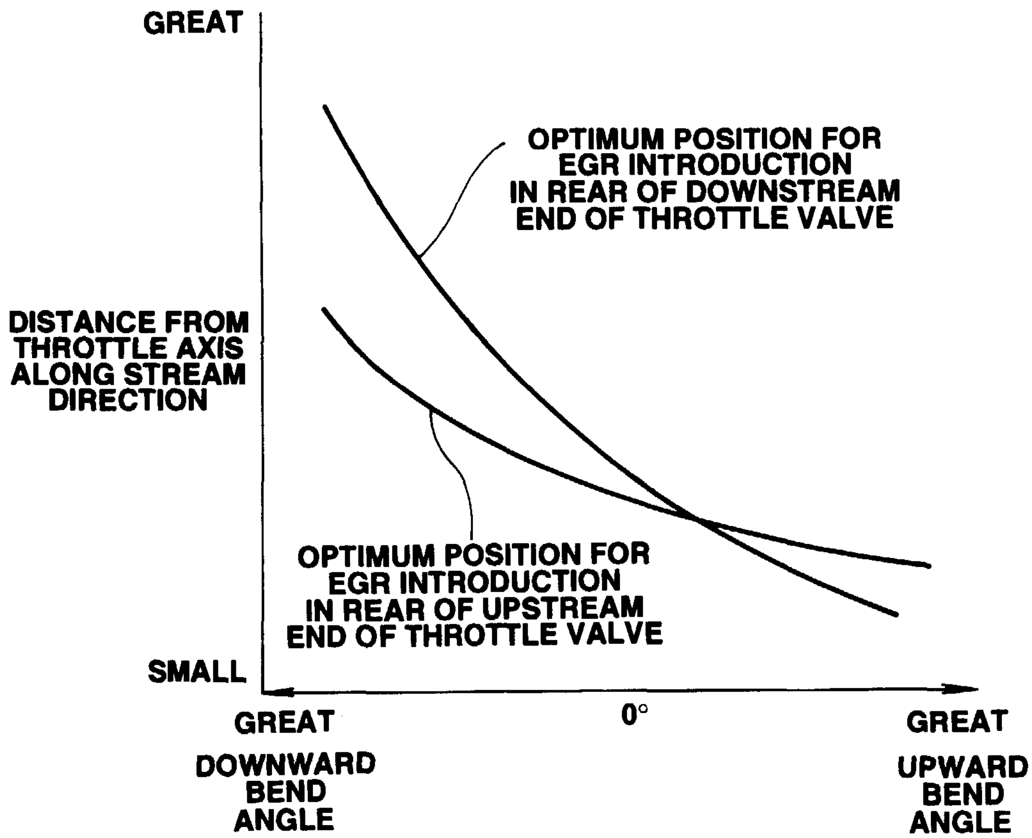


FIG.33


GREAT
OPTIMUM POSITION FOR
EGR INTRODUCTION
IN REAR OF DOWNSTREAM
END OF THROTTLE VALVE
DISTANCE FROM
THROTTLE AXIS
ALONG STREAM
DIRECTION
OPTIMUM POSITION FOR
EGR INTRODUCTION
IN REAR OF UPSTREAM
END OF THROTTLE VALVE
SMALL
GREAT
0°
GREAT
DOWNWARD
BEND
ANGLE
UPWARD
BEND
ANGLE