

[54] **METHOD OF AND APPARATUS FOR
REDUCING HARMFUL EMISSIONS FROM
INTERNAL COMBUSTION ENGINES**

[76] Inventors: **Hubert Kirchhofer**,
General-Guisanstr. 47,
Nussbaumen; **Josef Perevuznik**,
Hagelerstr. 71; **Alfred Wunsch**, Im
Eichtal 4, both of Baden, all of
Switzerland

[22] Filed: Nov. 27, 1973

[21] Appl. No.: 419,275

[30] **Foreign Application Priority Data**

Nov. 29, 1972 Switzerland..... 17373/72

[52] U.S. Cl..... 60/39.02, 60/39.52, 60/39.45,
60/607, 123/119 C, 417/64

[51] Int. Cl..... F02b 1/06

[58] Field of Search 60/598, 599, 600, 604,
60/605, 611, 614, 616, 621, 623, 39.02,
39.45, 39.52; 123/119 C; 417/64

[56] **References Cited**

UNITED STATES PATENTS

2,848,871	8/1958	Jendrassik.....	417/64
2,957,304	10/1960	Berchold	60/39.45
3,074,620	1/1963	Spalding	60/39.45
3,120,920	2/1964	Waleffe et al.	417/64

3,221,981	12/1965	Spalding	417/64
3,234,736	2/1966	Spalding	60/39.45
3,802,801	4/1974	Wunsch	417/64

FOREIGN PATENTS OR APPLICATIONS

1,162,631	2/1964	Germany	417/64
-----------	--------	---------------	--------

Primary Examiner—Freeh William L.

Assistant Examiner—Warren Olsen

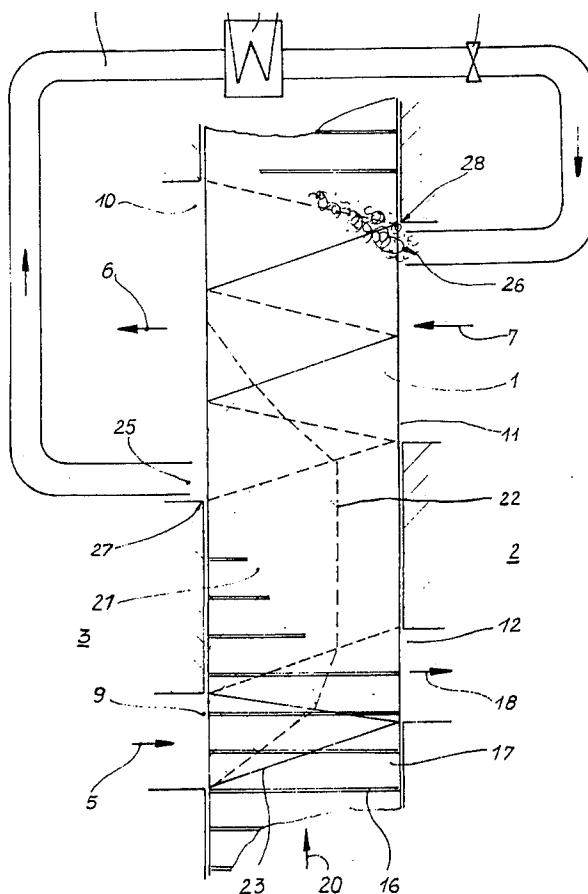
Attorney, Agent, or Firm—Pierce, Scheffler & Parker

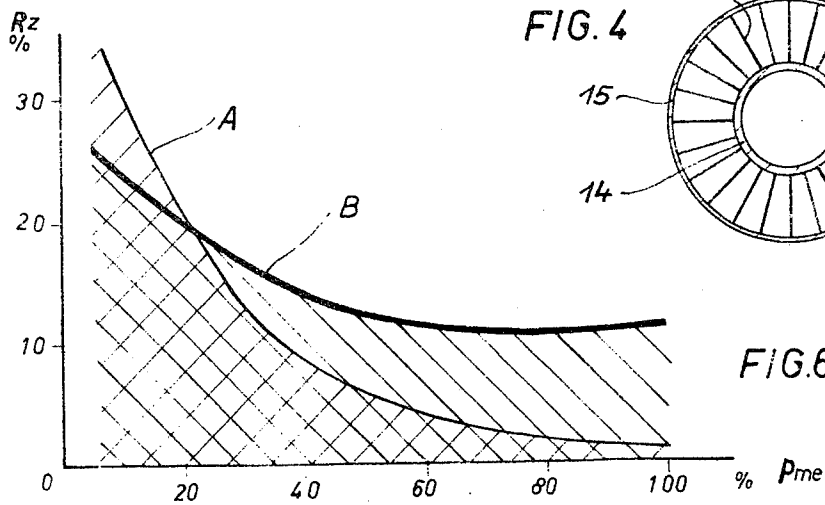
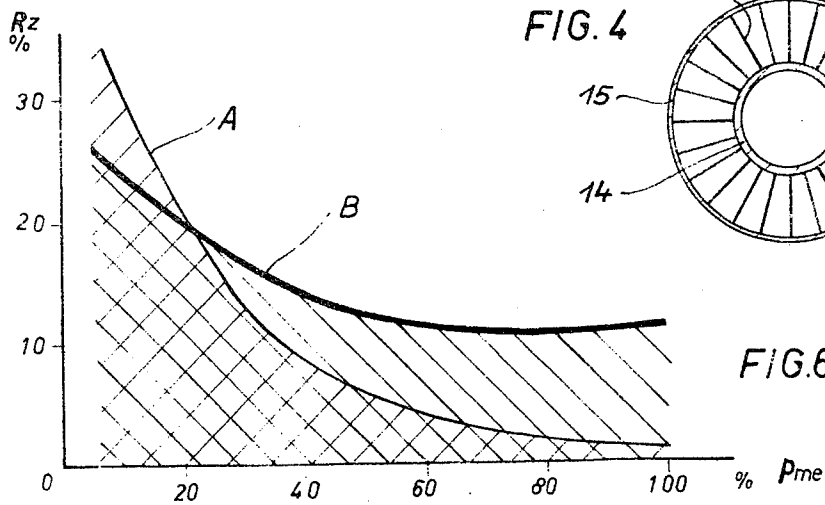
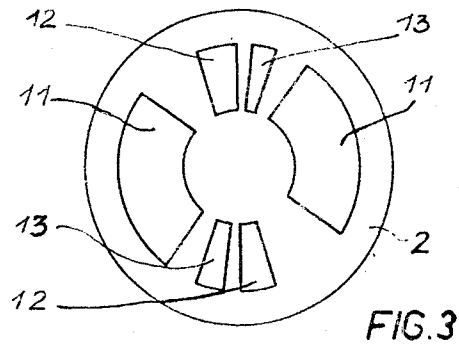
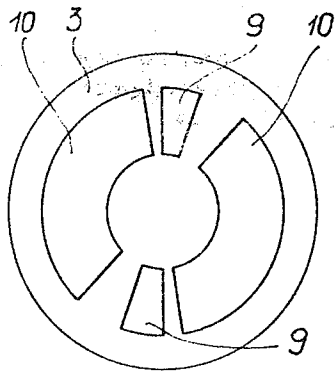
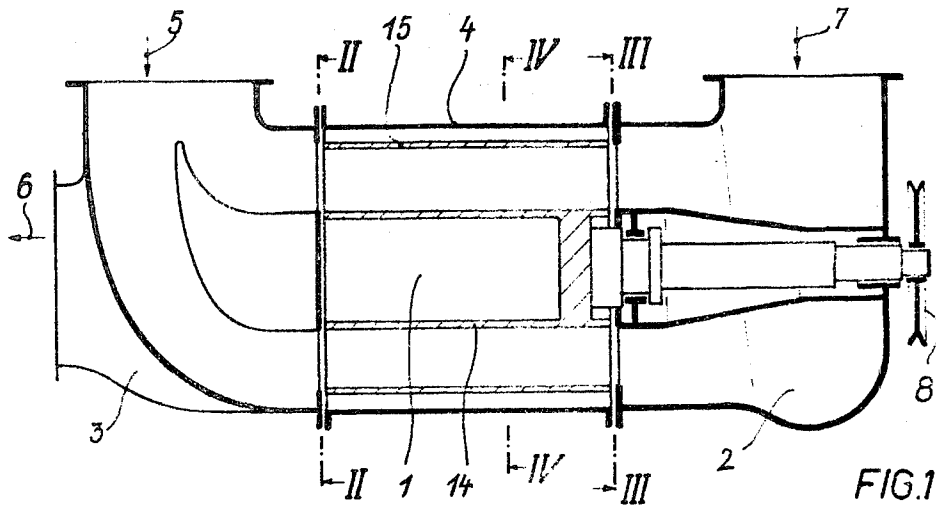
[57]

ABSTRACT

Combustion air for an internal combustion engine is compressed in a dynamic pressure-wave machine by utilization of heat remaining in the engine exhaust gases. A reduction in harmful emissions from the engine is effected within the rotor of the pressure-wave machine due to a primary recirculation of the exhaust gas into the air at the interface between the exhaust gas and the air, the amount of the recirculation being at its lowest value at full load on the engine and being increased sharply with decreasing load. The change in the amount of exhaust gas being recirculated is made more uniform over the whole load range by means of a secondary recirculation, increasing at full load, and which is brought about by introducing exhaust gas directly into the machine in at least one place at which the cells of the rotor are filled with air by means of a crossover pipe.

11 Claims, 8 Drawing Figures





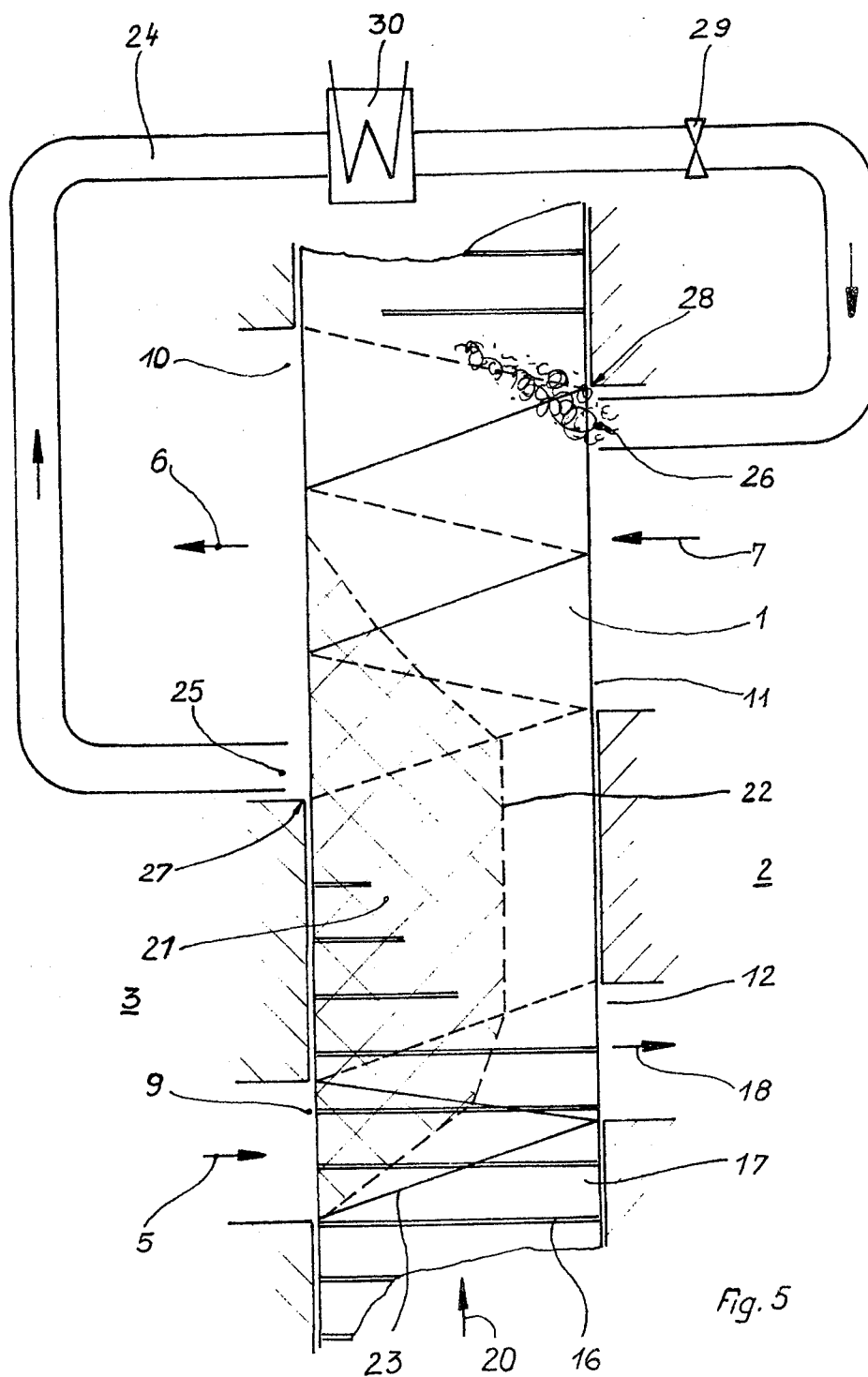
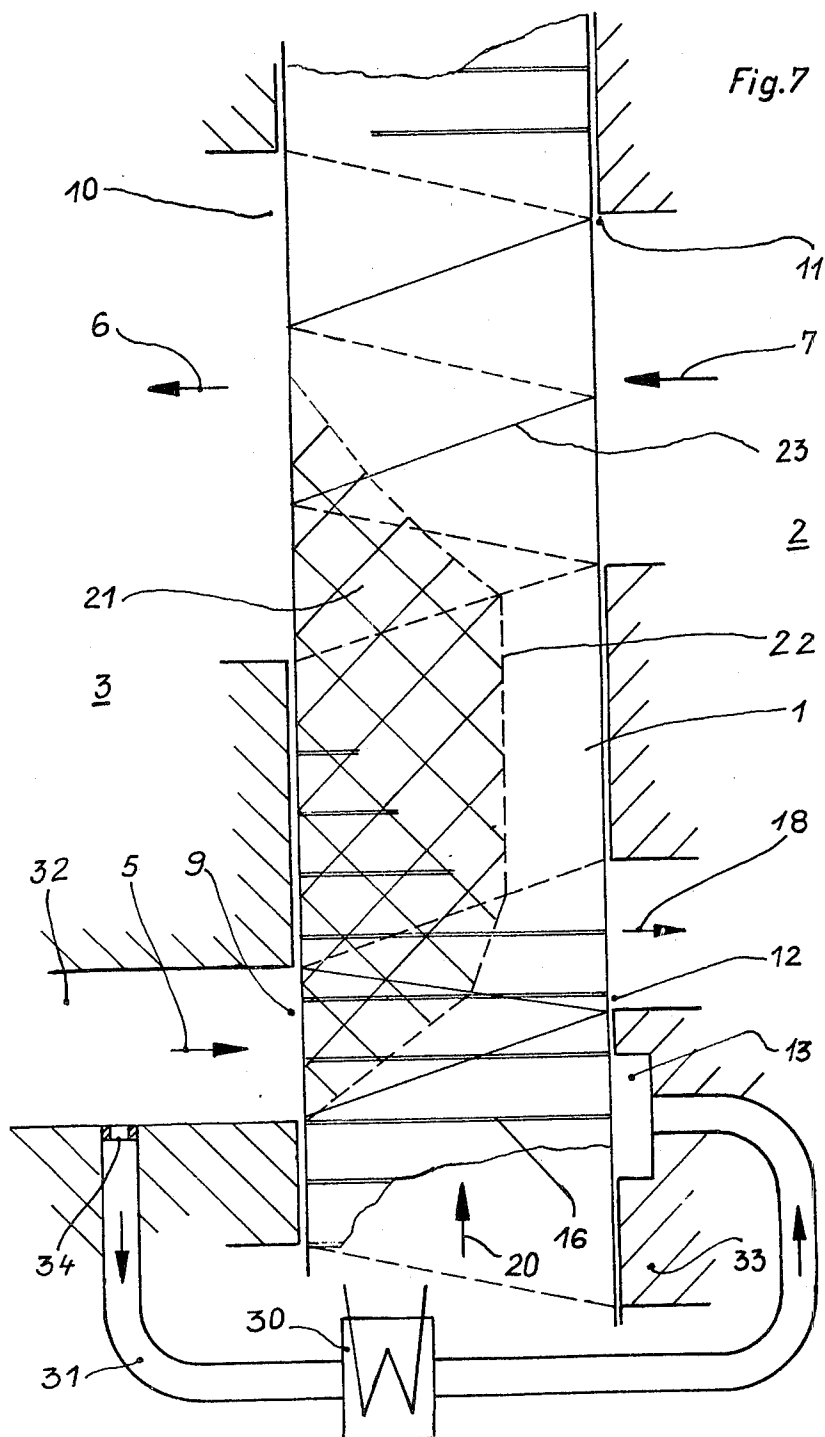
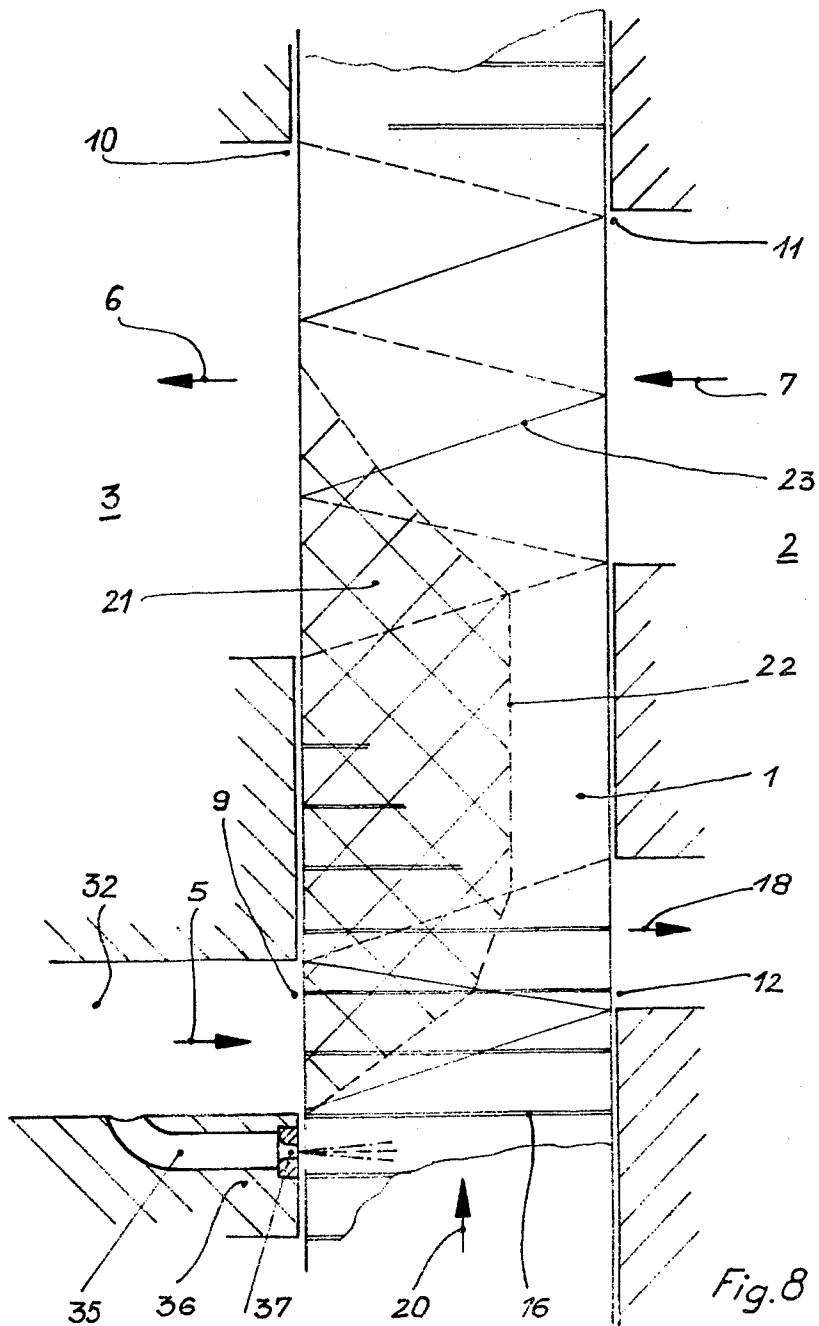


Fig. 5





METHOD OF AND APPARATUS FOR REDUCING HARMFUL EMISSIONS FROM INTERNAL COMBUSTION ENGINES

The present invention concerns a method of reducing harmful emissions from internal combustion engines the combustion air for which is compressed in a gas-dynamic pressure-wave machine by utilising energy still contained in the engine exhaust gases, a primary recirculation of exhaust gas into the air taking place in the rotor of the pressure-wave machine at the interface between the exhaust gas and the air, and further concerns apparatus for effecting this method.

Viewed from the overall economic standpoint there is at present no real alternative to the diesel engine for road vehicles. If, as to the future, the diesel engine is to continue to fulfil its objective, namely increased output with the highest possible power/weight ratio and lowest possible specific fuel consumption, then particular attention must be paid to the exhaust-gas behaviour of the diesel engine owing to the worldwide interest in environmental pollution.

It is known that the recirculation of exhaust gases into the combustion air of an internal combustion engine reduces the emission of harmful substances such as nitrous oxides and hydrocarbons. This recirculation, which with the diesel engine has proved especially effective for reducing nitrous oxide emission, consists in returning exhaust gas into the intake air, or in the case of a pressure-charged engine into the charge air.

Exhaust gas recirculation lowers the oxygen content of the combustion air and hence the effective excess air of the intake gases. By way of the O_2 concentration of the cylinder contents, therefore, influence is exerted on the kinetics of the combustion reaction, which in turn influences the combustion procedure and the exhaust-gas composition. Reducing the O_2 concentration by means of exhaust-gas recirculation means slower combustion, under certain circumstances also accompanied by a lowering of the maximum combustion temperature, on which the speed of reaction in the formation of nitrous oxide to a large degree depends. For this reason, reducing the maximum temperature of combustion is the most appropriate way of decreasing nitrous oxides in the exhaust gases. For the same reason, as regards nitrous oxide emission it is more effective to recirculate cooled exhaust gas.

Another very important aspect of exhaust-gas recirculation is the reduction of the ignition lag, i.e. the time from the commencement of fuel injection until the commencement of combustion. It is due to the higher final compression temperature resulting from the higher fresh gas inlet temperature. Apart from other advantages, e.g. reduction of ignition noise, shortening the ignition lag has the effect of improving combustion, which in turn reduces harmful emissions.

With a diesel engine, because load is regulated in terms of the calorific value of the mixture, the excess air coefficient rises as load decreases. At small loads, therefore, more exhaust gas can be recirculated without immediately causing an air deficiency because the combustion-air excess is then very large. Thus in the range of low and medium loads, nitrous oxide emission can be reduced particularly effectively by recirculating exhaust gas into the intake air. In the region of full load, on the other hand, heavy recirculation of exhaust gases would lower the attainable power output of the engine.

But it is desirable to recirculate more exhaust gas at partial load than at full load not only from the standpoint of the engine, but also in view of legal emission requirements, which take into account practical operation of the vehicle. The optimum quantity of exhaust gas to be recirculated is thus not constant: it depends on the duty point of the engine when in service.

The gas-dynamic pressure-wave machine is very well suited to pressure-charging internal combustion engines, and particularly vehicle diesel engines, for which rapid response of the charging device and high charging in the lower and middle speed range are desired. Since in the pressure-wave machine exhaust gas and intake air are in direct contact, a certain degree of mixing takes place at the interface between these two gases.

At full load the passage of exhaust gas into the air, in the following termed primary recirculation, can be largely prevented by ensuring in the design of the pressure-wave machine that the gas/air interface does not reach the high-pressure air outlet. A buffer zone of air then prevents the exhaust gas from passing into the combustion air. In addition, at full load the low-pressure section is greatly over-scavenged, i.e. the pressure-wave machine draws in more air than it compresses and feeds to the engine on the high-pressure side. This extra scavenging air is used to flush the mixing zone. However, it is not possible to maintain this over-scavenging of the pressure-wave machine at operating points in the region of partial engine loads. As load falls, it decreases progressively until finally, at low partial loads, it becomes under-scavenging, i.e. the pressure-wave machine draws in less air than it supplies compressed gas to the engine being charged.

These features of the pressure-wave machine thus already meet the requirements made of an exhaust-gas recirculation system for internal combustion engines with the purpose of reducing harmful emissions, in that gas recirculation increases as engine load falls. It is sufficient for certain engines which, in order to satisfy the California 13-point test, require exhaust-gas recirculation only at partial load.

Thus with the usual design of the pressure-wave machine for pressure-charging purposes, the quality of the engine exhaust gas is scarcely affected at full load because then practically no gas is recirculated. It is quite possible to increase gas recirculation over the whole operating range of the pressure-wave machine, but it is difficult to influence parts of the range. If gas recirculation is increased at full load, the engine soon begins to smoke as load decreases, and there is a danger that at the bottom of the load range it receives too much exhaust gas and stops. Recirculating very hot exhaust gas direct into the combustion air at full load would also be less effective because it is known that hot exhaust gas does not reduce the harmful components so greatly. Also, by diminishing the combustion air ratio, hot exhaust gas in the combustion air would cause a reduction in engine output.

The object of the present invention is to reduce emissions of harmful substances from an internal combustion engine pressured-charged by a gas-dynamic pressure-wave machine, particularly in the full-load region, to values below those resulting from primary exhaust-gas recirculation, without thus disturbing operation of the engine and as far as possible without forfeiting engine power.

This object is achieved in that primary exhaust-gas recirculation, which is least at full load and increases sharply with decreasing load, is made more uniform over the whole load range by secondary recirculation, which increases at full load, by introducing exhaust gas direct into the pressure-wave process in at least one place at which the cells of the rotor are filled with air.

Apparatus for effecting this method comprises at least one crossover duct for secondary recirculation from a space filled with exhaust gas to an opening, facing the cells, in one side of the pressure-wave machine.

An improvement can be achieved by means of a cooling device in the crossover duct for secondary exhaust-gas recirculation.

In another version of the invention the crossover duct is in the form of a return-flow pipe, the inlet opening of which, viewed in the direction of rotation of the rotor, lies within the first half, preferably immediately after the front edge of the low-pressure gas outlet port, and its outlet opening lies within the second half, preferably immediately before the rear edge of the low-pressure air inlet port.

Another version employs a return-flow pipe as the crossover duct which branches off the high-pressure gas inlet and, viewed in the direction of rotation of the rotor, emerges in the web before the high-pressure air outlet port.

If the pressure-wave machine incorporates a compression pocket, the crossover duct can be a return-flow pipe which branches off the high-pressure gas inlet and emerges in the compression pocket.

A further possibility comprises a connecting pipe as the crossover duct which branches off the high-pressure gas inlet and, viewed in the direction of rotation of the rotor, emerges in the web before the high-pressure gas inlet port.

An improvement is then achieved if the termination of the connecting pipe comprises at least one nozzle.

Such devices can easily be adapted to the motor in question by means of a throttle device in the crossover duct for secondary gas recirculation, and this can be further improved if the flow cross-section of the throttle is adjustable.

With the method described it is possible, by influencing the pressure-wave process, to alter the characteristic of primary exhaust-gas recirculation in a gas-dynamic pressure-wave machine with the aid of secondary gas recirculation in such a way that it is approximately optimum at all duty points of the engine. Comparable methods which operate with exhaust-gas turbochargers require a separate control system for this purpose.

Recirculated exhaust gas, especially when cooled, is particularly effective where it is most needed within the operating range of the internal combustion engine to reduce severe harmful emission, namely at high loads and high speeds. Cooling the recirculated gas improves the reduction of harmful substances in the ranges of engine operation with the greatest emission of such substances, and decreases the unavoidable drop in engine output which is caused by the lowering of the combustion air density but can be reduced by suitable cooling.

When an engine is charged with a pressure-wave machine, it is easy in this way to improve the quality of the exhaust gas by recirculating exhaust gas into the combustion air to be compressed.

The method described is also superior to comparable methods operating with exhaust-gas turbochargers in that the gas-dynamic pressure-wave machine, which even in its known form exhibits considerable exhaust-gas recirculation, is to a large extent insensitive to contamination. The quantity of soot entrained into the pressure-wave machine with the secondary recirculated gas does not therefore impair the performance of the machine, whereas with a turbocompressor the consequences can be very serious. It is practically impossible to operate a turbocompressor for any length of time while introducing exhaust gases containing solid matter on the intake side. With the method described, the contamination problem is restricted to the cooler, but this can be so designed that it can easily be cleaned periodically.

Several examples of the invention are shown schematically in the drawings, in which:

FIG. 1 shows a gas-dynamic pressure-wave machine in longitudinal section;

FIG. 2 is a side section of the housing at line II - II of FIG. 1 and viewed in the direction of the arrows;

FIG. 3 is the other side section of the housing at line III—III in FIG. 1 and viewed in the direction of the arrows;

FIG. 4 is a cross-section of the rotor at line IV—IV in FIG. 1 and viewed in the direction of the arrows;

FIG. 5 is part of a developed projection of a cylindrical section at half the cell height through the rotor and through the adjacent portions of the side sections of the housing with a gas recirculation system according to the invention;

FIG. 6 is a diagram showing the effect achieved by the invention; and

FIG. 7 and 8 are alternative versions to FIG. 5;

In all the drawings, the same parts are identified by the same reference symbols.

FIG. 1 to 4 show a known construction of a gas-dynamic pressure-wave machine. The rotor 1 turns between fixed side sections of the housing, namely air housing 2 and gas housing 3, which are joined by the middle portion 4 of the housing, which encloses the rotor in the manner of a jacket. The high-energy, high-pressure gas, here the exhaust gas of an internal combustion engine, enters gas housing 3 at 5 and flows through inlet ports 9 into rotor 1, where it surrenders part of its energy to the air in the pressure-wave process. It leaves the rotor again as low-pressure gas through outlet ports 10 in gas housing 3, and flows out of the gas housing at 6, e.g. towards the exhaust pipe. Air normally at atmospheric pressure, termed low-pressure air, enters the air housing 2 at 7 and flows through inlet ports 11 into the rotor, where it is compressed. It leaves the rotor again as high-pressure air through the outlet ports 12 in air housing 2 and flows out of the air housing. This cannot be seen in these drawings because in the present case the direction of the outlet flow is perpendicular to the plane of the drawing.

A compression pocket 13, for pre-compressing the air, can be provided in the side of the air housing 2 facing the rotor before the high-pressure air outlet port 12, when viewed in the direction of rotation of the rotor.

The rotor 1 is overhung in air housing 2, is driven at 8 and in that portion in which the pressure-wave process takes place comprises hub 14 and shroud 15 between which cell walls 16 extend radially, enclosing

cells 17 which are open in the directions of the air housing and gas housing. Since there are two inlet and outlet ports each in the air housing and gas housing, as can be seen in FIGS. 2 and 3, the rotor passes through the gas-dynamic cycle twice per revolution.

FIG. 5 shows a developed projection of approximately half the rotor and of the adjacent parts of the side sections of the housing. The high-pressure gas entering at 5 only partially fills the cells 17, the direction of movement of which is indicated by the arrow 20, since a residue of air remains in the cells. The hatched area 21 is the space filled with engine exhaust gas, and the ideal interface between gas and air is denoted 22. 18 designates the high-pressure air outlet. The pressure-wave process taking place in the rotor is indicated by the sequence of lines 23.

The circumstances illustrated in FIG. 5 relate to full engine load. If the mixing zone of gas and air, as occurs in practice, is separated from the high-pressure air outlet port 12 by a sufficiently wide air buffer zone, exhaust gas cannot leave together with the compressed air. The buffer zone containing gas is completely scavenged in the low-pressure section so that in the following cycle impurities cannot be carried into the engine with the charge air. It can be seen that the interface 22 leaves the cells well before the end of the low-pressure gas outlet port 10. The cells are then purged with fresh air. This configuration of the pressure-wave machine is necessary in order to avoid excessive under-scavenging at very low engine load. When over-scavenging at full load is 30 percent, under-scavenging at no-load is of the same order of magnitude. Since at low loads the pressure differences between low-pressure air and low-pressure gas become very small, and consequently the pressure-wave effect in the low-pressure section is very weak, at low loads the interface 22 does not leave the rotor 1 before the end of the low-pressure pressure gas outlet port 10. The proportion of primary recirculated exhaust gas over the whole load range is determined by selecting one point. If the design chosen is such that at full load 5 to 10 per cent by volume of exhaust gas is recirculated, the quantity recirculated at no-load can become so great that the engine no longer runs stably.

Curve A of FIG. 6, for example, shows the quantity of primary recirculated exhaust gas at rated engine speed with a pressure-wave machine of the usual construction, plotted as degree of recirculation R_z in per cent volume against mean effective piston pressure p_{me} , where 100 p_{me} corresponds to the piston pressure at full load. It can be seen from this diagram that at full load the quantity of recirculated exhaust gas is very small, but rises sharply with decreasing load, corresponding to decreasing p_{me} . However, a flatter recirculation characteristic is desirable, and therefore to be aimed at: at full engine load the quantity of exhaust gas recirculated in the pressure-wave machine should be up to 10 per cent by volume, while at low partial loads it should not be greater than with a machine of the usual construction.

This is the purpose of the invention. A crossover duct which joins a space filled with engine exhaust gas to an opening facing the cells in one of the two end sections of the pressure-wave machine, is used to introduce a secondary flow of exhaust gas direct into the pressure-wave process at a place where the cells of the rotor are filled with air.

In FIG. 5 the crossover duct comprises return-flow pipe 24. It begins in the low-pressure gas outlet port 10 immediately after its leading edge 27 when viewed in the direction of rotation of the rotor, its inlet 25 faces the cells of the rotor and it ends in the low-pressure air inlet port 11 immediately before its rear edge 28, the outlet 26 of the return-flow pipe also facing the cells. At some arbitrary point along the return-flow pipe 24 is a throttle valve 29, and before it, viewed in the flow direction, is the exhaust-gas cooler 30.

The scavenging process ends as soon as the cells reach the end of the low-pressure gas outlet port 10. The gas flowing out of the return-flow pipe 24 into the rotor has no opportunity to flow straight out again through outlet port 10, but takes part in the next pressure-wave cycle, whereupon it is compressed together with the air flowing in through low-pressure air inlet port 11, is expelled through the next high-pressure air outlet port 12 and passed to the engine.

This secondary recirculation of exhaust gas is not simply superimposed on the primary recirculation, but has the effect of influencing and changing the whole pressure-wave process in such a way that the sum of primary and secondary recirculated gas flows corresponds to curve B in FIG. 6. The degree of recirculation can be raised to 10 percent by volume at full load, without causing a corresponding increase at partial load as well. Curve B is flatter than curve A over the whole load range, and in this example even shows smaller values at low partial loads than does curve A, which represents primary recirculation alone.

The shape of curve B is by its nature subject to certain variations, depending on the point at which the secondary recirculated exhaust gas is introduced into the pressure-wave process (see the examples described below) and how the process is arranged. A criterion, however, is that the exhaust gas is introduced at a point where the cells of the rotor are filled with air. The configuration shown in FIG. 5, for example, can be varied in that the inlet 25 of the return-flow pipe 24 is located within the first half of the low-pressure gas outlet port 10 and its outlet 26 lies within the second half of the low-pressure air inlet port 11.

The dimensions of return-flow pipe 24 depends on the required degree of recirculation, while account must also be taken of the available pressure drop. A simplification is achieved by fitting a throttle device so that the pipe cross-section does not have to be matched to each individual case. By providing the throttle with a variable flow cross-section, better optimisation is possible and fine adjustment of the secondary recirculated gas flow is made easier. It is of course also possible to regulate the flow cross-section in relation to duty point, for example, in which case curve B of FIG. 6 could be made even more uniform, if this is desired.

The recirculated exhaust gas is cooled in cooler 30 before being introduced into the pressure-wave process. In this way excessive density loss of the compressed air due to heating of the low-pressure air intake is avoided, and the flow rate of this secondary recirculated gas can be influenced. Cooling the recirculated gas, however, also further reduces the emission of nitrous oxides, as has already been mentioned. But the exhaust-gas cooler 30 cannot replace cooling of the entire high-pressure air on its way to the engine. This cooling is well known in connection with turbo-

charging, and is particularly effective when pressure-charging with a pressure-wave machine.

An example with recirculation of high-pressure gas is shown in FIG. 7. Exhaust gas coming from the engine is bled off supply duct 32 and fed to the air housing 2 by way of return-flow pipe 31. The return-flow pipe ends in the compression pocket 13, from where the gas is introduced into the pressure-wave process. The compression pocket is incorporated in the web 33 before the high-pressure air outlet port 12, when viewed in the direction of rotation of the rotor. The throttling device consists of an interchangeable holed diaphragm 34 located in the return-flow pipe at its junction with the supply duct 32.

The action of the compression pocket is dependent on speed. At high speeds the pocket has no influence on the pressure-wave process, while at low speeds it has the effect of pre-compressing the ingested fresh air. Throughout the whole speed range, however, the pressure relationships are such that at full load the pressure drop from the high-pressure gas supply duct 32 to the compression pocket is greater than at partial load so that a correspondingly larger quantity of exhaust gas is recirculated at full load.

A similar configuration is possible even when there is no compression pocket. The return-flow pipe 31 then terminates in web 33, with its opening facing the cells of the rotor.

The curves of the degree of recirculation resulting from primary and secondary recirculation are in both cases similar to curve B in FIG. 6.

An example of high-pressure gas recirculation with the inlet flow on the gas side is shown in FIG. 8. The connecting pipe 35 contained within gas housing 3 branches from the high-pressure gas supply duct 32 and terminated in web 36 before the high-pressure gas inlet port 9, when viewed in the direction of rotation of the rotor, i.e. once again at a point where the cells of the rotor are filled with air. This advance inlet flow not only influences the pressure-wave process, but at the same time also displaces the mixing zone further towards the air side. The result is that principally at full load, and especially at high speeds, part of the mixing zone discharges with the compressed air into the high-pressure air outlet port 12. The effect can be intensified in the termination of the connecting pipe 35 is fitted with a nozzle 37, which also replaces the throttle.

This version is of great advantage because no external piping is required. Incorporating a cooler would necessarily be difficult, and it would therefore be more convenient to cool the recirculated exhaust together with the compressed on its way to the engine.

In all the examples the crossover duct is so arranged that a pressure difference exists between its inlet and outlet. It is also possible in principle to include a means of propelling the gas in order to raise the flow velocity of the recirculating gas if the pressure difference is small, or even to overcome a negative pressure difference, but this would make the whole apparatus more complicated and, moreover, requires additional energy.

Also included in the invention is the possibility of providing in a given case a number of crossover ducts in parallel, or one or more for each pressure-wave cycle. Furthermore, the various possibilities can be combined.

It should also be noted that the method described for reducing harmful emissions from internal combustion engines is equally applicable to diesel and Otto-cycle engines.

We claim:

1. In the method of providing combustion air for an internal combustion engine by compressing the air in a gas-dynamic pressure-wave machine by utilization of heat still contained in the engine exhaust gases and wherein harmful emissions from the engine are reduced as a result of a primary recirculation of exhaust gas into the air at the interface between the exhaust gas and the air in the celled rotor of the machine, the amount of the exhaust-gas recirculation being at its lowest value at full load and increasing sharply with decreasing load, the improvement which comprises the step of introducing exhaust gas directly into the machine in at least one place at which the cells of the rotor are filled with air thereby effecting a secondary recirculation of the exhaust gas which increases at full load and which serves to render recirculation of the exhaust gas more uniform over the whole load range.

2. Apparatus for providing combustion air for an internal combustion engine comprising a gas-dynamic pressure-wave machine in which the air is compressed by utilization of heat still contained in the exhaust gases from the engine, harmful emissions from the engine being reduced as a result of primary recirculation of exhaust gas into the air at the interface between the exhaust gas and the air in the celled rotor of the machine, said gas recirculation being at its lowest value at full load and increasing sharply with decreasing load, and means for rendering said recirculation of exhaust gas more uniform over the whole load range of the engine comprising a crossover duct for effecting secondary exhaust-gas recirculation extending from a space filled with exhaust gas to an opening facing air filled cells in the rotor in one side of the machine.

3. Apparatus as defined in claim 2 and which further includes a cooling device located in said crossover duct.

4. Apparatus as defined in claim 2 wherein said crossover duct is constituted by a return-flow pipe, the inlet opening of which as viewed in the rotational direction of the rotor lies within the first half of the low-pressure gas outlet port from the rotor and the outlet opening of which lies within the second half of the low-pressure air inlet port to the rotor.

5. Apparatus as defined in claim 4 wherein the inlet opening of said return-flow pipe is located immediately after the front edge of said low-pressure gas outlet port, and wherein the outlet opening of said return-flow pipe is located immediately in front of the rear edge of said low-pressure air inlet port.

6. Apparatus as defined in claim 2 wherein said crossover duct is constituted by a return-flow pipe which branches off the high-pressure gas inlet pipe and which as viewed in the rotational direction of the rotor emerges in a web located before the high-pressure air outlet port.

7. Apparatus as defined in claim 2 wherein said pressure-wave machine includes a compression pocket located adjacent one end of the rotor and wherein said crossover duct is constituted by a return-flow pipe which branches off the high-pressure gas inlet duct and emerges in said compression pocket.

9

8. Apparatus as defined in claim 2 wherein said crossover duct is constituted by a connecting pipe which branches off the high-pressure gas inlet duct and which as viewed in the rotational direction of the rotor emerges from a web located before the high-pressure gas inlet port.

9. Apparatus as defined in claim 8 wherein said connecting pipe terminates in at least one nozzle.

10

10. Apparatus as defined in claim 2 and which further includes a throttling device in said crossover duct provided for the secondary exhaust-gas recirculation.

11. Apparatus as defined in claim 10 and wherein the flow cross-section of said throttling device is adjustable.

* * * * *

10

15

20

25

30

35

40

45

50

55

60

65

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,874,166
DATED : April 1, 1975

INVENTOR(S) : Hubert Kirchhover, Josef Perevuznik, Alfred Wunsch

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

[73] Assignee: BBC BROWN BOVERI & COMPANY LIMITED

Signed and Sealed this
twenty-second Day of July 1975

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks