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(54) Title: TURBOCHARGED ENGINE ARRANGEMENT WITH EXHAUST GASES RECIRCULATION INSTALLATIONS AND ROTARY FLOW CONTROL VALVE

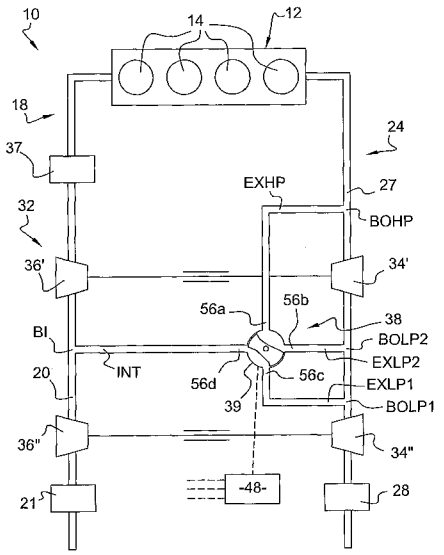


Fig. 2

(57) Abstract: A turbocharged engine arrangement having an exhaust gases recirculation system (38) comprising at least: • a higher and a lower pressure exhaust-side conduit (EXHP, EXLP) • a principal intake-side conduit (INT, INTLP, INTHP) connected to the intake line; and comprising a single rotary valve (39) configured to define at least • - a higher pressure exhaust gas recirculation mode; • - a lower pressure exhaust gas recirculation mode; • -a turbine by-pass mode. Also provided is a rotary valve comprising: • at least four ports openings (58a,...) • a rotary valve body (60) having a separation wall (64) extending to divide the internal volume in two separate flow chambers (52A, 52B); wherein first and second adjacent port openings may be set in communication through one of the flow chambers, while a third port is obstructed by an obstructing sector.

Turbocharged engine arrangement with exhaust gases recirculation installations and rotary flow control valve

Technical field

The invention relates to the field of turbo charged internal combustion engine arrangements with exhaust gases recirculation systems and to a valve which can be used in such systems. Such an engine arrangements may be used for example in vehicles, in construction equipment machines or as stationary arrangements.

Background art

It is known to provide internal combustion engine arrangements with exhaust gas recirculation (EGR) systems whereby a portion of the exhaust gases produced by the combustion inside the engine are recirculated to the engine rather than being released the atmosphere. The EGR gases which are fed to the engine, generally through an EGR line connecting an exhaust line to an intake line of the engine, allow modifying the temperature and the composition of the gases inside the engine, thus modifying the conditions of the combustion. Depending on the engine operating conditions and on the EGR recirculation rate, it is possible, amongst other things, to alter the production of noxious emissions in the exhaust gases, especially nitrogen oxides (NOx), to reduce fuel consumption and/or to alter exhaust gases temperatures. To control the flow of EGR gases, an EGR valve is generally provided in a conduit of the EGR system.

More and more engine arrangements are now also charged air engine arrangements where the intake gases provided to the engine for the combustion are compressed, to increase efficiency. Although air charging can be performed by compressors driven electrically or driven mechanically by the engine crankshaft, most charged air engines are equipped with a turbo-compressor system having at least one turbine driven by exhaust gases flowing in the exhaust line and at least one compressor for compressing gases flowing in the intake line. One compressor of a given turbo-compressor is driven by the corresponding turbine through a mechanical connection. Turbo-compressor systems may comprise several turbo-compressors, with different possible arrangements. The turbines

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and/or the compressors can be arranged in series and/or in parallel respectively in the exhaust line and in the intake line.

In turbocharged engines arrangements, various EGR systems have been proposed where an EGR line can be connected to the exhaust line either upstream or downstream of the turbine(s), or even between turbines in the case of several serially arranged turbines. In such systems various combinations have been proposed where the EGR line can be connected to the intake line either upstream or downstream of the compressor(s), or even between compressors in the case of several serially arranged compressors.

Systems where the EGR line is connected to the exhaust line downstream of at least one turbine have the advantage of providing cooler EGR gases, which is generally favorable for reducing the production of NOx during the combustion.

Document US-2011/000470 describes an internal combustion engine arrangement equipped with a complex exhaust gas recirculation system which would allow at least theoretically different EGR recirculation schemes. Such system is very complex, thus costly, both in terms of the hardware installation and in terms of the process for controlling the arrangement. Document US-7.963.276 describes a rotary valve for controlling the flow of EGR gases into an EGR cooler.

In turbocharged engine arrangements, is also known to provide that, at least under certain engine operating conditions, at least part of the exhaust gases are caused to by-pass the turbine of a turbocharger. Turbochargers are often equipped with a so-called waste-gate to achieve this by-pass. In other cases, the by-pass may be external to the turbocharger, with a dedicated conduit and dedicated valve.

Both EGR valves and the turbine by-pass valves need to withstand the high temperatures of exhaust gases, typically over 600°c or more. They should also allow the flow of quite a large quantity of high pressure and high velocity gases without entailing too much flow resistance. Finally, such valves preferably provide proportional control so as to adjust as precisely as possible the flow of EGR gases or the flow of by-pass gases.

Therefore one object of the invention is to provide a new turbocharged engine arrangement allowing an optimal control of the flow of exhaust gases under varying engine operating conditions with a cost effective design.

Summary

According to a first aspect of the invention, a turbocharged engine arrangement is provided having:

- an internal combustion engine;

- an exhaust line collecting exhaust gases from the engine and conveying those exhaust gases to the atmosphere;

- an intake line conveying fresh air from the atmosphere to the engine;

- a turbocharger system comprising at least one turbocharger comprising a compressor in the intake line driven by a turbine in the exhaust line;

- an exhaust gases recirculation system comprising at least:

* one higher pressure exhaust-side conduit connected to the exhaust line upstream of a least one turbocharger turbine of the turbocharger system;

* one lower pressure exhaust-side conduit connected to the exhaust line downstream of a least one turbocharger turbine of the turbocharger system;

* one principal intake-side conduit connected to the intake line;

characterized in that the exhaust gases recirculation system comprises a single rotary valve (39) having at least three ports opening and a rotary body, each of said port openings being fluidically connected to one different of said exhaust gases recirculation system conduits, and in that the valve is configured to define at least the following operating modes by connecting:

- higher pressure exhaust-side conduit (EXHP) with one intake-side conduit (INT, INTHP), preferably with a proportionally a variable cross section through the valve, to achieve a higher pressure exhaust gas recirculation mode;

- lower pressure exhaust-side conduit (EXLP, EXLP1, EXLP2) with one intake-side conduit (INT, INTLP), preferably with a proportionally a variable cross section through the valve, to achieve a lower pressure exhaust gas recirculation mode;

- higher pressure exhaust-side conduit (EXHP) with lower pressure exhaust-side conduit (EXLP, EXLP2), preferably with a proportionally variable cross section through the valve, to achieve a turbine by-pass mode.

Thereby, the engine arrangement can be operated in different modes through the use of simple and reliable components.

Moreover, the valve preferably provides proportional control, meaning that the flow through the valve between two conduits connected by the valve can be controlled by the valve to at least one intermediate value between full flow and no flow, preferably several intermediate values. The valve may be configured to provide continuous or quasi continuous proportional control, in which case the number of intermediate values is such that the difference between two values can be considered as the minimum difference having a measurable impact on the operation of the engine arrangement. The valve may be configured to provide full proportional control if the proportional control is available over the full range of 0 to 100% of the full flow through the valve. Proportional control through the valve may be achieved by a valve configured to achieve a proportionally variable cross section through the valve.

Following are further optional features of the invention, which can be incorporated alone or in combination, involving a single valve:

- The rotary valve may be configured to be able to achieve each of the higher pressure exhaust gas recirculation mode, of the lower pressure exhaust gas recirculation mode and of the turbine by-pass mode exclusively of the other modes, thereby allowing optimum efficiency in each of said modes;

- The rotary valve may be configured to be able to achieve a blocking mode where no port opening is connected to another port opening through the valve, thereby allowing a further mode of operation, still without any additional component.

- Each mode may correspond to a distinct range of positions of the valve body;

- The single rotary valve may comprise at least 4 port and a rotary body, and the exhaust gas recirculation system may comprise an additional lower pressure exhaust-side conduit connected to the exhaust line downstream of a least one turbocharger turbine of the turbocharger system, and in that the each of said port openings is fluidically connected to one different conduit of the exhaust gases recirculation system. Such arrangement allows still further operational modes, such as combined modes. For example, the rotary valve may configured to be able to achieve a combined higher pressure exhaust gas recirculation and turbine by-pass mode, wherein a lower pressure exhaust-side conduit is connected to an intake-side conduit through the valve, and wherein the higher pressure exhaust-side conduit is connected independently with the other lower pressure exhaust-side conduit through the valve. The rotary valve may be configured to be able to proportionally control, in the combined higher pressure exhaust

gas recirculation and turbine by-pass mode, the flow rate of exhaust gases by-passing the turbine or the flow rate of exhaust gases being recirculated, by a proportionally variable cross section across the valve

- The single rotary valve may comprises at least 4 opening ports and a rotary body, and the exhaust gas recirculation system may comprise an additional higher pressure intake-side conduit (INTHP) connected to the intake line downstream of a least one turbocharger compressor of the turbocharger system, and the principal intake-side conduit may be connected to the intake line upstream of a least one turbocharger compressor, and each of said opening ports may be fluidically connected to one different of the said exhaust gases recirculation conduits. Such arrangement allows still further operational modes, such as combined modes. For example, the rotary valve may be configured to be able to achieve a combined higher and lower pressure exhaust gas recirculation mode, wherein both the higher and lower pressure exhaust-side conduits are connected simultaneously respectively to the higher and the lower intake-side conduits through the valve. Alternatively, or in addition, the rotary valve may be configured to be able to achieve a compressor by-pass mode, wherein the additional higher pressure intake-side conduit is connected with the principal pressure intake-side conduit, with a variable cross section through the valve, to achieve a compressor by-pass mode. As still another example, the rotary valve may configured to be able to achieve a combined turbine and compressor by-pass mode, wherein the additional higher pressure intake-side conduit is connected with the principal pressure intake-side conduit, while the higher pressure exhaust-side conduit is connected independently with the lower pressure exhaust-side conduit. Such modes may be proportionally controlled by a proportionally variable cross section across the valve.

- The turbocharging system may comprise a second turbocharger comprising a compressor in the intake line driven by a turbine in the exhaust line. Is such a case, the two turbines may be arranged in series in the exhaust line and the two compressors may be arranged in series in the intake line.

The invention further provides a rotary valve for an exhaust gases system, comprising:

- a valve housing of circular cylindrical shape wherein:

* an internal volume is defined by an internal circular cylindrical surface (54) around a central axis;

* at least four ports openings are formed in the internal circular cylindrical surface to allow entry or exit of exhaust gases in or out of the valve internal volume, the four port openings being angularly spaced around the central axis;

* at least four inter-port sectors of the internal circular cylindrical surface are defined, each extending between two adjacent port openings, and each having an angular extent around the central axis;

- a rotary valve body received in the internal volume of the valve housing and able to rotate around the central axis, the rotary valve body having a separation wall extending across the internal volume to divide the internal volume in two separate flow chambers thanks to a first obstructing sector and a second obstructing sectors of the wall which cooperate with the inter-port sectors of the internal circular cylindrical surface to fluidically separate the two flow chambers;

characterized in that the obstructing sectors of the valve body and the port openings of the valve housing are arranged such a first and a second adjacent port openings may be set in communication through one of the flow chambers, while a third port is obstructed by an obstructing sector. This allows selective communication between the conduits connected to the valve.

Further optional features of the invention include:

- The obstructing sectors of the valve body and the port openings of the valve housing may be arranged such that, for a further position or range of positions of the valve body, the first and second adjacent ports are set in only partial communication, while the third port is maintained port is obstructed by an obstructing sector. This allows proportional control of the flow through the two adjacent ports which are set in communication. In some embodiments, such proportional control is available for any pair of two adjacent port openings.

- The obstructing sectors of the valve body may comprise a wider and a narrower obstructing sector which are of a different angular extent around the central axis.

- The obstructing sectors may be arranged so that, for a range of angular positions of the body, the wider obstructing sector obstructs a given port opening while the smaller obstructing sector only partially obstructs the port opening which is not adjacent to the given port opening, the degree of obstruction of the not adjacent port being variable over the range of angular positions.

- The port openings are arranged by pairs of two non-adjacent port openings, and in that the obstructing sectors of the valve body are arranged to:

* for a first position or range of positions of the valve body, obstruct both port openings of one pair;

* for a second position or range of positions of the valve body, obstruct one port opening of the pair and at least partially clearing the other port opening of the pair.

- The second position or range of positions may be adjacent to the first position or range of positions.

- The angular extent of the narrower obstructing sector may be at least as large as the angular extent of a port opening;

- The angular extent of the wider obstructing sector may be at least twice as large as the angular extent of a port opening.

- The angular extent of the wider obstructing sector may be at least three times as large as the angular extent of a port opening.

- The difference in angular extent between the two obstructing sectors is at least twice as large as the angular extent of a port opening.

- The opening ports may be arranged by pairs where two port openings of the same pair are diametrically opposed with respect to the central axis (A0).

- The separation wall may be symmetrical with respect to a diametrical plane of the rotary body.

- At least one inter-port sector may be narrower in angular extent than at least one other inter-port sector.

- Each flow chamber may extend angularly around the central axis along an open sector between the two obstructing sectors, and at least one of the open sectors may have an extent so as to allow unobstructed flow of fluid through the corresponding chamber from at least one port opening to at least one adjacent port opening.

- At least one of the open sectors may have an extent so as to allow unobstructed flow of fluid through the corresponding chamber from at least one port opening to only one adjacent port opening.

According to another aspect of the invention, a turbocharged engine arrangement may be provided having:

- an internal combustion engine;

- an exhaust line collecting exhaust gases from the engine and conveying those exhaust gases to the atmosphere;

- an intake line conveying fresh air from the atmosphere to the engine;

a turbocharger system comprising at least one turbocharger comprising a compressor in the intake line driven by a turbine in the exhaust line;

- an exhaust gases recirculation system comprising at least:

* one higher pressure exhaust-side conduit connected to exhaust line upstream of a least one turbocharger turbine of the turbocharger system;

* one lower pressure exhaust-side conduit connected to the exhaust line downstream of a least one turbocharger turbine of the turbocharger system;

* one principal intake-side conduit connected to the intake line

wherein the exhaust gases recirculation system comprises at least one additional conduit connected to the intake line or to the exhaust line, where said additional conduit is one of:

□ an additional lower pressure exhaust-side conduit connected to the exhaust line downstream of a least one turbocharger turbine of the turbocharger system, or

□ an additional higher pressure intake-side conduit connected to the intake line downstream of a least one turbocharger compressor of the turbocharger system, the principal intake-side conduit being connected to the intake line upstream of a least one turbocharger compressor of the turbocharger system,

an wherein each of the four conduits of the exhaust gases recirculation system is connected to a different port opening of a single rotary valve as described above.

Description of figures

- Figure 1 is a schematic view of a first embodiment of an engine arrangement according to the invention;

- Figures 1A to 1D show various positions of a rotary valve corresponding to selected operating modes of the engine arrangement of Figure 1;

- Figure 2 is a schematic view of a second embodiment of an engine arrangement according to the invention;

- Figure 3 is a schematic view of a four-way rotary valve;

- Figures 3A to 3F show various positions of the embodiment of the rotary valve of Figure 3, corresponding to selected operating modes of the engine arrangement of Figure 2;

- Figures 4A to 4E show various positions of another embodiment of a rotary valve corresponding to selected operating modes of the engine arrangement of Figure 2;

- Figures 5A to 5G shows various positions of another embodiment of a rotary valve corresponding to selected operating modes of the engine arrangement of Figure 2;

- Figure 6 is a schematic view of a third embodiment of an engine arrangement according to the invention;

- Figures 7A to 7F show various positions of the rotary valve of figure 3, corresponding to selected operating modes of the engine arrangement of Figure 6;

- Figures 8A to 8E show various positions of the rotary valve illustrated in figures 7A-7D, with a different branching of the valve to the conduits of the arrangement of Figure 6, corresponding to selected operating modes of the engine arrangement of Figure;

- Figures 9A to 9E show various positions of another embodiment of a rotary valve corresponding to selected operating modes of the engine arrangement of Figure 6;

- Figures 10A to 10E show various positions of another embodiment of a rotary valve corresponding to selected operating modes of the engine arrangement of Figure 6;

- Figures 11A to 11E show various positions of another embodiment of a rotary valve corresponding to selected operating modes of the engine arrangement of Figure 6.

Detailed description

On Figures 1, 2 and 6 are shown some of the elements of an internal combustion arrangement 10.

The arrangement 10 comprises an internal combustion engine 12. The engine 12 is for example a multi-cylinder reciprocating piston engine, which is here shown as an in-line engine having several cylinders 14 and which provides mechanical output power through a crankshaft. The engine can be a compression-ignition engine, such as a Diesel engine, but could be a spark ignited engine.

The arrangement further comprises an intake line 18 for conveying fresh air from the atmosphere to the engine. The intake line comprises at least one gas conduit 20 which draws fresh air from the atmosphere, and may comprise an air filter 21. The intake line 18

may typically also comprise an intake manifold (not represented) which may be connected to the engine 12 and which distributes intake gases to the cylinder(s) of the engine 12. In some engine arrangements, the intake line could comprise an intake throttle and/or a fuel injection apparatus for injecting fuel in the intake line before the intake gases are delivered to the engine 12.

The arrangement further comprises an exhaust line 24 for conveying exhaust gases out of the engine to the atmosphere. The exhaust line 24 may typically comprise an exhaust manifold which is connected to the engine 12 and which collects the exhaust gases resulting from the combustion in the cylinders. The exhaust line comprises at least one exhaust conduit 27 which conveys the gases towards the atmosphere. In the exhaust line can be provided one or several exhaust after-treatment devices 28 which remove at least part of the noxious substances from the exhaust gases. Such exhaust after-treatment devices 28 may comprise one or several of a particle filter, an oxidation catalyst, a reduction catalyst (such as a so called SCR catalyst), a NOx trap, a SOx trap, a three-way catalyst, etc.... The exhaust line 24 may also comprise a muffler for reducing the noise generated by the exhaust gases. The exhaust line could also comprise an exhaust throttle.

The engine arrangement 12 is a charged air engine arrangement in which the intake gases which participate in the combustion are compressed in the intake line 18, before being delivered to the engine 12, to a level above atmospheric pressure. Preferably, the energy required by such compression is provided by energy which is recovered from the exhaust gases, preferably via an expander located in the exhaust line 24, most preferably by one or several turbines located in the exhaust line 24.

Therefore, the engine arrangement preferably comprises a turbo-compressor system 32 having at least one turbine driven by exhaust gases flowing in the exhaust line and at least one compressor for compressing gases flowing in the intake line. In the embodiment of Figure 6, the compressor system 32 comprises a single turbo-compressor having a turbine 34 in the exhaust line 24 and a rotary compressor 36 in the intake line 28, the compressor 36 being mechanically driven by the turbine 34. In such a system, the turbine is used as an expander for recovering energy from the exhaust gases by converting the energy of the exhaust gases into mechanical energy, and said recovered mechanical energy is used for compressing gases flowing in the intake line thanks to the compressor.

The turbo-compressor system 32 can comprise several turbo-compressors. A common layout is then to have two turbo-compressors, with the turbines being arranged in series in the exhaust line and with the corresponding compressors arranged in series in the intake

line, as shown in Figures 1 and 2 with a high pressure turbine 34' being arranged upstream of low pressure turbine 34''. The high pressure turbine 34' drives a high pressure compressor 36' which is located downstream in the intake line of a low pressure compressor 36'' driven by the low pressure turbine 34'. Nevertheless, other layouts are possible, for example with the turbines in parallel in the exhaust line and/or with the compressors in parallel in the intake line. The engine arrangement could also comprise an electrically driven compressor in the intake line and/or a compressor driven mechanically by the engine crankshaft through an appropriate mechanical transmission.

The engine arrangement may comprise, in the intake line 18, one or several "charge air coolers" 37 for cooling the intake gases before they are delivered to the engine 12. Such charge air coolers 37 are provided downstream of at least one compressor of the compressor system 32. The embodiments of figures 1 and 2 have two such charge air coolers 37, one located between the low pressure compressor 36'' and the high pressure compressor 36', and one located downstream of the high pressure compressor 36' in the intake line 18. The embodiment of Figure 6, having only one turbocharger, exhibits only one such charge air cooler 37 in the intake line between the compressor 36 and the engine 12.

The engine arrangement further comprises an exhaust gas recirculation (EGR) system 38 which is external to the engine 12 itself. In all embodiments, the EGR system comprises at least:

- one higher pressure exhaust-side conduit EXHP, fluidically connected to the exhaust line 24 at a higher pressure branch-out location BOHP located in the exhaust line 24 upstream of at least one turbine of the turbo-compressor system,
- one lower pressure exhaust-side conduit EXLP fluidically connected to the exhaust line 24 at a lower pressure branch-out location BOLP located in the exhaust line 24 downstream of at least one turbine of the turbo-compressor system, and,
- one principal intake-side conduit INT fluidically connected to the intake line 18 at a branch-in location BI for conveying recirculated exhaust gases from the exhaust line to the intake line.

The exhaust gases recirculation system comprises a single rotary valve 39 having at least three opening ports and a rotary body, each of said opening ports being fluidically connected to one different of the exhaust gases recirculation system conduits.

The recirculated exhaust gases, or EGR gases, are a portion of the exhaust gases coming out of the engine cylinders which are recirculated at least once through the engine cylinders for participating in a further combustion event. In the shown embodiments, it is clear that this recirculation is achieved via the EGR system 38 which is external to the engine itself. The lower pressure exhaust-side conduit EXLP forms, together with intake-side conduit INT, part of a lower pressure EGR circuit inasmuch as the EGR gases circulating in that circuit are taken from the exhaust line downstream of at least one expander (in this case a turbine of a turbo-compressor) and that they are therefore at a lower pressure than if they had been taken upstream of said at least one expander.

In the shown embodiments, the higher pressure branch-out location BOHP for the higher pressure exhaust-side conduit EXHP is located in the exhaust line 24 in the exhaust conduit 27 upstream of the sole or most upstream turbine 34, 34', or at the entry of the sole or most upstream turbine 34, 34'. In some cases it can be advantageous that the higher pressure branch-out location BOHP may be located as close as possible to the engine 12, i.e. where the pressure is the highest in the exhaust line 24, for example located at or near an exhaust manifold.

In the case of a single turbo-compressor, as in the embodiment of Figure 6, the higher pressure branch-out location BOHP for the higher pressure exhaust-side conduit EXHP is therefore located in the exhaust line 24 upstream of the sole turbine 34. Nevertheless, in an engine arrangement having several turbines in series in the exhaust line, as shown in figures 1 and 2, the higher pressure branch-out location BOHP for the higher pressure exhaust-side conduit EXHP could be located in the exhaust line 24 between an upstream and a downstream turbine, provided that there would be at least one turbine between the higher pressure branch-out location BOHP for the higher pressure exhaust-side conduit EXHP and the lower pressure branch-out location BOLP for the lower pressure exhaust-side conduit EXLP.

In the case of a single turbo-compressor, the lower pressure branch-out location BOLP for the lower pressure exhaust-side conduit EXLP is located in the exhaust line 24 downstream of the sole turbine 34. In the case where the turbo-compressing system comprises several turbines 34' 34'' in series in the exhaust line, i.e. with a downstream or low pressure turbine 34'' receiving at its input exhaust gases coming from the output of an upstream or high pressure turbine 34', the lower pressure branch out location BOLP where the lower pressure exhaust-side conduit EXLP is connected to the exhaust line 24 could be

located downstream of all turbines, or can be located between an upstream turbine 34' and a downstream turbine 34'', such as shown in Figure 1.

The lower pressure branch-out location BOLP, is preferably located upstream of at least one of:

- an exhaust after-treatment device 28;
- a muffler;
- an exhaust throttle.

Indeed, any of such devices located in the exhaust line would generate a resistance to the flow of exhaust gases, and therefore create a counter pressure at the lower pressure branch-out location BOLP which would facilitate the circulation of EGR gases through the EGR system from the exhaust line 24 towards the intake line. Nevertheless, any of such devices could also be located upstream of the branch-out location BOLP.

In the case where there are several compressors 36' 36'' in series, as in Figures 1 and 2, the branch-in location BI at which intake-side conduit INT is connected to the intake line can be located in between two compressors arranged in series, as is shown in figure 1, although it could be located as upstream of all compressors in the intake line.

The terms "higher pressure" and "lower pressure" used in connection with the branch-out locations and in connection with conduits are used to indicate the relative pressure levels between two locations or two conduits, not necessarily implying specific absolute pressure levels, nor necessarily implying that they are respectively the highest or the lowest pressure levels in the exhaust or intake lines.

In any embodiment, the branch-in location BI could be formed in a Venturi system where the flow of gases in the intake line would generate a lower pressure zone to facilitate the circulation of EGR gases through the EGR line from the exhaust line towards the intake line.

In any embodiment, one or several heat exchangers can be installed on an intake-side conduit for cooling the EGR gases flowing towards the intake line. Such a cooler 35 is represented in the embodiment of Figure 6.

The engine arrangement further comprises, in the EGR system 38, a rotary flow control valve 39 for controlling the flow of EGR gases, but also for controlling a flow of turbine by-pass gases.

The rotary valve can be driven for example by an electric motor controlled in a conventional way through a controller, such as an electronic control unit, which can be a dedicated controller or which can be shared with other elements of the engine arrangement. The controller can be formed of several units operatively connected one to the other. Preferably, the controller 48 has access to one or several operating parameters of the engine arrangement, for example through a digital communication network such as a CAN-bus. The controller 48 for the rotary control valve 39 can include a PID controller. The controller can for example have as an input a target EGR rate (which may be expressed as a percentage of EGR gases in the total amount of intake gases fed to the engine by the intake line – this rate may be expressed as a function, a map, or a table depending on engine arrangement operating conditions such as engine torque and speed), and the flow of EGR gases in the EGR system 38. The flow of EGR gases may be determined in various ways, for example using on or several flow rate sensors in the EGR system conduits, possibly in combination with a temperature sensor and/or a pressure sensor.

Now will be described more specifically the embodiment of Figure 1. In this embodiment, the EGR system 38 comprises only three conduits, namely:

- one higher pressure exhaust-side conduit EXHP connected to exhaust line 27 upstream of a least one turbocharger turbine of the turbocharger system, in this case upstream of the high pressure turbine 34', i.e. here upstream of all turbines of the turbocharger system;
- one lower pressure exhaust-side conduit EXLP connected to the exhaust line downstream of a least one turbocharger turbine of the turbocharger system, in this case downstream of the high pressure turbine 34' but upstream of the low pressure turbine 34'', i.e. between the high pressure turbine 34' and the low pressure turbine 34''.
- one principal intake-side conduit INT connected to the intake line downstream of the low pressure compressor 36'' but upstream of the high pressure compressor 36', i.e. between the two compressors 36' 36''.

The three conduits are connected through a three way rotary valve 39 having 3 ports, each port being connected to one of the higher pressure exhaust-side conduit EXHP, of the lower pressure exhaust-side conduit EXLP and of the principal intake-side conduit INT.

An exemplary embodiment of the three-way rotary valve 39 is schematically depicted in Figures 1A to 1D, in various operating positions.

The rotary valve 39 may comprise a valve housing 50 of circular cylindrical shape wherein an internal volume 52 is defined by an internal circular cylindrical surface 54 around a central axis A0. The valve housing 50 has three ports 56a, 56b and 56c (visible on Figure 1) which communicate with internal volume 52 through port openings 58a, 58b, 58c respectively, which are formed in the internal circular cylindrical surface 54 to allow entry or exit of exhaust gases in or out of the valve internal volume 52, the 3 port openings being angularly spaced around the central axis A0.

In the embodiment described at figures 1A to 1D, the ports 56a, 56b, 56c are arranged in that order around central axis A0 and are respectively connected to the higher pressure conduit exhaust-side EXHP, to the lower pressure conduit exhaust-side EXLP and to the intake-side conduit INT.

In the shown example, the ports and port openings are regularly spaced around central axis A0, i.e. located at 120 degrees of each other around A0, but other designs are possible. The port openings may have a certain angular extent P around A0, depending on the diameter of the port opening, which will be chosen as a function of the wanted fluid section passage, and on the diameter of the valve housing. For port openings having a 40 mmm diameter, and a valve housing having a 90 mm internal volume diameter, this would amount to approximately 50° of angular port extent P. Between the port openings 58a, 58b, 58c, three inter-port sectors 59ab, 59bc and 59ca of the internal circular cylindrical surface 54 are defined, each extending between two adjacent port openings (with first inter-port sector 59ab between first and second port openings 58a 58b, second inter-port sector 59bc between second and third port openings 58b 58c, and third inter-port sector 59ca between third and first port openings 58c 58a), and each having an angular extent IP around the central axis A0, for example 70° with the numeral values above for the port angular extent.

The rotary valve 39 has a rotary valve body 60 received in the internal volume 52 of the valve housing and able to rotate around the central axis A0, for example under the action of an electric motor as explained above. The body 60 is designed to as be able to shut-off either only one of the port openings, or two port openings simultaneously. The valve body therefore rotates with respect to the valve housing around the axis A0 which is perpendicular to an axis of each port opening. In other words, the ports and port openings are arranged radially around the axis A0 of the valve housing and of the rotary valve body.

The various positions or range of positions of the valve body around its rotation axis determine which ports of the valve are set in fluid communication.

In the shown example, the body exhibits an obstructing sector 62, which is for example formed by an external circular cylindrical surface of the body 60 cooperating intimately with the internal circular cylindrical surface 54 of the housing 52. The obstructing sector 62 may be equipped with seals in contact with the internal circular cylindrical surface 54 of the housing 52 to achieve good sealing properties. However, a reasonable amount of leakage may be tolerable, preferably lower than 5 percent of the flow through the valve when two ports are set in communication.

In the shown embodiment of Figures 1A to 1D, the obstructing sector 62 is a single obstructing sector and extends continuously over an angular extent OS. In such a case, the obstructing sector should preferably fulfill the below conditions:

- its angular extent OS should be wider than the widest extent P of all port openings 58, to as to be able to shut-off all ports 56 individually;

- its angular extent OS should be wider than the angular extent P of two adjacent ports 56 plus the extent IP of corresponding inter-port section, in order to be able to shut off both these two ports simultaneously;

- its angular extent OS should however be narrower than the angular extent of one of the ports plus the angular extent of the two inter-port sectors adjacent to that port in order to allow the two other ports to be left in communication.

In a regularly arranged valve (three ports of equal angular extent and three inter-port sectors of equal extent), as shown on the figures 1A- 1D, the valve may be defined with the following approximate dimensions:

Port diameter	Valve internal volume diameter	Port opening extent	Inter-port extent	Obstructing sector extent
40 mm	90 mm	50°	70°	170-190°

Opposite its obstructing sector, the rotary valve body does not occupy the full internal volume 52 so as to make room in the internal volume 52 for a flow chamber, which, depending on the position of the body, is able to set into communication any two adjacent port openings. Preferably, the flow chamber has an available fluid section at least equal to the section of the port openings 58. The body 60 may have, opposite its obstructing sector, a generally concave wall 64 to maximize the chamber flow section. In the shown embodiment, the body 60 is contained in a volume representing approximately half of the internal volume 52.

The rotary valve may be controlled so that its body may be set in any of the following positions:

- the position of Figure 1A, where the obstructing sector 62 closes the port opening 58c connected to intake-side conduit INT, while allowing flow of gases from the port opening 58a connected to the higher pressure exhaust-side conduit EXHP with the port opening 58b connected the lower pressure exhaust-side conduit EXLP, to achieve a turbine by-pass mode. Preferably, a variable cross section through the valve 39 can be created by rotating the body so that it partially closes one of the port openings 58a, 58b connected to an exhaust-side conduit, without opening the port opening connected to the intake-side conduit INT, so as to control the amount of exhaust gas allowed to by-pass the turbine 34'.

- The position of figure 1B, where the obstructing sector 62 closes the port opening 58a connected to the higher pressure exhaust-side conduit EXHP, while allowing flow of gases from the port opening 58b connected to the lower pressure exhaust-side conduit EXLP with the port opening 58c connected to the intake-side conduit INT, to achieve a lower pressure exhaust gas recirculation mode. Preferably, a variable cross section through the valve 39 can be created by rotating the body so that it partially closes one of the port openings 58b, 58c connected to lower pressure exhaust-side conduit EXLP or to the intake-side conduit INT, without opening the port opening 58a connected to the higher pressure exhaust-side conduit EXHP, so as to control the amount of exhaust gases recirculated at lower pressure.

- The position of figure 1C, where the obstructing sector 62 closes the port opening 58b connected to the lower pressure exhaust-side conduit EXLP, while allowing flow of gases from the port opening 58a connected to the higher pressure exhaust-side conduit EXHP with the port opening 58c connected to the intake-side conduit INT, to achieve a higher pressure exhaust gas recirculation mode. Preferably, a variable cross section through the valve 39 can be created by rotating the body 60 so that it partially closes one of the ports 58b, 58c connected to the higher pressure exhaust-side conduit EXHP or to the intake-side conduit INT, without opening the port connected to the lower pressure exhaust-side conduit EXLP, so as to control the amount of gas recirculated at higher pressure.

Thanks to this valve design, the rotary valve is configured to be able to achieve each of the higher pressure exhaust gas recirculation mode, of the lower pressure exhaust gas recirculation mode exclusively and of the turbine by-pass mode exclusively of

the other modes. In a given mode, the rotary valve connects at most two port openings simultaneously through the valve.

As visible on figure 1D, the rotary valve 39 is configured to be able to achieve a blocking mode where no port opening is connected to another port opening through the valve. This may be achieved with the valve of Figures 1A to 1D with the rotary body in a position where it blocks two port openings. These two openings could be openings 58b and 58c connected respectively to the lower pressure exhaust-side conduit EXLP and to the intake-side conduit INT, as shown in Figure 1D, but this particular design would allow any combination of two ports to be closed by the rotary body.

The embodiment described in Figures 1 and 1A to 1D allows to obtain a versatile EGR system able to achieve a high pressure recirculation mode, a low pressure recirculation mode or a turbine by-pass mode, with a very simple system and with a single valve which is relatively simple to build, robust and which does not entail any complex control algorithm contrary to systems where two or more valves need to be controlled simultaneously. In each of these modes, control of the flow can be made proportional. Thanks to the preferred design of the valve, each mode corresponds to a distinct range of positions of the valve body, which allows each mode to be performed exclusively from the other modes.

As indicated already above, according to variants of this embodiment, the branch-out location BOLP of the lower pressure exhaust-side conduit EXLP could be located downstream of the low pressure turbine 34'', or downstream of all turbines. In such a case, it may be advantageous to have the branch-in location BI of the intake-side conduit INT upstream of the low pressure compressor 36''; i.e. upstream of all compressors.

With the branch-out location BOLP of the lower pressure exhaust-side conduit EXLP located upstream of the low pressure turbine 34'', as shown in figure 1, it can still be advantageous to install the branch-in location BI of the intake-side conduit INT upstream of the low pressure compressor 36''; i.e. upstream of all compressors.

It can be noted that a further variant of this embodiment is easily conceived by removing the low pressure turbocharger (34'', 36''), the rest of the arrangement being unaffected.

The layout of the embodiment Figure 2 is identical to that of figure 1, with the only differences that the exhaust gas recirculation system 38 comprises an additional or second

lower pressure exhaust-side conduit EXLP2, in addition to the a main or first lower pressure exhaust-side conduit EXLP1, both being connected to the exhaust line downstream of a least one turbocharger turbine of the turbocharger system. Each of the lower pressure exhaust-side conduits has its own branch-off location BOLP1, BOLP2 for fluid connection to the exhaust line 27. Branch-off locations BOLP1, BOLP2 are located in the exhaust line at points which are preferably at a similar pressure level, downstream of at least one turbine, possibly downstream of all turbines, preferably not on either sides of a turbine.

It can be noted that both of the lower pressure exhaust-side conduits EXLP1 EXLP2 are said to belong to the exhaust gases recirculation system 38 because both are connected to the single rotary valve 39 which controls the EGR system, and even though, as will be seen later on, one of these conduits is not flown through by EGR gases but only by exhaust gases which are caused to by-pass the turbine.

Additionally the single rotary valve comprises at least 4 ports 56a, 56b, 56c, 56d, each of said ports being fluidically connected to one different of the conduits EXHP, EXLP1, EXLP2, INT of the exhaust gases recirculation system 38.

In Figure 3 is shown a 4-way rotary valve which can be used with the arrangement of Figure 2.

The rotary 4-way flow control valve of Figure 3 comprises a valve housing 50 of circular cylindrical shape wherein an internal volume 52 is defined by an internal circular cylindrical surface 54 around a central axis A0. The valve housing 50 has four ports 56a, 56b, 56c and 56d (shown on Figure 2) which communicate with internal volume 52 through port openings 58a, 58b, 58c and 58d respectively, which are formed in the internal circular cylindrical surface 54 to allow entry or exit of exhaust gases in or out of the valve internal volume 52, the 4 port openings being angularly spaced around the central axis A0.

The four port openings may be irregularly spaced around A0. Each port opening has two adjacent port openings which are located the closest to that port opening in terms of angular position around A0. The other of the four port openings is considered as the non-adjacent port opening, or opposed port opening. The angular position of a port opening around the central axis may be defined by its radial axis RAa, RAb, RAc, RAd, said axis being an axis perpendicular to the central axis A0 and passing through the center of the port opening.

In certain valve designs, the port openings may be arranged such that each pair of non-adjacent port openings are diametrically opposed, i.e. with their respective radial axis being aligned. Such a configuration is found in the embodiment of Figure 3 where the port openings 58a and 58c are diametrically aligned, as well as port openings 58b and 58d.

However, in the embodiment of figure 3, each port opening has two adjacent port openings which are located at a different angular distance. Thereby, when considering two adjacent port openings, their form either a closely arranged couple or a remotely arranged couple of port openings. For example the angular distance between two closely arranged port openings, can be for example 70°, such as when considering port couple 58a and 58b or port couple 58c and 58d, or can be 110° such as when considering port couple 58a and 58d or port couple 58b and 58c.

Of course, other angular positions could be chosen.

The port openings may have a certain angular extent P around A0, depending on the diameter of the port opening, which will be chosen as a function of the wanted fluid section passage, and on the diameter of the valve housing. In the following embodiments, the four port openings may have the same angular extent. However, some port openings may exhibit a different angular extent. For port openings having a 40 mmm diameter, and a valve housing having a 160 mm internal volume diameter, this would amount to approximately 28° of angular port extent P.

Four inter-port sectors 59ab, 59bc, 59cd and 59da of the internal circular cylindrical surface 54 are defined, each extending between two adjacent port openings (with first inter-port sector 59ab between first and second port openings 58a 58b, second inter-port sector 59bc between second and third port openings 58b 58c, third inter-port sector 59cd between third and fourth port openings 58c 58d, and fourth inter-port sector 59da between fourth and first port openings 58d 58a), and each having an angular extent around the central axis A0, for example around 45° or 80° with the numeral values above for the port angular extent, taking into account that the ports are arranged by pairs diametrically opposed. In this embodiment, two of the inter-port sectors are therefore narrower than the two others.

A rotary valve body 60 is received in the internal volume of the valve housing and is able to rotate around the central axis A0, for example under the action of an electric motor as explained above. The valve body rotates with respect to the valve housing around the axis A0 which is perpendicular to an axis of each port opening. In other words, the

ports and port openings are arranged radially around the axis A0 of the valve housing and of the rotary valve body.

The various positions or range of positions of the valve body around its rotation axis with respect to the valve housing determine which ports of the valve are set in fluid communication.

The rotary valve body has a separation wall 64 extending across the internal volume 52 to divide the internal volume in two separate flow chambers 52A, 52B thanks to a first obstructing sector 621 and a second obstructing sector 622 of the wall 64 which cooperate with the inter-port sectors 59ab, 59bc, 59cd and 59da of the internal circular cylindrical surface 54 to fluidically separate the two flow chambers 52A, 52B.

The separation wall 64 may extend along the whole dimension of the internal chamber 52 along axis A0.

The separation wall 64 extends across the internal volume 52 along a main direction perpendicular to central axis A0. In the shown example, the two obstructing sectors 621 and 622 are at opposite ends of the wall 64 along the main direction.

The obstructing sectors may each be formed by a sector of a convex external circular cylindrical surface, which has the central axis A0 as axis, and which has a radius nearly equal, but slightly smaller than that of the internal circular cylindrical surface 54. The obstructing sectors 621, 622 may be equipped with seals in contact with the internal circular cylindrical surface 54 of the housing 52 to achieve good sealing properties. However, a reasonable amount of leakage may be tolerable, preferably lower than 5 percent of the flow though the valve when two ports are set in communication. Therefore, the seals may be omitted and an adequate degree of separation between the flow chambers may be obtained thanks to the clearance between the obstructing sectors and the internal circular cylindrical surface 54 being minimal.

The obstructing sectors 621, 622 of the valve body and the port openings 58a to 58d of the valve housing are arranged such that a first and a second adjacent port opening may be set in communication through one of the flow chambers 52A, 52B, while a third port opening is obstructed by an obstructing sector.

For the same position of the valve body with respect to the valve housing, it is preferably provided that the fourth port opening is preferably either obstructed, or in communication only with the other flow chamber. Thereby, this fourth port opening is not set in communication with any other port opening.

Thanks to this feature, the rotary valve is able to set in communication exclusively two adjacent port openings.

Furthermore, obstructing sectors 621,622 of the valve body and the port openings 58a to 58d of the valve housing may be arranged such that, for a further position or range of positions of the valve body, the first and second adjacent port openings are set in only partial communication, while the third port opening is maintained obstructed by an obstructing sector. Thanks to this feature, the flow through the second and third ports may be proportionally controlled, while there is no flow through the third and fourth ports.

In the various embodiments of the valve which will be described, the obstructing sectors of the valve body comprise a wider 621 and a narrower 622 obstructing sector which are of a different angular extent, respectively OS1 and OS2, around the central axis A0. Thereby, it may be obtained that, for a certain range of positions of the valve body, one port is maintained obstructed, while the other ports are maintained at least partly unobstructed.

With the numerical values cited above, the angular extent OS1 of the wider obstructing sector 621 can be of around 80° and that OS2 of the narrower one 622 can be of around 30 degrees.

The obstructing sectors 621, 622 are arranged so that, for a certain range of angular positions of the body, the wider obstructing sector 621 obstructs a given port opening while the narrower obstructing sector 622 only partially obstructs the port opening which is not adjacent to the given port opening, the degree of obstruction of the not adjacent port opening being variable over the range of angular positions.

In the shown embodiment, each flow chamber 52A, 52B is delimited, radially with respect to the central axis AO:

- radially to the interior: by a lateral surface, respectively 61A and 61B, of the separation wall 64;

- radially to the exterior, by the sector 59ab, 59bc, 59cd, 59da of the internal circular cylindrical surface 54 which faces the corresponding lateral surface 61A, 61B.

In other words, in the shown embodiments, the flow chambers are not limited radially towards the exterior by the valve body,

The flow chambers have an angular extent FCA, FCB around central axis A0 which corresponds to the angular extent between the two obstructing sectors, on the corresponding side of the separation wall 64. Preferably, the flow chambers exhibit an

open sector along their whole angular extent FCA, FCB, being devoid of any obstructing sector which may obstruct a port opening. Preferably, the angular extent of an open sector of a flow chamber is at least equal to the angular extent of two adjacent port openings plus the angular extent of the inter-port sector between those two port openings. Such feature may provide that, for at least one position of the valve body, the valve allows unrestricted flow through both valve openings which are set in communication by the flow chamber.

Preferably at least one of flow chambers exhibits an open sector which has an extent FCA, FCB so as to allow unobstructed flow of fluid through the corresponding chamber from at least one port opening to only one adjacent port opening.

The lateral surfaces 61A, 61B of the separation wall 64 are for example surfaces which are parallel to central axis A0. Each lateral surface may extend from an edge of one obstructing sector to an edge the other obstructing sector. They may be concave.

In the embodiment of figure 3, the separation wall 64 is symmetrical with respect to one diametrical plane DP of the rotary body, containing the central axis A0. The obstructing sectors are arranged at opposite ends of that diameter of the valve rotary body.

Preferably, the angular extent of the narrower 622 obstructing sector is at least as large as the angular extent of a port opening. Thereby, the narrower obstructing sector 622 may obstruct that port as well as any other port having an angular extent narrower or equal to that of the narrower obstructing sector.

In some embodiments, such as the embodiment of Figure 3, the narrower obstructing sector 622 is narrower in angular extent than at least one of the inter-port sectors, preferably narrower than the smallest of the inter-port sectors. This allows that the narrower obstructing sector 322 may separate the two ports on each side of the inter-port sector, without obstructing any of the two ports.

In the embodiment of Figure 3, all port openings 58a to 58d have the same angular extent around central axis A0. As one consequence, each of them may be shut-off by the narrower obstructing sector.

The angular extent of the wider obstructing sector is wider than, but preferably at least twice as large as the angular extent of a port opening. In combination with the feature of embodiment of Figure 3 whereby the angular extent of the narrower 622 obstructing sector is at least as large as the angular extent of a port opening, and to the

other feature whereby the opening ports are arranged by pairs which are diametrically opposed, this feature allows that:

- for a first position or range of positions, the valve body 60 obstructs both opening ports of one pair of opposed port openings;
- for a second position or range of positions, the valve body 60 obstructs one opening port of the pair and at least partially clears the other port of the pair of opposed port openings.

As a summary, the valve 39 as shown in Figure 3 may have the following dimensions, in terms of angular extent around the central axis A0:

Port openings	Inter-port sect. 59ab	Inter-port sector 59bc	Inter-port sector 59cd	Inter-port sector 59de	Wider obstructing sector	Narrower Obstructing sector	Flow Chamber 52A	Flow chamber 52B
28.5°	45°	78°	45°	78°	81°	29°	125°	125°

When the rotary valve of figure 3 is used in the engine arrangement of Figure 2, various operating modes of the engine arrangement can be obtained, which will be described in connection with figures 3A to 3F.

In this arrangement:

- a first port opening 58a is connected to the higher pressure exhaust-side conduit EXHP;
- a second port opening 58b, adjacent and closely arranged to the first port, is connected to the second lower pressure exhaust-side conduit EXLP2;
- a third port opening 58d, non-adjacent and diametrically opposed to the first port, is connected to the main lower pressure exhaust-side conduit EXLP1
- a fourth port opening 58d, adjacent and remotely arranged to the first port, is connected to the intake-side conduit INT.

In Figure 3A, the arrangement is shown in an exclusive turbine by-pass mode, with no flow of EGR gases towards the intake. The third port opening 58c connected to the main lower pressure exhaust-side conduit EXLP1 is obstructed by the wider obstructing sector 621, while the narrower obstructing sector 622 only partially obstructs the first port opening 58a connected to the higher pressure exhaust-side conduit EXHP. The first port opening 58a connected to the higher pressure exhaust-side conduit EXHP is partially set in

fluid communication with second port opening 58b connected to the second lower pressure exhaust-side conduit EXLP2 through a first flow chamber 52A. The fourth port opening 58d connected to the intake-side conduit INT is in communication only with the second flow chamber 52B.

In the range of positions around the position of Figure 3A, it can be seen that only the amount of obstruction of the first port opening 58a would change, from 0 to 100%. Thereby, the range of positions around the position of Figure 3A allows full proportional control of the flow by-passing the turbine through the valve 39.

In figure 3B, the arrangement is shown in an exclusive lower pressure EGR mode, with no flow of HP EGR gases towards the intake-side conduit INT, and no flow by-passing the turbine. The second port opening 58b connected to the second lower pressure exhaust-side conduit EXLP2 is obstructed by the wider obstructing sector 621, while the narrower obstructing sector 622 only partially obstructs the fourth port opening 58d connected to the intake-side conduit INT. The fourth port opening 58d is partially set in fluid communication with third port opening 58c through the second flow chamber 52B. The first port opening 58a connected to the intake-side conduit INT is in communication only with the first flow chamber 52A.

In the range of positions around the position of Figure 3B, it can be seen that only the amount of obstruction of the fourth port opening 58d would change, from 0 to 100%. Thereby, the range of positions around the position of Figure 3A allows full proportional control of the flow of lower pressure EGR gases through the valve 39.

In figure 3C, the arrangement is shown in a combined turbine-bypass and low pressure EGR mode. First and second port openings 58a 58b are set in full communication through the second flow chamber 52B, achieving full turbine by-pass flow, while third and fourth port openings 58c, 58d are set only partially in communication through the first flow chamber 52A, thereby achieving controlled flow of low pressure EGR gases. The wider obstructing sector 621 partially obstructs fourth port opening. Range of position around position 3B makes it possible to fully control the flow of lower pressure EGR gases.

Figure 3D shows the same mode as Figure 3C, but with full lower pressure EGR flow and controlled partial flow of turbine by-pass gases.

In figure 3E, it is shown that the second port opening 58b is fully obstructed by the wider obstructing sector 621 while the fourth port opening 58d is partially obstructed by the narrower obstructing sector 622, and is set-in communication with the first port opening 58a via the first flow chamber 52A. The third port opening 58c is connected only

to the second flow chamber 52B and is isolated from all other port openings. The range of positions around the position of Figure 3E allows full proportional control of the flow of higher pressure EGR gases through the valve 39, in an exclusive higher pressure EGR mode.

In figure 3F, the valve 39 is shown in a blocking mode where no gases can flow through the valve. Two diametrically opposed port openings, in this case the second and the fourth port openings, are simultaneously fully obstructed, respectively by the wider and by the narrower obstructing sectors 621, 622. The other two port openings are set in communication only with one of the two respective flow chambers, and are therefore separated fluidically by the separation wall.

In Figure 4A to 4E, is shown another embodiment of a four way valve. In this embodiment, the valve housing 50 exhibits four ports and port openings 58a, 58b, 58c, 58d which are arranged at regular angular distance one from the other, i.e. with their at 90° one from the other. However, the valve body 60 is not symmetrical, so that the wider and narrower obstructing sectors 621, 622 are not diametrically opposed. The wider and narrower obstructing sectors 621, 622 are asymmetrical in the angular extent, but also in their angular position, with their respective median axis MA1, MA2 (as defined by a radial direction perpendicular to central axis A0, intersecting central axis A0, and going thought the middle of the angular extent of the corresponding obstructing sector), which are not aligned. As a result of the port openings being diametrically opposed and the obstructing sectors having an asymmetrical position, it will be seen that the valve according to Figures 4A to 4C exhibits at least four positions where one port is obstructed while the three other parts are unobstructed or substantially unobstructed. In this design, the narrower obstructing sector does not obstruct a port opening and is only used for achieving separation between first and second flow chambers 52A, 52B.

As a summary, the valve 39 as shown in Figures 4A-4E may have the following dimensions, in terms of angular extent around the central axis A0:

Port openings	Inter-port sect. 59ab	Inter-port sector 59bc	Inter-port sector 59cd	Inter-port sector 59da	Wider obstructing sector	Narrower Obstructing sector	Flow Chamber 52A	Flow chamber 52B
35°	55°	55°	55°	55°	57°	20°	162°	121°

In Figures 4A to 4E, the valve is shown as it could be arranged in the arrangement of Figure 2, with:

- first port opening 58a connected to the higher pressure exhaust-side conduit EXHP;
- second port opening 58b, adjacent to the first port, connected to the second lower pressure exhaust-side conduit EXLP2;
- third port opening 58c, non-adjacent and diametrically opposed to the first port, connected to the main lower pressure exhaust-side conduit EXLP1, and
- fourth port opening 58d, adjacent to the first port, is connected to the intake-side conduit INT.

The respective modes obtained with the valve are:

- Figure 4A: exclusive turbine by-pass mode, with third port opening 58c obstructed by the wider obstructing sector 621, communication between first and second port openings 58a 58b through first flow chamber 52A, fourth port opening 58d only in communication with second flow chamber 52B.
- Figure 4B: exclusive lower pressure EGR mode, with first port opening obstructed by the wider obstructing sector 621, communication between third and fourth port openings through first flow chamber 52A, second port opening only in communication with second flow chamber 52B.
- Figure 4C: exclusive higher pressure EGR mode, with second port opening obstructed by the wider obstructing sector 621, communication between first and fourth port openings through first flow chamber 52A, third port opening only in communication with second flow chamber 52B.
- Figure 4D: combined turbine by-pass and lower pressure EGR mode, communication between first and second port openings through second flow chamber 52B, communication between third and fourth port openings through first flow chamber 52A. In this mode, the wider obstructing sector 621 cooperates with the fourth inter-port sector 59da, while the narrower obstructing sector 622 cooperates with second the inter-port sector 59bc.
- Figure 4E: blocking mode, with fourth port opening obstructed by the wider obstructing sector 621, communication between second and third port openings through first flow chamber 52A, first port opening only in communication with second flow chamber 52B. In this mode, it can be noted that fluid could flow through the second and third port openings, via the first flow chamber 52A, but the pressure levels in the two

exhaust-side lower pressure conduits being substantially similar, it is expected that little flow would occur through the valve, and in any case, any flow through the valve would not have any significant impact on the engine arrangement operation.

In figures 5A to 5G is shown a further variant of a four way rotary control valve which can be used in an engine arrangement according to the invention.

In this design, the valve housing 50 exhibits four ports and port openings 58a, 58b, 58c, 58d which are arranged at irregular angular distance one from the other, with no port being diametrically opposed to any other. Similarly to the embodiment of figures 4A-4E, the valve body 60 is not symmetrical, so that the wider and narrower obstructing sectors 621, 622 are not diametrically opposed. The wider and narrower obstructing sectors 621, 622 are asymmetrical in angular extent, but also in their angular position, with their respective median axis which are not aligned. In this design, the narrower obstructing sector does not obstruct a port opening and is only used for achieving separation between first and second flow chambers 52A, 52B.

As a summary, the valve 39 as shown in Figures 5A-5G may have the following dimensions, in terms of angular extent around the central axis A0:

Port openings	Inter-port sect. 59ab	Inter-port sector 59bc	Inter-port sector 59cd	Inter-port sector 59da	Wider obstructing sector	Narrower Obstructing sector	Flow Chamber 52A	Flow chamber 52B
26°	33°	67°	46°	110°	77°	22°	148°	113°

This valve can be used in the layout of the engine arrangement as shown on figure 2, with the same connections between port openings and conduits as detailed for the embodiment of figures 4A-4E.

With such an arrangement, at least the following modes of operation of the engine arrangement are possible:

- Figure 5A: exclusive turbine by-pass mode, with third port opening obstructed by the wider obstructing sector, communication between first and second port openings through first flow chamber 52A, fourth port opening 58d only in communication with second flow chamber 52B.

- Figure 5B shows an exclusive lower pressure EGR mode, with second port opening obstructed by the wider obstructing sector 621, communication between third and

fourth port openings through second flow chamber 52B, first port opening only in communication with first flow chamber 52A. In figure 5B, the narrower obstructing sector obstructs partially the fourth port opening connected to the intake-side conduit. In the range of positions around that of Figure 5B, it will be understood that it is possible to vary the degree of obstruction of the fourth port, without modifying the situation for the other ports, thereby achieving proportional control of the flow of lower pressure EGR gases through the valve, at least through a span of degree of obstruction, for example a span from 0 to approximately between 80% and 90% of obstruction.

- Figure 5C shows a combined turbine by-pass and lower pressure EGR mode, with communication between first and second port openings through first flow chamber 52A, and with communication between third and fourth port openings through second flow chamber 52B. In this mode, the wider obstructing sector 621 cooperates with the second inter-port sector 59bc, while the narrower obstructing sector 622 cooperates with the fourth inter-port sector 59da. However, the wider obstructing sector partially obstructs the third port opening (to a varying extent when considering the range of positions around that of figure 5C), thereby allowing proportional control of the flow of lower pressure EGR gases though the valve, at least through a span of degrees of obstruction.

- Figure 5D shows a very similar mode to that of figure 5C, with combined turbine by-pass and lower pressure EGR. However, the valve body has been rotated nearly 180° so that the wider obstructing sector 621 cooperates with fourth the inter-port sector 59da, while the narrower obstructing sector 622 cooperates with the second inter-port sector 59bc, and so that all port openings are fully cleared, thereby achieving full flow of turbine by-pass gases and of lower pressure EGR gases through the valve 39.

- Figure 5E shows a very similar mode to that of figure 5D, with combined turbine by-pass and lower pressure EGR. However, the valve body has been rotated so that the wider obstructing partially obstructs the first port opening (to a varying extent when considering the range of positions around that of figure 5C), thereby allowing full proportional control of the flow of turbine by-pass gases though the valve, over the whole span from 0 to 100%.

- Figure 5F shows an exclusive higher pressure EGR mode, with second port opening 58b obstructed by the wider obstructing sector 621, communication between first and fourth port openings through first flow chamber 52A, and with third port opening only in communication with second flow chamber 52B.

- Figure 5G shows a blocking mode, with first port opening 58a obstructed by the wider obstructing sector, communication between second 58b and third 58c port openings

through second flow chamber 52B, fourth port 58d opening only in communication with first flow chamber 52A. In this mode also, although fluid could flow through the second and third port openings, via the second flow chamber 52B, but the pressure levels in the two exhaust-side lower pressure conduits being substantially similar, it is expected that little flow would occur through the valve, and in any case, any flow through the valve would not have any significant impact on the engine arrangement operation.

In figure 6 is shown another embodiment of an engine arrangement 10 according to the invention. A first difference with the layouts of Figure 1 and 2 is that the engine arrangement is shown to have only one turbocharger 34, 36.

The engine arrangement comprises an exhaust gases recirculation system comprising:

* a higher pressure exhaust-side conduit EXHP connected to the exhaust line at a higher pressure branch-out location BOHP upstream of at least one turbocharger turbine of the turbocharger system, in this case, upstream of the sole turbine 34;

* a lower pressure exhaust-side conduit EXLP connected to the exhaust line at a lower pressure branch-out location BOLP downstream of a least one turbocharger turbine of the turbocharger system, in this case, downstream of the sole turbine 34;

* a principal or lower pressure intake-side conduit INTLP connected to the intake line, which is connected at a lower pressure branch-in location BILP upstream of at least one compressor of the turbocharger system, in this case upstream of the sole compressor 36.

Additionally, the exhaust gas recirculation system comprises an additional higher pressure intake-side conduit INTHP connected to the intake line 18 downstream of a least one turbocharger compressor, at a branch-in location BIHP, in this case downstream of the sole compressor 36.

The engine arrangement of figure 6 comprises a single rotary valve having at least 4 ports 56a, 56b, 56c, 56d, each of said ports being fluidically connected to one different of the conduits EXHP, EXLP, INTLP, INTHP of the exhaust gases recirculation system 38.

It can be noted that variants of the layout of Figure 6 include engine arrangements having two turbochargers in series, as shown in the layout of Figure 1. As non-limiting examples, the second turbocharger could be installed according to any of the following layouts:

- turbine upstream of the higher pressure branch-out location BOHP in the exhaust line, and compressor in the intake line downstream of the connection BIHP of the higher pressure intake-side conduit INTHP to the intake line;

- turbine downstream of the lower pressure branch-out location BOLP in the exhaust line, and compressor in the intake line upstream of the connection BILP of the lower pressure intake-side conduit INTLP to the intake line;

- turbine in the exhaust line between the higher pressure branch-out location BOHP in the exhaust line and the turbine of the first compressor, and compressor in the intake line between the compressor of the first turbocharger and the connection BIHP of the higher pressure intake-side conduit to the intake line.

In the layout of Figure 6, an EGR cooler 35 is shown on the lower pressure intake-side conduit INTLP. Also, a charge air cooler 37 is shown on the intake line downstream of the higher pressure branch-in location BIHP. Other coolers could be provided.

The layout of Figure 6, and its variants, can be implemented with any of the above mentioned valve designs. However, it can be implemented for example with the valve design as described above in connection with Figure 3.

In Figures 7A-7F are shown various operating modes of the engine arrangement which can be obtained when the valve design of Figure 3 is used in a layout as described in Figure 6. In relation to Figures 7A-7F, the valve is arranged as follows:

- first port opening 58a is connected to the higher pressure intake-side conduit INTHP;

- second port opening 58b, adjacent and closely arranged to the first port is connected to the higher pressure exhaust-side conduit EXHP;

- third port opening 58c, non-adjacent and diametrically opposed to the first port is connected to the lower pressure exhaust-side conduit EXLP, and

- fourth port opening 58d, adjacent and remotely arranged to the first port, is connected to the lower pressure intake-side conduit INTLP.

With this arrangement, at least the following operating modes can be obtained:

- Figure 7A shows an exclusive turbine by-pass mode, with fourth port opening obstructed by the wider obstructing sector 621, communication between second and third port openings through first flow chamber 52A, first port opening 58a only in communication with second flow chamber 52B. In figure 7A, the narrower obstructing sector 622 obstructs partially the second port opening connected to the higher pressure

exhaust-side conduit EXHP. In the range of positions around that of Figure 7A, it will be understood that it is possible to vary the degree of obstruction of the second port, without modifying the situation for the other ports, thereby achieving full proportional control of the flow of gases by-passing the turbine through the valve, spanning from 0 to 100% of available cross section through the valve.

- Figure 7B shows an exclusive lower pressure EGR mode, with second port opening obstructed by the wider obstructing sector, communication between third and fourth port openings through second flow chamber 52B, second port opening only in communication with first flow chamber 52A. In figure 7B, the narrower obstructing sector 622 obstructs partially the fourth port opening connected to the lower pressure intake-side conduit INTLP. In the range of positions around that of Figure 7B, it will be understood that it is possible to vary the degree of obstruction of the fourth port, without modifying the situation for the other ports, thereby achieving full proportional control of the flow of lower pressure EGR gases through the valve.

- Figure 7C shows a combined higher pressure EGR and lower pressure EGR mode, with communication between first and second port openings through second flow chamber 52B, and with communication between third and fourth port openings through first flow chamber 52A. In this mode, the wider obstructing sector 621 cooperates with the fourth inter-port sector 59da, while the narrower obstructing sector 622 cooperates with the second inter-port sector 59bc. In figure 7C full flow is available for both higher pressure EGR gases and for the lower pressure EGR gases. However, in a range of positions around that of Figure 7C, the wider obstructing sector 621 may partially obstruct the fourth port opening 58d or the first port opening 58a (to a varying extent when considering the range of positions around that of figure 7C), thereby allowing full proportional control of the flow either of the higher pressure EGR gases or of the lower pressure EGR gases through the valve. The same mode could be obtained by rotating the valve body by 180°. This mode allows having simultaneously a flow of higher pressure EGR gases and a flow of lower pressure EGR gases.

- Figure 7D shows an exclusive compressor by-pass mode, were the second port opening 58b is fully obstructed by the wider obstructing sector while the fourth port opening 58d is partially obstructed by the narrower obstructing sector 622, and is set in communication with the first port opening 58a via the first flow chamber 52A. The third port opening 58c is connected only to the second flow chamber 52B and is isolated from all other port openings. The range of positions around the position of Figure 7D allows full

proportional control of the flow of gases by-passing the compressor 36 through the valve 39. Such compressor by-pass may be used to promote heating-up of the engine arrangement.

- Figure 7E shows an exclusive higher pressure EGR mode, with third port opening obstructed by the wider obstructing sector 621, communication between first and second port openings through first flow chamber 52A, and with fourth port opening only in communication with second flow chamber 52B. The range of positions around the position of Figure 7D allows full proportional control of the flow of higher pressure EGR gases through the valve 39.

- Figure 7F shows a blocking mode, where no gases can flow through the valve. Two diametrically opposed port openings, in this case the first and the third port openings, are simultaneously obstructed, respectively by the wider and by the narrower obstructing sectors 621, 622. The other two port openings are set in communication only with one of the two respective flow chambers 52A, 52B, and are therefore separated fluidically by the separation wall 64. The same blocking mode can be obtained with the obstructing sectors blocking simultaneously the second and fourth opening ports.

Figures 8A-8E shows an embodiment of the invention very close to the embodiment of figures 7A-7F, with the use of a valve as depicted in Figure 3 in an engine arrangement layout as shown in Figure 6. However, is this embodiment, the valve is connected differently, with:

- first port opening 58a is connected to the higher pressure exhaust-side conduit EXHP;
- second port opening 58b, adjacent and closely arranged to the first port is connected to the lower pressure exhaust-side conduit EXLP;
- third port opening 58c, non-adjacent and diametrically opposed to the first port is connected to the lower pressure intake-side conduit INTLP, and
- fourth port opening 58d, adjacent and remotely arranged to the first port, is connected to the higher pressure intake-side conduit INTHP.

This embodiment allows the following modes:

- fully controllable turbine by-pass mode, as shown in Figure 8A;
- fully controllable lower pressure EGR mode, as shown in figure 8B;
- fully controllable higher pressure EGR mode, as shown in figure 8C;
- fully controllable compressor by-pass mode, as shown in Figure 8E; and

- blocking mode, as shown in Figure 8D.

Moreover, with a valve position analogous to that of figure 7C, the embodiment of Figures 8A-to 8E would allow a further combined compressor and turbine by-pass mode.

On Figures 9A to 9E is shown a further embodiment of a four way rotary valve 39 which can be used in an engine arrangement according to the invention.

In this design, the valve housing 50 exhibits four ports and port openings 58a, 58b, 58c, 58d which are arranged at irregular angular distance one from the other, with no port being diametrically opposed to any other. The valve body 60 is not symmetrical, so that the wider and narrower obstructing sectors 621, 622 are not diametrically opposed. The wider and narrower obstructing sectors 621, 622 are asymmetrical in angular extent, but also in their angular position, with their respective median axis MA1, MA2 which are not aligned. In this design, the narrower obstructing sector may however obstruct a port opening.

As a summary, the valve 39 as shown in Figures 9A-9G may have the following dimensions, in terms of angular extent around the central axis A0:

Port openings	Inter-port sect. 59ab	Inter-port sector 59bc	Inter-port sector 59cd	Inter-port sector 59da	Wider obstructing sector	Narrower Obstructing sector	Flow Chamber 52A	Flow chamber 52B
26°	21°	95°	55°	85°	72°	50°	134°	104°

This valve can be used in the layout of the engine arrangement as shown on figure 6, with the following connections in the EGR circuit:

- first port opening 58a is connected to the higher pressure intake-side conduit INTHP;
- second port opening 58b, adjacent and closely arranged to the first port is connected to the higher pressure exhaust-side conduit EXHP;
- third port opening 58c, non-adjacent to the first port, is connected to the lower pressure exhaust-side conduit EXLP, and
- fourth port opening 58d, adjacent and remotely arranged to the first port, is connected to the lower pressure intake-side conduit INTLP.

This embodiment allows the following modes:

- turbine by-pass mode, as shown in Figure 9A;

- combined lower pressure EGR and higher pressure EGR mode, as shown in figure 9B;
- higher pressure EGR mode, as shown in figure 9C;
- compressor by-pass mode, as shown in Figure 9E; and
- blocking mode, as shown in Figure 9D.

On Figures 10A to 10E is shown a further embodiment of a four way rotary valve 39 which can be used in an engine arrangement according to the invention.

In this design, the valve housing 50 exhibits four ports and port openings 58a, 58b, 58c, 58d which are arranged at irregular angular distance one from the other, with no port being diametrically opposed to any other. The valve body 60 is not symmetrical, so that the wider and narrower obstructing sectors 621, 622 are not diametrically opposed. The wider and narrower obstructing sectors 621, 622 are asymmetrical in angular extent, but also in their angular position, with their respective median axis MA1, MA2 which are not aligned. In this design, the narrower obstructing sector may however obstruct a port opening.

As a summary, the valve 39 as shown in Figures 10A-10E may have the following dimensions, in terms of angular extent around the central axis A0:

Port openings	Inter-port sect. 59ab	Inter-port sector 59bc	Inter-port sector 59cd	Inter-port sector 59da	Wider obstructing sector	Narrower Obstructing sector	Flow Chamber 52A	Flow chamber 52B
26°	37°	66°	45°	108°	90°	41°	90°	139°

This valve can be used, for example, in the layout of the engine arrangement as shown on figure 6, with the following connections in the EGR circuit:

- first port opening 58a is connected to the higher pressure exhaust-side conduit EXHP;
- second port opening 58b, adjacent and closely arranged to the first port is connected to the lower pressure exhaust-side conduit EXLP;
- third port opening 58c, non-adjacent to the first port is connected to the lower pressure intake-side conduit INTLP, and
- fourth port opening 58d, adjacent and remotely arranged to the first port, is connected to the higher pressure intake-side conduit INTHP.

This embodiment allows the following modes:

- controllable turbine by-pass mode, as shown in Figure 10A;
- controllable lower pressure EGR mode, as shown in figure 10B;
- controllable higher pressure EGR mode, as shown in figure 10C;
- combined turbine and compressor by-pass mode, as shown in Figure 10E; and
-blocking mode, as shown in Figure 10D.

In Figure 11A-11E is shown another embodiment of a four way rotary valve 39 which can be used in any of the arrangements as those shown in figures 2 or 6 or any variant thereof.

The rotary valves of Figures 3 and of Figures 11A-11E have in common that:

- the 4 ports are arranged by pairs where two opening ports of the same pair are diametrically opposed with respect to central axis;
- the obstructing sectors of the valve body comprise a wider 621 and a narrower 622 obstructing sectors which are of a different angular extent around the central axis;
- the separation wall 64 is symmetrical with respect to a diametrical plane DP of the rotary body;
- the angular extent of the narrower obstructing sector 622 is at least as large as the angular extent of a port opening, preferably at least as large as the angular extent of any of the port openings;
- the angular extent of the wider obstructing sector 621 is at least twice as large as the angular extent of a port opening, preferably twice as large as the angular extent of any of the port openings;
- each flow chamber extends angularly around the central axis along an open sector between the two obstructing sectors, and both of the open sectors have an extent so as to allow unobstructed flow of fluid through the corresponding chamber from one port opening to only one adjacent port opening.

Also, the wider obstructing sector 621 is preferably narrower than at least one of the inter port sectors, preferably narrower than all the inter-port sectors.

The 4 port openings are arranged in diametrically opposite pairs, preferably regularly at 90° from each other as in the case of embodiment of Figures 11A-11E. Especially in the latter case, the four port openings may have the same angular extent, so that the four inter-port sectors have also the same angular extent.

The embodiment of Figures 11A-11E has the further features that the difference in angular extent between the two obstructing sectors is at least twice as large as the angular extent of a port opening. This allows that one port opening is fully cleared by the narrower obstructing sector 622 before the opposite port opening starts to be cleared by the wider obstructing sector 621. In the case where the narrower obstructing sector 622 has approximately the same angular extent as a port opening, the angular extent of the wider obstructing sector 621 may be at least three times as large as the angular extent of at least one of the port openings. Preferably, this is true for all ports.

As a summary, the valve 39 as shown in Figures 11A-11E may have the following dimensions, in terms of angular extent around the central axis A0:

Port openings	Inter-port sect. 59ab	Inter-port sector 59bc	Inter-port sector 59cd	Inter-port sector 59da	Wider obstructing sector	Narrower Obstructing sector	Flow Chamber 52A	Flow chamber 52B
20°	70°	70°	70°	70°	65°	25	135°	135°

The valve design of Figure 11 allows having the same possible sets of positions and operating modes for each of the four ports, thereby multiplying the number of available modes of operation.

Some of these modes are represented on Figures 11A to 11E.

Figure 11A shows a position of the valve 39 where the wider obstructing sector 621 obstructs the second port opening 58b, while the narrower obstructing sector obstructs the fourth port opening 58d. The first port opening 58a is connected to only the first flow chamber 52A, so that no flow is possible though the first port opening. The third port opening 58a is connected to only the second flow chamber 52B, so that no flow is possible through the third port opening 58c. This is a blocking state of the valve where no fluid may flow through the valve 39.

At Figure 11B, the valve body 60 has been rotated in one direction such that the fourth port opening 58d is now partially cleared by the narrower obstructing sector 622, and is now set in fluid communication with the third port 58c. The wider obstructing sector still obstructs the second port opening 58b, and the first port opening is also still separated of all other ports. A controlled amount of fluid may therefore flow through the second flow chamber 52B of the valve 39 between the third and fourth openings.

At figure 11C, the valve body has been further rotated such that now the fourth port opening 58d is now fully cleared by the narrower obstructing sector 622, and is in fluid communication with the third port 58c, which itself is still fully cleared. The wider obstructing sector still obstructs the second port opening 58b, and the first port opening 58a is also still separated of all other ports. A full flow of fluid may therefore flow through the second flow chamber 52B of the valve 39 between the third and fourth openings. The range of positions between those of Figures 11A and 11C allows full proportional control of the flow between the third and fourth openings, while flow through the other two port openings remains blocked

At Figure 11D, the valve body has been further rotated such that now the third and fourth port openings 58c, 58d remain fully cleared and in fluid communication through the second flow chamber 52B. However, the wider obstructing sector 621 now partially clears the second port opening 58b which is set in communication with the first port openings 58a, so that a controlled flow of fluid may therefore flow through the first flow chamber 52A of the valve 39 between the first and second port openings 58a, 58b, while a full flow of fluid may still flow through the second flow chamber 52B of the valve 39 between the third and fourth openings 58c, 58d.

At Figure 11E the valve body has been further rotated such all ports are fully cleared by the obstructing sectors, so that a full flow of fluid may flow through the first flow chamber 52A of the valve 39 between the first and second port openings 58a, 58b, while a full flow of fluid may still flow through the second flow chamber 52B of the valve 39 between the third and fourth openings 58c, 58d.

The same functioning can be repeated for each of the four quadrants of the valve, thereby allowing all possible combinations of fully controlled flows between two sets of two adjacent port openings.

From the above, it can be derived that the valve according to Figures 11A-11E allows full proportional control of the flow through the valve between any two adjacent port openings of the four port openings. It also allows controlling simultaneously two separate flows of fluid through the valve, where one flow can be fully proportionally controlled, while the other flow is set to full flow or no flow. It also allows controlling simultaneously two separate flows of fluid through the valve, where one flow can be fully proportionally controlled through any one of the pairs of adjacent port openings, while the other flow is set to full flow or no flow through the other two port openings.

The valve of Figure 11A-11D can be used with the layout of Figure 2 with the same port connections as those explained in relation to the embodiment of figures 3A to 3F. It can be also used in the context of a layout as shown in figure 6, with the same port connections as those explained in relation to the embodiment of figures 7A to 7F, or with the same port connections as those explained in relation to the embodiment of figures 8A to 8E.

For the sake of clarity, in the above description, the EGR circuit is not limited to conveying EGR gases, but is also used to convey by-pass gases by-passing one or several compressors or bypassing one or several turbine of the turbocharging system.

In the different designs of the valve which have been described here above, the valve can be closed axially at its both ends along the central axis by two terminal surfaces of the valve housing perpendicular to the central axis A0, thereby fully delimiting the internal volume 52 of the valve in which the valve body can rotate.

CLAIMS

1. Turbocharged engine arrangement having:

- an internal combustion engine (12);

- an exhaust line (24) collecting exhaust gases from the engine and conveying those exhaust gases to the atmosphere;

- an intake line (20) conveying fresh air from the atmosphere to the engine;

- a turbocharger system (32) comprising at least one turbocharger comprising a compressor (36, 36', 36'') in the intake line driven by a turbine (34, 34', 34'') in the exhaust line;

- an exhaust gases recirculation system (38) comprising at least:

* one higher pressure exhaust-side conduit (EXHP) connected to the exhaust line upstream of a least one turbocharger turbine of the turbocharger system;

* one lower pressure exhaust-side conduit (EXLP, EXLP1, EXLP2) connected to the exhaust line downstream of a least one turbocharger turbine of the turbocharger system;

* one principal intake-side conduit (INT, INTLP, INTHP) connected to the intake line;

characterized in that the exhaust gases recirculation system comprises a single rotary valve (39) having at least three ports opening (58a, 58b, 58c, 58d) and a rotary body (60), each of said port openings being fluidically connected to one different of the exhaust gases recirculation system conduits, and in that the valve is configured to define at least the following operating modes by connecting:

- higher pressure exhaust-side conduit (EXHP) with one intake-side conduit (INT, INTHP), to achieve a higher pressure exhaust gas recirculation mode;

- lower pressure exhaust-side conduit (EXLP, EXLP1, EXLP2) with one intake-side conduit (INT, INTLP), to achieve a lower pressure exhaust gas recirculation mode;

- higher pressure exhaust-side conduit (EXHP) with lower pressure exhaust-side conduit (EXLP, EXLP2), to achieve a turbine by-pass mode.

2. Turbocharged engine arrangement according to claim 1, characterized in that the rotary valve (39) is configured to be able to achieve each of the higher pressure exhaust

gas recirculation mode, of the lower pressure exhaust gas recirculation mode and of the turbine by-pass mode exclusively of the other modes.

3. Turbocharged engine arrangement according to claim 1 or 2, characterized in that the rotary valve (39) is configured to be able to achieve a blocking mode where no port opening is connected to another port opening through the valve.

4. Turbocharged engine arrangement according to any preceding claim, characterized in that each mode corresponds to a distinct range of positions of the valve body.

5. Turbocharged engine arrangement according to any preceding claim, characterized in that the single rotary valve (39) comprises at least 4 port openings (58a, 58b, 58c, 58d) and a rotary body (60), in that the exhaust gas recirculation system comprises an additional lower pressure exhaust-side conduit (EXLP2) connected to the exhaust line downstream of a least one turbocharger turbine of the turbocharger system, and in that the each of said port openings is fluidically connected to one different conduit of the exhaust gases recirculation system.

6. Turbocharged engine arrangement according to claim 5, characterized in that the rotary valve (39) is configured to be able to achieve a combined higher pressure exhaust gas recirculation and turbine by-pass mode, wherein a lower pressure exhaust-side conduit (EXLP1) is connected to an intake-side conduit (INT) through the valve, and wherein the higher pressure exhaust-side conduit (EXHP) is connected independently with the other lower pressure exhaust-side conduit (EXLP2) through the valve (39).

7. Turbocharged engine arrangement according to claim 6, characterized in that the rotary valve (39) is configured to be able to proportionally control, in the combined higher pressure exhaust gas recirculation and turbine by-pass mode, the flow rate of exhaust gases by-passing the turbine or the flow rate of exhaust gases being recirculated.

8. Turbocharged engine arrangement according to any of claims 1 to 4, characterized in that the single rotary valve (39) comprises at least 4 opening ports (58a, 58b, 58c, 58d) and a rotary body (60), in that the exhaust gas recirculation system comprises an additional higher pressure intake-side conduit (INTHP) connected to the intake line

downstream of a least one turbocharger compressor of the turbocharger system, in that the principal intake-side conduit (INTLP) is connected to the intake line upstream of a least one turbocharger compressor, and in that each of said port openings is fluidically connected to one different of said exhaust gases recirculation conduits.

9. Turbocharged engine arrangement according to claim 8, characterized in that the rotary valve (39) is configured to be able to achieve a combined higher and lower pressure exhaust gas recirculation mode, wherein both the higher and lower pressure exhaust-side conduits (EXHP, EXLP) are connected simultaneously respectively to the higher and the lower intake-side conduits (INTHP, INTLP) through the valve.

10. Turbocharged engine arrangement according to claim 8 or 9, characterized in that the rotary valve (39) is configured to be able to achieve a compressor by-pass mode, wherein the additional higher pressure intake-side conduit (INTHP) is connected with the principal pressure intake-side conduit (INTLP), with a variable cross section through the valve, to achieve a compressor by-pass mode.

11. Turbocharged engine arrangement according to any of claims 8 to 10, characterized in that the rotary valve (39) is configured to be able to achieve a combined turbine and compressor by-pass mode, wherein the additional higher pressure intake-side conduit (INTHP) is connected with the principal pressure intake-side conduit (INTLP), while the higher pressure exhaust-side conduit (EXHP) is connected independently with the lower pressure exhaust-side conduit (EXLP, EXLP2).

12. Turbocharged engine arrangement according to any preceding claim, characterized in that the turbocharging system comprises a second turbocharger comprising a compressor in the intake line driven by a turbine in the exhaust line.

13. Turbocharged engine arrangement according to claim 12, characterized in that the two turbines (34', 34'') are arranged in series in the exhaust line and the two compressors (36', 36'') are arranged in series in the intake line.

14. Rotary valve for an exhaust gases system, comprising:

- a valve housing (50) of circular cylindrical shape wherein:

* an internal volume (52) is defined by an internal circular cylindrical surface (54) around a central axis (A0);

* at least four ports openings (58a, 58b, 58c, 58d) are formed in the internal circular cylindrical surface to allow entry or exit of exhaust gases in or out of the valve internal volume, the four port openings being angularly spaced around the central axis (A0);

* at least four inter-port sectors (59ab, 59bc, 59cd, 59da) of the internal circular cylindrical surface (54) are defined, each extending between two adjacent port openings, and each having an angular extent around the central axis (A0);

- a rotary valve body (60) received in the internal volume (52) of the valve housing and able to rotate around the central axis (A0), the rotary valve body having a separation wall (64) extending across the internal volume to divide the internal volume in two separate flow chambers (52a, 52B) thanks to a first obstructing sector (621) and a second obstructing sectors (622) of the wall which cooperate with the inter-port sectors of the internal circular cylindrical surface to fluidically separate the two flow chambers;

characterized in that the obstructing sectors (621,622) of the valve body and the port openings (58a, 58b, 58c, 58d) of the valve housing are arranged such a first and a second adjacent port openings may be set in communication through one of the flow chambers (52A, 52B), while a third port is obstructed by an obstructing sector.

15. Rotary valve according to claim 14, characterized in that the obstructing sectors of the valve body and the port openings of the valve housing are arranged such that, for a further position or range of positions of the valve body, the first and second adjacent ports are set in only partial communication, while the third port is maintained port is obstructed by an obstructing sector.

16. Rotary valve according to claim 14 or 15, characterized in that the obstructing sectors of the valve body comprise a wider (621) and a narrower (622) obstructing sectors which are of a different angular extent around the central axis.

17. Rotary valve according to any of claims 14 to 16, characterized in that the obstructing sectors are arranged so that, for a range of angular positions of the body, the wider obstructing sector (621) obstructs a given port opening while the smaller obstructing sector (622) only partially obstructs the port opening which is not adjacent to the given

port opening, the degree of obstruction of the not adjacent port being variable over the range of angular positions.

18. Rotary valve according to any of claims 14 to 17, characterized in that the port openings are arranged by pairs of two non-adjacent port openings, and in that the obstructing sectors of the valve body are arranged to:

- for a first position or range of positions of the valve body, obstruct both port openings of one pair;

- for a second position or range of positions of the valve body, obstruct one port opening of the pair and at least partially clearing the other port opening of the pair.

19. Rotary valve according to claim 18, characterized in that the second position or range of positions is adjacent to the first position or range of positions.

20. Rotary valve according to any of claims 16 to 19, characterized in that the angular extent of the narrower obstructing sector (622) is at least as large as the angular extent of a port opening.

21. Rotary valve according to any of claims 16 to 20, characterized in that the angular extent of the wider obstructing sector (621) is at least twice as large as the angular extent of a port opening.

22. Rotary valve according to claim 21, characterized in that the angular extent of the wider obstructing sector (621) is at least three times as large as the angular extent of a port opening.

23. Rotary valve according to any of claims 14 to 22, characterized in that the difference in angular extent between the two obstructing sectors (621, 622) is at least twice as large as the angular extent of a port opening.

24. Rotary valve according to any of claims 14 to 23, characterized in the opening ports are arranged by pairs where two port openings of the same pair are diametrically opposed with respect to the central axis (A0).

25. Rotary valve according to any of claims 14 to 24, characterized in that the separation wall (64) is symmetrical with respect to a diametrical plane (DP) of the rotary body (60).

26. Rotary valve according to any of claims 14 to 25, characterized in that at least one inter-port sector (59ab, 59bc, 59cd, 59da) is narrower in angular extent than at least one other inter-port sector.

27. Rotary valve according to any of claims 14 to 26, characterized in that each flow chamber (52A, 52B) extends angularly around the central axis (AO) along an open sector between the two obstructing sectors (621, 622), and in that at least one of the open sectors has an extent (FCA, FCB) so as to allow unobstructed flow of fluid through the corresponding chamber (52A, 52B) from at least one port opening to at least one adjacent port opening.

28. Rotary valve according to claim 27, characterized in that at least one of the open sectors has an extent (FCA, FCB) so as to allow unobstructed flow of fluid through the corresponding chamber from at least one port opening to only one adjacent port opening.

29. Turbocharged engine arrangement having:

- an internal combustion engine (12);
- an exhaust line (24) collecting exhaust gases from the engine and conveying those exhaust gases to the atmosphere;
- an intake line (18) conveying fresh air from the atmosphere to the engine;

a turbocharger system (32) comprising at least one turbocharger comprising a compressor in the intake line driven by a turbine in the exhaust line;

- an exhaust gases recirculation system (38) comprising at least:

* one higher pressure exhaust-side conduit (EXHP) connected to exhaust line upstream of a least one turbocharger turbine of the turbocharger system;

* one lower pressure exhaust-side conduit (EXLP, EXLP1) connected to the exhaust line downstream of a least one turbocharger turbine of the turbocharger system;

* one principal intake-side conduit (INT, INTLP) connected to the intake line

wherein the exhaust gases recirculation system (38) comprises at least one additional conduit connected to the intake line or to the exhaust line, where said additional conduit is one of:

- an additional lower pressure exhaust-side conduit (EXLP2) connected to the exhaust line downstream of a least one turbocharger turbine of the turbocharger system, or
- an additional higher pressure intake-side conduit (INTHP) connected to the intake line downstream of a least one turbocharger compressor of the turbocharger system, the principal intake-side conduit (INTLP) being connected to the intake line upstream of a least one turbocharger compressor of the turbocharger system,

an wherein each of the four conduits of the exhaust gases recirculation system is connected to a different port opening (58a, 58b, 58c, 58d) of a single rotary valve (39) according to any of the claims 14 to 28.

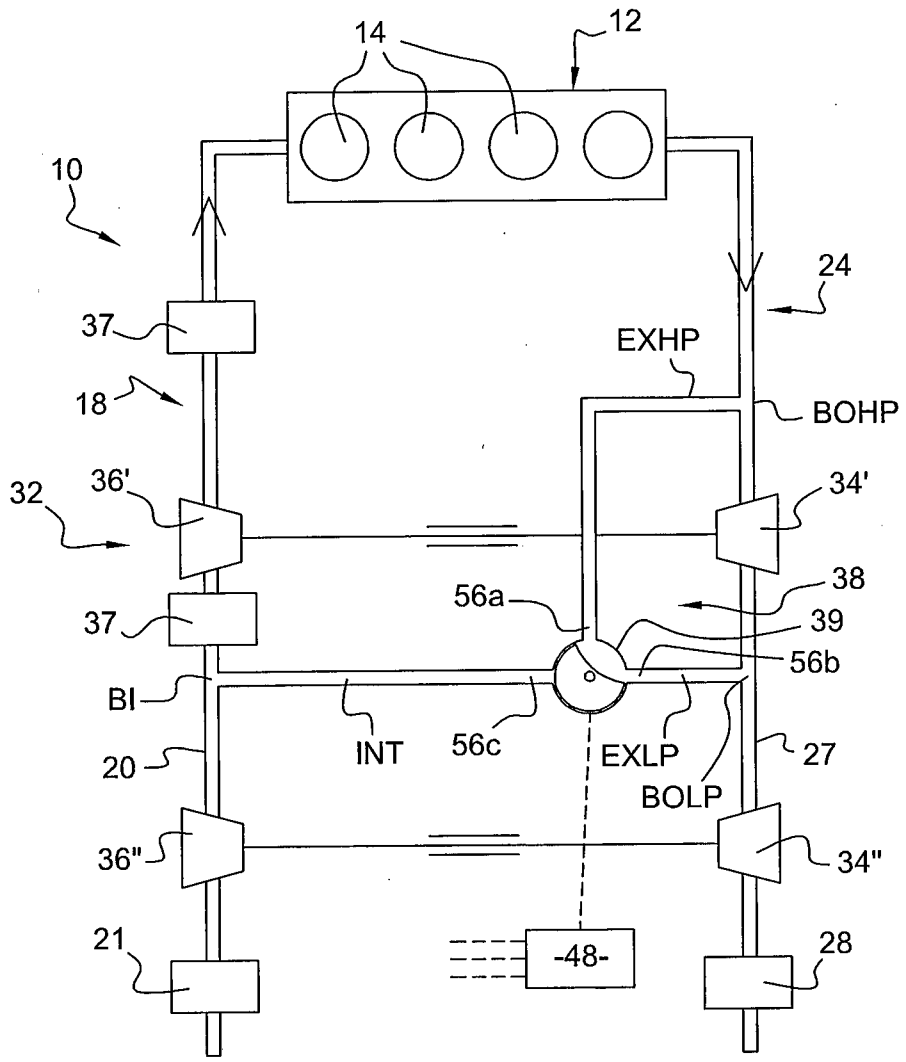

14
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37
EXHP
18
BOHP
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36'
34'
38
56a
37
39
56b
BI
INT
56c
EXLP
27
20
BOLP
36"
34"
21
-48-
28

Fig. 1

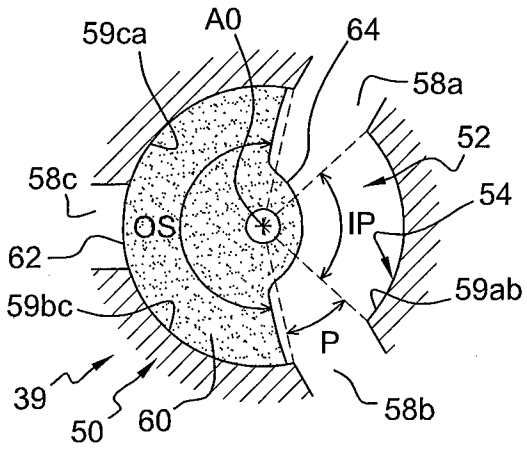


Fig. 1A

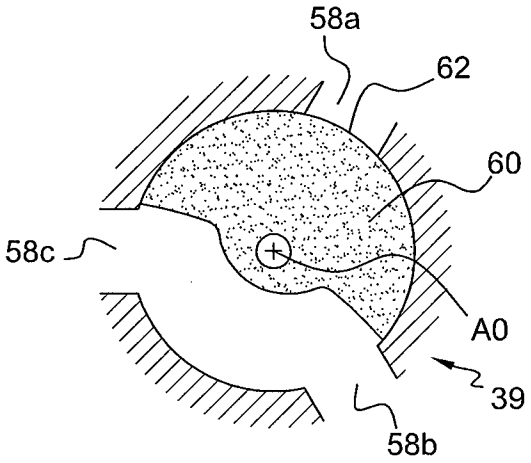


Fig. 1B

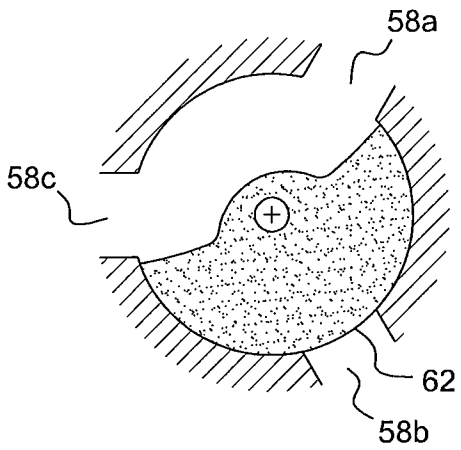


Fig. 1C

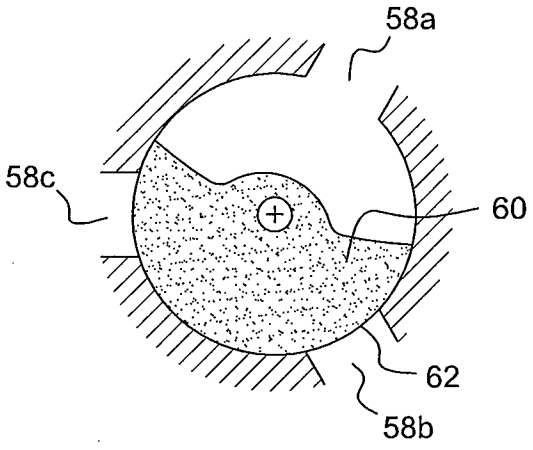


Fig. 1D

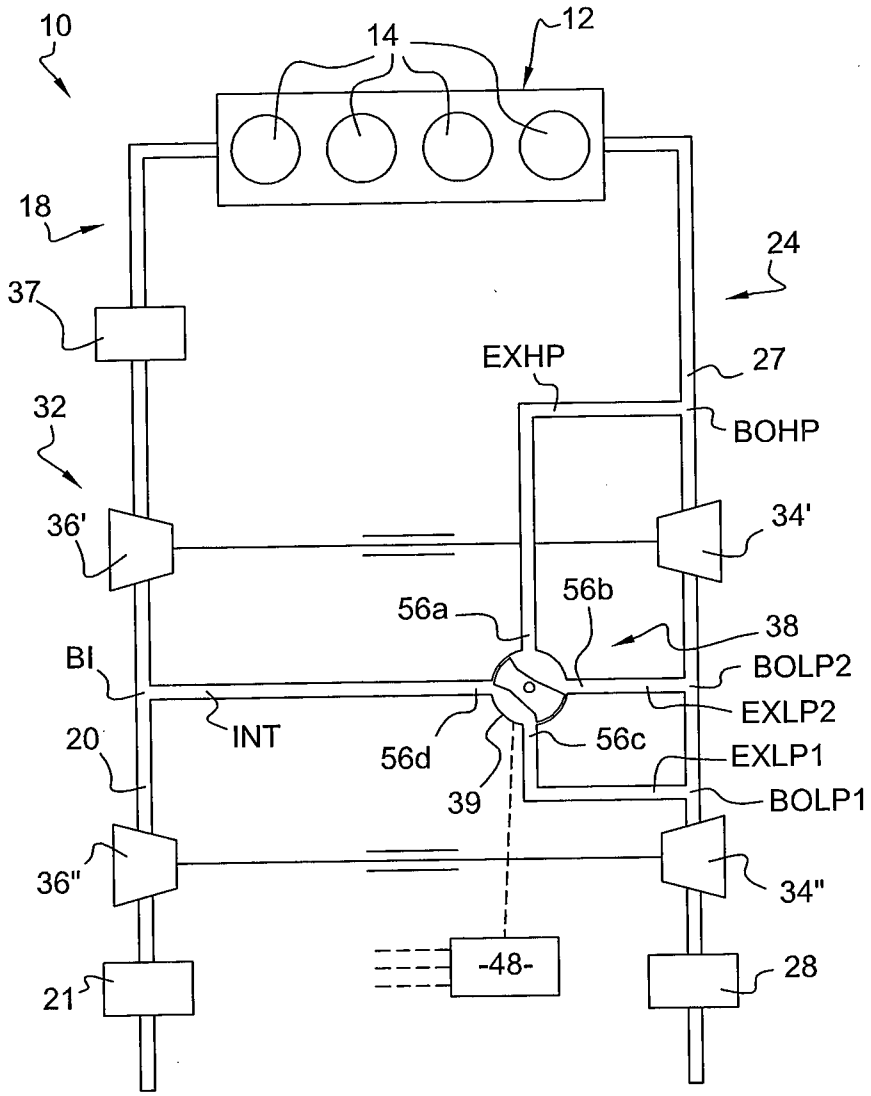

10
14
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37
EXHP
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32
BOHP
36'
34'
56a
56b
38
BI
BOLP2
INT
EXLP2
20
56d
56c
EXLP1
39
BOLP1
36"
34"
-48-
21
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Fig. 2

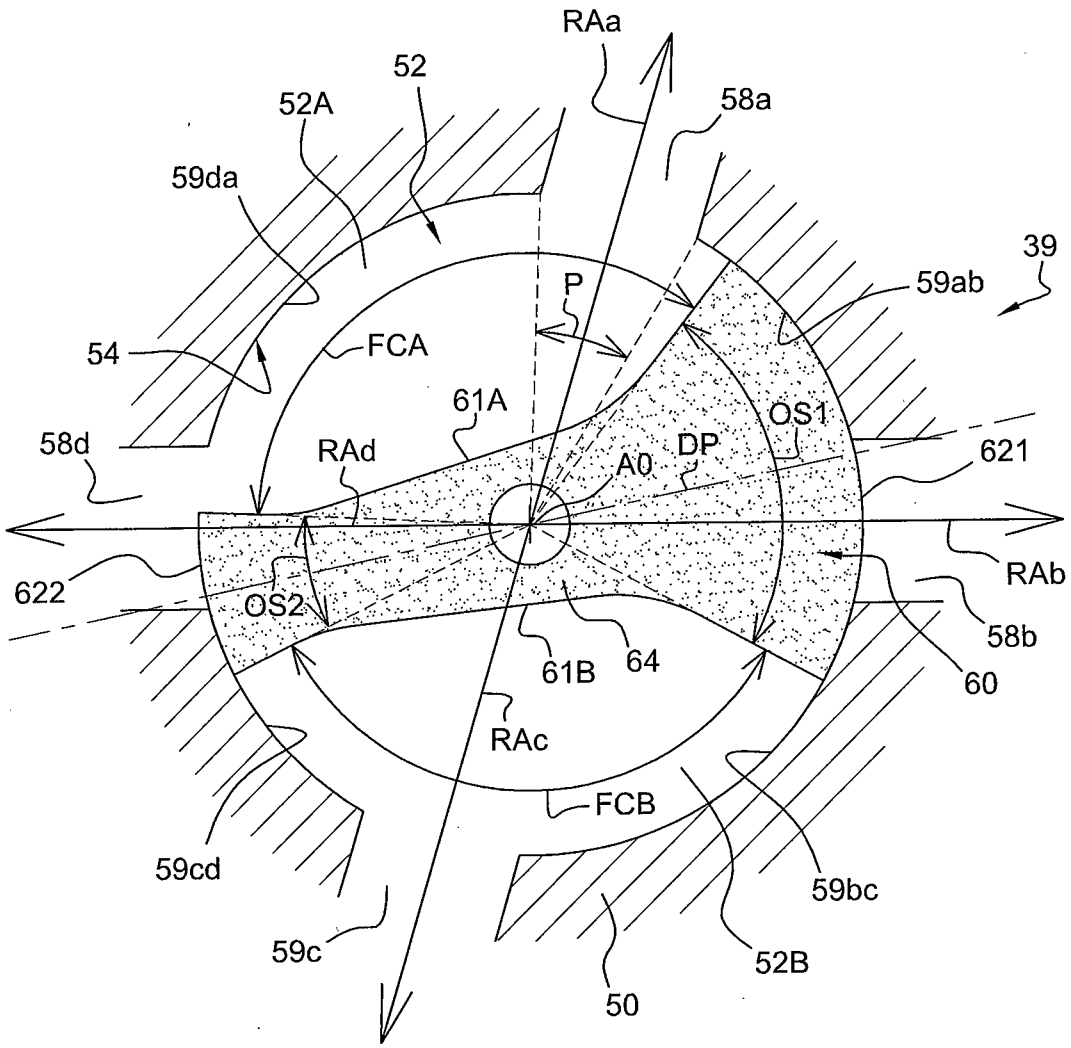

RAa
52
52A
58a
59da
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59ab
P
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FCA
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OS1
58d
RAd
A0
DP
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RAb
OS2
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RAc
FCB
59cd
59bc
59c
52B
50

Fig. 3

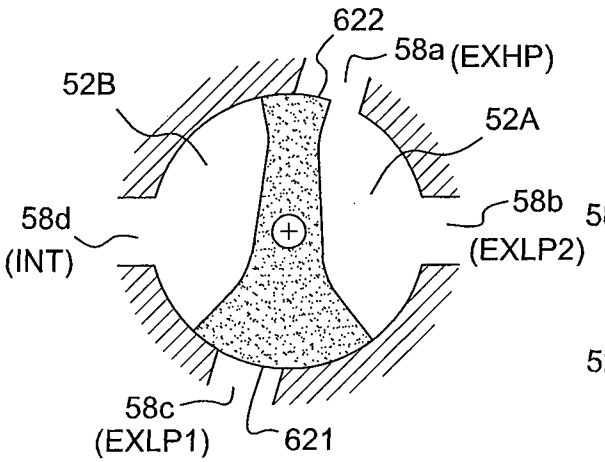


Fig. 3A

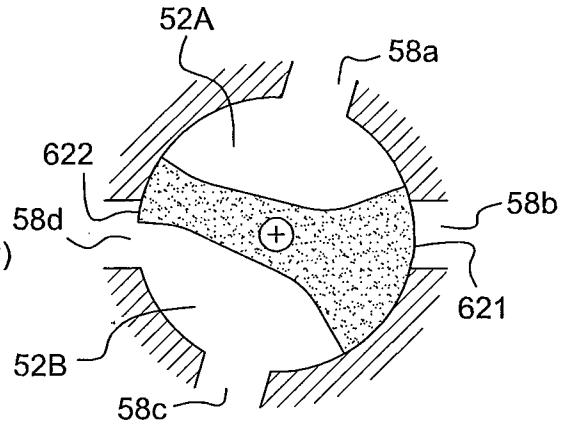


Fig. 3B

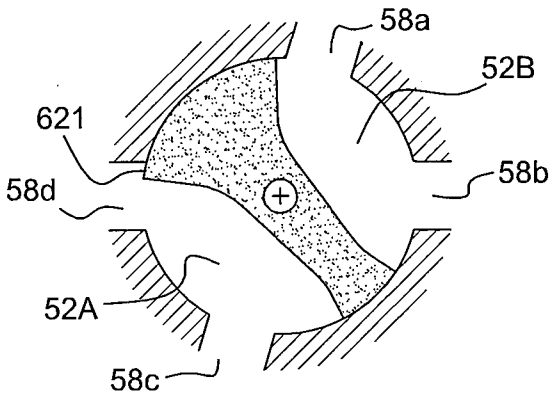


Fig. 3C

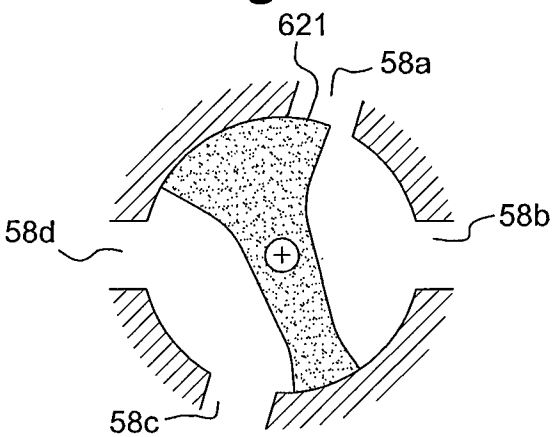


Fig. 3D

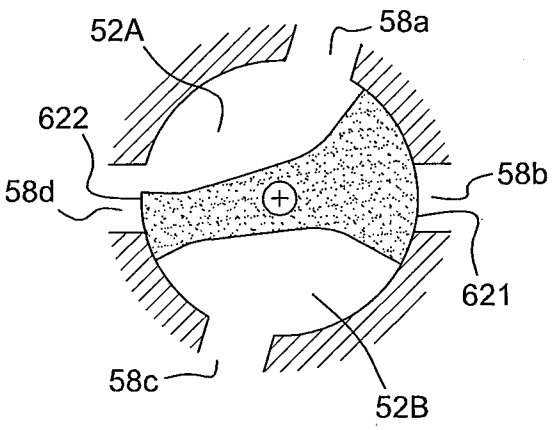


Fig. 3E

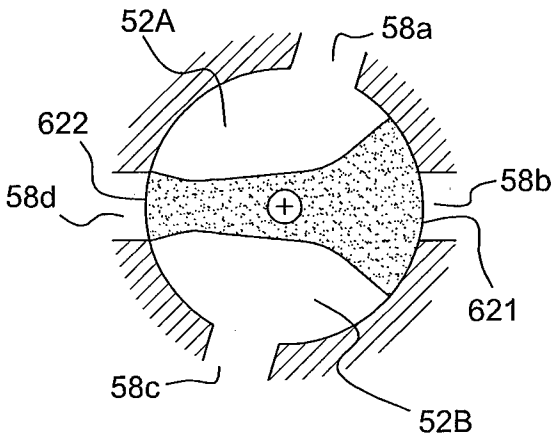


Fig. 3F

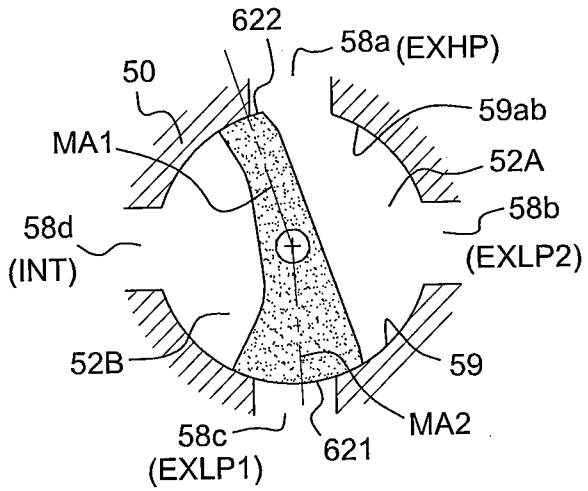


Fig. 4A

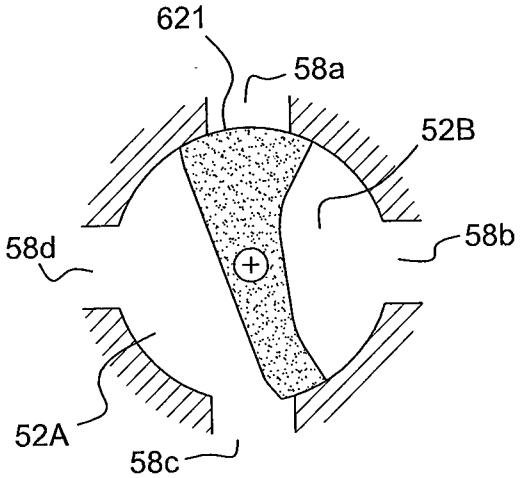


Fig. 4B

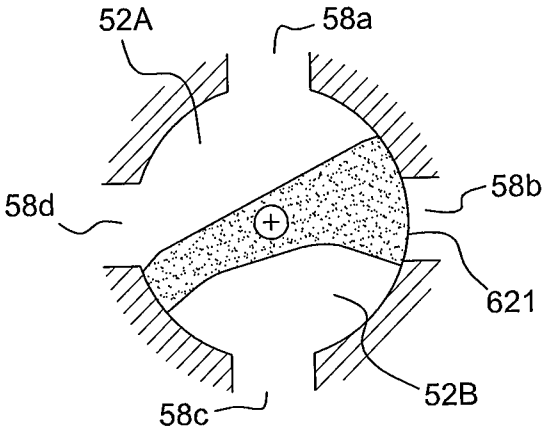


Fig. 4C

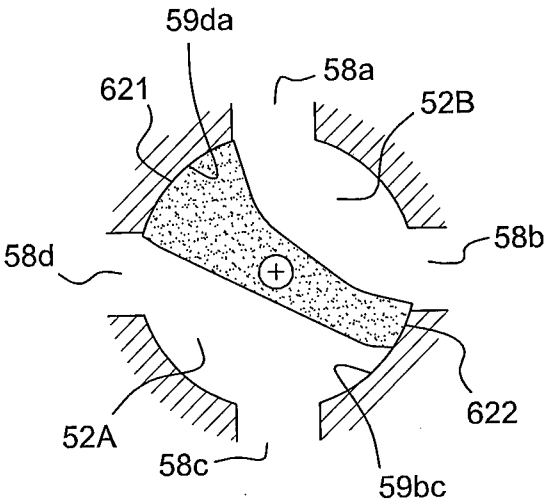


Fig. 4D

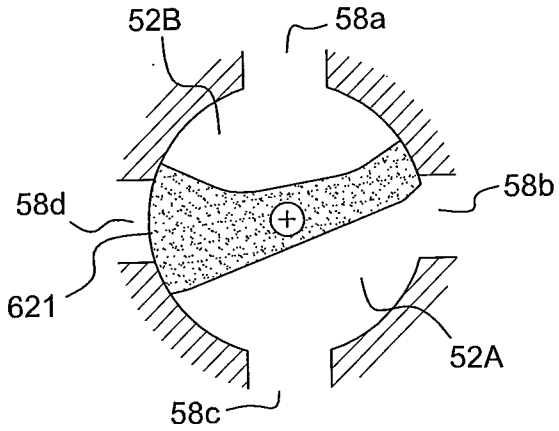


Fig. 4E

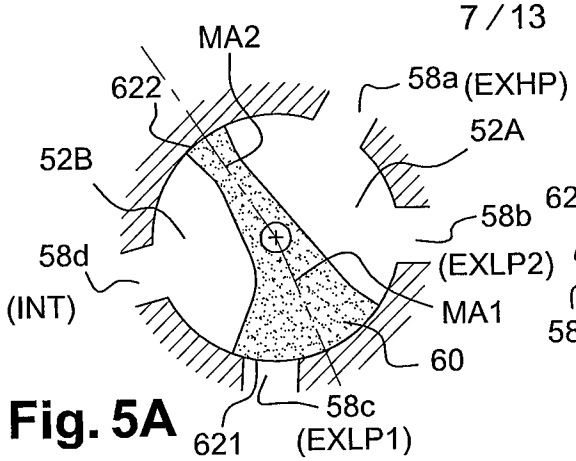


Fig. 5A

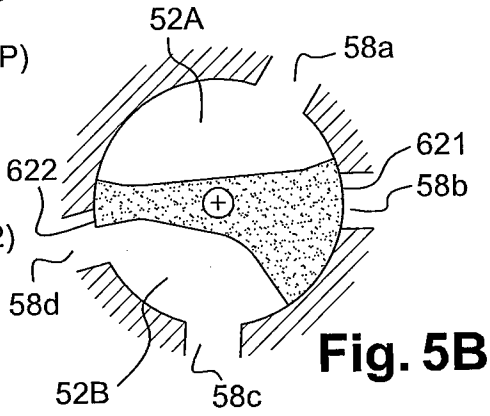


Fig. 5B

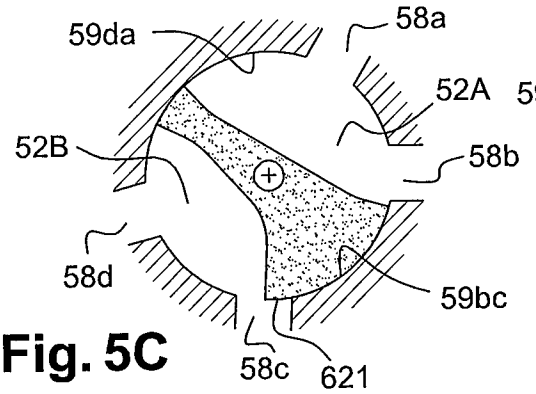


Fig. 5C

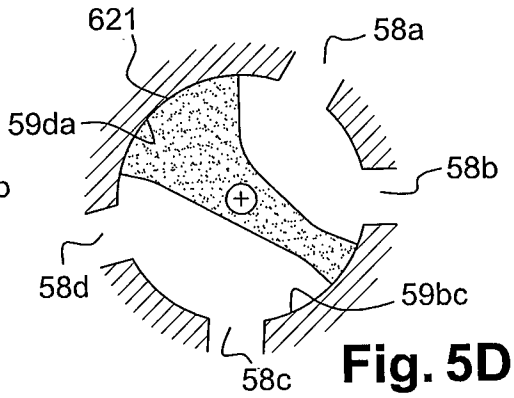


Fig. 5D

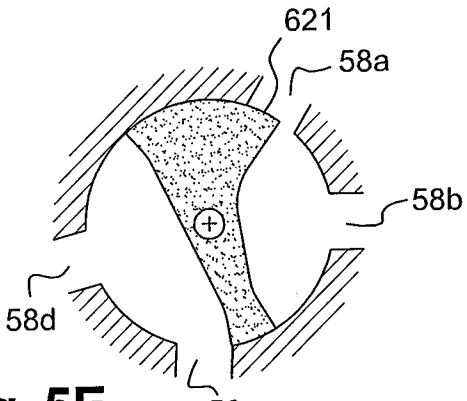


Fig. 5E

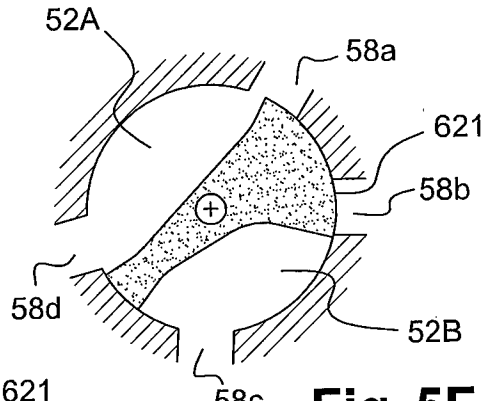


Fig. 5F

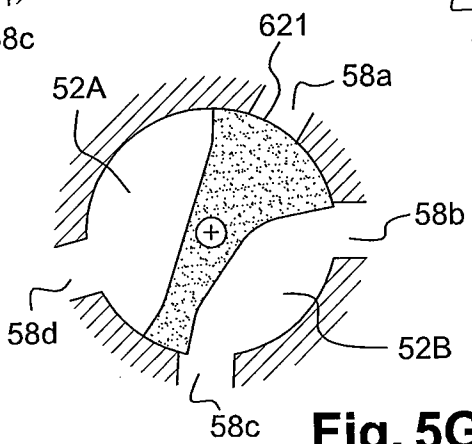


Fig. 5G

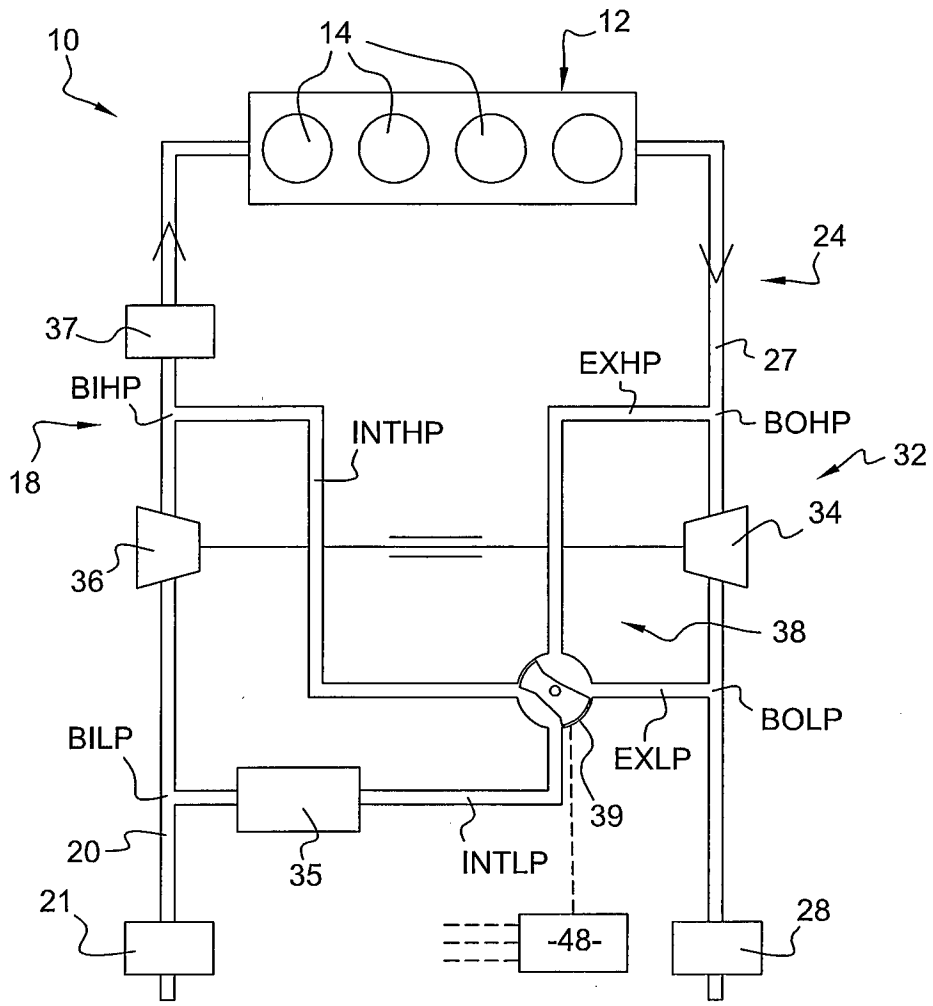

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Fig. 6

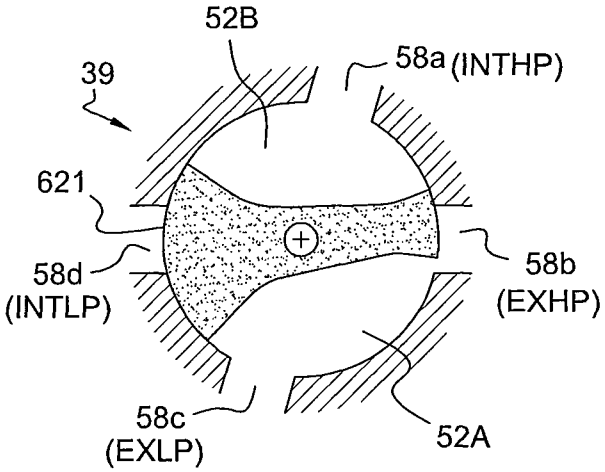


Fig. 7A

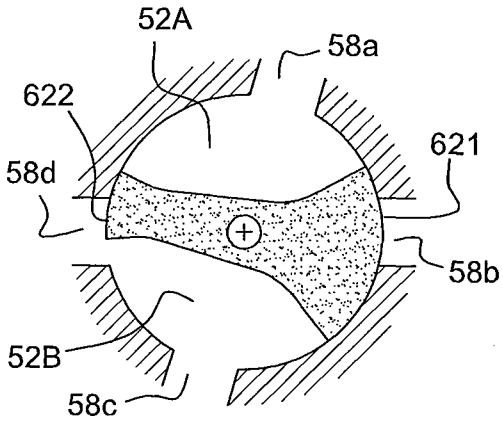


Fig. 7B

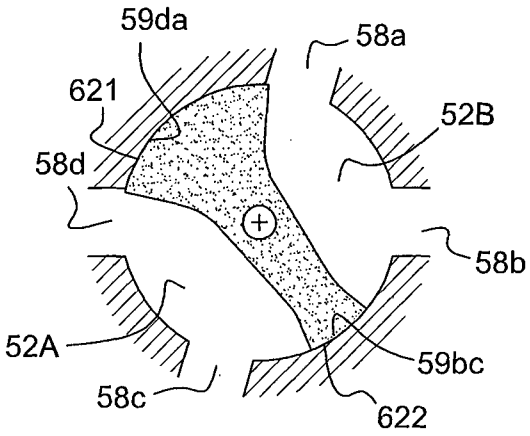


Fig. 7C

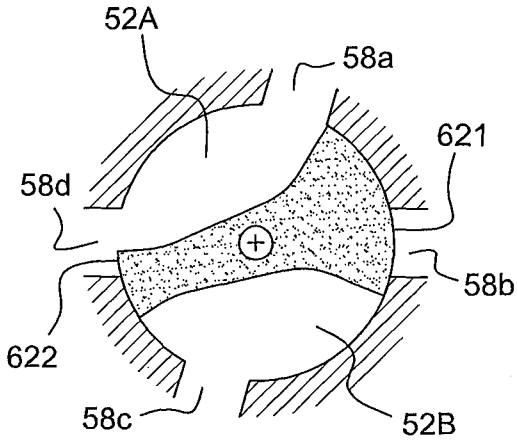


Fig. 7D

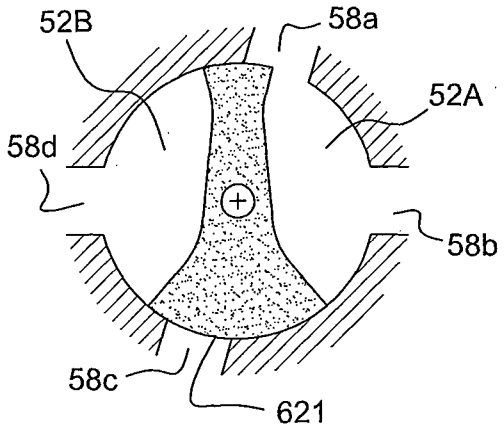


Fig. 7E

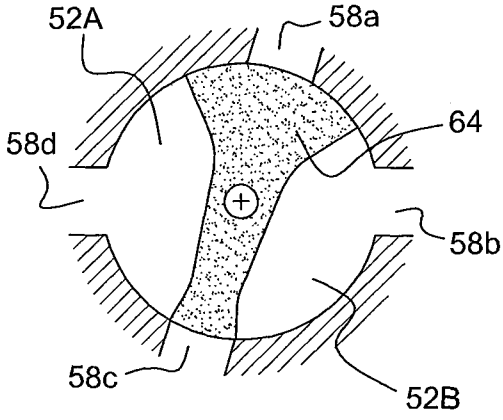


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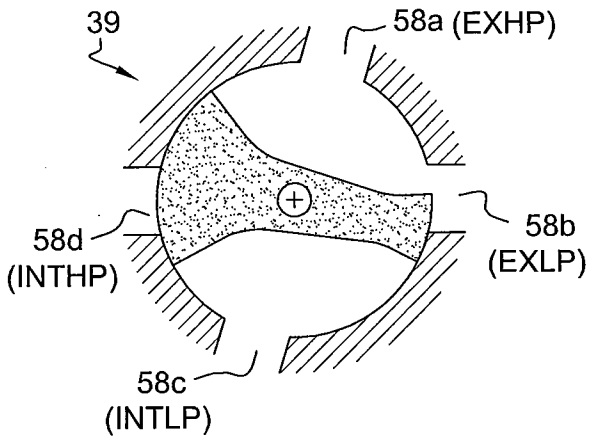


Fig. 8A

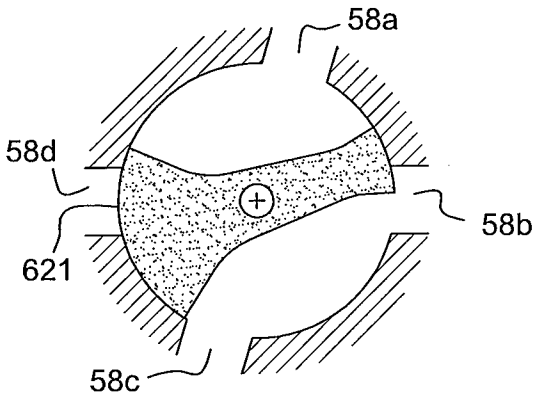


Fig. 8B

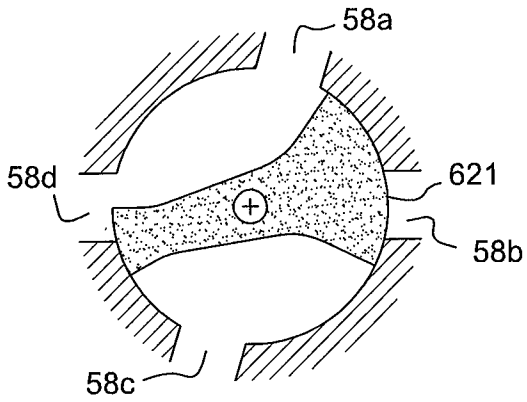


Fig. 8C

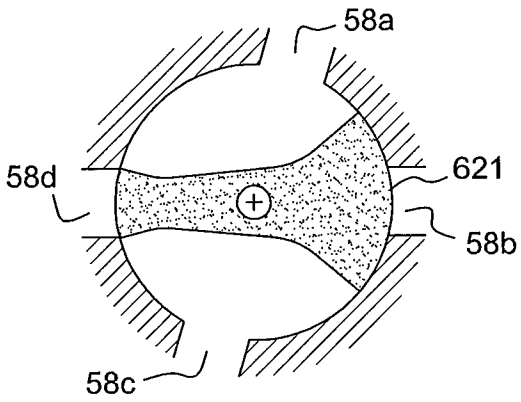


Fig. 8D

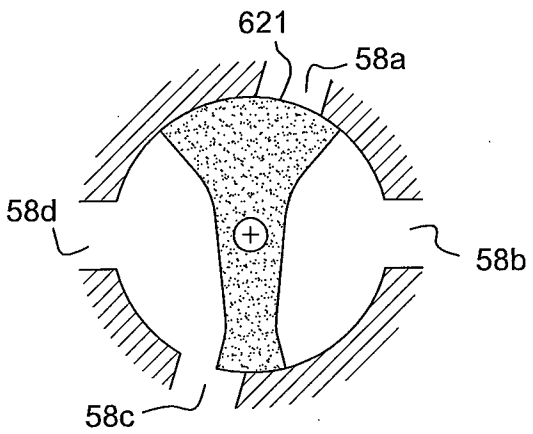


Fig. 8E

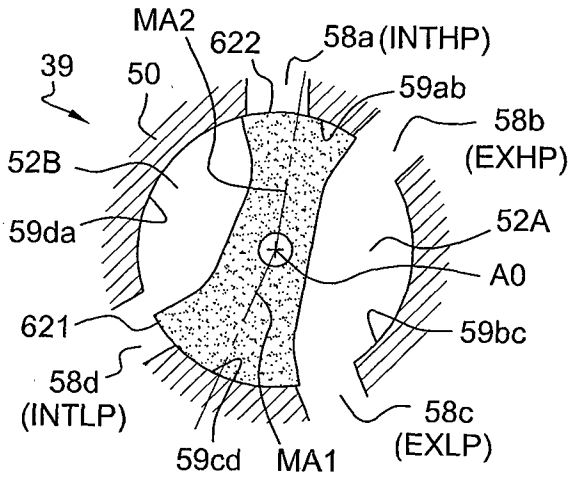


Fig. 9A

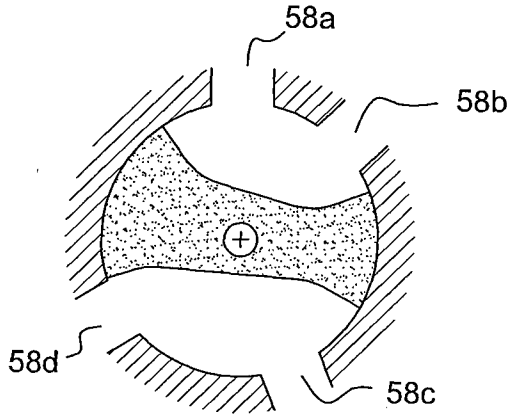


Fig. 9B

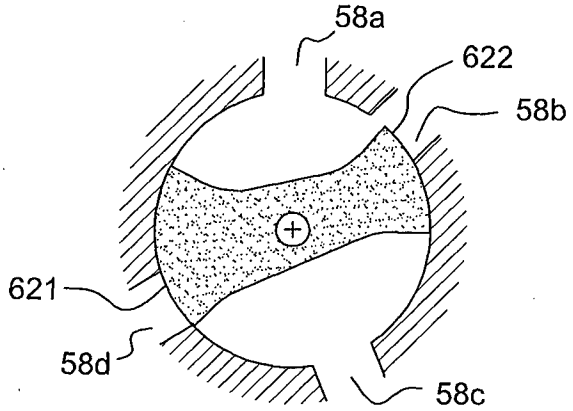


Fig. 9C

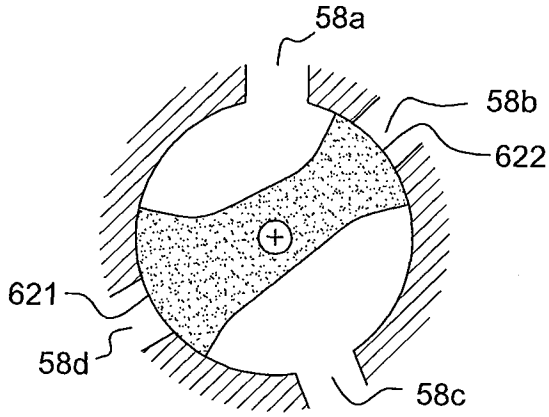


Fig. 9D

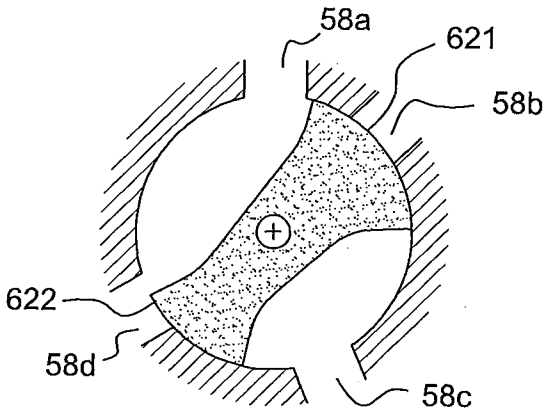


Fig. 9E

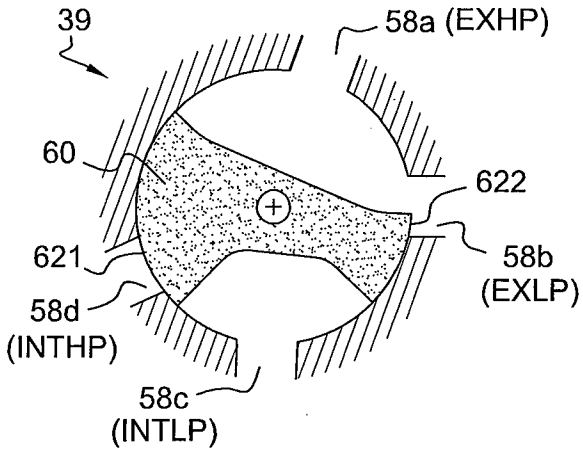


Fig. 10A

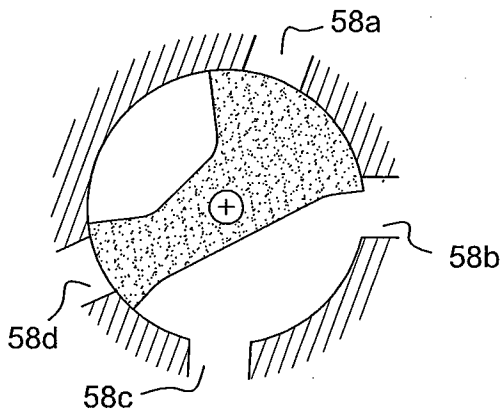


Fig. 10B

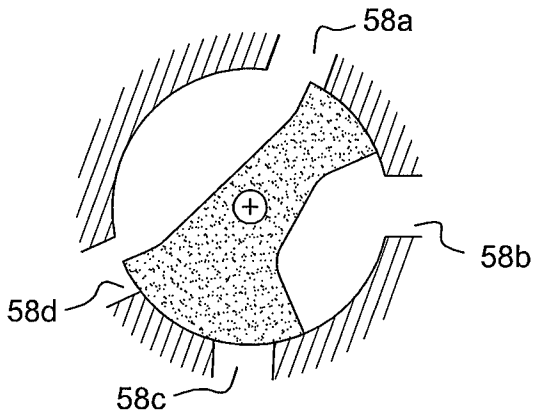


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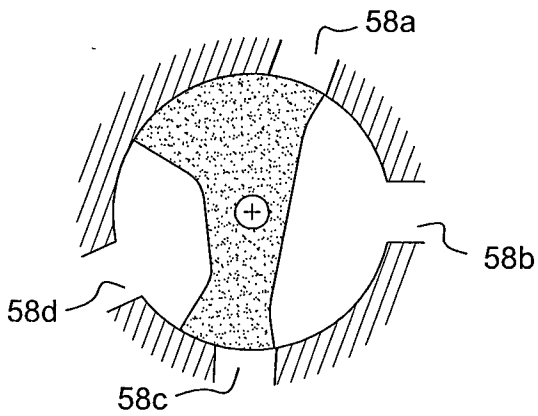


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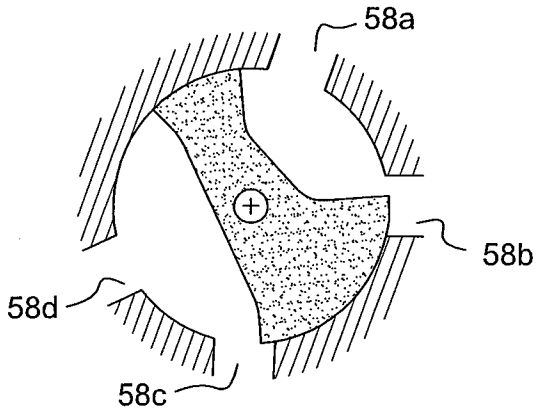


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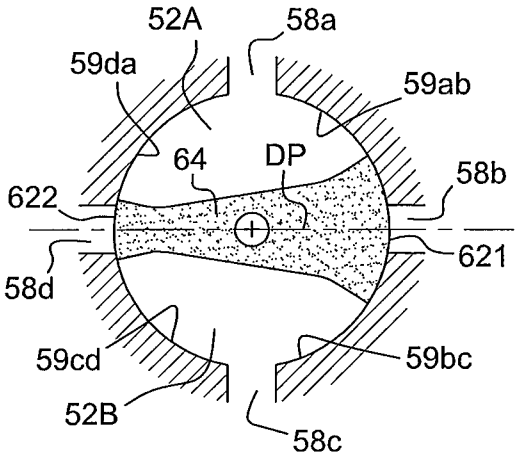


Fig. 11A

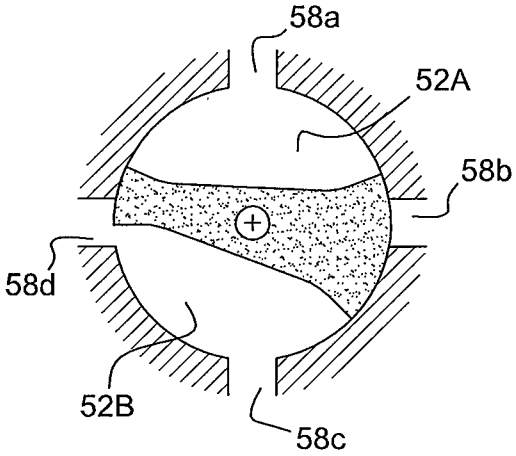


Fig. 11B

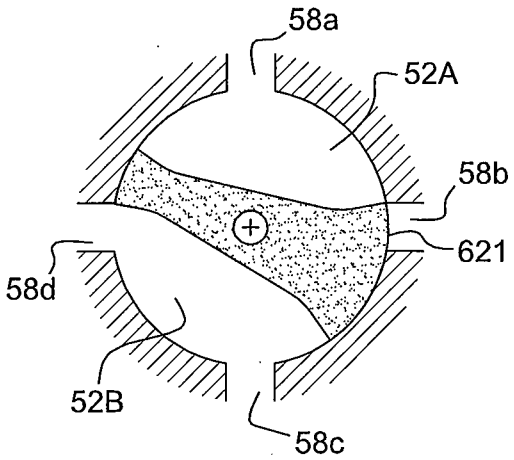


Fig. 11C

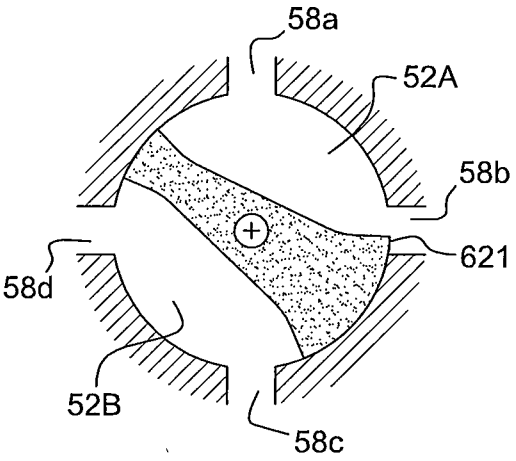


Fig. 11D

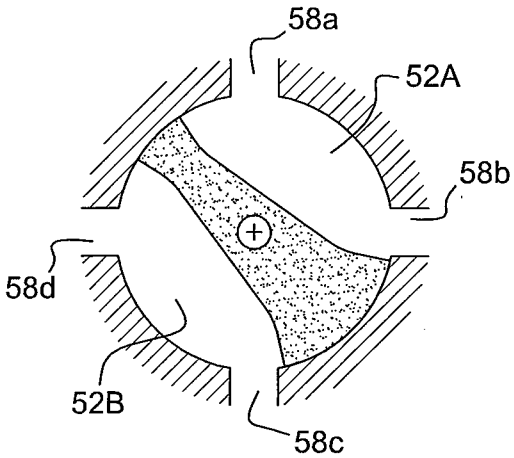


Fig. 11E

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/001907

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02M25/07 F02B37/18 F02B37/16 F16K11/085
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F02M F02B F16K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2011/000470 A1 (ROTH DAVID B [US]) 6 January 2011 (2011-01-06) cited in the application figure 1 paragraph [0030] - paragraph [0040] -----	1-13,29
A	DE 102 22 919 A1 (MAN NUTZFAHRZEUGE AG [DE]) 24 December 2003 (2003-12-24) abstract; figures 1-21 -----	1-29
A	US 6 973 786 B1 (LIU ZHENGBAI [US] ET AL) 13 December 2005 (2005-12-13) abstract figures 1,3 column 3, line 37 - column 4, line 17 ----- -/--	1-13

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 March 2014	11/04/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Payr, Matthias

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/001907

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2006/236693 A1 (WEI PUNING [US] ET AL) 26 October 2006 (2006-10-26) abstract figures 1-7B	1-29
A	WO 2008/015397 A1 (CUMMINS TURBO TECH LTD [GB]; MCEWEN JAMES A [GB]; ROBINSON LEE J [GB]) 7 February 2008 (2008-02-07) abstract; figures 1-15	1-29
X	US 7 963 276 B2 (WEIS CHRISTIAN [DE]) 21 June 2011 (2011-06-21) cited in the application	14-28
A	abstract figures 1-6 claim 1	29
A	GB 2 475 534 A (CUMMINS TURBO TECH LTD [GB]) 25 May 2011 (2011-05-25) abstract figures 1-3e page 20, paragraph 3 - page 21, paragraph 1	14-29
A	EP 0 864 737 A1 (MAN NUTZFAHRZEUGE AG [DE]) 16 September 1998 (1998-09-16) abstract figures 1,2,3,4,7-10	14-29
A	DE 10 2006 009298 A1 (DAIMLER CHRYSLER AG [DE]) 6 September 2007 (2007-09-06) abstract figures 1-3	14-29
A	DE 43 24 749 A1 (FREUDENBERG CARL FA [DE]) 26 January 1995 (1995-01-26) abstract column 3, line 4 - line 8 figures 1-6	14-29

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2013/001907

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-13

   Layout of a turbocharged engine with single rotary valve with at least three port openings configured to define three operation modes, i.e. exhaust gas recirculation with exhaust gas taken upstream of a turbine, exhaust gas recirculation with exhaust gas taken downstream of the turbine and a turbine by-pass mode.

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2. claims: 14-29

   Design of a rotary valve with at least four port openings.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2013/001907

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