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(54) **A low pressure exhaust gas recirculation system for a combustion engine**

(57) The invention relates to a low pressure exhaust gas recirculation system (10) for a combustion engine (12), preferably for use in a vehicle, at least partially directing an exhaust gas from an exhaust gas line (16) to an air intake line (14) of the combustion engine (12),

wherein the exhaust gas recirculation system (10) comprises first means (42) for actively forwarding the exhaust gas at least partially, and second means (44) for dehumidifying the at least partially forwarded exhaust gas.

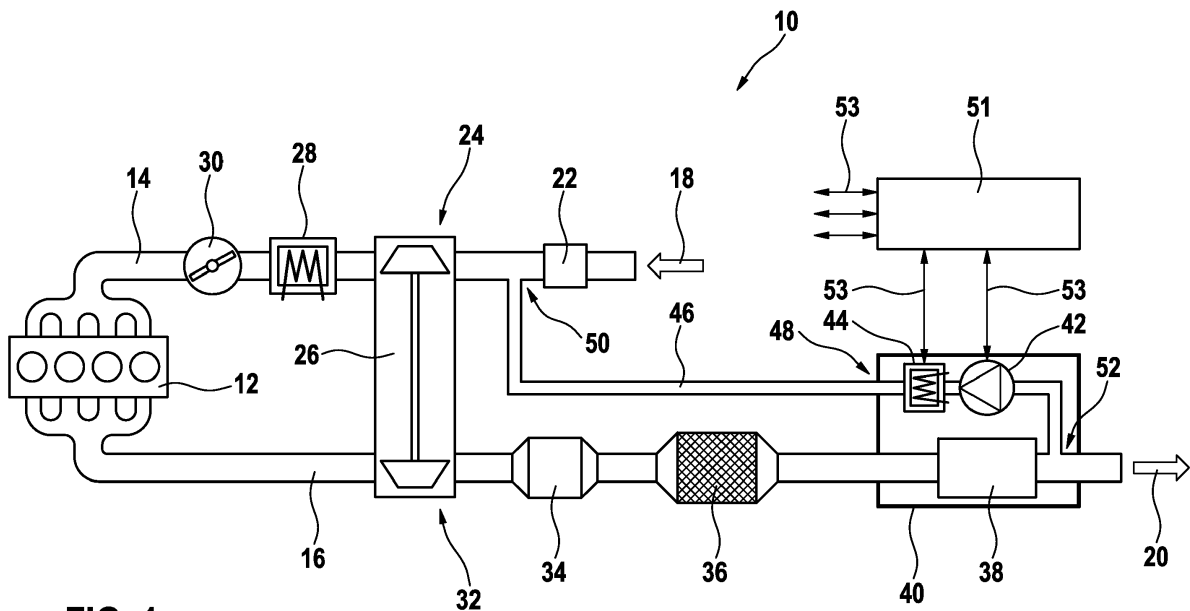


FIG. 1

Description

Prior Art

[0001] The invention relates to a low pressure exhaust gas recirculation system for a combustion engine and to two methods for operating the system.

[0002] It is known in prior art to recirculate an exhaust gas of a combustion engine at least partially. Two methods are known in general: First, a recirculation of the exhaust gas in the vicinity of inlets and outlets of the combustion engine, i.e., a high pressure recirculation. Second, a recirculation of the exhaust gas rather in the vicinity of an exhaust gas exit or an air intake, respectively. This is called a low pressure recirculation. To avoid a possible engine damage, it is necessary to decrease the absolute humidity level in a low pressure exhaust gas recirculation system as much as possible. Preferably the recirculated exhaust gas is cooled down along the so-called water vapor saturation curve.

Disclosure of the Invention

[0003] The invention is related to a low pressure exhaust gas recirculation system for a combustion engine according to claim 1 and to a method for operating the system according to claim 10 and the respective dependent claims. Further features of the invention are given in the following description and in the drawings, wherein the features may be important for the invention either alone or in different combinations, without explicitly being notified.

[0004] In a first part the invention relates to a low pressure exhaust gas recirculation system for a combustion engine, preferably for use in a vehicle, at least partially directing an exhaust gas from an exhaust gas line to an air intake line of the combustion engine, wherein the exhaust gas recirculation system comprises first means for actively forwarding the exhaust gas at least partially, and second means for dehumidifying the at least partially forwarded exhaust gas. More specifically, the meaning of "actively forwarding" may include a procedure of conveying and/or pumping the exhaust gas from the exhaust gas line to the air intake line. By this, several advantages may be achieved: First, an electrical driven valve in a recirculation pipe between the exhaust gas line and the air intake line may be omitted. Second, an electrical driven valve located downstream of a catalyst, for example, a SCR catalyst (selective catalytic reduction) or NSC catalyst ("NO_x storage catalyst"), may be omitted also. Moreover, NO_x emissions (NO_x means "oxides of nitrogen") may be reduced significantly due to higher possible flow rates in the recirculation pipe. Almost independent with regard to a length of the recirculation pipe, possible problems related to condensing the exhaust gas could be minimized, especially in a cold engine phase. Further, a system control of the recirculation system may be improved, too. Overall, a functionality of the combustion

engine may be improved and component corrosion may be decreased. The inventive exhaust gas recirculation system may be constructed simply and may achieve reduced overall costs also. Preferably the exhaust gas is fed from the exhaust gas line into the first means, then pumped from the first means to the second means, and then conveyed to the air intake line. The combustion engine may be a diesel engine, an otto engine (spark ignition engine) or a gas engine. In an embodiment the invention may be applied to a natural aspired combustion engine without a turbo charger. A high pressure exhaust gas recirculation system may be omitted also.

[0005] In an embodiment, the first means for actively forwarding the exhaust gas comprise at least an air blower, preferably driven by an electric motor. By this, a relative simple and robust solution for forwarding the exhaust gas may be realized.

[0006] In a further embodiment the inventive system comprises a control means for controlling the speed and/or the sense of rotation of the electric motor. Therefore the air blower may be controlled effectively in at least three modes of operation, however may be driven also in a continuously variable manner. In a normal mode, the air blower partially forwards the exhaust gas through the recirculation pipe into the air intake line. In a regeneration mode, the air blower is driven reversely so as to pump fresh air from the air intake line to the exhaust gas line. By this, a NSC catalyst ("NO_x storage catalyst") may be regenerated by achieving a low air flow as needed. During regeneration, an engine operating point may be modified temporarily such that it operates in a rich combustion mode. The advantage is to control the flow of a turbocharger in the suction side and not in the high pressure side. In a third mode, the air blower is operated in an idle or near-to-idle mode, so as to significantly reduce or even stop the flow of the exhaust gas through the recirculation pipe, taking into account a pressure drop in the recirculation pipe. The control means may be integrated in an engine ECU (electronic control unit).

[0007] In a further embodiment the second means is also for cooling the at least partially forwarded exhaust gas. That is, the inventive system advantageously provides cooling and dehumidifying the exhaust gas in a combined way.

[0008] In a further embodiment the exhaust gas is extracted from the exhaust gas line downstream of a muffler. The properties of the exhaust gas downstream of the muffler are well conditioned for the inventive principle of actively forwarding the exhaust gas. Thus, the operation of the low pressure exhaust gas recirculation system may be improved.

[0009] The inventive principle includes several possible locations for extracting the exhaust gas from the exhaust gas line. Preferably downstream of the muffler, but also upstream of the muffler, downstream of a SCR catalyst, or upstream of the SCR catalyst may be possible. Even further configurations along the exhaust gas line may also be used for the inventive principle.

[0010] In a further embodiment the exhaust gas is extracted from the exhaust gas line downstream of a selective catalyst. This provides an advantageous option for the inventive system to effectively recirculate the exhaust gas.

[0011] In a further embodiment the cooled exhaust gas is fed into the air intake line upstream of a turbo charger and preferably also upstream of an intake air cooler. By this, the turbo charger additionally may be driven with the recirculated exhaust gas. Thus, the so called "turbo lag effect" may be reduced. The intake air cooler of the air intake line additionally may cool the exhaust gas after being mixed with the fresh air from the air intake and after being compressed by the turbo charger.

[0012] A further advantageous option is achieved if the second means for cooling the exhaust gas comprise a controllable bypass for the exhaust gas flow. By this, a temperature of the recirculated exhaust gas may be controlled independently of a mass flow and of an operation of the air blower.

[0013] In a further embodiment the first and second means and the muffler are one integrated unit. Therefore, the inventive exhaust gas recirculation system may be arranged in a compact and optionally preassembled unit (that also may be referred as an "integrated muffler system"), so as to reduce space and costs as well.

[0014] In a second part the invention relates to a method for operating a low pressure exhaust gas recirculation system for a combustion engine, preferably for use in a vehicle, according to any of the foregoing claims, characterized in that a rate of actively forwarded exhaust gas from an exhaust gas line to an air intake line is controlled by modifying a speed and/or a blowing sense of an air blower. Therefore, the system may be operated in a simple and reliable way using well known techniques of controlling an electric motor of the air blower.

[0015] In an embodiment the air blower is regulated depending on an operating state of the combustion engine and/or of an exhaust gas equipment and/or of the vehicle. As a result, an additional reduction of emissions may be achieved.

[0016] In a further embodiment the air blower at least temporarily is operated in a way that a reverse air flow is achieved from the air intake line to the exhaust gas line, preferably fed into the exhaust gas line downstream of a selective catalyst. Thus, an improved way to regenerate the NSC catalyst or a diesel particulate filter may be possible.

[0017] In a further embodiment the air blower is operated independently from an operating state of the combustion engine. That is, an exhaust gas flow rate is decoupled from the engine operating point itself. The operation of the system may be simplified and costs may be reduced.

[0018] Further embodiments of the present invention are described in more detail with respect to the enclosed figures, wherein

Figure 1 shows a schematic drawing of a combustion engine together with an air intake line, an exhaust gas line and a recirculation path;

5 Figure 2 shows an integrated muffler system of the exhaust gas line of figure 1 in more detail;

Figure 3 shows a psychrometric diagram for sea-level elevation;

10 Figure 4 shows a first flowchart of a method for operating a low pressure exhaust gas recirculation system for a combustion engine; and

15 Figure 5 shows a second flowchart of a method for operating the low pressure exhaust gas recirculation system.

[0019] Functionally equal or similar elements are denoted with equal or similar reference signs, wherein a repetition of the explanation of these elements mostly is omitted.

[0020] Figure 1 shows a simplified arrangement of a low pressure exhaust gas recirculation system 10 for a combustion engine 12 of a vehicle (not shown), for at least partially directing or "actively forwarding", respectively, an exhaust gas from an exhaust gas line 16 to an air intake line 14. The arrangement of figure 1 comprises the combustion engine 12 (left area of the figure), the air intake line 14 (upper area of the figure) and the exhaust gas line 16 (lower area of the figure). An intake air flow is marked with an arrow 18, and an exiting exhaust gas flow is marked with an arrow 20. In figure 1 in general, the air flow through the air intake line 14 is from the right to the left, and the exhaust gas flow through the exhaust gas line 16 is from the left to the right. The combustion engine 12 depicted in figure 1 is a diesel engine, but the inventive solution also may be used for an otto engine (spark ignition engine) or a gas engine.

[0021] In the air intake line 14, beginning from the air intake, the air may flow through a hot film probe 22, a first section 24 (i.e. the compressor section) of a turbo charger 26, an intake air cooler 28 ("inter cooler"), a throttle valve 30, and then into the combustion engine 12. In the exhaust gas line 16, beginning from the combustion engine 12, the exhaust gas may flow through a second section 32 (i.e. the turbine section) of the turbo charger 26, an oxidation catalyst 34, a diesel particulate filter 36, a muffler 38, and then to the exhaust gas exit ("environment emission"). Optionally a SCR catalyst ("selective catalytic reduction") may be inserted in the exhaust gas line 16 downstream of the diesel particulate filter 36 and upstream of the muffler 38.

[0022] In the present arrangement of figure 1 the muffler 38 is a component of an integrated unit 40 ("integrated muffler system"). The exhaust gas line 16, the second section 32 of the turbo charger 26, the oxidation catalyst 34, the diesel particulate filter 36 and the integrated unit

40 may generally be referred to as an "exhaust gas equipment" of the vehicle. Component 34 may be an oxidation catalyst or a NSC ("NOx storage catalyst"). Component 36 may be a diesel particulate filter or a diesel particulate filter plus/or a SCR catalyst.

[0023] The integrated unit 40 comprises the muffler 38, first means 42 for actively forwarding (i.e., conveying or pumping) the exhaust gas at least partially from downstream of the muffler 38, and second means 44 for dehumidifying (and, in an alternative embodiment, also for cooling) the at least partially forwarded exhaust gas. Further, the arrangement comprises a recirculation pipe 46, that is a pipeline used for an interconnection between an access or port 48 of the integrated unit 40 and a branch connection 50 at the air intake line 14, being located upstream of the first section 24 of the turbo charger 26.

[0024] On one hand, said first means 42 are connected to the exhaust gas line 16 at a branch connection 52 downstream of the muffler 38, and on the other hand, the first means 42 are connected to said second means 44. The second means 44, on the other hand, are connected via said access 48 of the integrated unit 40 to the recirculation pipe 46. In the arrangement of figure 1 the first means 42 for actively forwarding the exhaust gas comprise an air blower, preferably driven by an electric motor (not shown). The second means 44 comprise a cooler (preferably an air-air-cooler) and a condenser for dehumidifying the at least partially forwarded exhaust gas.

[0025] Further, the exhaust gas recirculation system 10 comprises control means 51 to provide control of the first means 42, the second means 44, and further elements of the exhaust gas recirculation system 10 and/or of the combustion engine 12. Some control lines to the respective elements symbolically are marked with arrows 53. The control means 51 may be integrated in an ECU (engine control unit).

[0026] In an alternative embodiment (not depicted) the exhaust gas line 16 comprises, beginning from the combustion engine 12: the second section 32 of the turbo charger 26, the oxidation catalyst 34, the diesel particulate filter 36, an SCR catalyst (selective catalytic reduction, used for reduction of NOx emissions) and the muffler 38. The branch connection 52 for providing a part of the exhaust gas to said first means 42 is located at the exhaust gas line 16 between the diesel particulate filter 36 and the SCR catalyst. The second means 44 are connected to the first means 42 and to the air intake line 14 via the branch connection 50 as already described with figure 1.

[0027] Returning back to figure 1, when the combustion engine 12 is operated, fresh air is sucked at the air intake, compressed by the first section 24 of the turbocharger 26 and is fed to an inlet of the combustion engine 12. As well an exhaust gas generated by the combustion engine 12 is fed through the exhaust gas line 16 to the exhaust gas exit. The turbo charger 26 is operated normally. At the integrated unit 40, a part of the exhaust gas of the exhaust gas line 16 is branched via the branch

connection 52 to the air blower of the first means 42. Said part of the exhaust gas is forwarded from the air blower to the second means 44. After cooling and dehumidifying/condensing, the part of the exhaust gas is fed via the recirculation pipe 46 into the air intake line 14. A mixture of fresh air (from the air intake) and dehumidified and cooled recirculated exhaust gas (from the recirculation pipe 46) are compressed by the first section 24 of the turbo charger 26 and cooled again in the cooler 28.

[0028] It is to be understood that a flow rate of said part of the exhaust gas preferably is controlled by modifying a speed and/or a blowing sense of the air blower. That is, a mass flow of the recirculated exhaust gas conveyed through the recirculation pipe 46 may be varied. In particular said mass flow may significantly be increased with respect to systems having no means for actively forwarding the exhaust gas. Thus, the operation of the combustion engine 12 may be improved and certain emissions in the exhaust gas may be decreased.

[0029] Preferably the air blower is regulated depending on an operating state of the combustion engine 12 and/or of the exhaust gas equipment and/or of the vehicle. The air blower preferably is driven in a way that the exhaust gas is forwarded from the exhaust gas line 16 to the air intake line 14 as depicted by the triangle in the drawing symbol of the first means 42 in figure 1.

[0030] In an alternative mode of operation ("regeneration mode" of a NSC catalyst or a diesel particulate filter) of the low pressure exhaust gas recirculation system 10, the air blower at least temporarily is operated in a way that a reverse air flow is achieved from the air intake line 14 to the exhaust gas line 16. That is, fresh air can be provided from the upstream side of the first section 24 of the turbo charger 26 via branch connection 50 to the exhaust gas line 16 for creating the condition for NOx selective catalytic rich mode regeneration combustion (λ preferably below a value of "1"). The advantage is to control the charger flow in the suction side and not in the high pressure side of the air intake line 14. With respect to the latter case the throttle valve 30 at least partially may be closed. Therefore a possible overload of the turbo charger 26 may be reduced or even be avoided. The same alternative mode of operation may be applied to the "alternative embodiment" (see above), wherein the exhaust gas preferably is fed into the exhaust gas line 16 downstream of the SCR catalyst.

[0031] In a further alternative mode of operation the integrated unit 40 is operated independently from an operating state of the combustion engine 12, therefore a required exhaust gas flow rate is decoupled from the engine operating point itself. In particular, the air blower may be operated independently from the operating state of the combustion engine 12.

[0032] Figure 2 presents an additional view of the integrated unit 40 of figure 1, wherein the second means 44 additionally comprise a controllable bypass 54 for optionally bypassing a part of the exhaust gas flow at the second means 44. Downstream from the muffler 38 ("si-

lencer") the exhaust gas partially is provided from the exhaust gas line 16 via the branch connection 52 to the air blower. The air blower may be realized by an electrical fan or by any other suitable type of a gas conveying machine, e.g. a centrifugal blower. The second means 44 are used for cooling down the exhaust gas flow and to separate the condensating water. The control means 51 also are depicted in figure 2, now additionally providing control for the bypass 54.

[0033] Depending on the environmental conditions and an operating point of the combustion engine 12, a desired temperature of the exhaust gas flow therefore may be controlled by the controllable bypass 54. In an embodiment, the bypass 54 is realized by "active flaps" of the cooler in the second means 44.

[0034] Figure 3 shows a psychrometric diagram for sea-level elevation describing several dependencies of physical variables. The physical variables are: a dry bulb temperature 60 (on a horizontal line at the bottom of the diagram), an absolute humidity 62 (on a vertical line rightmost on the diagram, scaled from 0 to 30), a relative humidity 64 (see the leftmost arrow on the diagram, scaled from 0% to 100%), an enthalpy 66 at saturation (scaled from 20 to 100), a saturation temperature 68 (scaled from 0 to 30, unit is °C), and a specific volume 70 (scaled from 0.80 to 0.95). A first elliptic area 72 denotes an area of operation related to conventional systems. A second elliptic area 74 denotes an area of operation being possible with the inventive exhaust gas recirculation system 10.

[0035] Figure 4 shows a first flowchart of a method for operating the low pressure exhaust gas recirculation system 10 for a combustion engine 12 of a vehicle. In a first block 76 an operating state of the combustion engine 12 and the related exhaust gas equipment and the vehicle are determined. In a following block 78 the rate of the actively forwarded exhaust gas from the exhaust gas line 16 to the air intake line 14 is controlled by modifying a speed and/or a blowing sense of the air blower, that is, the air blower is regulated.

[0036] Figure 5 shows a second flowchart of a method for operating the low pressure exhaust gas recirculation system 10. In a block 80 the system 10 is operated according to the procedure described with figure 4. In a block 82 the air blower at least temporarily is operated in a way that a reverse air flow is achieved from the air intake line 14 to the exhaust gas line 16, fed into the exhaust gas line upstream or downstream (dependent on an embodiment) of a SCR catalyst. Different catalyst configurations may be possible. As already described above, component 34 may be an oxidation catalyst or a NSC, and component 36 may be a diesel particulate filter or a diesel particulate filter plus/or a SCR catalyst. Therefore a regeneration of the NSC catalyst is possible, applying a rich combustion mode, wherein a low air flow is required in the air intake line 14. After regeneration the method returns to block 80.

Claims

1. A low pressure exhaust gas recirculation system (10) for a combustion engine (12), preferably for use in a vehicle, at least partially directing an exhaust gas from an exhaust gas line (16) to an air intake line (14) of the combustion engine (12), **characterized in that** the exhaust gas recirculation system (10) comprises first means (42) for actively forwarding the exhaust gas at least partially, and second means (44) for dehumidifying the at least partially forwarded exhaust gas.
2. The system (10) according to claim 1, wherein the first means (42) for actively forwarding the exhaust gas comprise at least an air blower, preferably driven by an electric motor.
3. The system (10) according to claim 2, wherein it comprises a control means (51) for controlling the speed and/or the sense of rotation of the electric motor.
4. The system (10) according to any of the foregoing claims, wherein the second means (44) is also for cooling the at least partially forwarded exhaust gas.
5. The system (10) according to any of the foregoing claims, wherein the exhaust gas is extracted from the exhaust gas line (16) downstream of a muffler (38).
6. The system (10) according to any of the foregoing claims, wherein the exhaust gas is extracted from the exhaust gas line (16) downstream of a selective catalyst.
7. The system (10) according to any of the foregoing claims, wherein the cooled exhaust gas is fed into the air intake line (14) upstream of a turbo charger (26) and preferably also upstream of an intake air cooler (28).
8. The system (10) according to any of the foregoing claims, wherein the second means (44) for cooling the exhaust gas comprise a controllable bypass (54) for an exhaust gas flow.
9. The system (10) according to any of the foregoing claims, wherein the first and second means (42, 44) and the muffler (38) are one integrated unit (40).
10. A method for operating a low pressure exhaust gas recirculation system (10) for a combustion engine (12), preferably for use in a vehicle, **characterized in that** a rate of actively forwarded exhaust gas from an exhaust gas line (16) to an air intake line (14) is controlled by modifying a speed and/or a blowing sense of an air blower.

11. The method according to claim 10, wherein the air blower is regulated depending on an operating state of the combustion engine (12) and/or of an exhaust gas equipment and/or of the vehicle. 5
12. The method according to claim 11, wherein the air blower at least temporarily is operated in a way that a reverse air flow is achieved from the air intake line (14) to the exhaust gas line (16), preferably fed into the exhaust gas line (16) downstream of a selective catalyst. 10
13. The method according to claim 10, wherein the air blower is operated independently from an operating state of the combustion engine (12). 15

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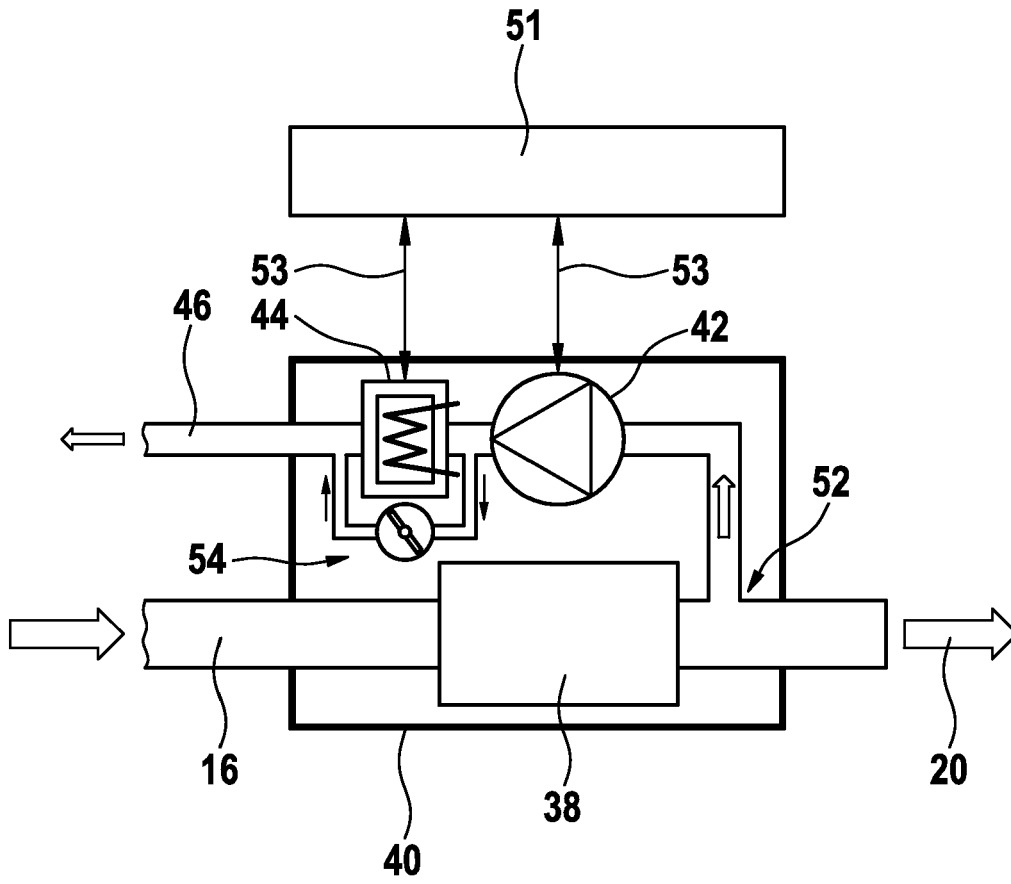


FIG. 2

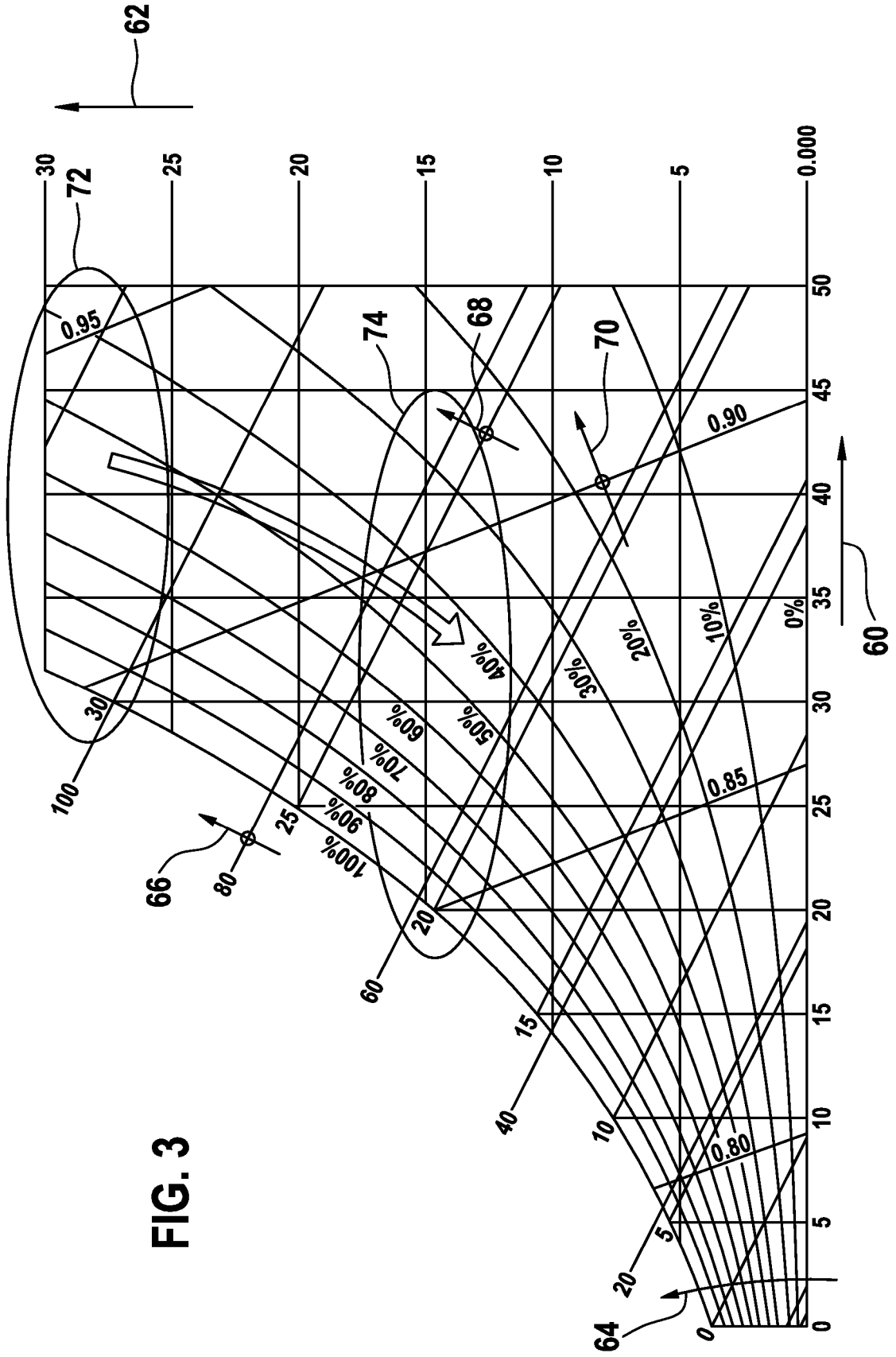


FIG. 3

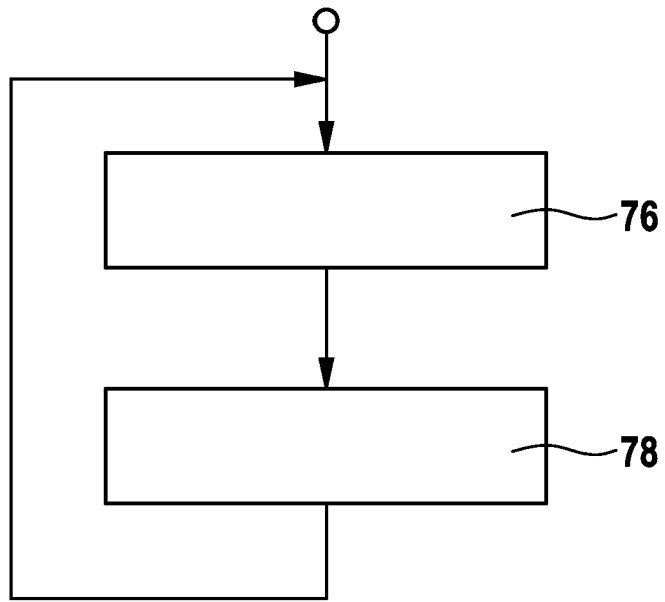


FIG. 4

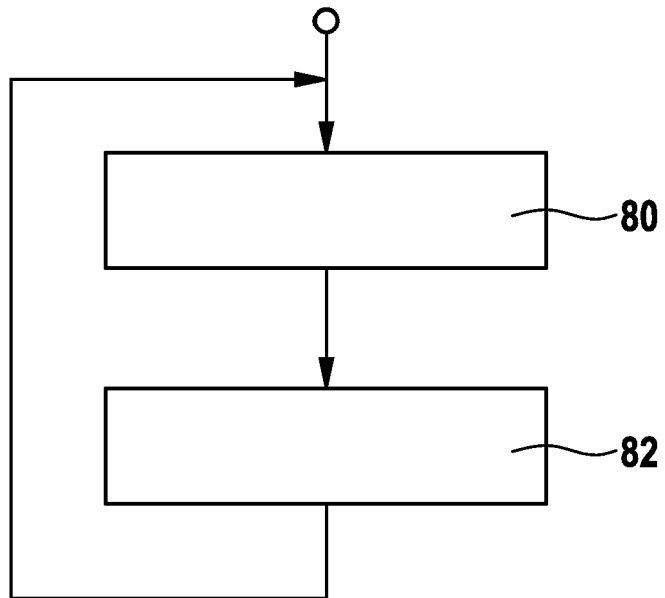


FIG. 5



EUROPEAN SEARCH REPORT

Application Number
EP 14 17 6680

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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 13 October 2014	Examiner Marsano, Flavio
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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ANNEX TO THE EUROPEAN SEARCH REPORT
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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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