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(54) Method of operating a combustion engine

(57) A method of operating a combustion engine comprises injecting fuel with the injection valve (17) into the combustion chamber according to an injection signal and measuring a pressure signal in the combustion chamber of the indicated cylinder (10) with the pressure sensor (18), determining an actual operating parameter for the indicated cylinder (10) depending on the pressure signal, determining a difference between the actual operating parameter and a corresponding nominal operating parameter, adapting the injection signal for the indicated cylinder (10) depending on the difference, determining a desired temporal course of the crank angle for the indicated cylinder (10) based on the adapted injection signal, determining an actual temporal course of the crank angle for a non-indicated cylinder (9) based on a non-adapted injection signal, determining a difference between the actual course and the desired course, and adapting the injection signal of the non-indicated cylinder (9) depending on the difference.

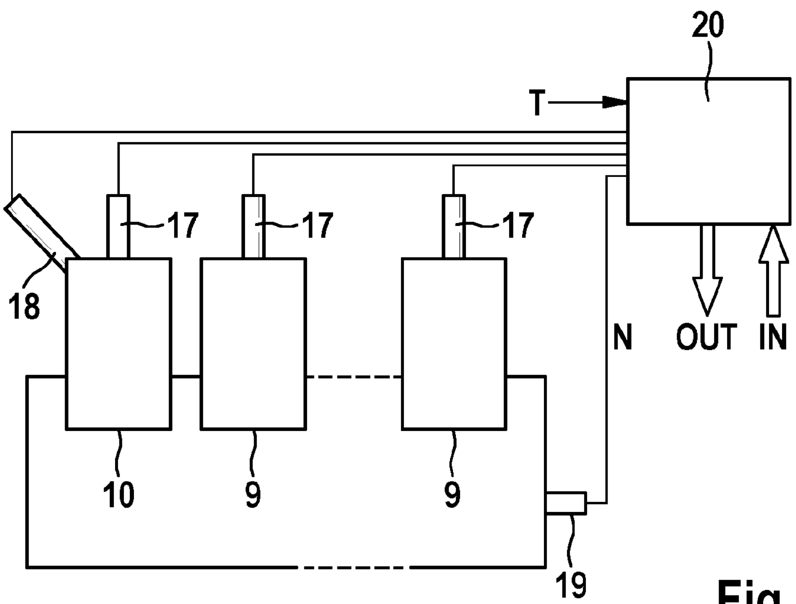

Fig. 1a

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Description

Prior Art

[0001] The invention relates to a method of operating a combustion engine. The invention also relates to a control unit for operating a combustion engine and to a combustion engine comprising such a control unit.

[0002] E.g. US 2010/0121555 A1 discloses a combustion engine comprising a pressure sensor for measuring a pressure signal in a combustion chamber of the combustion engine. Furthermore, the combustion engine comprises an injection valve for injecting fuel into the combustion chamber. Based on the measured pressure signal, a point of injection is determined and then used for influencing the amount of fuel injected into the combustion chamber.

[0003] It is an object of the invention to improve the prior art systems.

Disclosure of the Invention

[0004] The invention solves this object by a method according to claim 1. As well, the invention solves this object by a control unit according to claim 8.

[0005] According to the invention, the combustion engine comprises: a number of cylinders being coupled with a crank shaft, and a sensor for determining a crank angle of the crank shaft, wherein each cylinder comprises a piston and an injection valve, wherein an indicated cylinder comprises a pressure sensor, wherein each cylinder and each piston delimit a combustion chamber. Furthermore, the method comprises: injecting fuel with the injection valve into the combustion chamber according to an injection signal, measuring a pressure signal in the combustion chamber of the indicated cylinder with the pressure sensor, determining an actual operating parameter for the indicated cylinder depending on the pressure signal, determining a difference between the actual operating parameter and a corresponding nominal operating parameter, adapting the injection signal for the indicated cylinder depending on the difference, determining a desired temporal course of the crank angle for the indicated cylinder based on the adapted injection signal, determining an actual temporal course of the crank angle for a non-indicated cylinder based on a non-adapted injection signal, determining a difference between the actual course and the desired course, and adapting the injection signal of the non-indicated cylinder depending on the difference.

[0006] The invention offers the advantage that only one cylinder, i.e. the indicated cylinder, has to be provided with a pressure sensor. All other cylinders of the combustion engine do not need to have a pressure sensor. Apparently, the necessary efforts and costs in connection with the combustion engine are reduced.

[0007] Further advantageous embodiments of the inventions are described herein.

[0008] In the following, specific embodiments of the invention are explained in greater detail with reference to the drawings.

[0009] Figure 1a and 1b show schematic block diagrams of an embodiment of a combustion engine according to the invention, figure 2 shows a schematic time diagram of operating parameters of the combustion engine of figure 1, figure 3 shows a schematic flow diagram of a method according to the invention to obtain operating parameters of a premaster of the combustion engine of figure 1, and figures 4 and 5 show schematic flow diagrams of methods according to the invention for operating an individual item of the combustion engine of figure 1.

[0010] In figure 1a, a combustion engine with a number of cylinders is shown. The combustion engine may be a diesel engine or a gasoline engine and may have e.g. four or six cylinders.

[0011] On the left-hand side of figure 1a, a cylinder 10 is shown which is denoted as an indicated cylinder. The indicated cylinder 10 will be described in connection with figure 1b. Furthermore, two further exemplary cylinders 9 are shown in figure 1a which are denoted as non-indicated cylinders.

[0012] In figure 1b, the indicated cylinder 10 is shown. In the cylinder 10, a piston 11 is movable in an up- and down direction as shown by arrow 12. The piston 11 is coupled by a connecting rod or the like to a crank shaft 13 so that the up- and down movement of the piston 11 is converted into a rotation of the crank shaft 13 as shown by arrow 14.

[0013] The cylinder 10 and the piston 11 delimit a combustion chamber 16. An injection valve 17 is allocated to the cylinder 10 such that fuel may be injected into the combustion chamber 16 by the injection valve 17. Furthermore, a pressure sensor 18 is allocated to the cylinder 10 such that the pressure in the combustion chamber 16 may be measured by the pressure sensor 18.

[0014] As can be taken from figure 1a, the non-indicated cylinders 9 basically have the same configuration as the indicated cylinder 10 shown in figure 1b. In particular, each of the non-indicated cylinders 9 comprises an injection valve 18. However, the non-indicated cylinders 9 do not comprise a pressure sensor. Only the indicated cylinder 10 comprises the pressure sensor 18.

[0015] According to figure 1a, the combustion engine may comprise further sensors, e.g. a sensor 19 assigned to the crank shaft 13 for measuring a rotational speed signal N and/or a crank angle φ of the crank shaft 13, and/or a sensor assigned to the cylinder 10 for measuring a temperature signal T of the combustion engine, and so on. Furthermore, the combustion engine may comprise known functions, e.g. an exhaust gas recirculation, a turbo-charger, a fuel-tank ventilation and the like, with additional sensors.

[0016] A control unit 20, in particular a computer with a computer program, is assigned to the combustion engine. For each of the indicated and non-indicated cylinders 10, 9, the control unit 20 generates an injection signal TI which is forwarded to the respective injection valve 17 for driving the injection valve 17 into a state in which fuel is injected by the injection valve 17. The pressure sensor 18 generates a pressure signal P which corresponds to the pressure measured in the combustion chamber 16 of the indicated cylinder 10 and which is input to the control unit 20. Furthermore, a number of other signals IN, OUT are input to the control unit 20 and/or are output from the control unit 20. E.g. the rotational speed signal N and/or the temperature signal T are forwarded to the control unit 20.

[0017] It is now assumed that the combustion engine of figures 1a, 1b is in an overrun condition. Generally, this means that the crank shaft of the combustion engine is rotating although no fuel is injected in the cylinders of the combustion engine. If the combustion engine is incorporated e.g. in a vehicle, the overrun condition may be present when the vehicle is driving down a hill and the driver of the vehicle does not activate the accelerator pedal of the vehicle.

[0018] Figure 2, firstly, shows an exemplary injection signal TI of a single fuel injection which is depicted over the crank angle φ of the crank shaft 13. The injection signal TI relates to the indicated cylinder 10 only, i.e. the fuel is only injected into the indicated cylinder 10. It is noted that the crank angle φ may be derived from the rotational speed signal N. Furthermore, it is noted that the crank angle φ of the crank shaft 13 is similar to and may therefore be replaced by the time t.

[0019] The injection signal TI comprises a single test injection TEST. As described above, it is assumed that the combustion engine is in an overrun condition in which - generally - no fuel is injected into the combustion chamber, so that - generally - no torque is produced by the combustion engine. In order to avoid a noticeable deviation from these overrun conditions, the amount of fuel injected by the test injection TEST should be very low. Furthermore, the test injection TEST should be carried out at a crank angle which also avoids or at least decreases any deviation from the overrun conditions.

[0020] The course of the injection signal TI with the test injection TEST corresponds to the movement of a valve needle within the injection valve 17. At the beginning, the valve needle starts from a closed position and is moved into an open position in which the fuel is injected into the combustion chamber 16. After an energizing time ET, the valve needle is moved back into its closed position. Among others, the amount of injected fuel depends on the energizing time ET during which the injection valve 17 is in its opened position.

[0021] Secondly, figure 2 shows an exemplary pressure signal P which is depicted over the crank angle φ of the crank shaft 13. The pressure signal P corresponds to the injection signal TI and therefore to a single fuel injection.

[0022] Basically, the pressure signal P would have - without any fuel combustion - a sine-wave form due to the up- and down movement of the piston 11 which leads to an increase and a decrease of the pressure within the combustion chamber 16. In figure 2, one wave of such basic pressure signal may be identified using the dotted line.

[0023] However, due to the fuel injected by the test injection TEST into the combustion chamber 16 and due to a subsequent combustion of the injected fuel within the combustion chamber 16, the pressure signal P is increased during a period of time and therefore comprises deviations from the sine-wave form. In particular, the pressure signal P comprises a pressure peak PP.

[0024] Thirdly, figure 2 shows a heat release rate signal HRR which is depicted over the crank angle φ of the crank shaft 13. The heat release rate signal HRR corresponds to a single fuel injection.

[0025] The heat release rate signal HRR may be derived from the pressure signal P. For example, the heat release rate signal HRR may be evaluated using a so-called "schnelles Heizgesetz (fast heating rule)"; reference is made e.g. to Pischinger, Kraßnig, Taucar, Sams, Thermodynamik der Verbrennungskraftmaschine, Wien, New York, Springer, 1989. According to this exemplary rule, the pressure within the combustion chamber, the volume of the combustion chamber and a so-called "kalorischer Wert (caloric value)" is used to calculate the heat release rate.

[0026] The heat release rate signal HRR may be evaluated e.g. by the control unit 20.

[0027] The heat release rate signal HRR comprises a heat release rate peak HRRP which results from the test injection TEST and the corresponding pressure peak PP. The heat release rate peak HRRP is located at a crank angle φa and has a value Va.

[0028] Fourthly, figure 2 shows an integrated heat release signal IHR which is depicted over the crank angle φ of the crank shaft 13. The integrated heat release signal IHR may be derived from the heat release rate signal HRR by an integration over the time t. This can be done e.g. by the control unit 20.

[0029] The integrated heat release signal IHR comprises an integrated heat release plateau IHRP which results from the test injection TEST and the corresponding pressure peak PP and heat release rate peak HRRP. The integrated heat release plateau IHRP relates to the total amount of released heat resulting from the test injection TEST.

[0030] It is now assumed that the operating parameters shown in figure 2 and explained above, belong to a specific type of combustion engine and that a number of combustion engines of this specific type are assembled in a production run. Then, the following procedures are carried out.

[0031] Figure 3 relates to a method carried out at a premaster of the combustion engines of the specific type. The premaster is understood to be a kind of a prototype or master form which is used to define the respective specific type of combustion engine.

[0032] In a step 31, one combustion engine - i.e. the premaster- is selected out of the combustion engines of the specific type. This selection may be done e.g. at the end of the development process of the specific type of combustion engine or in particular at the beginning of the production run.

[0033] In a step 32, the premaster is evaluated in detail and is optimized with regard to its operating parameters. In particular, the course of the injection signal TI of figure 2 is optimized e.g. with regard to a decrease of fuel consumption and/or a decrease of the pollution of the exhaust gases or with regard to other given constraints or requirements.

[0034] In a step 33, the corresponding pressure signal P of the optimized premaster is measured by the pressure sensor 18. Then, the heat release rate signal HRR is evaluated from the pressure signal P as described above, e.g. by the control unit 20. In particular, the value Va of the heat release rate peak HRRP is determined. Furthermore, the integrated heat release signal IHR may be evaluated from the heat release rate signal HRR as described above, e.g. by the control unit 20.

[0035] The evaluations of step 33 are repeated e.g. for different rotational speeds N and/or different engine torques or the like so that in particular the resulting values Va may constitute an operating map of the premaster.

[0036] In a step 34, the obtained operating parameters for the optimized operation of the premaster are stored as nominal operating parameters, in particular as nominal values of the heat release rate peak HRRP. For example, these operating parameters may be stored in the afore-mentioned operating map e.g. in the control unit 20.

[0037] Figure 4 relates to all combustion engines of the specific type. The method of figure 4 is carried out during the normal mode, i.e. during the day-to-day operation of the combustion engines. The method of figure 4 may be carried out for any one of the combustion engines of the specific type.

[0038] In the following, the method of figure 4 is described in connection with an individual item out of the combustion engines of the specific type which is not the premaster. It is assumed that the nominal operating paramaters obtained from the premaster according to the above described method of figure 3, are stored in the individual item of the combustion engine, in particular in the control unit 20 of the individual item.

[0039] It is furthermore assumed that the individual item of the combustion engine is in an overrun condition. Then, the injection signal TI comprising the single test injection TEST is injected into the combustion chamber 16 of the indicated cylinder 10. It is noted that the test injection TEST is only injected into the indicated cylinder 10 but not in the non-indicated cylinders 9 of the combustion engine.

[0040] In a step 41, the pressure signal P of the individual item of the combustion engine is measured by the pressure sensor 18. Then, the heat release rate signal HRR is evaluated from the pressure signal P e.g. by the control unit 20. In particular, the value Va of the heat release rate peak HRRP is determined. Furthermore, the integrated heat release signal IHR may be evaluated from the heat release rate signal HRR e.g. by the control unit 20.

[0041] The obtained operating parameters for the individual item of the combustion engine are used as actual operating parameters, i.e. as an actual value Va of the heat release rate peak HRRP.

[0042] In a step 42, the actual operating parameters obtained from the individual item are compared with the stored nominal operating parameters obtained from the premaster. With regard to this comparison, it is possible that other operating parameters of the combustion engine have to be considered. For example, it is possible that the nominal operating parameters have to be selected depending on the actual rotational speed N and/or the actual engine torque of the individual item.

[0043] In a step 43, the resulting difference is evaluated with regard to its amount and whether it is positive or negative. Depending on this evaluation, the injection signal TI and in particular the energizing time ET of the test injection TEST into the indicated cylinder 10 of the individual item of the combustion engine is/are adapted.

[0044] For example, the energizing time ET may be extended or shortened depending on whether the resulting difference is positive or negative. Furthermore, the amount of the extension or shortening of the energizing time ET may be determined in particular depending on the amount of the resulting difference.

[0045] In a modified embodiment, the amount of the extension or shortening of the energizing time ET may be a given fixed value.

[0046] With regard to steps 41 to 43, it is possible to only determine the actual value Va of the heat release rate peak HRRP and to compare it with the respective stored nominal value. Alternatively, it is possible to define and determine an actual value Vb of the integrated heat release plateau IHRP and to compare it with the respective stored nominal value. Furthermore, it is also possible to carry out both alternatives.

[0047] Then, after step 43, the method of figure 4 is continued with step 41. This means that steps 41 to 43 are repeated subsequently with the result that the injection signal TI and in particular the energizing time ET of the individual item of the combustion engine is/are also adapted subsequently. The operating parameters of the indicated cylinder 10 of the individual item of the combustion engine, in particular the injection signal TI and/or the energizing time ET of the test injection TEST, are adjusted to the optimized operating parameters of the premaster.

[0048] It is now assumed that the operating parameters of the indicated cylinder 10 of the individual item of the combustion engine, in particular the injection signal TI and/or the energizing time ET of the test injection TEST, are at least almost identical to the corresponding optimized operating parameters of the premaster. Furthermore, it is assumed that the overrun condition of the individual item of the combustion engine is still present.

[0049] Then, the method of figure 5 is carried out.

[0050] In a step 51, fuel according to the optimized injection signal TI is continued to be injected into the indicated cylinder 10 only and the temporal course of the crank angle for the time duration of an engine cycle is stored. This course of the crank angle is used as a desired course. Alternatively or additionally, the course of the rotational speed signal N for the same time duration may also be stored.

[0051] In a step 52, the injection of fuel into the indicated cylinder 10 is finished and a test injection according to a non-adapted, i.e. non-optimized injection signal TI is injected into a selected one of the non-indicated cylinders 9. The term non-adapted and non-optimized mean that the respective injection signal TI has not gone through a correction or adaptation or optimization yet.

[0052] Then, the temporal course of the crank angle for the time duration of an engine cycle is stored. This course of the crank angle is used as an actual course. Alternatively or additionally, the course of the rotational speed signal N for the same time duration may also be stored.

[0053] In a step 53, the actual course is compared with the stored desired course. With regard to this comparison, it is possible that other operating parameters of the combustion engine have to be considered.

[0054] In a step 54, the resulting difference is evaluated with regard to its amount and whether it is positive or negative. Depending on this evaluation, the non-optimized injection signal TI for the selected non-indicated cylinder 9 is adapted.

[0055] For example, the energizing time ET may be extended or shortened depending on whether the resulting difference is positive or negative. Furthermore, the amount of the extension or shortening of the energizing time ET may be determined in particular depending on the amount of the resulting difference.

[0056] In a modified embodiment, the amount of the extension or shortening of the energizing time ET may be a given fixed value.

[0057] Then, after step 54, the method of figure 5 is continued with step 52. This means that steps 52 to 54 are repeated subsequently with the result that the injection signal TI and in particular the energizing time ET of the selected non-indicated cylinder 9 of the combustion engine is/are also adapted subsequently.

[0058] It is now assumed that the actual course of the crank angle φ of the selected non-indicated cylinder 9 of the combustion engine is at least almost identical to the desired course. Furthermore, it is assumed that the overrun condition of the individual item of the combustion engine is still present.

[0059] Then, the method of figure 5 is repeated in connection with another selected one of the non-indicated cylinders 9. This repetition is repeated until all non-indicated cylinders 9 are completed. After all non-indicated cylinders 9 are competed, the overrun condition of the combustion engine may be finished.

[0060] In modified embodiments, it is possible to carry out the described methods of figures 3 to 5 based on the crank angle φa of the heat release rate peak HRRP and/or based on a crank angle of the integrated release plateau IHRP.

Claims

1. A method of operating a combustion engine, wherein the combustion engine comprises a number of cylinders (10, 9) being coupled with a crank shaft (13), and a sensor for determining a crank angle (φ) of the crank shaft (13), wherein each cylinder (10, 9) comprises a piston (11) and an injection valve (17), wherein an indicated cylinder (10) comprises a pressure sensor (18), wherein each cylinder (10, 9) and each piston (11) delimit a combustion chamber (16), and wherein the method comprises injecting fuel with the injection valve (17) into the combustion chamber (16) according to an injection signal (TI) and measuring a pressure signal (P) in the combustion chamber (16) of the indicated cylinder (10) with the pressure sensor (18), **characterized by** the steps of: determining (41) an actual operating parameter for the indicated cylinder (10) depending on the pressure signal (P), determining (42) a difference between the actual operating parameter and a corresponding nominal operating parameter, adapting (43) the injection signal (TI) for the indicated cylinder (10) depending on the difference, determining (51) a desired temporal course of the crank angle (φ) for the indicated cylinder (10) based on the adapted injection signal (TI), determining (52) an actual temporal course of the crank angle (φ) for a non-indicated cylinder (9) based on a non-adapted injection signal (TI), determining (53) a difference between the actual course and the desired course, and adapting (54) the injection signal (TI) of the non-indicated cylinder (9) depending on the difference.

2. The method of claim 1 wherein the operating parameter is a value (Va) of a heat release rate peak (HRRP).

3. The method of claim 2 wherein the value (Va) of the heat release rate peak (HRRP) is replaced by a crank angle (φa) of the heat release rate peak (HRRP) and/or by a value (Vb) of an integrated heat release plateau (IHRP) and/or by a crank angle of the integrated heat release plateau (IHRP).

4. The method of one of claims 2 or 3 wherein the heat release rate peak (HRRP) depends on a heat release rate signal (HRR) which is derived from the pressure signal (P).

5. The method of one of the preceding claims wherein, for adapting the injection signal (TI), an energizing time (ET) during which the injection valve (17) is in its opened position, is extended or shortened.

6. The method of one of the preceding claims wherein, for determining the corresponding nominal operating parameter, a premaster of the combustion engine is selected (31), the premaster is optimized with regard to given requirements (32), and the nominal operating parameter is determined (33) for the premaster.

7. The method of one of the preceding claims wherein the combustion engine is in an overrun condition.

8. A control unit (20) for operating a combustion engine, wherein the combustion engine comprises a number of cylinders (10, 9) being coupled with a crank shaft (13), and a sensor for determining a crank angle (φ), wherein each cylinder (10, 9) comprises a piston (11) and an injection valve (17), wherein an indicated cylinder (10) comprises a pressure sensor (18), wherein each cylinder (10, 9) and each piston (11) delimit a combustion chamber (16), wherein the control unit (20) is coupled with the injection valve (17) and the pressure sensor (18), and wherein the control unit (20) is adapted to carry out the method steps of one of claims claim 1 to 7.

9. The control unit (20) of claim 8 comprising a computer and a computer program, wherein the computer program carries out the method steps of one of claims 1 to 7 when it is executed on the computer.

10. A combustion engine comprising the control unit (20) of one of claims 8 or 9.

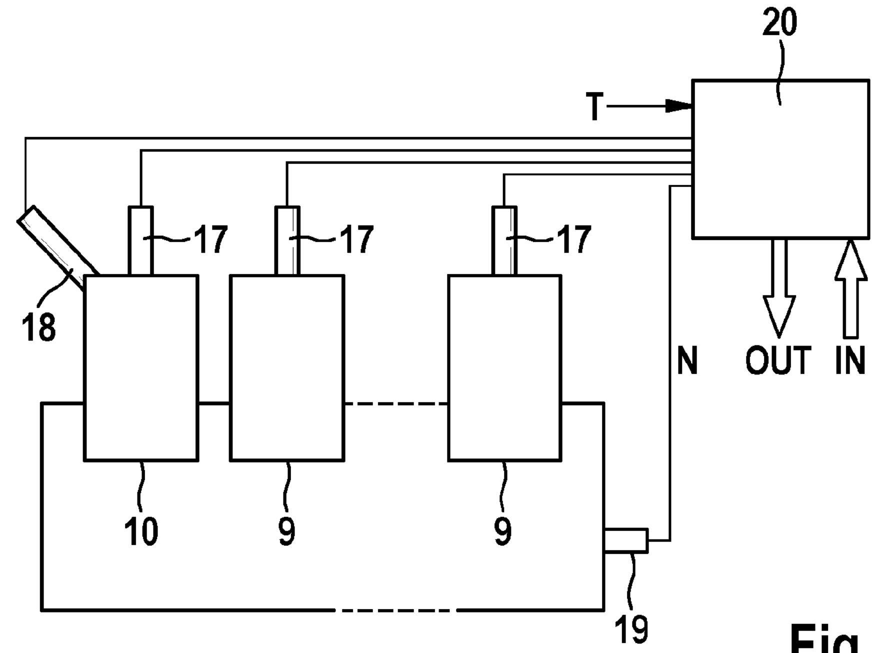

Fig. 1a

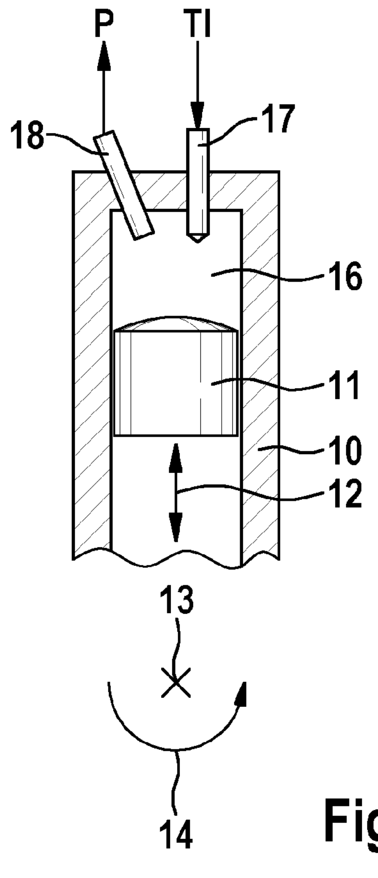

Fig. 1b

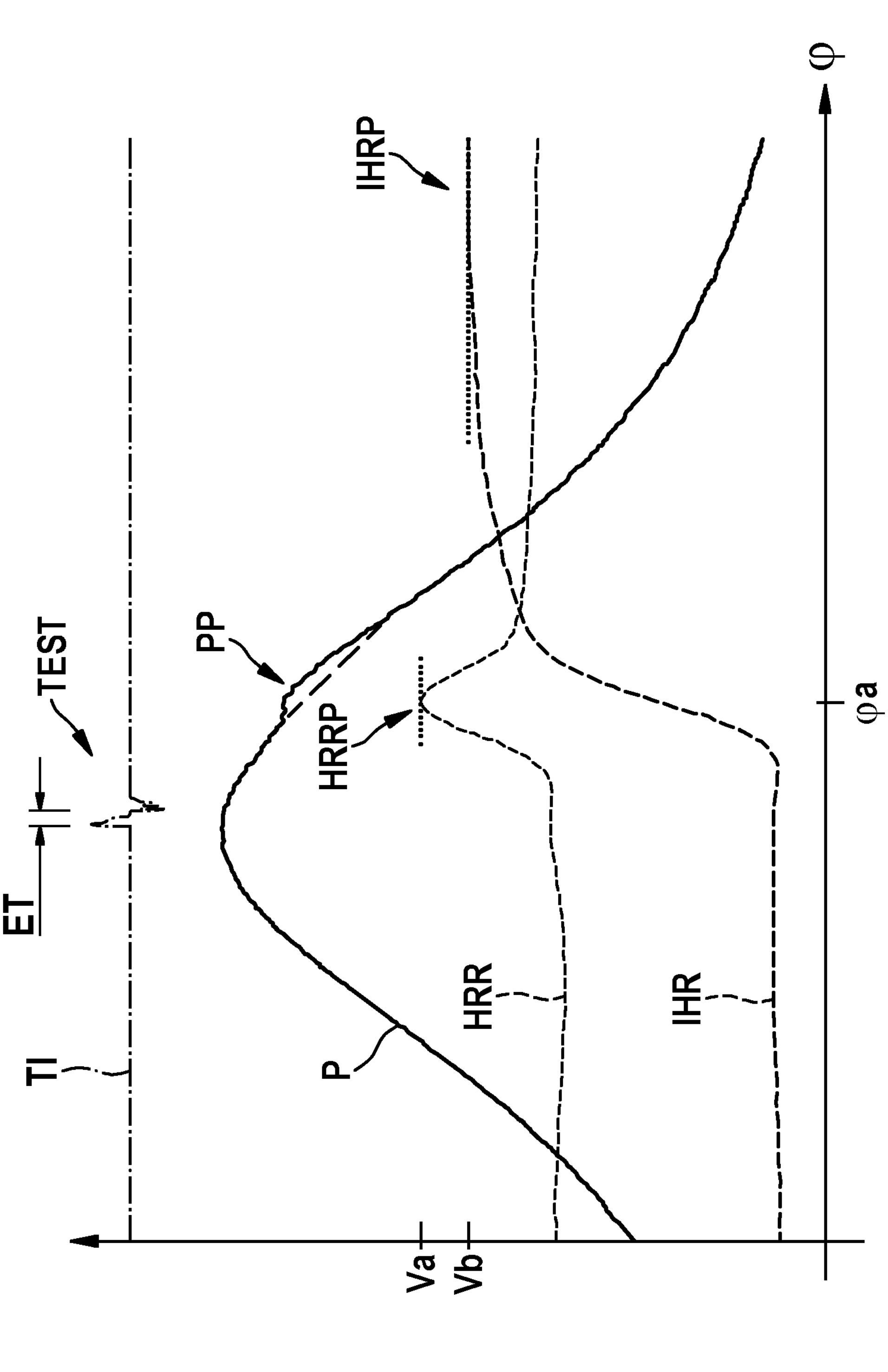

Fig. 2

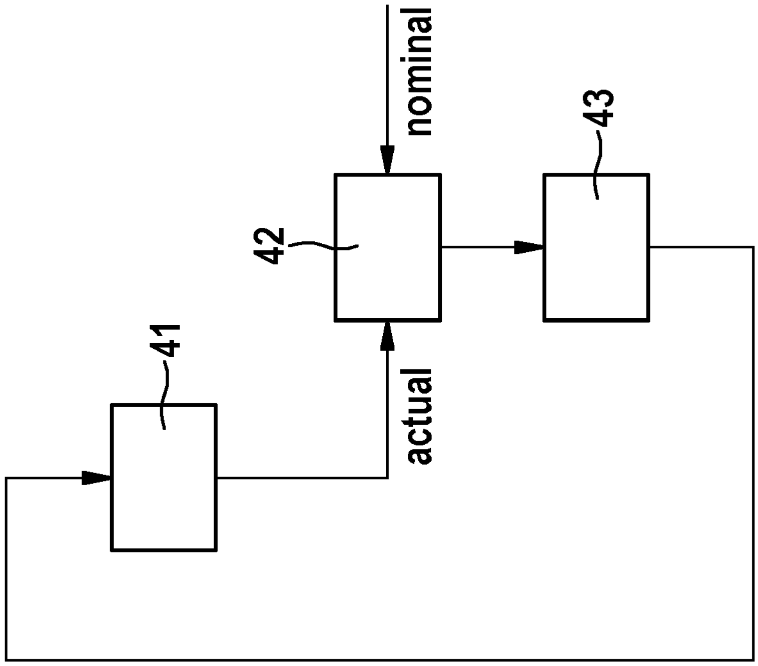

Fig. 4

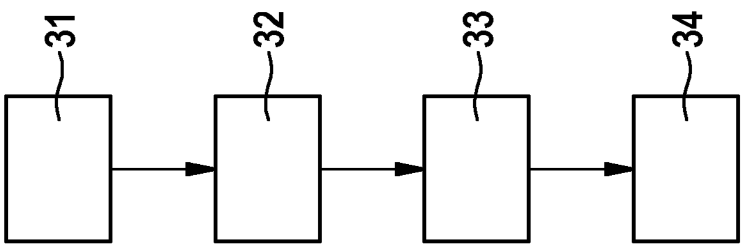

Fig. 3

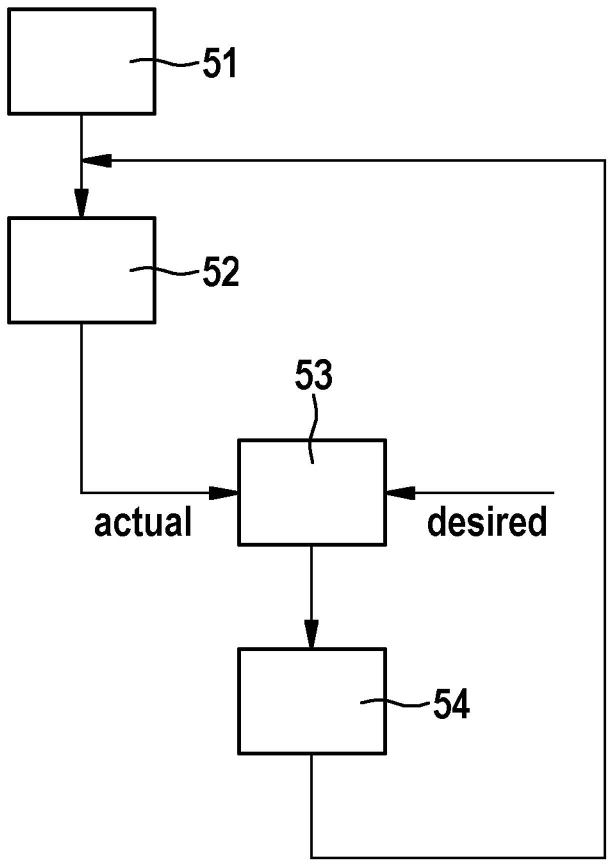

Fig. 5

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EUROPEAN SEARCH REPORT

Application Number
EP 13 15 1310

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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TECHNICAL FIELDS SEARCHED (IPC)

F02D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	21 June 2013	Röttger, Klaus

CATEGORY OF CITED DOCUMENTS

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