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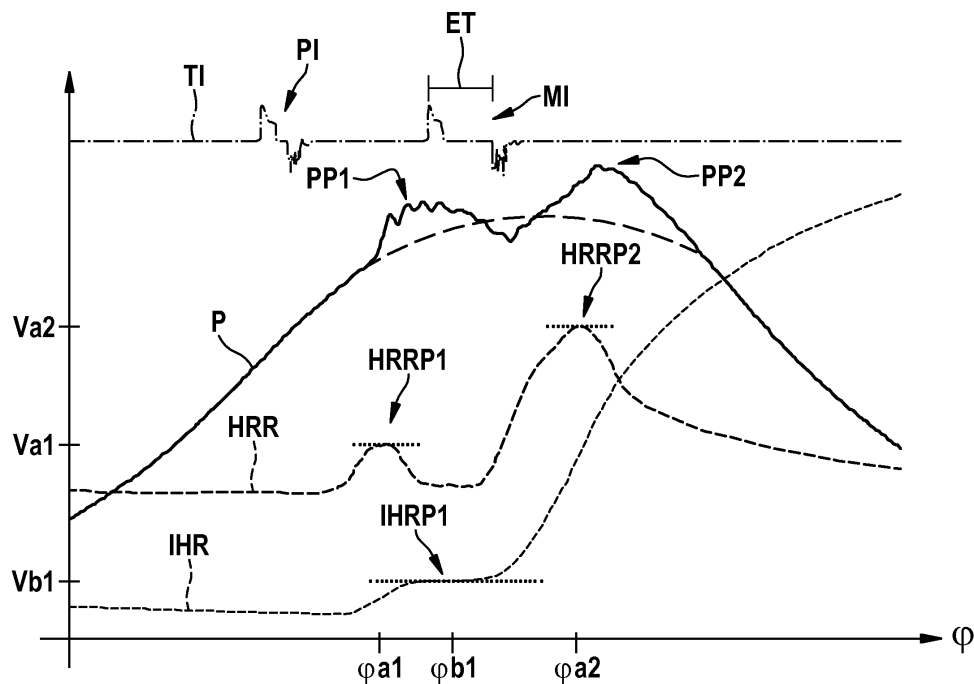
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(54) **Method of operating a combustion engine**

(57) A method of operating a combustion engine is described. The combustion engine comprises a cylinder, a piston, an injection valve and a pressure sensor, where in the cylinder and the piston delimit a combustion chamber. The method comprises injecting fuel with the injection valve into the combustion chamber according to an injection signal (TI) and measuring a pressure signal (P)

in the combustion chamber with the pressure sensor. The method comprises the further steps of: determining an actual value (Va1) of a heat release rate peak (HRRP1) depending on the pressure signal (P), determining a difference between the actual value and a corresponding nominal value, and adapting the injection signal (TI) depending on the difference.

**Fig. 2**

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 or claim 2. As well, the invention solves this object by a control unit according to claim 7.

[0005] The methods according the invention comprise the steps of: determining an actual value of a heat release rate peak or an integrated heat release plateau depending on a pressure signal, determining a difference between the actual value and a corresponding nominal value, and adapting an injection signal depending on the difference.

[0006] These methods allow a real-time adaptation of the combustion engine. In particular, the combustion engine may be optimized in real-time to optimized operating parameters. This means in other words that any calibration which would be necessary due to slight differences in the assembly of the combustion engine in a production run, is not necessary but is replaced by the invention. As well, any adaptation which would be necessary over the lifetime of the combustion engine, is also automatically corrected in real-time using the invention.

[0007] The invention, therefore, allows to control the combustion engine during its entire lifetime with optimized operating parameters. As a consequence, the pollution of the exhaust gases as well as the fuel consumption of the combustion engine are reduced.

[0008] In an embodiment of the invention, the heat release rate peak or the integrated heat release plateau depends on a heat release rate signal which is derived from the pressure signal. As an example, the heat release rate signal may be evaluated using a so-called "schnelles Heizgesetz (fast heating rule)". This embodiment allows fast calculations and facilitates the real-time adaptation of the injection signal.

[0009] In another embodiment of the invention, an energizing time during which the injection valve is in its opened position, is extended or shortened. This is a very

effective possibility to optimize the injection signal.

[0010] In another embodiment of the invention, a pre-master of the combustion engine is selected, the pre-master is optimized with regard to given requirements, and a nominal value of a heat release rate peak and/or a nominal value of an integrated heat release plateau is determined for the pre-master. This embodiment allows in a very effective manner to determine the corresponding nominal value/s.

[0011] Further advantageous embodiments of the inventions are described herein.

[0012] In the following, specific embodiments of the invention are explained in greater detail with reference to the drawings.

[0013] Figure 1 shows a schematic block diagram 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 pre-master of the combustion engine of figure 1, and figure 4 shows a schematic flow diagram of a method according to the invention for operating the combustion engine of figure 1.

[0014] In figure 1, one cylinder 10 of a number of cylinders of an internal combustion engine is shown. The combustion engine may be a diesel engine or a gasoline engine and may have e.g. four or six cylinders.

[0015] 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.

[0016] 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.

[0017] The combustion engine may comprise further sensors, e.g. a sensor 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.

[0018] A control unit 20, in particular a computer with a computer program, is assigned to the combustion engine. The control unit 20 generates an injection signal TI which is forwarded to the 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 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.

[0019] Figure 2, firstly, shows an exemplary injection signal TI of a single engine cycle which is depicted over the crank angle φ of the crank shaft 13. 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.

[0020] The injection signal TI comprises a pilot injection PI and a main injection MI. The injection signal TI may, in a modified embodiment, comprise further pilot and/or main injections.

[0021] The course of the injection signal TI of the pilot injection PI or the main injection MI 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. As an example, the energizing time ET is shown in figure 2 in connection with the main injection MI.

[0022] 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 engine cycle.

[0023] 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.

[0024] However, due to the injection of fuel into the combustion chamber 16 and a subsequent combustion of the injected fuel within the combustion chamber 16, the pressure signal P is increased during one or more periods of time and therefore comprises deviations from the sine-wave form, i.e. one or more pressure peaks. In figure 2, a first exemplary pressure peak PP1 results from the pilot injection PI and a second exemplary pressure peak PP2 results from the main injection MI.

[0025] 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 the pilot injection PI and the main injection MI.

[0026] 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.

[0027] The heat release rate signal HRR may be evaluated e.g. by the control unit 20.

[0028] The heat release rate signal HRR comprises a first heat release rate peak HRRP1 which results from the pilot injection PI and the corresponding first pressure peak PP1, and a second heat release rate peak HRRP2 which results from the main injection MI and the corresponding second pressure peak PP2. The first heat release rate peak HRRP1 is located at a crank angle φ_{a1} and has a value V_{a1} and the second heat release rate peak HRRP2 is located at a crank angle φ_{a2} and has a value V_{a2} .

[0029] 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.

[0030] The integrated heat release signal IHR comprises a first integrated heat release plateau IHRP1 which results from the pilot injection PI and the corresponding first pressure peak PP1 and first heat release rate peak HRRP1. A second integrated heat release plateau may also be present but is not shown in figure 2. The first integrated heat release plateau IHRP1 is located at a crank angle φ_{b1} wherein this crank angle e.g. is defined to be present in the middle of the plateau. The first integrated heat release plateau IHRP1 has a value V_{b1} .

[0031] 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.

[0032] 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.

[0033] 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.

[0034] In a step 32, the premaster is evaluated in detail and is optimized with regard to its operating parameters. In particular, the temporal 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.

[0035] 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 Va1 of the first heat release rate peak HRRP1 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. In particular, the value Vb1 of the first integrated heat release plateau IHRP1 may be determined.

[0036] 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 Va1 may constitute an operating map of the premaster.

[0037] 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 first heat release rate peak HRRP1 and/or nominal values of the first integrated heat release plateau IHRP1. For example, these operating parameters may be stored in the afore-mentioned operating map e.g. in the control unit 20.

[0038] 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.

[0039] In the normal mode, the injection signal TI is determined by the control unit 20 based on a number of dependencies. Among others, the energizing time ET within the injection signal TI is calculated depending e.g. on the rotational speed N and/or the engine torque of the combustion engine or the like. The injection valve 17 is then driven according to the injection signal TI into its opened and closed position.

[0040] 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 parameters 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.

[0041] 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 Va1 of the first heat release rate peak HRRP1 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. In particular, the value Vb1 of the first integrated heat release plateau IHRP1 may be determined.

[0042] The obtained operating parameters for the individual item of the combustion engine are used as actual operating parameters, i.e. as an actual value of the first heat release rate peak HRRP1 and/or an actual value of

the first integrated heat release plateau IHRP1.

[0043] 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.

[0044] 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 individual item of the combustion engine is/are adapted.

[0045] 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.

[0046] In a modified embodiment, the amount of the extension or shortening of the energizing time ET may be a given fixed value.

[0047] With regard to steps 41 to 43, it is possible to only determine the actual value Va1 of the first heat release rate peak HRRP1 and to compare it with the respective stored nominal value. Alternatively, it is possible to only determine the value Vb1 of the first integrated heat release plateau IHRP1 and to compare it with the respective stored nominal value. Furthermore, it is also possible to carry out both alternatives.

[0048] 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.

[0049] Therefore, the operating parameters of the individual item of the combustion engine, in particular the injection signal TI and/or the energizing time ET, are adjusted continuously to the optimized operating parameters of the premaster.

[0050] The above description of figures 3 and 4 relates to the pilot injection PI and the corresponding first heat release rate peak HRRP1 and/or the first integrated heat release plateau IHRP1. However, the methods of figures 3 and 4 may also be carried out in connection with any other pilot injection PI and/or any main injection MI.

[0051] In modified embodiments, it is possible to carry out the described methods of figures 3 and 4 based on the crank angle φ_{a1} of the first heat release rate peak HRRP1 and/or based on the crank angle φ_{b1} of the first integrated release plateau IHRP1. Alternatively or additionally, it is possible to do the same with the corresponding values at the crank angles of the second heat release rate peak HRRP2 and/or the second integrated heat release plateau.

[0052] The above description refers to one cylinder of a combustion engine, i.e. the cylinder 10. It is possible to carry out the methods of figures 3 and 4 for every cylinder of the combustion engine. Alternatively, it is possible to apply the described methods not for all, but only for a partial number or only for one of the cylinders. In this case, the resulting adaptation of the injection signal of the applied cylinder/s may be used as a basis to evaluate an adaptation as well for the injection signals of the non-applied cylinders.

Claims

1. A method of operating a combustion engine, wherein the combustion engine comprises a cylinder (10), a piston (11), an injection valve (17), and a pressure sensor (18), wherein the cylinder (10) and the 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) with the pressure sensor (18), **characterized by** the steps of: determining (41) an actual value (Va1, Va2) of a heat release rate peak (HRRP1, HRRP2) depending on the pressure signal (P), determining (42) a difference between the actual value and a corresponding nominal value, and adapting (43) the injection signal (TI) depending on the difference.
2. A method of operating a combustion engine, wherein the combustion engine comprises a cylinder (10), a piston (11), an injection valve (17) and a pressure sensor (18), wherein the cylinder (10) and the 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) with the pressure sensor (18), **characterized by** the steps of: determining (41) an actual value (Vb1) of an integrated heat release plateau (IHRP1) depending on the pressure signal (P), determining (42) a difference between the actual value and a corresponding nominal value, and adapting (43) the injection signal (TI) depending on the difference.
3. The method of claim 1 or of claim 2 wherein the heat release rate peak (HRRP1, HRRP2) or the integrated heat release plateau (IHRP1) depends on a heat release rate signal (HRR1, HRR2) which is derived from the pressure signal (P).
4. 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.
5. The method of one of the preceding claims wherein, for determining the corresponding nominal value, a premaster of the combustion engine is selected (31), the premaster is optimized with regard to given requirements (32), and a nominal value (Va1, Va2) of a heat release rate peak (HRRP1, HRRP2) and/or a nominal value (Vb1) of an integrated heat release plateau (IHRP1) is determined (33) for the premaster.
6. The method of one of the preceding claims wherein the value (Va1, Va2, Vb1) of the heat release rate peak (HRRP1, HRRP2) and/or the integrated heat release plateau (IHRP1) is replaced by a crank angle ($\phi a1$, $\phi a2$) of the heat release rate peak (HRRP1, HRRP2) and/or by a crank angle ($\phi b1$) of the integrated release plateau (IHRP1).
7. A control unit (20) for operating a combustion engine, wherein the combustion engine comprises a cylinder (10), a piston (11), an injection valve (17) and a pressure sensor (18), wherein the cylinder (10) and the 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 1 to 6.
8. The control unit (20) of claim 7 comprising a computer and a computer program, wherein the computer program carries out the method steps of one of claims 1 to 6 when it is executed on the computer.
9. A combustion engine comprising the control unit (20) of one of claims 7 or 8.

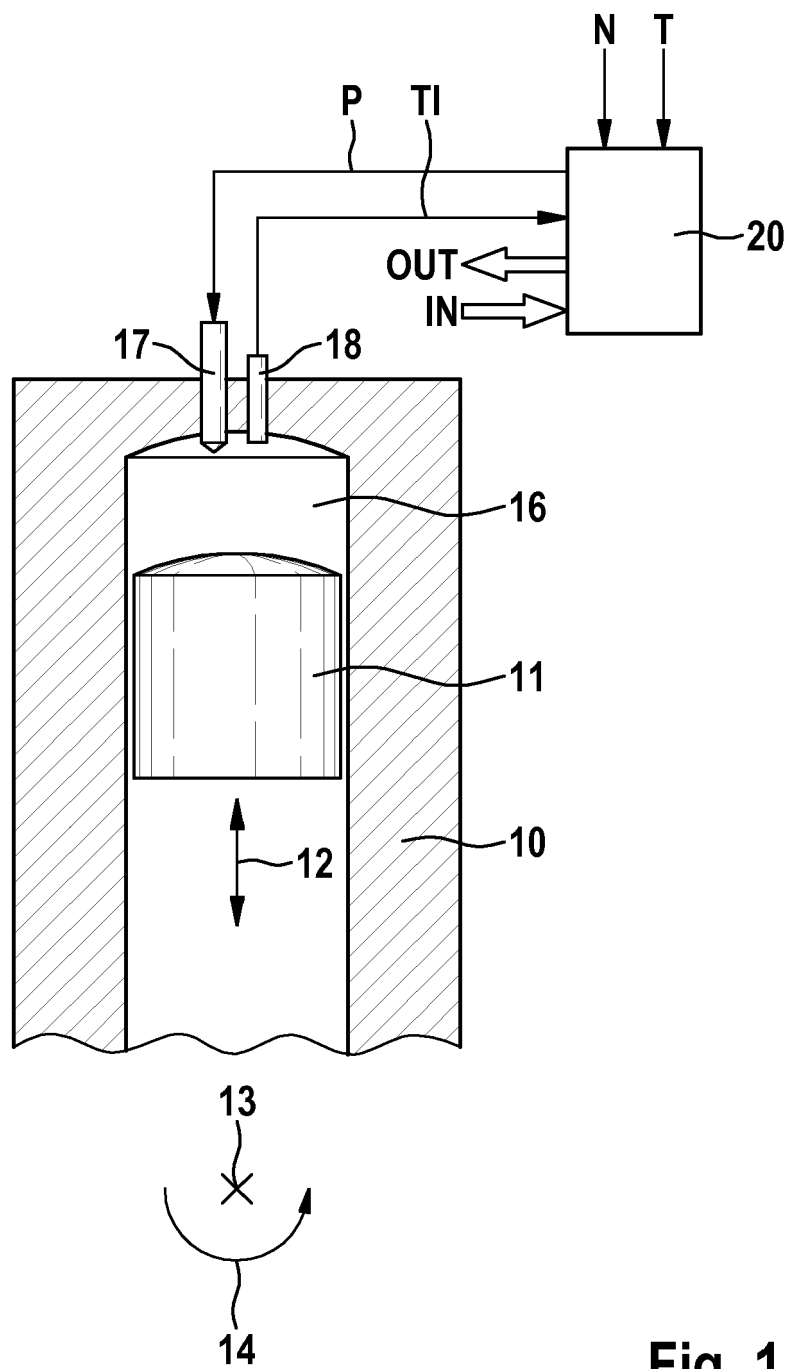


Fig. 1

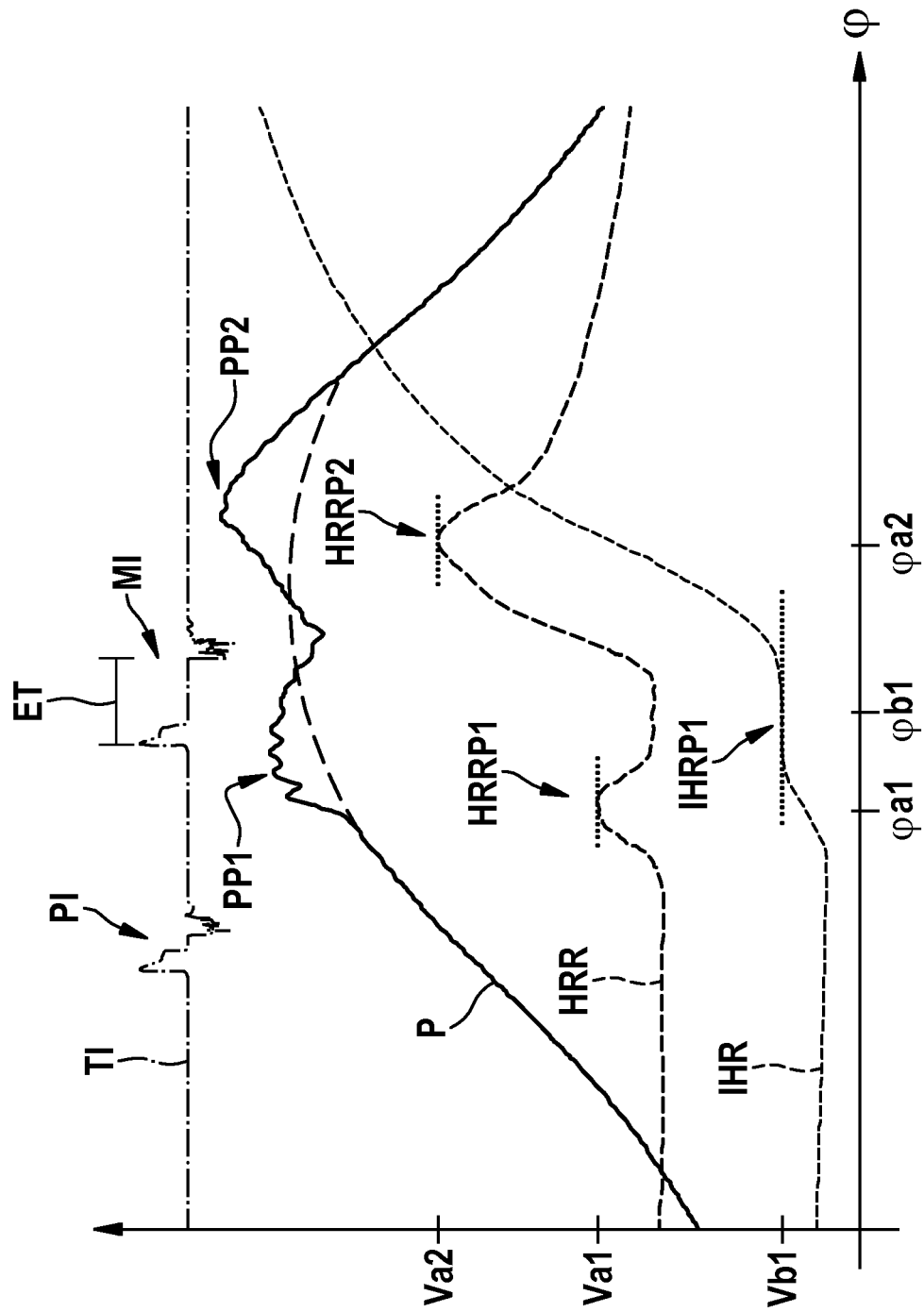


Fig. 2

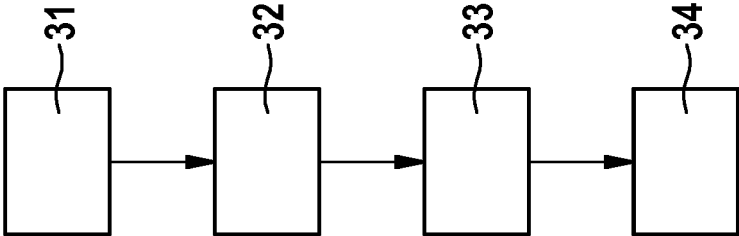


Fig. 3

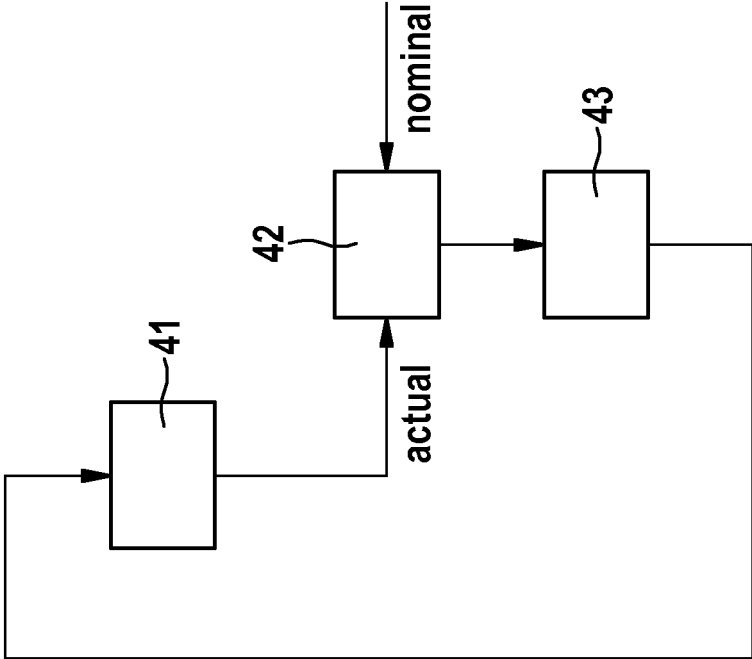


Fig. 4



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