(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 296 494 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
19.02.2025 Bulletin 2025/08

(21) Application number: **23179990.9**

(22) Date of filing: **19.06.2023**

(51) International Patent Classification (IPC):
F02D 41/00 *(2006.01)* *F02D 41/14* *(2006.01)*

(52) Cooperative Patent Classification (CPC):
F02D 41/1405; F02D 41/0002; F02D 2041/1433;
F02D 2041/1436; F02D 2200/0402;
F02D 2200/0406; F02D 2200/0408;
F02D 2200/0411; F02D 2200/0414; F02D 2200/101

(54) METHOD FOR ESTIMATING AN AIR MASS FLOW RATE ENTERING A FOUR-STROKE SPARK IGNITED ENGINE

VERFAHREN ZUR SCHÄTZUNG EINES ANSAUGLUFTMASSENSTROMS EINES FREMDGEZÜNDETEN VIERTAKTMOTORS

PROCÉDÉ D’ESTIMATION D’UN DÉBIT MASSIQUE D’AIR ENTRANT DANS UN MOTEUR À QUATRE TEMPS À ALLUMAGE COMMANDÉ

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR

(30) Priority: **23.06.2022 IT 202200013324**

(43) Date of publication of application:
27.12.2023 Bulletin 2023/52

(73) Proprietor: **FPT Industrial S.p.A.**
10156 Torino (IT)

(72) Inventors:
- **RAMUNDO, Fabio**
  9320 Arbon (CH)
- **CANGEMI, Tommaso**
  9320 Arbon (CH)
- **RODRIGUEZ, Raul**
  9320 Arbon (CH)

(74) Representative: **Fiume, Orazio**
Praxi Intellectual Property S.p.A.
Corso Vittorio Emanuele II, 3
10125 Torino (IT)

(56) References cited:
WO-A1-2019/198047 **IT-A1- 201800 004 431**
US-B1- 11 125 202 **US-B1- 11 174 809**
US-B1- 11 286 871

- **PER ANDERSSON: "Intake Air Dynamics on a Turbocharged SI-Engine with Wastegate", INTAKE AIR DYNAMICS ON A TURBOCHARGED SI-ENGINE WITH WASTEGATE, DEPARTMENT OF ELECTRICAL ENGINEERING, LINKÖPING UNIVERSITY, LINKÖPING, SWEDEN, 1 January 2002 (2002-01-01), pages 1 - 84, XP002696866, ISBN: 978-91-7373-282-6**
- **TSENG T-C ET AL: "AN ADAPTIVE AIR/FUEL RATIO CONTROLLER FOR SI ENGINE THROTTLE TRANSIENTS", SAE 2010 COMMERCIAL VEHICLE ENGINEERING CONGRESS SAE TECHNICAL PAPERS, SAE INTERNATIONAL, US, vol. 1999-01-0552, 1 January 1999 (1999-01-01), pages 37 - 48, XP001077055, ISSN: 0148-7191**

Processed by Luminess, 75001 PARIS (FR)

Description

Field of the invention

[0001] The present invention relates to the field of methods for estimating the air mass flow entering a positive ignited engine by controlling the pressure at the intake manifold.

State of the art

[0002] The difficulty in calculating the quantity of air trapped in the cylinder lies in the fact that the quantity of air is not directly measurable with sensors having a reasonable cost for mass production.

[0003] Thus, the amount of air trapped in the cylinder is estimated, see for example WO 2019/198047 A1.

[0004] Thus, the estimation of the quantity of air ("air charge estimation") which is trapped in the cylinders of a spark ignition internal combustion engine is essential for calculating the quantity of fuel to be injected, in such a way as to maintain the Air/Fuel at the stoichiometric or desired value.

[0005] Therefore, the estimation is of crucial importance for the approvals relating to the regulations on pollutant emissions and for the reduction of fuel consumption to the minimum possible.

[0006] Digital computing systems in the last 30 years have allowed the calculation of this estimation through its implementation in the Engine Control Unit (ECU). Increasingly refined and complex estimation methods have been gradually developed to ensure compliance with the regulations on pollutant emissions and ensure that the engine consumes the minimum fuel possible based on the value of the Air/Fuel ratio required.

[0007] The mass flow rate of the air entering a cylinder can be described by a set of well-known physical laws, known as the Navier-Stokes equations. The aforementioned equations both in their one-dimensional form and, *a fortiori,* in their three-dimensional form are not practical and feasible to implement in the ECUs on the market, as they require modelling with non-lumped parameters but on several points, the greater in number the more precise is desired the calculation, with the related problem of boundary and initial conditions which are essential in this context.

[0008] The ECUs must meet the fundamental requirement of "running" a real-time calculation system with all the limitations in computational terms that it entails. Finally, any ECU must manage all the various aspects related to engine operation, where the estimation and control of the mass flow of air entering the engine represents only a portion of the overall computational load.

[0009] For these reasons, this estimation tends to be an approximation of complex thermo-fluid dynamic phenomena based on considerations and intuitions, left to the inventiveness of the designer, which produce an estimate model which is a compromise between physical laws, computational cost and effort in calibrating and maintain the estimation model itself.

[0010] Over the years, estimation methods have been developed based on the more or less extensive use of functions of one or two variables, implemented through interpolation on fixed points and whose value is known/determined, the so-called "maps" and/or "curves". These maps try to characterize the thermo-fluid dynamic phenomena during engine operation. Well-known equations often contain parameterized adjustment coefficients on such maps and/or curves to allow the ideal behaviour given by the equations to adhere to the real behaviour of the engine.

[0011] The most commonly used equations are those relating to the equations of ideal gases and/or the equation of isentropic mass flow through a valve or a constriction of a duct and/or other physical relations of thermo-fluid dynamics to derive relations, approximations of certain phenomena and mathematical-numerical adjustments to carry out the calculation of this estimate.

[0012] Another requirement of the estimation methods is that they must be invertible, in the sense of allowing control of the mass of air that the cylinder traps in order to control the generated/delivered torque. In general, the estimation method provides, in a given time instant, the mass flow rate trapped in the cylinder starting from the value assumed at that instant by the quantities measured by the sensors available and the positions of the actuators present in the intake system and engine exhaust. On the other hand, the control method aims at controlling the position of the actuators to impose a predetermined mass flow rate value of air entering the engine to achieve a corresponding predetermined torque value.

[0013] The models used, therefore, must allow both the calculation of the estimate of the amount of air and its control to be reliable and easily implementable in the ECU.

[0014] An important point to take into consideration is that the estimation methods generally adopted are based on an average value, as each single cylinder does not suck in exactly the same air as the others and their pumping generates a periodic oscillation of the pressure at the inside of the intake manifold. Therefore, the estimate is based on an average value of the pressure trend both in terms of time and with respect to the single cylinder.

[0015] The estimation of the amount of air when the engine is stationary, i.e. at a constant engine rotation speed and with the actuators stationary, does not present any particular problems. Over the years, estimations based initially on simple two-dimensional maps have been taken into consideration, and later on increasingly complex calculations based on the physics of cylinder operation, up to the use of very sophisticated and complex algorithms.

[0016] One of the best-known equations implemented is named Speed-density:

$$\dot{m} = \rho V_{cyl} \frac{N_e}{120} \eta$$

where $\dot{m}$ denotes the average air mass flow rate drawn by a single cylinder of a 4-stroke engine, ρ the air density, V_{cyl} the cylinder volume, N_e the engine rotation speed and η is the so-called volumetric filling coefficient or volumetric efficiency.

[0017] The problem becomes more complicated when the engine is not in stationary conditions.

[0018] In this case, several techniques based on various approaches have been devised and implemented, including many that attempt to estimate the volumetric coefficient of the engine in the event of a transient. The estimation of the amount of air during a transient therefore represents a notable complicating factor and the most consistent efforts are based on transients to develop ideas and methods with which to obtain the aforementioned estimate.

[0019] Further complications are due to the presence of systems aimed at increasing the volumetric efficiency such as the cam phase variators in the intake and exhaust.

[0020] Typically, available sensors are temperature, pressure and/or air mass flow sensors. They are generally located somewhere between the throttle valve and the engine head. This positioning is identified by considering the high temperatures reached by the engine head, in order not to damage the sensors themselves.

[0021] Unless specifically excluded in the detailed description that follows, what is described in this chapter is to be considered as an integral part of the detailed description.

Summary of the invention

[0022] The object of the present invention is to indicate a method for estimating an air mass flow rate entering a spark ignited engine that is reliable, accurate and at the same time simple to implement with a reasonable computational load.

[0023] The basic idea of the present invention is to consider an estimation model based on pressure and temperature measured at the intake manifold and related derivatives.

[0024] The idea arose when, by installing a thermocouple near the intake valve, a significant variation in temperature was observed in relation to the mass flow rate entering the engine. However, the positioning of the temperature sensor away from the cylinder head does not allow to detect these important variations in the event of sudden openings of the butterfly valve followed by sudden closures. Probably, this is the reason why historically everybody have always been satisfied with the well-known Speed-Density formula.

[0025] We asked ourselves how the temperature and its variation could be appropriately taken into account in the modelling of the mass flow rate of air entering the engine.

[0026] A method for estimating the mass flow rate of air entering the SI engine is shown below with a relative mathematical justification.

[0027] The dependent claims describe preferred variants of the invention, forming an integral part of the present description.

Brief description of the figures

[0028] Further objects and advantages of the present invention will become clear from the detailed description that follows of an embodiment of the same (and of its variants) and from the annexed drawings given for purely explanatory and non-limiting purposes, in which:

Fig. 1 shows an example of an estimation scheme according to the method object of the present invention;
Fig. 2 shows a spark ignited internal combustion engine implementing the present estimation method.

[0029] The same reference numbers and letters in the figures identify the same elements or components or functions.

[0030] It should also be noted that the terms "first", "second", "third", "superior", "inferior" and the like may be used herein to distinguish various elements. These terms do not imply a spatial, sequential, or hierarchical order for the modified items unless specifically indicated or inferred from the text.

[0031] The elements and characteristics illustrated in the various preferred embodiments, including the drawings, can be combined with each other without however departing from the scope of protection of the present application as described below.

Detailed description

[0032] With reference to Fig. 2, an Otto-cycled internal combustion engine E comprises a cylinder closed by a head (not shown) and a piston slidingly associated with the cylinder C to achieve reciprocating motion. At least one intake valve and at least one exhaust valve and a spark plug (not shown) are arranged in the cylinder head.

[0033] The engine is supplied with fresh air via an intake manifold IM on which a throttle valve TV is arranged.

[0034] A temperature sensor TS and a pressure sensor PS are arranged between the throttle valve TV and the intake valve.

[0035] They are generally arranged at an intermediate point between the throttle valve and the intake valve, so as not to be damaged by the high temperatures reached in the engine head. This is the reason why it is possible to have a thermocouple placed in the head close to the intake valve only during bench tests. However, as we will see, the operations carried out on the bench are sufficient to model the temperature at the intake valve even though a temperature sensor TS is used which is located away from the cylinder head.

[0036] The idea behind the control scheme illustrated below with the help of Fig. 1 is based on the consideration that the mass of air trapped in the cylinder is given by the relation

$$m = \rho V_{cyl} \qquad \text{(a)}$$

[0037] From this equality it can be deduced that the flow of air passing through the intake valve is given by the time derivative of the mass. For convenience, the time derivative is indicated by the operator $\dot{[\,]}$. However, downstream of the experiments mentioned above it was realized that the temperature variation close to the intake valve involves a variation in the density of the fluid, therefore the derivative of the air mass becomes:

$$\dot{m} = \rho\dot{V}_{cyl} + \dot{\rho}V_{cyl} \qquad \text{(b)}$$

[0038] Il term $\rho\dot{V}_{cyl}$ generates to the well-known "speed-density" equation described above, for calculating the fresh air trapped in the cylinders and thus represents the mean steady-state mass flow.

[0039] The term $\dot{\rho}V_{cyl}$, instead, takes into account the variation of air density in the volume under consideration. The density variation is precisely the factor that takes into account the transient phenomena due to pressure and temperature variations in the volume considered. The density is given by the well-known ideal gas equation:

$$\rho = \frac{p}{R_s T} \qquad \text{(c)}$$

[0040] Therefore, differentiating in respect of the pressure p and the temperature T it is obtained:

$$\dot{\rho} = \frac{\dot{p}}{R_s T} - \frac{p\dot{T}}{R_s T^2} \qquad \text{(d)}$$

[0041] Multiplying the first member by $\frac{p}{p}$ and the second member by $\frac{T}{T}$ it follows:

$$\dot{\rho} = \frac{p}{R_s T}\frac{\dot{p}}{p} - \frac{p}{R_s T}\frac{\dot{T}}{T} = \rho\frac{\dot{p}}{p} - \rho\frac{\dot{T}}{T} \qquad \text{(e)}$$

[0042] From which it is derived:

$$\dot{m} = \rho\dot{V}_{cyl} + \left(\rho\frac{\dot{p}}{p} - \rho\frac{\dot{T}}{T}\right)V_{cyl} \qquad \text{(f)}$$

[0043] If one approximates the operation of the 4-stroke internal combustion engine as a positive displacement pump it is obtained

$$\dot{V}_{cyl} = V_{cyl}\frac{N_e}{120} \qquad \text{(g)}$$

[0044] Thus,

$$\dot{m} = \rho V_{cyl}\frac{N_e}{120} + \rho V_{cyl}\frac{\dot{p}}{p} - \rho V_{cyl}\frac{\dot{T}}{T} \qquad \text{(h)}$$

[0045] It can therefore be seen that the mass flow of air is now a function of the density and volume of the cylinder, but not of the relative derivatives, and a function of pressure and temperature and of the relative derivatives over time.

[0046] If we limit ourselves to the first member of the equation, we return to the speed-density used for the estimation of the average mass flow rate in stationary conditions to which the well-known adjustment coefficient named "volumetric filling coefficient" is generally associated η. η has the aim not only to make the ideal model adhere to the real behaviour of the engine in stationary conditions, but also to take into account the fact that the mass flow rate is variable due to an integer and finite number of cylinders that suck in air from the intake manifold at different times according to the crankshaft angle and also according to the adjustments made by a possible phase variator relating to the opening of the intake valves, creating dynamic effects connected to pressure oscillations generated by this cause. By analogy, the previous equation can be rewritten as:

$$\dot{m} = \rho V_{cyl}\frac{N_e}{120}\eta + \rho V_{cyl}\frac{\dot{p}}{p}\mu - \rho V_{cyl}\frac{\dot{T}}{T}\nu \qquad \text{(i)}$$

[0047] Where μ and ν are adjustment coefficients for the transient phenomena related respectively to pressure and temperature. The factor μ, implemented through a lookup table, can be made a function of the most suitable variables, preferably of the engine rotation speed, and is calibrated so as to reduce deviations from the stoichiometric ratio and more precisely, so as to reduce the first lean peak of the air/fuel ratio and the consequent rich peak of the ratio, when a rapid opening followed by a rapid closing of the throttle valve is performed.

[0048] u can be also a function of one or two variables and is used to calibrate transients due to temperature variations. In order for the control to be most effective, the temperature to be considered must be as close as possible to the intake valve and more preferably in a point between the valve and the injector in the case of a PFI type engine. In the following, the expression "close to the intake valve" means that the point at which the air temperature is estimated and its first derivative in time are estimated as close as possible to the intake valve, in contrast to the fact that the temperature sensor in mass-produced engines is located away from the cylinder head.

[0049] This is because the temperature at that point is significantly different from the temperature measured by the typical sensor TS placed in the intake manifold. The temperature measured near the intake valve has been seen to differ from that measured by the sensor TS both in stationary conditions and in transients. The temperature and its first derivative over time near the intake valve can be estimated on the basis of the temperature measurements made by the sensor TS and other quantities measured by the ECU, such as, for example, the temperature of the cooling liquid and the rotation speed of the engine. This estimate can be made using a closed formula or using a lookup table. According to another variant of the invention, the temperature and its first derivative in the vicinity of the intake valve is more preferably estimated by using a learning neural network which takes as input the temperature signal generated by the temperature sensor TS, the engine rotation speed signal. However, the neural network can be suitably trained by implementing a thermocouple, placed near the intake valve, of a "sample" engine. Obviously, after training the neural network, it is not necessary to put into production engines equipped with a thermocouple located close to the intake valve. Also in this case, the aim is to adequately estimate the air temperature close to the intake valve during sudden openings followed by sudden closings of the throttle valve, in order to reduce as much as possible deviations from the stoichiometric ratio and more precisely, so as to reduce the first lean peak of the air/fuel ratio and the consequent rich peak of this ratio.

[0050] In addition, the last contribution of the aforesaid equation makes it possible to be more precise in calculating the estimated air both when the engine is cold, shortly after its ignition, and when the engine is already running at a predetermined temperature, since the two situations present significant differences.

[0051] Therefore, thanks to the present invention, the pressure and the temperature and the respective derivatives are taken into account in the calculation of the mass flow rate of the air intended to be trapped in the cylinder. While the temperature is necessarily modelled because in general, mass-produced engines do not have a temperature sensor close to the intake valve, the pressure must be modelled to calculate its average value with respect to that measured by the sensor PS, for the reasons described above about the finite number of cylinders that define the internal combustion engine.

[0052] Preferably, the models must also produce an estimate of the derivatives, trying to limit the high-frequency noise typical of derivation operations.

[0053] As far as pressure is concerned, simple low-pass filtering results in transient distortion which introduces significant delay.

[0054] Preferably, also the estimate of the average pressure and its first derivative is performed by means of a learning neural network which takes as input the pressure signal generated by the pressure sensor PS and the engine rotation speed signal.

[0055] Rearranging the above equation, we get the following formulation:

$$\dot{m} = \rho V_{cyl}\frac{N_e}{120}\left(\eta + \frac{120}{N_e}\left(\frac{\dot{p}}{p}\mu - \frac{\dot{T}}{T}v\right)\right) \qquad \text{(l)}$$

[0056] The term $\eta + \frac{120}{N_e}\left(\frac{\dot{p}}{p}\mu - \frac{\dot{T}}{T}v\right)$ can be arranged as $\eta + \Delta\eta$ where the term $\Delta\eta = \frac{120}{N_e}\left(\frac{\dot{p}}{p}\mu - \frac{\dot{T}}{T}v\right)$ is the portion which represents the dynamic contribution of the volumetric coefficient η. Therefore, while η is modelled in steady-state conditions, $\Delta\eta$ helps to fit the speed-density equation to real engine conditions in transient regime.

[0057] It is observed that the higher the rotation speed of the engine, the more the effect of the transients is reduced as $\Delta\eta$ is reduced. Similarly, when the engine is in stationary conditions $\Delta\eta$ tends to zero and therefore, the equation tends to the classic speed-density equation which is well representative in stationary conditions.

[0058] Furthermore, the more significant the pressure derivative, the greater the effect of the transient since $\Delta\eta$ increases in absolute value. The same reasoning can be applied to the temperature, which however gives a contribution of the opposite sign.

[0059] Thanks to the present invention, a closed formulation of $\Delta\eta$ is given, which allows to more easily identify the variables that have an impact on the estimation of the mass flow rate of air entering the engine in transients.

[0060] Restarting from the equation:

$$\dot{m} = \rho V_{cyl}\frac{N_e}{120}\eta + \rho V_{cyl}\frac{\dot{p}}{p}\mu - \rho V_{cyl}\frac{\dot{T}}{T}v \qquad \text{(h)}$$

a generalization can be achieved with:

$$\dot{m} = f(p, T, N_e, \ldots) + m(p, T, \ldots)\frac{\dot{p}}{p}\mu - m(p, T, \ldots)\frac{\dot{T}}{T}v \qquad \text{(m)}$$

Establishing

$$f(p, T, N_e, \ldots) = \rho V_{cyl}\frac{N_e}{120}\eta$$

and

$$m(p, T, \ldots) = \rho V_{cyl}$$

[0061] It is understood that the stationary portion $f(p, T, N_e, \ldots)$ can be calculated by means of any known method using the estimated temperature and modelled close to the intake valve. Likewise, the expression of the air mass $m(p, T, \ldots)$ entering the engine in stationary conditions can be calculated by means of any known method using the temperature estimated and modelled close to the intake valve.

[0062] Preferably, the model that calculates the mass of fresh air in steady state trapped in the cylinder can be given by any relationship that links the measurement of the pressure at the intake manifold, the pressure at the exhaust manifold, the temperature at the intake manifold, the engine rotation speed and the position of any VVT type actuators, etc. which directly influence this quantity. In that case we can write:

$$\dot{m} = f(p, T, N_e, \Phi \dots) \qquad \text{(n)}$$

[0063] Where Φ takes into account the position of any VVT type actuators. VVT comes from the Anglo-Saxon acronym (Variable Valve Timing) and indicates the variation of the opening angles of the intake and/or exhaust valves. Advantageously, thanks to the present invention, it is not necessary to estimate $\Delta\eta$ as a function of η, calculated in stationary regime. $\Delta\eta$ assumes an independent meaning from η and therefore it is not necessary to implement "observers", "Kalman filters" or similar and virtual sensors which very often introduce distortions and unexpected behaviours.

[0064] Thanks to the present invention, it is sufficient to calibrate η in stationary conditions by means of lookup tables and to calibrate μ and ν by means of other lookup tables so as to always keep the air/fuel ratio stoichiometric. These are simple and rapid operations, within the reach of the person skilled in the art.

[0065] The present invention can advantageously be implemented through a computer program comprising coding means for carrying out one or more steps of the method, when this program is executed on a computer. Therefore, it is understood that the scope of protection extends to said computer program and also to computer-readable means comprising a recorded message, said computer-readable means comprising program coding means for carrying out one or more steps of the method, when said program is run on a computer. Variants of the non-limiting example described are possible, without however departing from the scope of protection of the present invention, as defined by the appended claims. From the description given above, the person skilled in the art is capable of realizing the object of the invention without introducing further constructive details.

Claims

1. Method for estimating an air mass flow rate (m) entering a cylinder of a four-stroke spark-ignition engine (E), equipped with an intake manifold (IM) and at least one intake valve and a pressure (PS) and temperature (TS) sensor associated with the intake manifold, the method being based on an air mass flow estimation model comprising

   - a first contribution ($f(p,T,N_e,\eta,.,.)$) calculated by means of a steady-state modelling of the estimate of the mass air flow entering the engine,
   - a second contribution $(m(p,T,\dots)\frac{\dot{p}}{p}\mu)$ function of an average pressure and a relative derivative over time, estimated as a function of

     + an estimate of an average pressure at the intake manifold based on a pressure measurement acquired by means of said pressure sensor (PS) and
     + an estimate of a temperature (T) in the vicinity of said engine intake valve,

   - a third contribution $(m(p,T,\dots)\frac{\dot{T}}{T}\upsilon)$ function of a temperature and a relative derivative over time estimated in the vicinity of said engine intake valve, as a function of at least one temperature measurement (T) at the intake manifold acquired by means of said temperature sensor (TS), and as a function of said estimate of said average pressure at the intake manifold and

   wherein the first and second contributions have a positive sign and the third contribution has a negative sign.

2. Method according to claim 1, wherein said third contribution is proportional to the ratio between the derivative of the temperature and the value of the temperature estimated close to said at least one intake valve as a function of said temperature measurement at the intake manifold and in addition is function of an engine rotation speed and of an engine coolant temperature.

3. Method according to claim 1 or 2, wherein said second contribution is proportional to the ratio between the pressure time derivative and the value of the average pressure.

4. Method according to any one of claims 1 - 3, wherein said first contribution is given by a Speed-density model.

5. A method according to any one of claims 1 - 4, wherein said model of the estimation of the air mass flow rate is expressed by the following equation

$$\dot{m} = \rho V_{cyl} \frac{N_e}{120} \eta + \rho V_{cyl} \frac{\dot{p}}{p} \mu - \rho V_{cyl} \frac{\dot{T}}{T} \nu \qquad \text{(i)}$$

Where

- $\dot{m}$ represents the mass flow of air entering the four-stroke spark-ignition engine (E),
- ρ represents a density of the air entering the engine,
- V_{cyl} represents an engine displacement,
- N_e represents an engine rotation speed,
- p and T represent respectively estimates of the average pressure and temperature of the air entering the engine (E);
- $\dot{p}$ and $\dot{T}$represent the time derivative of pressure and temperature, respectively,
- η, μ and ν represent adjustment coefficients, a function of at least the engine rotation speed, where η is called the "volumetric filling coefficient".

6. Air mass flow control system (m) at the inlet of a four-stroke positive ignition engine (E) equipped with an intake manifold (IM) and at least one intake valve, the system comprising

- a first pressure measurement sensor (PS) able to be operatively associated with the intake manifold (IM),
- a second temperature sensor (TS) able to be operatively associated with the intake manifold (IM),
- a third rotation speed sensor able to be operatively associated with a drive shaft of the engine (E),
- a processing unit (ECU) operatively connected to said first, second and third sensors and configured to implement the air mass flow estimation model according to any one of the preceding claims 1 - 5.

7. Spark-ignited engine (E) equipped with an intake manifold (IM) and with a system for controlling a mass flow of air ($\dot{m}$) entering the engine according to claim 6.

8. A computer program comprising instructions for causing the processing unit of claim 6 to implement the model of the method according to claim 1.

9. A computer readable medium having stored the program of claim 8.

Patentansprüche

1. Verfahren zur Schätzung eines Luftmassenstroms ($\dot{m}$), der in einen Zylinder eines Viertakt-Ottomotors (E) eintritt, der mit einem Ansaugkrümmer (IM) und mindestens einem Ansaugventil und einem mit dem Ansaugkrümmer verbundenen Druck- (PS) und Temperatursensor (TS) ausgestattet ist, wobei das Verfahren auf einem Luftmassenstrom-Schätzmodell basiert, das Folgendes umfasst:

- einen ersten Beitrag ($f(p,T,N_e,\eta,.,.)$), der mittels einer stationären Modellierung der Schätzung des in den Motor eintretenden Luftmassenstroms berechnet wird,
- einen zweiten Beitrag $(m(p,T,...)\frac{\dot{p}}{p}\mu)$ Funktion eines Durchschnittsdrucks und einer relativen Ableitung über die Zeit, geschätzt als Funktion von
  + einer Schätzung eines Durchschnittsdrucks am Ansaugkrümmer basierend auf einer Druckmessung, die mittels des Drucksensors (PS) erfasst wird, und
  + einer Schätzung einer Temperatur (T) in der Nähe des Motoransaugventils,
- einen dritten Beitrag $(m(p,T,...)\frac{\dot{T}}{T}\upsilon)$ Funktion einer Temperatur und einer relativen Ableitung über die Zeit, geschätzt in der Nähe des Motoransaugventils, als Funktion von mindestens einer Temperaturmessung (T) am Ansaugkrümmer, mittels des Temperatursensors (TS) und als Funktion der Schätzung des Durchschnittsdrucks am Ansaugkrümmer erfasst, und wobei der erste und zweite Beitrag ein positives Vorzeichen und der dritte Beitrag ein negatives Vorzeichen haben.

2. Verfahren nach Anspruch 1, wobei der dritte Beitrag proportional zum Verhältnis zwischen der Ableitung der Temperatur und dem Wert der Temperatur ist, die in der Nähe des mindestens einen Ansaugventils als Funktion der Temperaturmessung am Ansaugkrümmer geschätzt wird, und zusätzlich eine Funktion einer Motordrehzahl und einer Motorkühlmitteltemperatur ist.

3. Verfahren nach Anspruch 1 oder 2, wobei der zweite Beitrag proportional zum Verhältnis zwischen der Druck-Zeit-Ableitung und dem Wert des Durchschnittsdrucks ist.

4. Verfahren nach einem der Ansprüche 1 bis 3, wobei der erste Beitrag durch ein Geschwindigkeitsdichtemodell gegeben ist.

5. Verfahren nach einem der Ansprüche 1 bis 4, wobei das Modell zur Schätzung des Luftmassenstroms durch die folgende Gleichung ausgedrückt wird:

$$\dot{m} = \rho V_{cyl} \frac{N_e}{120} \eta + \rho V_{cyl} \frac{\dot{p}}{p} \mu - \rho V_{cyl} \frac{\dot{T}}{T} \nu \qquad (i)$$

wobei

- $\dot{m}$ den Massenstrom der in den Viertakt-Ottomotor (E) eintretenden Luft darstellt,
- ρ eine Dichte der in den Motor eintretenden Luft darstellt,
- $\mathbf{V_{cyl}}$ einen Hubraum des Motors darstellt,
- $\boldsymbol{N_e}$ eine Motordrehzahl darstellt,
- p und T jeweils Schätzungen des durchschnittlichen Drucks und der durchschnittlichen Temperatur der in den Motor (E) eintretenden Luft darstellen;
- $\dot{p}$ und $\dot{T}$ jeweils die zeitliche Ableitung von Druck und Temperatur darstellen,
- η, μ und v Anpassungskoeffizienten darstellen, die zumindest von der Motordrehzahl abhängig sind, wobei η als "volumetrischer Füllkoeffizient" bezeichnet wird.

6. Luftmassenstrom-Steuersystem ($\dot{m}$) am Einlass eines Viertaktmotors mit Fremdzündung (E), der mit einem Ansaugkrümmer (IM) und mindestens einem Ansaugventil ausgestattet ist, wobei das System umfasst:

   - einen ersten Druckmesssensor (PS), der operativ mit dem Ansaugkrümmer (IM) verbunden werden kann,
   - einen zweiten Temperatursensor (TS), der operativ mit dem Ansaugkrümmer (IM) verbunden werden kann,
   - einen dritten Drehzahlsensor, der operativ mit einer Antriebswelle des Motors (E) verbunden werden kann,
   - eine Verarbeitungseinheit (ECU), die operativ mit den ersten, zweiten und dritten Sensoren verbunden ist und so konfiguriert ist, dass sie das Luftmassenstrom-Schätzmodell gemäß einem der vorhergehenden Ansprüche 1 bis 5 implementiert.

7. Fremdzündungsmotor (E), der mit einem Ansaugkrümmer (IM) und mit einem System zur Steuerung eines in den Motor eintretenden Luftmassenstroms (m) nach Anspruch 6 ausgestattet ist.

8. Computerprogramm, das Anweisungen umfasst, um die Verarbeitungseinheit von Anspruch 6 dazu zu veranlassen, das Modell des Verfahrens nach Anspruch 1 zu implementieren.

9. Computerlesbares Medium, auf dem das Programm nach Anspruch 8 gespeichert ist.

Revendications

1. Procédé d'estimation d'un débit massique d'air ($\dot{m}$) entrant dans un cylindre d'un moteur à allumage commandé à quatre temps (E), équipé d'un collecteur d'admission (IM) et d'au moins une soupape d'admission et d'un capteur de pression (PS) et de température (TS) associé au collecteur d'admission, le procédé étant basé sur un modèle d'estimation du débit massique d'air comprenant

   - une première contribution ($f(p, T, N_e, \eta, ., .)$) calculée au moyen d'une modélisation en régime permanent de l’estimation du débit massique d’air entrant dans le moteur,

- une deuxième contribution $(m(p,T,\ldots)\frac{\dot{p}}{p}\mu)$ fonction d’une pression moyenne et d’une dérivée relative dans le temps, estimée en fonction de

  + une estimation d’une pression moyenne au collecteur d’admission basée sur une mesure de pression acquise au moyen dudit capteur de pression (PS) et
  + une estimation d’une température (T) au voisinage de ladite soupape d’admission du moteur,

- une troisième contribution $(m(p,T,\ldots)\frac{\dot{T}}{T}\nu)$ fonction d’une température et d’une dérivée relative dans le temps estimée au voisinage de ladite soupape d’admission du moteur, en fonction d’au moins une mesure de température (T) au collecteur d’admission acquise au moyen dudit capteur de température (TS), et en fonction de ladite estimation de ladite pression moyenne au collecteur d’admission et

dans laquelle les première et deuxième contributions ont un signe positif et la troisième contribution a un signe négatif.

2. Procédé selon la revendication 1, dans lequel ladite troisième contribution est proportionnelle au rapport entre la dérivée de la température et la valeur de la température estimée à proximité de ladite au moins une soupape d’admission en fonction de ladite mesure de température au collecteur d’admission et est en outre fonction d’une vitesse de rotation du moteur et d’une température du liquide de refroidissement du moteur.

3. Procédé selon la revendication 1 ou 2, dans lequel ladite deuxième contribution est proportionnelle au rapport entre la dérivée pression-temps et la valeur de la pression moyenne.

4. Procédé selon l’une quelconque des revendications 1 à 3, dans lequel ladite première contribution est donnée par un modèle Vitesse-densité.

5. Procédé selon l’une quelconque des revendications 1 à 4, dans lequel ledit modèle d’estimation du débit massique d’air est exprimé par l’équation suivante

$$\dot{m} = \rho V_{cyl}\frac{N_e}{120}\eta + \rho V_{cyl}\frac{\dot{p}}{p}\mu - \rho V_{cyl}\frac{\dot{T}}{T}\nu \qquad \text{(i)}$$

où

- $\dot{m}$ représente le débit massique d’air entrant dans le moteur à allumage commandé à quatre temps (E),
- ρ représente une densité de l’air entrant dans le moteur,
- $\mathbf{V_{cyl}}$ représente une cylindrée du moteur,
- N_e représente une vitesse de rotation du moteur,
- p et T représentent respectivement des estimations de la pression et de la température moyennes de l’air entrant dans le moteur (E);
- p et $\dot{T}$ représentent respectivement la dérivée temporelle de la pression et de la température,
- η, μ et v représentent des coefficients d’ajustement, fonction au moins de la vitesse de rotation du moteur, où η est appelé "coefficient de remplissage volumétrique".

6. Système de commande de débit massique d’air ($\dot{m}$) à l’entrée d’un moteur à allumage commandé à quatre temps (E) équipé d’un collecteur d’admission (IM) et d’au moins une soupape d’admission, le système comprenant

- un premier capteur de mesure de pression (PS) pouvant être associé fonctionnellement au collecteur d’admission (IM),
- un deuxième capteur de température (TS) pouvant être associé fonctionnellement au collecteur d’admission (IM),
- un troisième capteur de vitesse de rotation pouvant être associé fonctionnellement à un arbre de transmission du moteur (E),
- une unité de traitement (ECU) reliée fonctionnellement auxdits premier, deuxième et troisième capteurs et

configurée pour mettre en œuvre le modèle d'estimation de débit massique d'air selon l'une quelconque des revendications 1 à 5 précédentes.

7. Moteur à allumage commandé (E) équipé d'un collecteur d'admission (IM) et d'un système de commande d'un débit massique d'air ($\dot{m}$) entrant dans le moteur selon la revendication 6.

8. Programme informatique comprenant des instructions pour amener l'unité de traitement selon la revendication 6 à mettre en œuvre le modèle du procédé selon la revendication 1.

9. Support lisible par ordinateur sur lequel est stocké le programme selon la revendication 8.

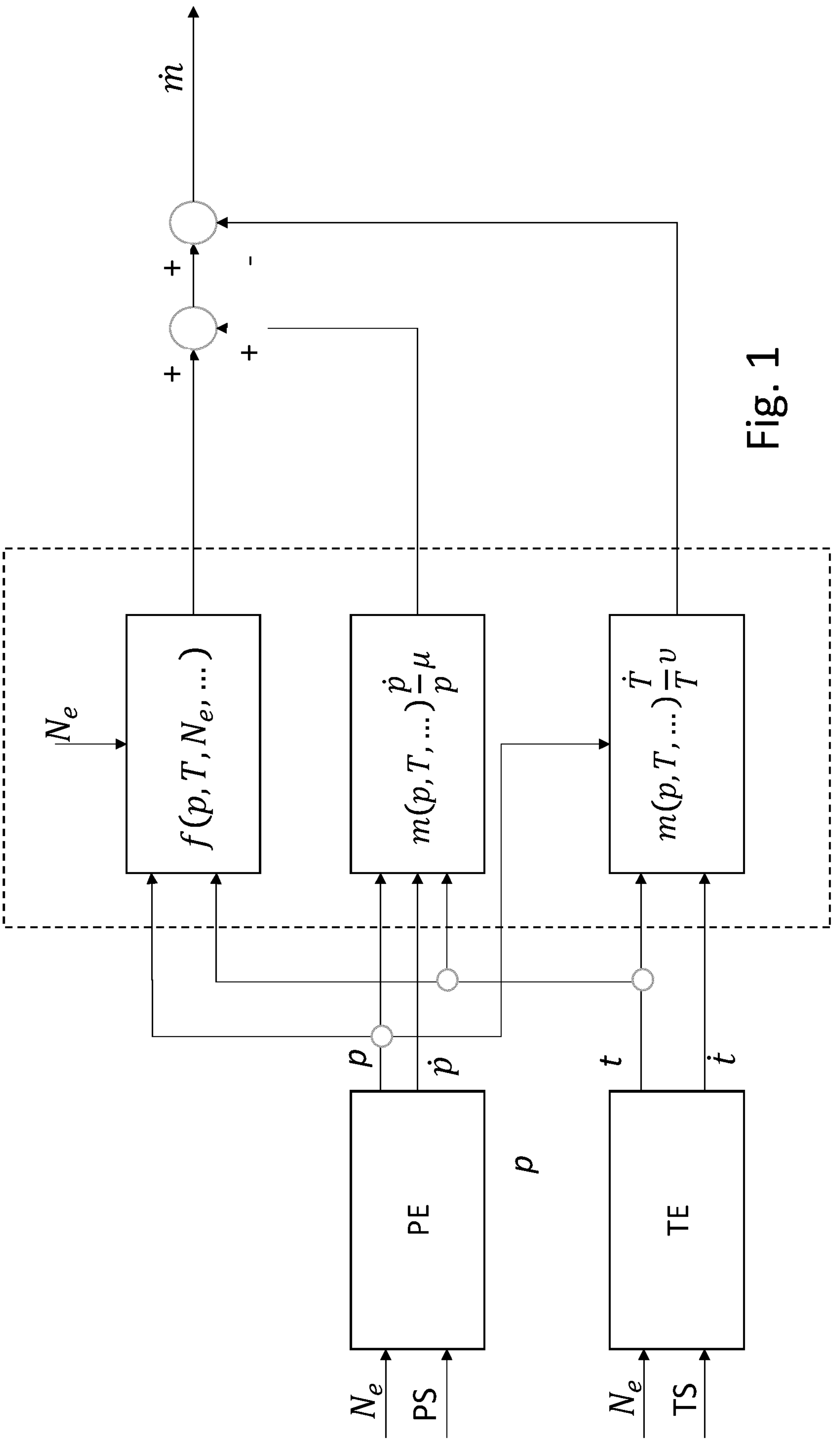
$\dot{m}$
+
+
+
-
N_e
$f(p, T, N_e, \ldots)$
$m(p, T, \ldots)\frac{\dot{p}}{p}\mu$
$m(p, T, \ldots)\frac{\dot{T}}{T}\upsilon$
p
$\dot{p}$
t
$\dot{t}$
p
PE
TE
N_e
PS
N_e
TS

Fig. 1

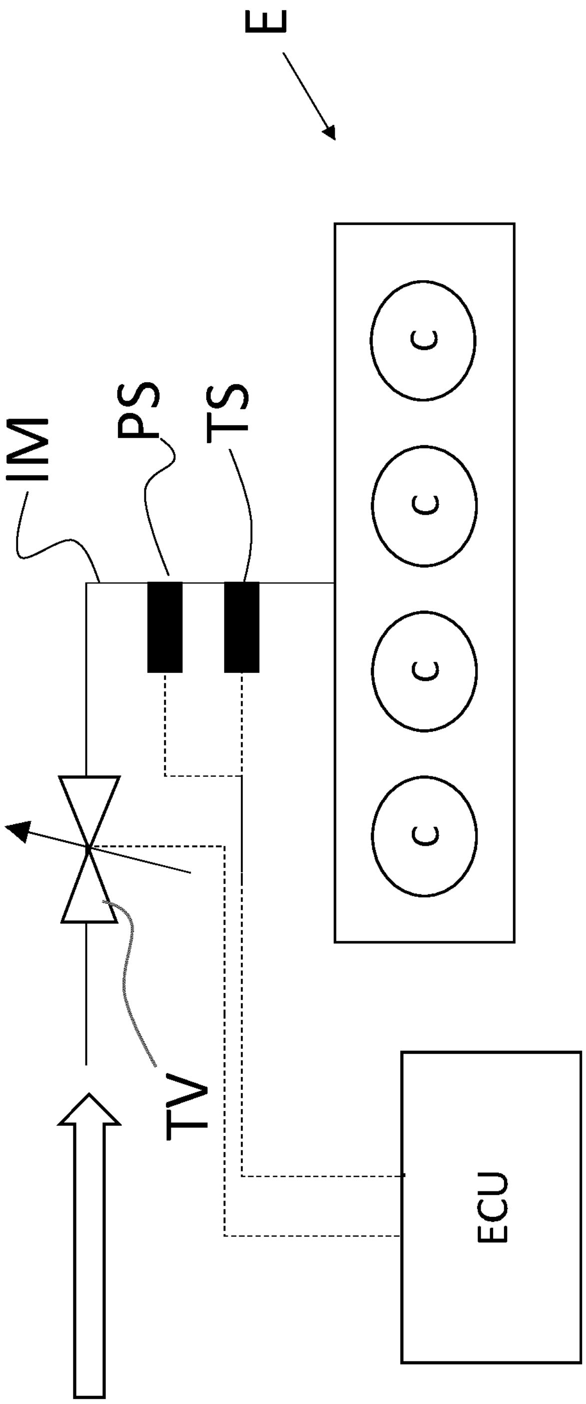

Fig. 2

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO 2019198047 A1 **[0003]**