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

(11) **EP 1 998 037 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
10.12.2014 Bulletin 2014/50

(51) Int Cl.:
F02M 25/08 *(2006.01)*

(21) Application number: **08105249.0**

(22) Date of filing: **04.09.2006**

(54) **Diagnosis of gas leakage**

Diagnose von Gasaustritt

Diagnostic de fuite de gaz

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI SK TR

(43) Date of publication of application:
03.12.2008 Bulletin 2008/49

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
06120073.9 / 1 895 144

(73) Proprietor: **Volvo Car Corporation**
405 31 Göteborg (SE)

(72) Inventors:
- **Lindgarde, Olof**
  436 54 Hovås (SE)
- **Johansson, Krister**
  519 39 Horred (SE)

(74) Representative: **Kraenzmer, Martin**
Volvo Car Corporation
50094 Intellectual Property
VAK-HBBVN
40531 Göteborg (SE)

(56) References cited:
DE-A1- 10 209 483
JP-A- 2004 324 476
US-A1- 2003 213 295
US-A1- 2004 149 016

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 1 998 037 B1

Description

TECHNICAL FIELD

[0001] The present relation relates to a method for estimating a leakage area in a vehicle tank assembly according to the preamble of claim 1 and to a method of estimating a performance from a plurality of pump assemblies and/or at least one pump assembly at different time periods according to the preamble of claim 25.

BACKGROUND OF THE INVENTION

[0002] Vehicles, for example cars, are generally equipped with at least one vehicle tank assembly comprising a tank adapted for storing a fluid, for example fuel for powering the vehicle. Furthermore, the vehicle tank assembly generally comprises a connector by which a content of the tank may be supplied to a receiving part of the vehicle. If the tank is adapted for storing fuel, an internal combustion engine of the vehicle is generally supplied with the fuel through the aforementioned connector.

[0003] As in the case of fuel, the fluid stored in the tank may be volatile, hence a leak in the vehicle tank assembly at a location above the actual fluid level may result in that evaporated fluid may exit the tank assembly and enter the surrounding atmosphere. If the evaporated fluid comprises noxious particles, such as hydrocarbons, the evaporated fluid may be harmful both to the environment in the vicinity of the vehicle tank assembly, as well as to the global environment.

[0004] As such, there is a need to test vehicle tank assemblies for leakage on a regular basis. In fact, in some countries, there are discussions about introducing legislation stating that a new vehicle should be equipped with systems capable of determining gas leakages having an area larger than a predetermined value. Preferably, the leakage test can be performed with equipment provided with the vehicle itself, i.e. a leakage test can be performed without having to visit a service facility or similar.

[0005] Prior art teaches the use of several leakage testing methods, but they generally require a large amount of measurement test results and generally only determine if a leakage is present or not, based on comparing the test results with empirically obtained reference values. Prior art further teaches that the initial gas volume of the vehicle tank assembly, being the total volume of the tank assembly minus the volume of the liquid stored within the tank assembly, has to be known prior to performing a leakage test. Determining the initial gas volume requires additional metering devices which may be required to provide results with an accuracy which is similar to the accuracy of the rest of the leakage test equipment. As such, a regular tank gauge may not be sufficiently accurate and thus there may be a need for introducing additional expensive metering devices in the vehicle tank assembly.

[0006] Prior art examples are disclosed by US 2003/213295 A1 and US 2004/149016 A1.

SUMMARY OF THE INVENTION

[0007] The object of the invention is to provide a method for estimating a performance of a pump assembly as a function of the applied pump electrical current, wherein differences between different pumps of the same model and/or aging of a pump are accounted for.

[0008] This object is achieved by a performance estimating function defined in the attached claim.

[0009] Thus, the invention relates to a method of estimating a performance from a plurality of pump assemblies and/or at least one pump assembly at different time periods. Each pump assembly comprises a gas pump, wherein the performance is indicative of at least a gas mass flow through the gas pump. Furthermore, each pump assembly comprises a reference opening and a gas valve for controlling the gas mass flow, the valve being operable to guide the gas mass flow at least either through the reference opening or through an outlet opening. The gas pump is supplied with electrical power. According to the invention, the method comprises the steps of:

- for each of the plurality of pump assemblies and/or the at least one pump assembly at different time periods:
    - measuring the performance for a plurality of applied pump electrical currents;
    - estimating the performance by the applied pump electrical current and thereby determining performance coefficients for a performance function;
    - operating the valve in order to guide the flow through the reference opening and determining the corresponding pump reference electrical current,
- for each performance coefficient, generating a performance coefficient function, which is dependent on at least the pump reference electrical current.

[0010] A further embodiment of the inventive performance testing method further comprises the steps of:

- for each of the plurality of pump assemblies and/or the at least one pump assembly at different time periods:
    - ◦ operating the valve in order to guide the flow through the outlet opening and determining an initial corresponding pump minimum electrical current;
- for each performance coefficient, generating a performance coefficient function, which is dependent on at least the pump minimum electrical current.

[0011] Another embodiment of the inventive performance testing method further comprises the step of:

- for each of the plurality of pump assemblies and/or the at least one pump assembly at different time periods:
    - o determining a pump electrical voltage;
- for each performance coefficient, generating a performance coefficient function, which is dependent on at least the pump electrical voltage.

[0012] A further embodiment of the inventive performance testing method further comprises the step of estimating each of the performance functions by an affine performance function.

[0013] Another embodiment of the inventive performance testing method further comprises the step of estimating the coefficients to each of the affine performance functions by utilizing a least-squares method.

[0014] A further embodiment of the inventive performance testing method further comprises the step of estimating the coefficients to each of the affine performance functions by utilizing a recursive least-squares method.

[0015] In a further embodiment of the inventive method of performance testing, the pump assembly forms a part of a vehicle tank assembly, the pump assembly being in fluid communication with the rest of the tank assembly and the pump assembly performance comprises a resulting change in pressure in the tank assembly.

[0016] Thus, by utilizing the obtained performance coefficient function as previously described, an output, comprising the gas mass flow through the pump, from a pump assembly may be estimated. A method of estimating the output, based on the performance coefficient function, comprises the steps of:

- operating the valve in order to guide the flow through the reference opening and determining a corresponding pump reference electrical current,
- determining the performance coefficients, based on the pump reference electrical current,
- operating the valve in order to guide the flow through the outlet opening;
- determining the applied pump electrical current, and
- calculating the output, by utilizing the performance function with the performance coefficients, utilizing the applied pump electrical current as input to the performance function.

[0017] One embodiment of the output estimation method preferably further comprises the steps of:

- operating the valve in order to guide the flow through the outlet opening and determining a corresponding initial pump minimum electrical current, and
- determining the performance coefficients, based on the initial corresponding pump minimum electrical current.

[0018] Still another embodiment of the output estimation method preferably further comprises the steps of:

- determining an pump electrical voltage;
- determining said performance coefficients, based on the pump electrical voltage.

[0019] The output estimated may preferably comprise a change in pressure in a tank assembly if such a tank assembly is in fluid communication with the pump assembly.

[0020] Advantages of different embodiments of the performance testing method are similar to the advantages presented when previously discussing methods for estimating the performance of a gas pump as a function of supplied pump electrical current in conjunction with the leakage area estimation method, and are thus not presented here.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] The present invention will hereinafter be further explained by means of non-limiting examples with reference to the appended figures wherein;

Fig. 1 is schematic view of a vehicle tank assembly on which the method of the invention may be applied;

Fig. 2 is schematic view of an alternative vehicle tank assembly on which embodiments of the inventive method may be applied, and

Fig. 3 is a time history diagram of an electrical current supplied to a gas pump.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0022] Fig. 1 illustrates a vehicle tank assembly 10 on which at least the leakage area estimation method of the invention may preferably be applied. The tank assembly 10 comprises a tank 12 which is adapted to store a liquid 14, such as fuel. Due to e.g. improper handling of the vehicle tank assembly, the tank assembly 10, above a liquid level 16, may be provided with a leakage opening 18 having a leakage area A_{leak}. It has been observed that one frequent location of the leakage opening 18 is in the vicinity of a filler cap 22. Thus, evaporated liquid from the stored liquid 14 may exit the tank assembly 10 and enter the surrounding atmosphere.

[0023] The tank assembly 10 optionally comprises a canister 24 in fluid communication with the tank 12. Furthermore, the tank assembly preferably comprises a gas pump 26. However, in some implementations of the tank assembly 10 on which the method of the invention is preferably applied, the gas pump 26 may preferably be replaced by other gas pressurising means, for example a gas tank having an initial gas pressure which is different than the initial pressure in the rest of the tank assembly 10. The gas pump 26 is preferably adapted to provide a gas mass flow into, or out of, the tank assembly 10. The tank assembly 10 preferably comprises metering means for determining e.g. a pressure in the tank assembly. In the tank assembly 10 illustrated in Fig. 1, the metering means comprises a pressure gauge 30 within the tank assembly 10, but the metering means may be constituted by other gauges, and in some implementations of the tank assembly 10, additional physical properties may preferably be measured, such as a gas mass flow through the gas pump and the temperature within and/or outside of the tank assembly 10.

[0024] The following relates to a method for estimating the leakage area in a vehicle tank assembly 10 by varying the pressure in the tank assembly by applying the gas mass flow through the gas pump 26 during an area estimation time period.

[0025] The method further comprises the steps of establishing an instantaneous gas mass flow relation of the gas in the tank assembly 10 in which relation the leakage area A_{leak} is an unknown parameter. The aforesaid establishment is performed for each of a plurality of time instants during the area estimation time period, hence a plurality of gas mass flow relations are obtained. The method further comprises the step of estimating the leakage area A_{leak} by utilizing the instantaneous gas mass flow relations.

[0026] It should be realized that the method may be carried out by either increasing or decreasing the pressure within the tank assembly 10. Furthermore, in the leakage area testing methods disclosed herein, the gas pumped by utilizing the gas pump 26 is preferably air.

[0027] According to a further embodiment, estimation of the leakage area A_{leak} is executed by arranging the instantaneous gas mass flow relation of the gas in an equations system and determining the leakage area A_{leak} by utilizing a least-squares method. Preferably, the arrangement of the gas mass flow relation of the gas is solved by utilizing a recursive least-squares method.

[0028] In a further embodiment, each of the instantaneous gas mass flow relation is an equality based on an ideal gas law. The ideal gas law stipulates that:

$$pV = nRT \qquad \text{Eq. 1}$$

where:

p is the pressure (Pa);
V is the volume (m^3);
n is the number of moles of gas;
R is the gas constant $J/(mol \cdot K)$, and

T is the temperature (K).

[0029] The number of moles of gas is equal to the mass of the gas, divided by the molar mass of the gas:

$$n = \frac{m}{M} \qquad \text{Eq. 2}$$

where:

m is the mass of the gas, and
M is the molar mass of the gas.

[0030] Inserting Eq. 2 into Eq. 1, the following expression is obtained:

$$pV = nRT = \frac{m}{M}RT = m\frac{R}{M}T = mrT \qquad \text{Eq. 3}$$

where:

r is the specific gas constant. For example, the specific gas constant r for air is approximately 287 $J/(kg \cdot K)$.

[0031] As a starting point for the aforementioned embodiment, an initial state of the gas filled portion of the tank assembly is considered. Thus, at a selected starting time t_0 for starting the leakage area estimation method, the following relation is assumed to apply between the pressure (p_0), volume (V_0) and mass (m_0) of the gas initially entrapped in the tank assembly:

$$p_0 V_0 = m_0 r T_0 \qquad \text{Eq. 4}$$

[0032] By applying a gas mass flow q_{pump} to (or from) the tank assembly 10, the gas mass within the tank assembly 10 may vary. Thus, the pressure within the tank assembly 10 may also vary. Thus, utilizing the expression in Eq. 4 for a specific time instant t after the starting time to, the following expression is assumed to apply:

$$\begin{aligned}&\left(p_0 + \Delta p(t)\right)\left(V_0 + \Delta V(t)\right) = \left(m_0 + \Delta m(t)\right)rT(t) = \\ &\left(m_0 + \int_{t_0}^{t} q_{pump}(s)ds + \int_{t_0}^{t} q_{leak}(s)ds\right)rT(t)\end{aligned} \qquad \text{Eq. 5}$$

where:

$\Delta p(t)$	is a change in pressure;
$\Delta V(t)$	is a change in volume of the vehicle tank assembly, due to e.g. elasticity of one or more components of the tank assembly;
$\Delta m(t)$	is a change in mass;
$q_{pump}(t)$	is a flow of the gas pump of the system, and
$q_{leak}(t)$	is a flow through the possible leakage opening.

[0033] In Eq. 5 above, it is assumed that the only gas mass flows to the tank assembly 10 are from the gas pump 26 and the leakage 18. However, in embodiments of the method which are presented hereinbelow, additional flows may be taken into account.

[0034] Combining Eq. 4 and Eq. 5 and utilizing that p(t) = p_0 + $\Delta p(t)$, the following expression is obtained:

$$V_0 \Delta p(t) + p(t)\Delta V(t) = r\int_{t_0}^{t} T(s) q_{pump}(s) ds + r\int_{t_0}^{t} T(s) q_{leak}(s) ds \ , \qquad \text{Eq. 6}$$

which may be re-arranged to:

$$V_0 \Delta p(t) - r\int_{t_0}^{t} T(s) q_{leak}(s) ds = r\int_{t_0}^{t} T(s) q_{pump}(s) ds - p(t)\Delta V(t) \ . \qquad \text{Eq. 7}$$

[0035] Thus, a first side and a second side of the equality are obtained. The equality is assumed to be valid for each time instant during the area estimation time period.

[0036] As may be gleaned from Eq. 7, a first side of the equality comprises a first entity minus a second entity. The first entity comprises a product of: a change of pressure Δp in the tank assembly 10 from the start of the area estimation time period to the time instant t, and the initial gas volume V_0 of the tank assembly 10. Furthermore, the second entity comprises a product of: the accumulated leakage flow q_{leak} through the leakage 18 multiplied by a temperature T of the gas in the tank assembly during a time period from the start of the area estimation time period t_0 to the time instant t; and the specific gas constant r of the gas, wherein in which leakage flow q_{leak}, the leakage area A_{leak} is an unknown parameter.

[0037] Furthermore, the leakage flow q_{leak} may in one embodiment be determined by a leakage measure, wherein the leakage measure is a product of: the unknown leakage area A_{leak} and the value of a leakage function f_{leak}, wherein the leakage function f_{leak} is a function of at least the pressure p in the tank assembly 10, such as:

$$q_{leak}(t) = A_{leak} f_{leak}\left(p(t)\right) \ . \qquad \text{Eq. 8}$$

[0038] In the following description, the leakage function f_{leak} is denoted as a function of only the pressure p in the tank assembly 10, pursuant to Eq. 8, in order to save space. It should however be noted that whenever the leakage function is used hereinbelow, the function f_{leak} may preferably further be a function of the pressure of the surrounding medium and/or of the temperature of the gas in the tank and/or the temperature of the surrounding medium, i.e.

$$f_{leak} = f_{leak}\left(p(t), p_{surr}(t), T(t), T_{surr}(t)\right) \ . \qquad \text{Eq. 9}$$

[0039] Additionally, as may be appreciated from Eq. 7, a second side of the equality may comprise a third entity, wherein the third entity comprises a product of: the accumulated gas mass flow q_{pump} from the gas pump 26 multiplied by the temperature T of the gas in the tank assembly 10 during a time period from the start of the area estimation time period t_0 to the time instant t and the specific gas constant r of the gas.

[0040] As may be gleaned from Eq. 7, the second side of the equality comprises a term which relates to a change in volume of the tank assembly 10. In some applications of the inventive method, in which the tank assembly is considered to be rigid, it may be a sufficiently good approximation to assume that the change in volume is negligible and hence set to zero. However, in a further embodiment of the invention, the change in volume may be considered, such that the second side of the equality may comprise a fourth entity, subtracted from said third entity, wherein the fourth entity comprises a product of: the pressure p in the tank assembly 10 at the time instant t and a change in volume ΔV of the tank assembly from the start of the area estimation time period t_0 to the time instant t.

[0041] In a preferred embodiment of the method, the change in volume ΔV is modelled as a function of the gas temperature and pressure, i.e.

$$\Delta V(t) = h(p(t), T(t)) \qquad \text{Eq. 10}$$

[0042] The abovementioned volume change function may be empirically determined, for instance obtained by pressurizing the tank system for a plurality of different pressures and temperatures and measuring the change in volume. Optionally, the change in volume for a plurality of different pressures and temperatures may be obtained by structural analyzes, such as FE analyses, of the tank system. Irrespective of how the change in volume as a function of pressure and temperature has been determined, i.e. by experiments or analyses, the results are preferably tabulated and stored in a storage unit. During the area estimation method, the change in volume for an actual pressure and temperature may be obtained by utilizing an interpolation method on the aforementioned tabulated data.

[0043] The equality in Eq. 7 may preferably be re-written as:

$$r\int_{t_0}^{t} T(s)q_{pump}(s)ds - p(t)\Delta V(t) = \left(\Delta p(t) \quad -r\int_{t_0}^{t} T(s)f\big(p(s)\big)ds\right)\begin{pmatrix} V_0 \\ A_{leak}\end{pmatrix} \qquad \text{Eq. 11}$$

or:

$$y(t) = \varphi(t)\theta \qquad \text{Eq. 12}$$

where:

$$y(t) = r\int_{t_0}^{t} T(s)q_{pump}(s)ds - p(t)\Delta V(t) \qquad \text{Eq. 13}$$

$$\varphi(t) = \left(\Delta p(t) \quad -r\int_{t_0}^{t} T(s)f\big(p_{amb}, p(s), T(s)\big)ds\right) \qquad \text{Eq. 14}$$

$$\theta = \begin{pmatrix} V_0 \\ A_{leak}\end{pmatrix} \qquad \text{Eq. 15}$$

[0044] Thus, what is obtained in Eq. 12 is a gas equality which is valid for a time instant during the area estimation time period, wherein $t \in [t_0\ t_{end}]$. The gas equality of Eq. 12 is further in a form, suitable for generating an equations system such as:

$$\begin{pmatrix} y(t_0) \\ \vdots \\ y(t_{end})\end{pmatrix} = \begin{pmatrix} \varphi(t_0) \\ \vdots \\ \varphi(t_{end})\end{pmatrix}\theta \qquad \text{Eq. 16}$$

[0045] As may be appreciated when studying Eq. 16, an equation system may be obtained if $t_{end} > t_0$ and an over determined equation system may be obtained if the number of rows in the equations system is more than two. Thus, the parameter θ, comprising the sought leakage area A_{leak}, can be determined using conventional techniques, such as a least-squares method. However, as previously mentioned, in a preferred embodiment, a recursive least-squares method is used.

[0046] In a preferred embodiment a fifth entity is added to the first side of the equality, wherein the fifth entity comprises a product of: an accumulated gas mass flow $q_{canister}$ from the canister 24 multiplied by the temperature T of the gas in the tank assembly 10 during a time period from the start of the area estimation time period t_0 to the time instant t; and the specific gas constant r of the gas. Thus, the first side of the equality may be re-written as:

$$y(t) = r\int_{t_0}^{t} T(s)\left[q_{pump}(s) + q_{canister}(s) + q_{evapor}(s)\right]ds - p(t)\Delta V(t) \qquad \text{Eq. 17}$$

[0047] In a further embodiment of the method and as may gleaned from Eq. 17, a sixth entity is added to the first side of the equality, wherein the sixth entity is representative of a pressure change due to evaporation of the liquid and/or dewing of the gas in the tank assembly during a time period from the start of the area estimation time period t_0 to the time instant t. In Eq. 16 the pressure change is formulated as an additional gas mass flow q_{evapor}.

[0048] In order to simplify the analyses of measured data, as well as the data measurements, the gas temperature T in the tank assembly 10 is assumed to be constant throughout the area estimation time period. Thus, Eq. 12 and 13 may be rewritten as:

$$y(t) = rT\int_{t_0}^{t} q_{pump}(s)ds - p(t)\Delta V(t) \qquad \text{Eq. 18}$$

$$\varphi(t) = \begin{pmatrix} \Delta p(t) & -rT\int_{t_0}^{t} f\left(p_{amb}, p(s), T(s)\right)ds \end{pmatrix} \qquad \text{Eq. 19}$$

[0049] Consequently, when a canister 24 is present and/or if evaporation is taken into account, Eq. 17 may be re-written as:

$$y(t) = rT\int_{t_0}^{t}\left[q_{pump}(s) + q_{canister}(s) + q_{evapor}(s)\right]ds - p(t)\Delta V(t) \qquad \text{Eq. 20}$$

[0050] The gas pump 26 of the tank assembly 10 is generally supplied with electrical power. Thus, each of the change in pressure Δp and the gas mass flow q_{pump} through the gas pump 26, respectively, is in one preferred embodiment of the method estimated by a performance function of an applied pump electrical current I. Each performance function has a set of performance coefficients. Thus, an estimate of the gas mass flow q_{pump} through the gas pump 26 may the written as:

$$q_{pump} = k(I) \qquad \text{Eq. 21}$$

where:

$k(\cdot)$ is the performance function.

[0051] Herein, the gas mass flow q_{pump} is used as an example in the description of the performance estimation portion of the preferred embodiment of the method. It should however be realized that the description is equally valid for the change in pressure Δp.

[0052] A plurality of different functions are suitable for utilizing as the performance function. However, in a preferred embodiment of the invention each, of the performance functions is estimated by an affine performance function. Thus, for the aforementioned estimate of the gas mass flow q_{pump} through the gas pump 26, the following expression may be applied:

$$q_{pump} = \alpha_0 + \alpha_1 I \qquad \text{Eq. 22}$$

where:

α_0, α_1 are the performance coefficients of the affine performance function.

[0053] The electrical power is supplied to the gas pump 26 at a predetermined voltage U. The performance of the gas pump 26 may differ for separate voltages U applied. Thus, in a preferred embodiment, the performance coefficients of each of the affine performance functions are dependent on at least the voltage U supplied to the gas pump 26, such as

$$q_{pump} = \alpha_0(U) + \alpha_1(U) I \qquad \text{Eq. 23}$$

where:

U is the applied voltage.

[0054] In order to further enhance the estimate of the performance of the gas pump 26, a specific pump assembly 34, as illustrated in Fig. 2, may be used used. As may be gleaned from Fig. 2, the pump assembly 34 comprises a reference opening 36 and a valve 38 for controlling the gas mass flow p_{ump}. The valve 38 is operable to guide the gas mass flow q_{pump} at least either through the reference opening 36 or to an outlet opening 40 which outlet opening 40 may be in fluid communication with the tank assembly 10. The pump assembly 34 of Fig. 2 further comprises an inlet opening 42 which in some implementations of the pump assembly 34 may be in fluid communication with the surrounding atmosphere. The cross-sectional area of the reference opening 36 is preferably relatively small and is preferably less than 0.5 mm^2, more preferably less than 0.2 mm^2. Purely by way of example, the reference opening 36 may be a cylindrical opening having a diameter of 0.5 mm.

[0055] Utilizing a tank assembly 10, comprising a pump assembly 34 as previously described with reference to Fig. 2, introduction of additional steps in preferred embodiments of the method is enabled. As such, according to a preferred implementation of the performance estimation, the performance coefficients of the performance functions are established by a coefficient estimation method comprising the step of operating the valve 38 in order to guide the gas mass flow q_{pump} through the reference opening 36 and determining a corresponding pump reference electrical current I_{ref} and determining the performance coefficients of each of the performance functions depending on the corresponding pump reference electrical current I_{ref}. As such, in the aforementioned example where the gas mass flow q_{pump} through the gas pump 26 is estimated by an affine performance function, dependent on at least the supplied voltage U, the following expression may be obtained:

$$q_{pump} = \alpha_0(U, I_{ref}) + \alpha_1(U, I_{ref}) I \qquad \text{Eq. 24}$$

[0056] The performance estimation may be even further refined by a coefficient estimation method which comprises the step of operating the valve 38 in order to guide the flow q_{pump} to the tank assembly 10 and determining an initial corresponding pump minimum electrical current I_{min}, and determining the performance coefficients of each of the performance functions depending on the corresponding pump minimum electrical current I_{min}.

[0057] Again, utilizing the aforementioned example where the gas mass flow q_{pump} through the gas pump 26 is estimated by an affine performance function, dependent on at least the supplied voltage U and the reference current

I_{ref}, the following expression may be used:

$$q_{pump} = \alpha_0(U, I_{ref}, I_{\min}) + \alpha_1(U, I_{ref}, I_{\min})I \quad . \qquad \text{Eq. 25}$$

[0058] Any one embodiment previously described may preferably be used in a method for testing leakage in a vehicle tank assembly 10. For example, a leakage area A_{leak} may be estimated by utilizing the leakage estimation method and then comparing the estimated leakage area A_{leak} to a predetermined threshold value.

[0059] Preferably, the leakage testing method further comprises the step of transmitting a warning signal if the estimated leakage area A_{leak} exceeds the predetermined threshold value and/or the step of transmitting an acceptance signal if the estimated leakage area A_{leak} is lower than the predetermined threshold value.

[0060] The leakage estimation method and/or the leakage testing method may preferably be implemented in a computer program product. Thus, such a computer program product, may comprise a computer program containing computer program code executable in a computer or a processor to implement at least one of the steps of a aforementioned methods. The computer program product may preferably be stored on a computer-readable medium or a carrier wave. The computer program product may preferably be stored in an electronic control unit (ECU) 32 and the ECU 32 may preferably be located within a vehicle, which vehicle comprises the vehicle tank assembly 10.

[0061] As may be appreciated when studying the performance functions of the gas pump 26, it may be preferred to have a method to create performance functions which method takes into account individual differences between gas pumps 26 and/or a time dependent change in the performance of a gas pump 26, for example a decrease in performance due to aging.

[0062] Thus, what is proposed is a method of estimating performances from a plurality of pump assemblies 34 and/or at least one pump assembly 34 at different time periods. The performance is indicative of at least the gas mass flow q_{pump} through the gas pump 26 and each pump assembly 34 comprises the features previously disclosed with reference to Fig. 2.

[0063] The method comprises the steps of, for each of a plurality of pump assemblies 34 and/or at least one pump assembly 34 at different time periods:

- measuring the performance for a plurality of applied pump electrical currents *I*;
- estimating the performance by the applied pump electrical current *I* and thereby determining performance coefficients for a performance function;
- operating the valve 38 in order to guide the gas mass flow q_{pump} through the reference opening 36 and determining the corresponding pump reference electrical current I_{ref},
- for each performance coefficient, generating a performance coefficient function, which is dependent on at least the pump reference electrical current I_{ref}.

[0064] For example, if the gas mass flow q_{pump} may be estimated as a polynomial of the applied pump electrical current / as:

$$q_{pump} = \alpha_0 + \alpha_1 I + \alpha_2 I^2 + \ldots + \alpha_n I^n \quad , \qquad \text{Eq. 26}$$

wherein the value of each performance coefficient may be a function of the pump reference electrical current I_{ref}, i.e.

$$\alpha_k = g_k(I_{ref}) \qquad k = 0, \ldots, n \qquad \text{Eq. 27}$$

[0065] Fig. 3 illustrates the electrical current / applied to the gas pump 26 as a function of time, the pump electrical current / being denoted by lines 44. As may be gleaned from Fig. 3, when the gas mass flow q_{pump} is guided through the reference opening 36, a throttling of the gas mass flow q_{pump} is obtained, resulting in an increase in applied pump electrical current / required to drive the gas pump 26, as indicated by area B in Fig. 3.

[0066] The valve 38 of the pump assembly 34 may preferably be further operated so that the gas mass flow q_{pump} is guided out of the pump assembly 34. If the initial pressure out of the pump assembly 34 is significantly equal to the

pressure at the inlet 42, a pressure difference between the inlet and outlet 42, 40 is substantially zero, resulting in a minimum of applied electrical current *I* to the pump, as indicated by area C in Fig. 3. This illustrates additional steps of a further embodiment of the estimation method which comprises the steps of operating the valve 38 in order to guide the flow p_{pump} out of the pump assembly 34 and determining an initial corresponding pump minimum electrical current I_{min} and generating the performance coefficient function, which is dependent on at least the pump minimum electrical current I_{min}. As illustrated by the plurality of lines 44 in Fig. 3, after obtaining the pump minimum applied electrical current I_{min}, the pump electrical current *I* may remain at the minimum level or increase with time. An increase in pump electrical current may indicate that the pump assembly is in fluid communication with a closed system, for example a tank assembly 10.

[0067] Thus, utilizing the expression in Eq. 27, the following expression may be obtained:

$$\alpha_k = g_k(I_{ref}, I_{\min}) \qquad k = 0,\ldots,n \qquad \text{Eq. 28}$$

[0068] Furthermore, the pump electrical voltage *U* applied may preferably be measured and used when generating the performance coefficient functions, such as:

$$\alpha_k = g_k(I_{ref}, I_{\min}, U) \qquad k = 0,\ldots,n \qquad \text{Eq. 29}$$

[0069] According to a preferred embodiment of the performance estimation method, each performance function is estimated by an affine performance function, i.e.

$$\hat{q}_{pump} = \alpha_0 + \alpha_1 I \qquad \text{Eq. 30}$$

[0070] The performance coefficients of the affine performance function are preferably estimated by utilizing a least-squares method, more preferably a recursive least-squares method.

[0071] The aforementioned pump assembly 34 may preferably form a part of a vehicle tank assembly 10, wherein the pump assembly 34 is in fluid communication with the rest of the tank assembly 10. Then, an additional performance of the pump assembly 10 may be a resulting change in pressure Δp in the tank assembly 10 when the pump 26 of the pump assembly 34 is operated.

[0072] The performance coefficient functions may preferably be used when estimating the output of a pump assembly. However, since this technique has been previously described with respect to the leakage area estimation methods, it will not be further detailed here.

[0073] Further modifications of the invention within the scope are feasible. For instance, the gas mass flow relation used in the aforementioned leakage area estimation method could take into account the compressibility of the gas.

Claims

1. A method of estimating a performance from a plurality of pump assemblies (34) and/or at least one pump assembly (34) at different time periods, each pump assembly (34) comprising a gas pump (26), wherein said performance is indicative of at least a gas mass flow (q_{pump}) through said gas pump (26), wherein each pump assembly (34) comprises a reference opening (36) and a gas valve (38) for controlling said gas mass flow (q_{pump}), said valve (38) being operable to guide said gas mass flow (q_{pump}) at least either through said reference opening (36) or through an outlet opening (40), wherein said gas pump (26) is supplied with electrical power,
characterized in that the method comprises the steps of:

    - for each of said plurality of pump assemblies (34) and/or said at least one pump assembly (34) at different time periods:

        o measuring said performance for a plurality of applied pump electrical currents (*I*);

o estimating said performance by said applied pump electrical current (I) and thereby determining performance coefficients for a performance function;
o operating said valve (38) in order to guide said flow (q_{pump}) through said reference opening (36) and determining the corresponding pump reference electrical current (I_{ref});

- for each performance coefficient, generating a performance coefficient function, which is dependent on at least said pump reference electrical current (I_{ref}).

2. The method according to claim 1, **wherein** the method further comprises the steps of:

- for each of said plurality of pump assemblies (34) and/or said at least one pump assembly (34) at different time periods:

◦ operating said valve (38) in order to guide said flow (q_{pump}) through said outlet opening (40) and determining an initial corresponding pump minimum electrical current (I_{min});

- for each performance coefficient, generating a performance coefficient function, which is dependent on at least said pump minimum electrical current (I_{min}).

3. The method according to claim 1 or 2, **wherein** the method further comprises the steps of:

- for each of said plurality of pump assemblies (34) and/or said at least one pump assembly (34) at different time periods:

o determining a pump electrical voltage (U);

- for each performance coefficient, generating a performance coefficient function, which is dependent on at least said pump electrical voltage (U).

4. The method according to any ones of claims 1 to 3, **wherein** the method further comprises the step of:

- estimating each of said performance functions by an affine performance function.

5. The method according to claim 4, **wherein** the method further comprises the step of:

- estimating said coefficients to each of said affine performance functions by utilizing a least-squares method.

6. The method according to claim 5, **wherein** that the method further comprises the step of:

- estimating said coefficients to each of said affine performance functions by utilizing a recursive least-squares method.

7. The method according to any one of the preceding claims, **wherein** said pump assembly (34) forms a part of a vehicle tank assembly (10), said pump assembly (34) being in fluid communication with the rest of said tank assembly (10) and said pump assembly performance is indicative of at least a change in pressure (Δp) in said tank assembly (10).

8. A method of estimating an output from a pump assembly (34), wherein said output comprises a gas mass flow (q_{pump}) through said gas pump (26), wherein said pump assembly (34) is provided with said performance coefficient functions by utilizing the method according to any one of claims 1 - 7, **characterized in that** the method comprises the steps of:

- operating said valve (38) in order to guide said flow (q_{pump}) through said reference opening (36) and determining a corresponding pump reference electrical current (I_{ref});
- determining said performance coefficients, based on said pump reference electrical current (I_{ref});
- operating said valve in order to guide said flow (q_{pump}) through said outlet opening (40);
- determining said applied pump electrical current (I), and
- calculating said output, by utilizing said performance function with said performance coefficients, wherein said

applied pump electrical current (*I*) is input to said performance function.

9. The method of estimating an output from a pump assembly according to claim 8, when dependent on any one of claims 2 - 7, wherein the method further comprises the steps of:

- operating said valve (38) in order to guide said flow (q_{pump}) through said outlet opening (40) and determining a corresponding initial pump minimum electrical current (I_{min}), and
- determining said performance coefficients, based on said initial corresponding pump minimum electrical current (I_{min}).

10. The method of estimating an output from a pump assembly according to claim 8 or 9, when dependent on any one of claims 3-7, wherein the method further comprises the steps of:

- determining an pump electrical voltage (*U*), and
- determining said performance coefficients, based on said pump electrical voltage (*U*).

11. The method of estimating an output from a pump assembly according to any one of claim 8-9, when dependent on claims 7, wherein said output further comprises a change in pressure (Δp) in said tank assembly (10).

Patentansprüche

1. Verfahren zum Schätzen einer Leistungsfähigkeit von mehreren Pumpenanordnungen (34) und/oder mindestens einer Pumpenanordnung (34) in unterschiedlichen Zeiträumen, wobei jede Pumpenanordnung (34) eine Gaspumpe (26) umfasst, wobei die Leistungsfähigkeit mindestens einen Gasmassendurchfluss (q_{pump}) durch die Gaspumpe (26) anzeigt, wobei jede Pumpenanordnung (34) eine Bezugsöffnung (36) und ein Gasventil (38) umfasst, um den Gasmassendurchfluss (q_{pump}) zu steuern, wobei das Ventil (38) betreibbar ist, den Gasmassendurchfluss (q_{pump}) mindestens entweder durch die Bezugsöffnung (36) oder durch eine Auslassöffnung (40) zu leiten, wobei die Gaspumpe (26) mit elektrischer Leistung versorgt wird,
dadurch gekennzeichnet, dass das Verfahren die folgenden Schritte umfasst:

- für jede der mehreren Pumpenanordnungen (34) und/oder mindestens eine Pumpenanordnung (34) in unterschiedlichen Zeiträumen:

  ◦ Messen der Leistungsfähigkeit für mehrere angelegte elektrische Pumpenströme (I);
  ◦ Schätzen der Leistungsfähigkeit durch die angelegten elektrischen Pumpenströme (I) und dadurch das Bestimmen der Leistungsfähigkeitskoeffizienten für eine Leistungsfähigkeitsfunktion;
  ◦ Betreiben des Ventils (38), um den Durchfluss (q_{pump}) durch die Bezugsöffnung (36) zu leiten und den entsprechenden elektrischen Pumpenbezugsstrom (I_{ref}) zu bestimmen;

- für jeden Leistungsfähigkeitskoeffizienten Erzeugen einer Leistungsfähigkeitskoeffizientenfunktion, die mindestens von dem elektrischen Pumpenbezugsstrom (I_{ref}) abhängig ist.

2. Verfahren nach Anspruch 1, wobei das Verfahren ferner die folgenden Schritte umfasst:

- für jede der mehreren Pumpenanordnungen (34) und/oder mindestens eine Pumpenanordnung (34) in unterschiedlichen Zeiträumen:
- Betreiben des Ventils (38), um den Durchfluss (q_{pump}) durch die Auslassöffnung (40) zu leiten und einen entsprechenden elektrischen Anfangspumpenmindeststrom (I_{min}) zu bestimmen;
- für jeden Leistungsfähigkeitskoeffizienten Erzeugen einer Leistungsfähigkeitskoeffizientenfunktion, die mindestens von dem elektrischen Pumpenmindeststrom (I_{min}) abhängig ist.

3. Verfahren nach Anspruch 1 oder 2, wobei das Verfahren ferner die folgenden Schritte umfasst:

- für jede der mehreren Pumpenanordnungen (34) und/oder mindestens eine Pumpenanordnung (34) in unterschiedlichen Zeiträumen:

  Bestimmen einer elektrischen Pumpenspannung (U);

- für jeden Leistungsfähigkeitskoeffizienten Erzeugen einer Leistungsfähigkeitskoeffizientenfunktion, die mindestens von der elektrischen Pumpenspannung (U) abhängig ist.

4. Verfahren nach einem der Ansprüche 1 bis 3, wobei das Verfahren ferner den folgenden Schritt umfasst:

- Schätzen jeder der Leistungsfähigkeitsfunktionen durch eine affine Leistungsfähigkeitsfunktion.

5. Verfahren nach Anspruch 4, wobei das Verfahren ferner den folgenden Schritt umfasst:

- Schätzen der Koeffizienten für jede der affinen Leistungsfähigkeitsfunktionen durch Verwenden eines Verfahrens der kleinsten Quadrate.

6. Verfahren nach Anspruch 5, wobei das Verfahren ferner den folgenden Schritt umfasst:

- Schätzen der Koeffizienten für jede der affinen Leistungsfähigkeitsfunktionen durch Verwenden eines rekursiven Verfahrens der kleinsten Quadrate.

7. Verfahren nach einem der vorhergehenden Ansprüche, wobei die Pumpenanordnung (34) einen Teil einer Fahrzeug-Tankanordnung (10) bildet, wobei die Pumpenanordnung (34) in Fluidkommunikation mit dem Rest der Tankanordnung (10) ist und die Leistungsfähigkeit der Pumpenanordnung mindestens eine Änderung des Drucks (Δp) in der Tankanordnung (10) anzeigt.

8. Verfahren zum Schätzen einer Ausgabe von einer Pumpenanordnung (34), wobei die Ausgabe einen Gasmassendurchfluss (q_{pump}) durch die Gaspumpe (26) umfasst, wobei die Pumpenanordnung (34) mit den Leistungsfähigkeitskoeffizientenfunktionen durch Verwenden des Verfahrens nach einem der Ansprüche 1-7 versehen ist, **dadurch gekennzeichnet, dass** das Verfahren die folgenden Schritte umfasst:

- Betreiben des Ventils (38), um den Durchfluss (q_{pump}) durch die Bezugsöffnung (36) zu leiten und einen entsprechenden elektrischen Pumpenbezugsstrom (I_{ref}) zu bestimmen;
- Bestimmen der Leistungsfähigkeitskoeffizienten auf der Grundlage des elektrischen Pumpenbezugsstroms (I_{ref});
- Betreiben des Ventils, um den Durchfluss (q_{pump}) durch die Auslassöffnung (40) zu leiten;
- das Bestimmen des angelegten elektrischen Pumpenstroms (I) und
- Berechnen der Ausgabe durch das Verwenden der Leistungsfähigkeitsfunktion mit den Leistungsfähigkeitskoeffizienten, wobei der angelegte elektrische Pumpenstrom (I) Eingabe an die Leistungsfähigkeitsfunktion ist.

9. Verfahren zum Schätzen einer Ausgabe von einer Pumpenanordnung nach Anspruch 8, wenn abhängig von einem der Ansprüche 2-7, wobei das Verfahren ferner die folgenden Schritte umfasst:

- Betreiben des Ventils (38), um den Durchfluss (q_{pump}) durch die Auslassöffnung (40) zu leiten und einen entsprechenden elektrischen Anfangsmindestpumpenstrom (I_{min}) zu bestimmen und
- Bestimmen der Leistungsfähigkeitskoeffizienten auf der Grundlage des entsprechenden elektrischen Anfangsmindestpumpenstroms (I_{min}).

10. Verfahren zum Schätzen einer Ausgabe von einer Pumpenanordnung nach Anspruch 8 oder 9, wenn abhängig von einem der Ansprüche 3-7, wobei das Verfahren ferner die folgenden Schritte umfasst:

- Bestimmen einer elektrischen Pumpenspannung (U) und
- Bestimmen der Leistungsfähigkeitskoeffizienten auf der Grundlage der elektrischen Pumpenspannung (U).

11. Verfahren zum Schätzen einer Ausgabe von einer Pumpenanordnung nach einem der Ansprüche 8 - 9, wenn abhängig von Anspruch 7, wobei die Ausgabe ferner eine Änderung des Drucks (Δp) in der Tankanordnung (10) umfasst.

Revendications

1. Procédé d'estimation d'un rendement fourni par une pluralité d'ensembles pompes (34) et/ou par au moins un

ensemble pompe (34) à différentes périodes de temps, chaque ensemble pompe (34) comprenant une pompe à gaz (26), dans lequel ledit rendement est indicatif d'au moins un débit massique de gaz (q_{pump}) à travers ladite pompe à gaz (26), dans lequel chaque ensemble pompe (34) comprend une ouverture de référence (36) et une soupape à gaz (38) pour contrôler ledit débit massique de gaz (q_{pump}), ladite soupape (38) pouvant être actionnée pour guider ledit débit massique de gaz (q_{pump}) au moins soit à travers ladite ouverture de référence (36), soit à travers une ouverture de sortie (40), dans lequel ladite pompe à gaz (26) est alimentée en énergie électrique, **caractérisé en ce que** ce procédé comprend les étapes consistant à :

- pour chacun de ladite pluralité d'ensembles pompes (34) et/ou ledit au moins un ensemble pompe (34) à différentes périodes de temps :

  ◦ mesurer ledit rendement pour une pluralité de courants électriques de pompe appliqués (I) ;
  ◦ estimer ledit rendement par ledit courant électrique de pompe appliqué (I) et déterminer ainsi des coefficients de rendement pour une fonction de rendement ;
  ◦ actionner ladite soupape (38) afin de guider ledit débit (q_{pump}) à travers ladite ouverture de référence (36) et déterminer le courant électrique de référence de pompe correspondant *(J_{ref}) ;*

- pour chaque coefficient de rendement, générer une fonction de coefficient de rendement, qui est dépendante d'au moins ledit courant électrique de référence de pompe (I_{ref}).

2. Procédé selon la revendication 1, ce procédé comprenant en outre les étapes consistant à :

- pour chacun de ladite pluralité d'ensembles pompes (34) et/ou ledit au moins un ensemble pompe (34) à différentes périodes de tempes :

  ◦ actionner ladite soupape (38) afin de guider ledit débit (q_{pump})à travers ladite ouverture de référence (40) et déterminer un courant électrique minimum de pompe correspondant initial (I_{min}) ;

- pour chaque coefficient de rendement, générer une fonction de coefficient de rendement, qui est dépendante d'au moins ledit courant électrique minimum de pompe (I_{min}).

3. Procédé selon la revendication 1 ou 2, ce procédé comprenant en outre les étapes consistant à :

- pour chacun de ladite pluralité d'ensembles pompes (34) et/ou ledit au moins un ensemble pompe (34) à différentes périodes de tempes :

  ◦ déterminer une tension électrique de pompe (U) ;

- pour chaque coefficient de rendement, générer une fonction de coefficient de rendement, qui est dépendante d'au moins ladite tension électrique de pompe (U).

4. Procédé selon l'une quelconque des revendications 1 à 3, ce procédé comprenant en outre l'étape consistant à :

- estimer chacune desdites fonctions de rendement par une fonction de rendement affine.

5. Procédé selon la revendication 4, ce procédé comprenant en outre l'étape consistant à :

- estimer lesdits coefficients à chacune desdites fonctions de rendement affines en utilisant une méthode des moindres carrés.

6. Procédé selon la revendication 5, ce procédé comprenant en outre l'étape consistant à :

- estimer lesdits coefficients à chacune desdites fonctions de rendement affines en utilisant une méthode des moindres carrés récursive.

7. Procédé selon l'une quelconque des revendications précédentes, dans lequel ledit ensemble pompe (34) fait partie d'un ensemble réservoir de véhicule (10), ledit ensemble pompe (34) étant en communication fluidique avec le reste dudit ensemble réservoir (10) et ledit rendement d'ensemble pompe est indicatif d'au moins un changement de

pression (Δp) dans ledit ensemble réservoir (10).

8. Procédé d'estimation d'un débit de refoulement fourni par un ensemble pompe (34), dans lequel ledit débit de refoulement comprend un débit massique de gaz (q_{pump}) à travers ladite pompe à gaz (26), dans lequel ledit ensemble pompe (34) est pourvu desdites fonctions de coefficient de rendement en utilisant le procédé selon l'une quelconque des revendications 1 à 7, **caractérisé en ce que** ce procédé comprend les étapes consistant à :

- actionner ladite soupape (38) afin de guider ledit débit (q_{pump}) à travers ladite ouverture de référence (36) et déterminer un courant électrique de référence de pompe correspondant *(J_{ref}) ;*
- déterminer lesdits coefficients de rendement, en se basant sur ledit courant électrique de référence de pompe (I_{ref});
- actionner ladite soupape afin de guider ledit débit (q_{pump}) à travers ladite ouverture de sortie (40) ;
- déterminer ledit courant électrique de pompe appliqué (I), et
- calculer ledit débit de refoulement, en utilisant ladite fonction de rendement avec lesdits coefficients de rendement, ledit courant électrique de pompe appliqué (I) étant entré dans ladite fonction de rendement.

9. Procédé d'estimation d'un débit de refoulement fourni par un ensemble pompe selon la revendication 8, lorsqu'elle dépend de l'une quelconque des revendications 2 à 7, ce procédé comprenant en outre les étapes consistant à :

- actionner ladite soupape (38) afin de guider ledit débit (q_{pump}) à travers ladite ouverture de sortie (40) et déterminer un courant électrique minimum de pompe initial correspondant (I_{min}), et
- déterminer lesdits coefficients de rendement, en se basant sur ledit courant électrique minimum de pompe correspondant initial (I_{min}).

10. Procédé d'estimation d'un débit de refoulement fourni par un ensemble pompe selon la revendication 8 ou 9, lorsqu'elle est dépend de l'une quelconque des revendications 3 à 7, ce procédé comprenant en outre les étapes consistant à :

- déterminer une tension électrique de pompe (U) ; et
- déterminer lesdits coefficients de rendement, en se basant sur ladite tension électrique de pompe (U).

11. Procédé d'estimation d'un débit de refoulement fourni par un ensemble pompe selon l'une quelconque des revendications 8 et 9, lorsqu'elle dépend de la revendication 7, dans lequel ledit débit de refoulement comprend en outre un changement de pression (Δp) dans ledit ensemble réservoir (10).

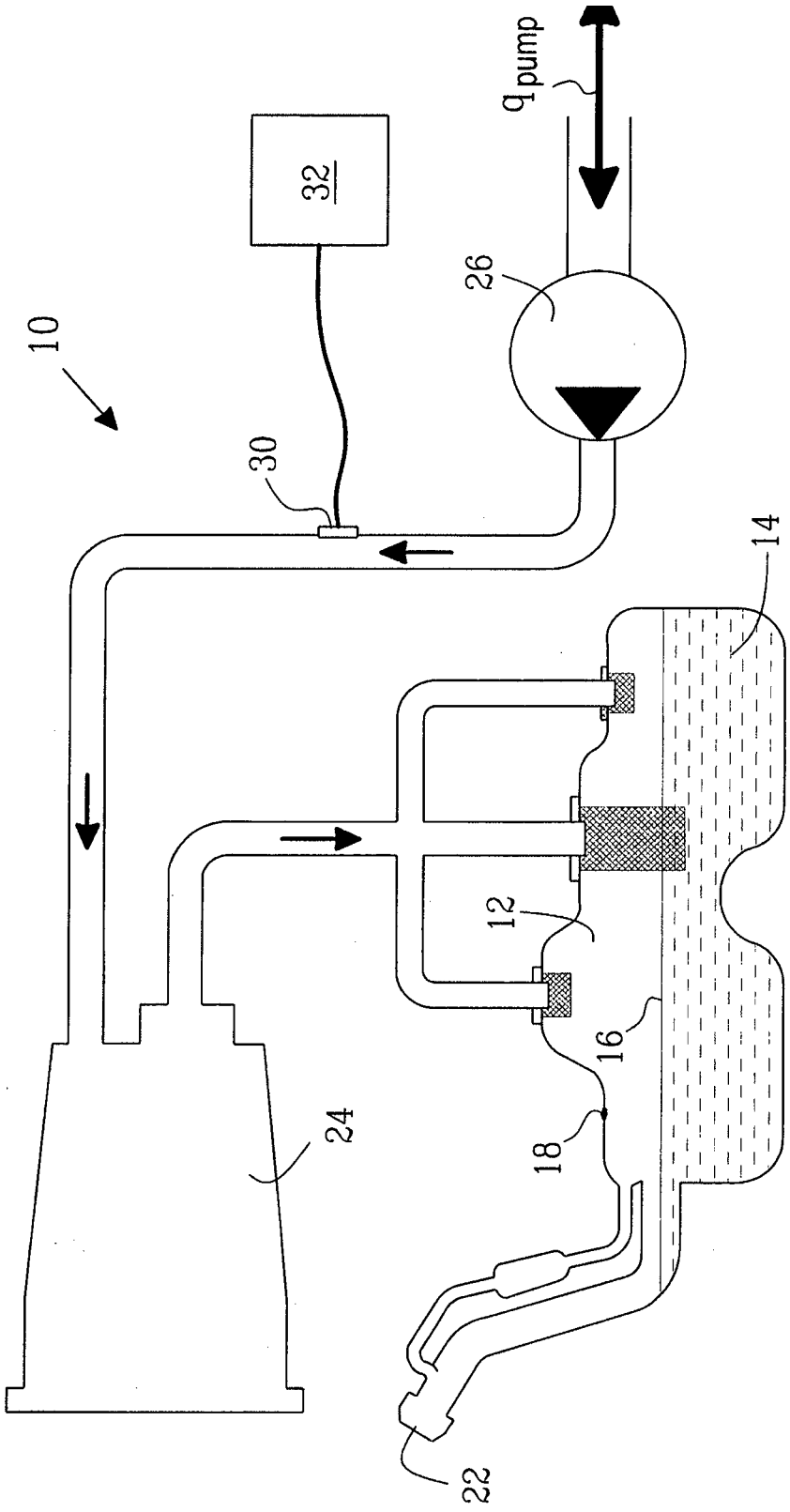


Fig. 1

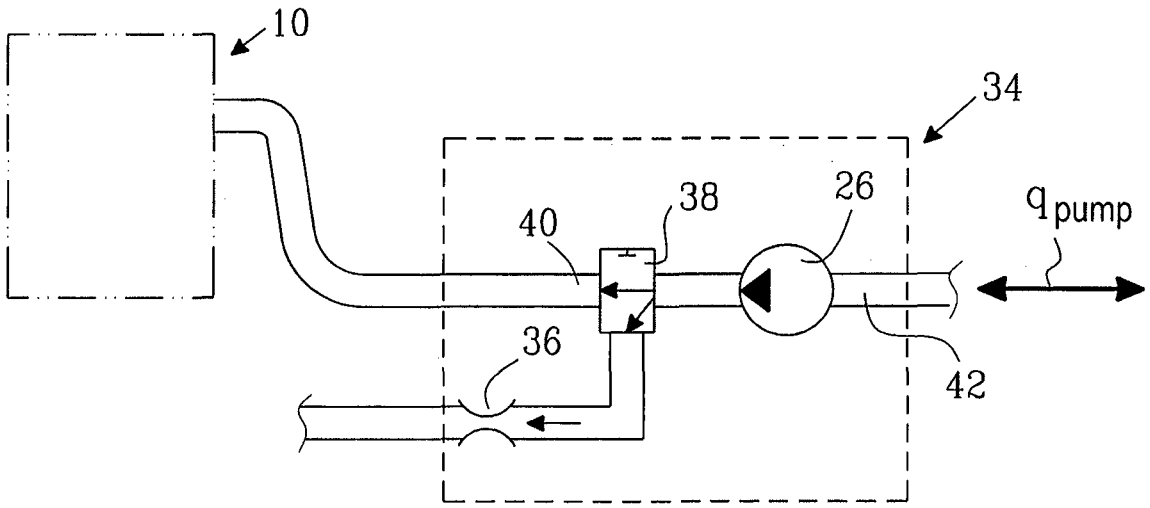


Fig.2

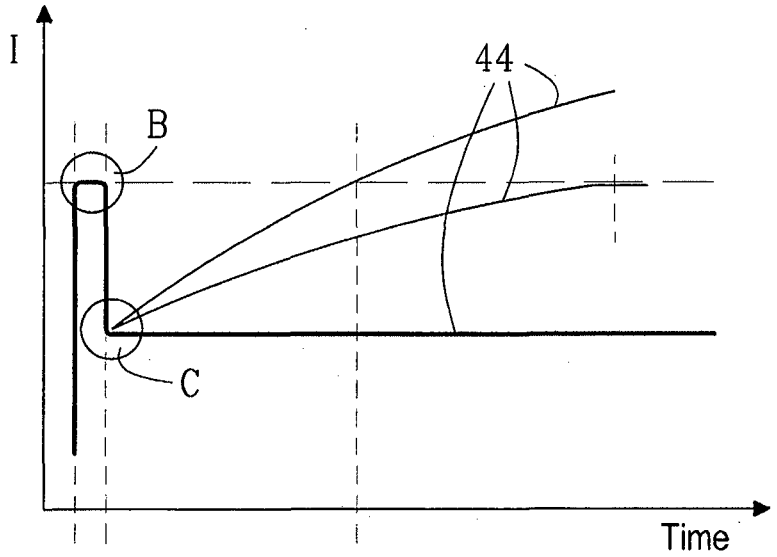


Fig.3

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 2003213295 A1 **[0006]**
- US 2004149016 A1 **[0006]**