



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:  
**15.06.2011 Bulletin 2011/24**

(51) Int Cl.:  
**F02M 25/08** <sup>(2006.01)</sup> **F02D 41/04** <sup>(2006.01)</sup>

(21) Application number: **09179024.6**

(22) Date of filing: **14.12.2009**

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

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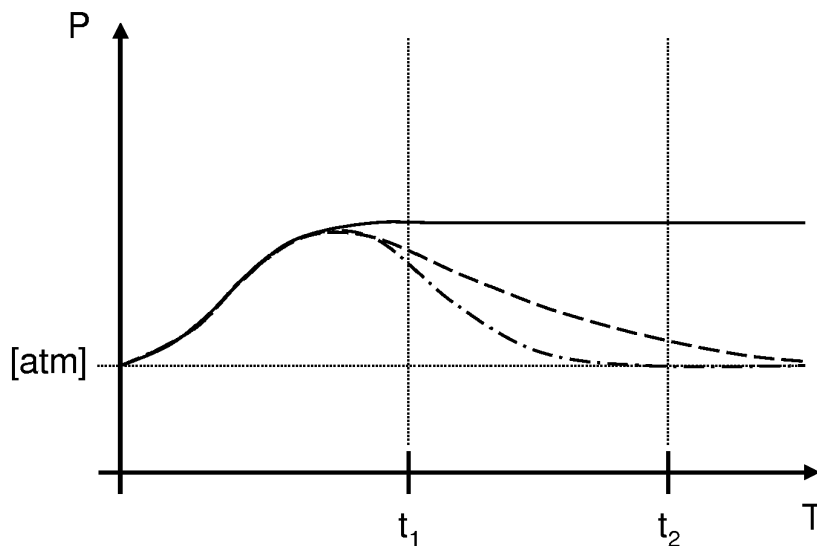
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(54) **Method and system to detect a leak in a vehicle fuel tank**

(57) The present invention relates a method and system (1) to detect a leak in a vehicle fuel tank (2). It comprises performing the following steps as well as means for performing these steps. Closing a valve (3) sealing the fuel tank (2) from ambient air (9) upon shut off of an engine of the vehicle. Measuring (4) and logging (5, 6)

the pressure in the fuel tank (2) over time to obtain a pressure curve. Analyzing the shape of the pressure curve over time from a first predetermined time  $t_1$  after closing of the valve (3) to a second predetermined time  $t_2$ . Separating a leaking and a non-leaking fuel tank (2) based on the result of said analysis.



**Fig. 2**

## Description

### Technical field

**[0001]** The present invention relates to a method to detect a leak in a vehicle fuel tank in accordance with the preamble of claim 1.

**[0002]** The present invention also relates to a system to detect a leak in a vehicle fuel tank in accordance with the preamble of claim 8.

### Background of the invention

**[0003]** The requirements for emission control for motor vehicles constantly increase. In connection with such requirements, there are also requirements for detecting that there are no emissions due to leaks in the tank system of the vehicle. If a leak is detected, this is usually indicated to the driver by a control system in the vehicle switching on a light on the instrument panel of the vehicle, a so-called MIL (Malfunction Indication Lamp). An example of a requirement regarding detection of leaks in the tank system of a vehicle is the CARB OBDII Leakage Detection Requirement (California Air Resources Board, On Board Detection) which requires the detection of leaks in a tank system which have a flow which corresponds to the flow through a circular hole, the diameter of which exceeds a certain given limit.

**[0004]** A previous method, engine-off natural vacuum (EONV), uses peak pressures for test value calculation. These peak pressures are dependant on a large number of physical factors, of which the most important ones are the temperature of the vehicle exhaust system, the temperature of the fuel, the temperature of the ambient air, the fuel quality and the wind conditions. Due to the large number of physical factors, the peak pressure is very hard to predict by the engine control module (ECM), not having information of all these conditions. For this reason, a large number of measures have to be made in the calibration process. These measures must be done in hot and cold climate respectively with a large number of different initial conditions, to make sure the algorithm does not misdetect a non-leaking system as a leaking system.

**[0005]** Through US6374663 an apparatus and methods for testing leakage in a tank system are previously known. The method includes sealing the tank system, creating a pressure variation in the sealed tank system, measuring the pressure values in the sealed tank system at predetermined time intervals for a measuring time period, and comparing the shape of a curve formed by the measured pressure values to a predetermined curve for the system, whereby if that comparison exceeds a predetermined limit value, the leakage test is disregarded. In accordance with one embodiment of US6374663, comparing of the shape of the measured curve to the predetermined curve comprises fitting a function with the predetermined curve to the shape of the measured curve

using the method of least squares. In accordance with another embodiment of US6374663, the predetermined curve comprises a second degree polynomial.

**[0006]** A drawback of the method of detecting leaks using pressure variations in a sealed system is that pressure variations may have other causes than leaks. Weather conditions such as, for example, cold or windy weather may cause pressure to fall down towards atmospheric pressure.

**[0007]** This means that during a leakage measurement there may be other circumstances, among them weather conditions, due to which difficulties in determining the origin of a pressure decrease may arise.

**[0008]** A method or system for leakage testing which is unable to recognize such circumstances may function well in a controlled environment, such as in a test lab where it is possible to check that such conditions are not present. However, under real circumstances, such as under normal driving conditions, such a system is likely to cause erroneous detections of leaks in the tank system.

**[0009]** In conclusion, there is a need to be able to take into consideration circumstances in a tank system, for example weather conditions, the presence of which may cause erroneous detections of leaks in the tank system.

### Summary of the invention

**[0010]** One object of the invention is to provide an improved method to detect a leak in a vehicle fuel tank, for avoiding or at least mitigating the above described problems.

**[0011]** This object is achieved by the method as claimed in claim 1.

**[0012]** Thanks to the provision of the steps of: closing a valve sealing the fuel tank from ambient air upon shut off of an engine of the vehicle; measuring and logging the pressure in the fuel tank over time to obtain a pressure curve; analyzing the shape of the pressure curve over time from a first predetermined time  $t_1$  after closing of the valve to a second predetermined time  $t_2$ ; separating a leaking and a non-leaking fuel tank based on the result of said analysis, a robust and easily calibrated method which also is less likely to lead to misdetection is provided.

**[0013]** A further object of the invention is to provide an improved system to detect a leak in a vehicle fuel tank, for avoiding or at least mitigating the above described problems.

**[0014]** This object is achieved by the system as claimed in claim 8.

**[0015]** Thanks to the provision of: means for closing a valve sealing the fuel tank from ambient air upon shut off of an engine of the vehicle; means for measuring and logging the pressure in the fuel tank over time to obtain a pressure curve; means for analyzing the shape of the pressure curve over time from a first predetermined time  $t_1$  after closing of the valve to a second predetermined time  $t_2$ ; and means for separating a leaking and a non-

leaking fuel tank based on the result of said analysis, a robust and easily calibrated system which also is less likely to lead to misdetection is provided.

**[0016]** Preferred embodiments are listed in the dependent claims.

### Description of drawings

**[0017]** In the following, the invention will be described in greater detail by way of example only with reference to attached drawings, in which

Fig. 1 is a schematic simplified illustration of a system to detect a leak in a vehicle fuel tank in accordance with the present invention.

Fig. 2 illustrates simplified pressure over time curves for an ideal system, a non-leaking weather exposed system and a leaking system.

**[0018]** Still other objects and features of the present invention will become apparent from the following detailed description considered in conjunction with the accompanying drawings. It is to be understood, however, that the drawings are designed solely for purposes of illustration and not as a definition of the limits of the invention, for which reference should be made to the appended claims. It should be further understood that the drawings are not necessarily drawn to scale and that, unless otherwise indicated, they are merely intended to conceptually illustrate the structures and procedures described herein.

### Description of embodiments

**[0019]** In overview, the present invention relates to a method and a system 1, as illustrated in figure 1, for detecting leaks in the fuel system of a vehicle, and more particularly to detect a leak in a vehicle fuel tank 2.

**[0020]** The method to detect a leak in a vehicle fuel tank 2 in accordance with the present invention comprises the step of closing a valve 3 sealing the fuel tank 2 from ambient air 9 upon shut off of an engine (not shown) of the vehicle. The valve 3 may e.g. be arranged in on a conduit 8 connecting the fuel tank 2 with a fuel management system of the vehicle (not shown). The valve 3 may further be arranged to communicate with a control module, such as an engine control module (ECM) 5, via suitable communication means 7 such as e.g. wired or wireless communication means 7. The pressure in the now sealed fuel tank 2 may after closing of the valve 3 start to change from atmospheric pressure.

**[0021]** The method also comprises the further step of measuring and logging the pressure in the fuel tank 2 over time to obtain a pressure curve. The pressure is preferably measured by pressure sensing means arranged within the fuel tank 2, such as by a pressure sensor 4 within the fuel tank 2, and logged by logging means,

such an engine control module (ECM) 5. The pressure sensor 4 may be arranged to communicate with the engine control module (ECM) 5 via suitable communication means 6, such as e.g. wired or wireless communication means 6.

**[0022]** The now proposed method is based on the further step of analyzing the shape of the pressure curve over time from a first predetermined time  $t_1$  after closing of the valve 3 to a second predetermined time  $t_2$ , and the step of separating a leaking and a non-leaking fuel tank 2 based on the result of this analysis.

**[0023]** As illustrated in figure 2, where the horizontal axis [T] is a time axis and the vertical axis [P] is a pressure axis upon which [atm] indicates atmospheric (ambient) pressure, the method further comprises the step of choosing the first predetermined time  $t_1$  and the second predetermined time  $t_2$  such that a falling pressure curve over time is obtainable. This because initially, after sealing the fuel tank 2 from ambient air upon shut-off of the engine of the vehicle, the pressure will usually rise due to a number of physical factors, of which the hot exhaust system (not shown) is one of the more important ones. Most importantly,  $t_1$  must be a few minutes, usually about 10 minutes, away from when the valve seals off the fuel tank 2 from the atmosphere [atm], when the engine is shut off. The exact choice of the first predetermined time  $t_1$  and the second predetermined time  $t_2$  will normally have to be calibrated to fit the particular vehicle and engine type.

**[0024]** In a leaking fuel tank 2 the pressure will later fall back towards atmospheric pressure [atm], while in a non-leaking fuel tank 2 the pressure will usually be kept at a high level. However, this is not always the case. Some weather conditions, usually cold or windy, may cause the pressure in a non-leaking system also to fall down towards atmospheric pressure [atm], but in these cases the pressure will fall with a different shape of the pressure curve.

**[0025]** Thus, the method further comprises the step of basing the analysis of the shape of the pressure curve on the realization that the pressure of a non-leaking fuel tank 2 will fall with a differently shaped pressure curve over time as compared to the pressure curve over time of a leaking fuel tank 2. This is illustrated in figure 2, where the full line curve illustrates an ideal fuel tank 2, in which the pressure of a sealed fuel tank 2 remains at a heightened level between times  $t_1$  and  $t_2$ , the dashed line curve illustrates a fuel tank 2, in which the pressure falls back towards atmospheric [atm] due to weather conditions such as, for example, cold or windy weather, and finally the dot-dashed curve illustrates a fuel tank 2, in which the pressure falls back towards atmospheric [atm] due to a leak.

**[0026]** Accordingly, in a non-leaking fuel tank 2 pressure may remain high, as illustrated by the full line curve of figure 2. However, some weather conditions, e.g. cold or windy weather, may cause the pressure in a non-leaking fuel tank 2 to fall back towards atmospheric [atm], but

in this case the pressure will fall with a differently shaped pressure curve as compared to the pressure curve of a leaking fuel tank 2.

[0027] The method further comprises the step of basing the analysis of the shape of the pressure curve on the further realization that the pressure of a non-leaking fuel tank 2 will fall with a second degree polynomial shaped pressure curve over time (e.g. the dashed curve of figure 2) as compared to a pressure curve over time of a leaking fuel tank 2 which will have a third degree polynomial shape (e.g. the dot-dashed curve of figure 2).

[0028] The method may further comprise the step of analyzing the shape of the pressure curve using the Least Squares method. The Least Squares method may be seen as a method of fitting data. The best fit, between modeled and observed data, in the least-squares sense is that instance of the model for which the sum of squared residuals has its least value, where a residual is the difference between an observed value and the value given by the model. Although the Least Squares method, as described above, is the herein preferred method, several other methods of fitting data could, as will be obvious to the person skilled in the art, be used for fitting a curve to a second order polynomial. The Least Squares method is the herein preferred method as it is relatively quick and requires a relatively moderate amount of calculations.

[0029] In accordance with the method the analysis of the shape of the pressure curve may further be based on a fitting of the pressure curve from the first predetermined time  $t_1$  to the second predetermined time  $t_2$  into a second order polynomial where three coefficients  $\theta_1$ ,  $\theta_2$  and  $\theta_3$  are given according to  $p(t) = \theta_1 x t^2 + \theta_2 \times t + \theta_3$ , where  $p(t)$  is the pressure at time  $t$ .  $\theta_1$  thus being linear to a second derivate of the function while  $\theta_2$  is linear to a first derivate of the function, and  $\theta_3$  is linear to the function itself.

[0030] Still further, in accordance with the method the analysis of the shape of the pressure curve may be based on a calculation of a final test value  $T = f_1 \times c_1 + f_2 \times c_2$  by creating  $f_1 = \theta_3 / \theta_1$  and  $f_2 = \theta_2 / \theta_1$  where the coefficients  $c_1$  and  $c_2$  are calculated in a calibration process using discriminant analysis, and using the test value  $T$  to determine the fitting of the obtained pressure curve to a 2<sup>nd</sup> order polynomial curve. The coefficients  $c_1$  and  $c_2$  must be correctly calculated. This calculation of the coefficients  $c_1$  and  $c_2$  should be performed in a calibration process, to fit the particular vehicle and engine type, using some kind of discriminant analysis. Although the final test value  $T$ , as described above, is the herein preferred final test value as it provides for relatively simple and robust calculations, other ways of calculating suitable test values indicative of the degree of curve fitting may be conceivable by those skilled in the art.

[0031] Should it be determined, as a result of said analysis, that a leak is detected, this may be indicated to a driver of the vehicle by a control system in the vehicle switching on a light on the instrument panel of the vehicle, a so-called MIL (Malfunction Indication Lamp), and/or by

any other appropriate and suitable means.

[0032] The advantage of the new method and system 1 therefore, in comparison to prior art solutions, is that although the peak pressure is dependent on a large number of physical factors, the curve shape is not. This makes the method and system 1 therefore much more robust and thereby a much shorter calibration plan may be made. The prior art EONV calibration plan requires long soaking times between calibration measures, which is not needed in accordance with this new method. Also, the measures may be made in climate cells, which decrease the need for costly expeditions to different climate locations. This will cut development cost and associated time consumption for vehicle manufacturers. Also, the method is less likely to lead to misdetection of non-leaking fuel tanks 2, which in turn may decrease warranty costs and improve customer quality impressions.

[0033] The present invention also relates to an automotive vehicle comprising a system to detect a leak in a vehicle fuel tank as described above.

[0034] The invention is not limited to the above-described embodiments, but may be varied within the scope of the following claims.

[0035] Thus, while there have been shown and described and pointed out fundamental novel features of the invention as applied to a preferred embodiment thereof, it will be understood that various omissions and substitutions and changes in the form and details of the devices illustrated, and in their operation, may be made by those skilled in the art. For example, it is expressly intended that all combinations of those elements and/or method steps which perform substantially the same function in substantially the same way to achieve the same results are within the scope of the invention. Moreover, it should be recognized that structures and/or elements and/or method steps shown and/or described in connection with any disclosed form or embodiment of the invention may be incorporated in any other disclosed or described or suggested form or embodiment as a general matter of design choice. It is the intention, therefore, to be limited only as indicated by the scope of the claims appended hereto.

## Claims

1. A method to detect a leak in a vehicle fuel tank, **characterized in that** it comprises the steps of:

closing a valve sealing the fuel tank from ambient air upon shut off of an engine of the vehicle; measuring and logging the pressure in the fuel tank over time to obtain a pressure curve; analyzing the shape of the pressure curve over time from a first predetermined time  $t_1$  after closing of the valve to a second predetermined time  $t_2$ ; separating a leaking and a non-leaking fuel tank

based on the result of said analysis.

2. A method according to claim 1, **characterized in that** it further comprises the step of:

choosing the first predetermined time  $t_1$  and the second predetermined time  $t_2$  such that a falling pressure curve over time is obtainable.

3. A method according to claim 2, **characterized in that** it further comprises the step of:

basing the analysis of the shape of the pressure curve on the realization that the pressure of a non-leaking fuel tank will fall with a differently shaped pressure curve over time as compared to the pressure curve over time of a leaking fuel tank.

4. A method according to claim 3, **characterized in that** it further comprises the step of:

further basing the analysis of the shape of the pressure curve on the realization that the pressure of a non-leaking fuel tank will fall with a second degree polynomial shaped pressure curve over time as compared to a pressure curve over time of a leaking fuel tank which will have a third degree polynomial shape.

5. A method according to claim 4, **characterized in that** it further comprises the step of:

analyzing the shape of the pressure curve using a method of fitting data such as the Least Squares method.

6. A method according to claim 5, **characterized in that** it further comprises the step of:

further basing the analysis of the shape of the pressure curve on a fitting of the pressure curve from the first predetermined time  $t_1$  to the second predetermined time  $t_2$  into a second order polynomial where three coefficients  $\theta_1$ ,  $\theta_2$  and  $\theta_3$  are given according to  $p(t) = \theta_1 \times t^2 + \theta_2 \times t + \theta_3$ , where  $p(t)$  is the pressure at time  $t$ .

7. A method according to claim 6, **characterized in that** it further comprises the step of:

further basing the analysis of the shape of the pressure curve on a calculation of a final test value  $T = f_1 c_1 + f_2 \times c_2$  by creating  $f_1 = \theta_3 / \theta_1$  and  $f_2 = \theta_2 / \theta_1$  where the coefficients  $c_1$  and  $c_2$  are calculated in a calibration process using discriminant analysis, and using the test value  $T$  to determine the fitting of the obtained pressure

curve to a second order polynomial curve.

8. A system (1) to detect a leak in a vehicle fuel tank (2), **characterized in that** it comprises:

means (5) for closing a valve (3) sealing the fuel tank (2) from ambient air (9) upon shut off of an engine of the vehicle;  
means for measuring (4) and logging (5, 6) the pressure in the fuel tank (2) over time to obtain a pressure curve;  
means (5) for analyzing the shape of the pressure curve over time from a first predetermined time  $t_1$  after closing of the valve to a second predetermined time  $t_2$ ; and  
means (5) for separating a leaking and a non-leaking fuel tank (2) based on the result of said analysis.

9. A system (1) according to claims 8, **characterized in that** it further comprises means for choosing the first predetermined time  $t_1$  and the second predetermined time  $t_2$  such that a falling pressure curve over time is obtainable.

10. A system (1) according to claim 9, **characterized in that** the means (5) for analyzing the shape of the pressure curve are arranged to base the analysis of the shape of the pressure curve on the realization that the pressure of a non-leaking fuel tank (2) will fall with a differently shaped pressure curve over time as compared to the pressure curve over time of a leaking fuel tank (2).

11. A system (1) according to claims 10, **characterized in that** the means (5) for analyzing the shape of the pressure curve are arranged to base the analysis of the shape of the pressure curve on the further realization that the pressure of a non-leaking fuel tank (2) will fall with a second degree polynomial shaped pressure curve over time as compared to a pressure curve over time of a leaking fuel tank (2) which will have a third degree polynomial shape.

12. A system (1) according to claims 11, **characterized in that** the means (5) for analyzing the shape of the pressure curve are arranged to analyze the shape of the pressure curve using a method of fitting data such as the Least Squares method.

13. A system (1) according to claims 12, **characterized in that** the means (5) for analyzing the shape of the pressure curve are arranged to further base the analysis of the shape of the pressure curve on a fitting of the pressure curve from the first predetermined time  $t_1$  to the second predetermined time  $t_2$  into a second order polynomial where three coefficients  $\theta_1$ ,

$\theta_2$  and  $\theta_3$  are given according to  $p(t) = \theta_1 \times t^2 + \theta_2 \times t + \theta_3$ , where  $p(t)$  is the pressure at time  $t$ .

14. A system (1) according to claims 13, **characterized in that** the means (5) for analyzing the shape of the pressure curve are arranged to further base the analysis of the shape of the pressure curve on a calculation of a final test value  $T = f_1 \times c_1 + f_2 \times c_2$  by creating  $f_1 = \theta_3/\theta_1$  and  $f_2 = \theta_2/\theta_1$  where the coefficients  $c_1$  and  $c_2$  are calculated in a calibration process using discriminant analysis, and using the test value  $T$  to determine the fitting of the obtained pressure curve to a second order polynomial curve. 5 10
15. An automotive vehicle, **characterized in that** it comprises a system (1) to detect a leak in a vehicle fuel tank (2) according to any one of claims 8 to 14. 15

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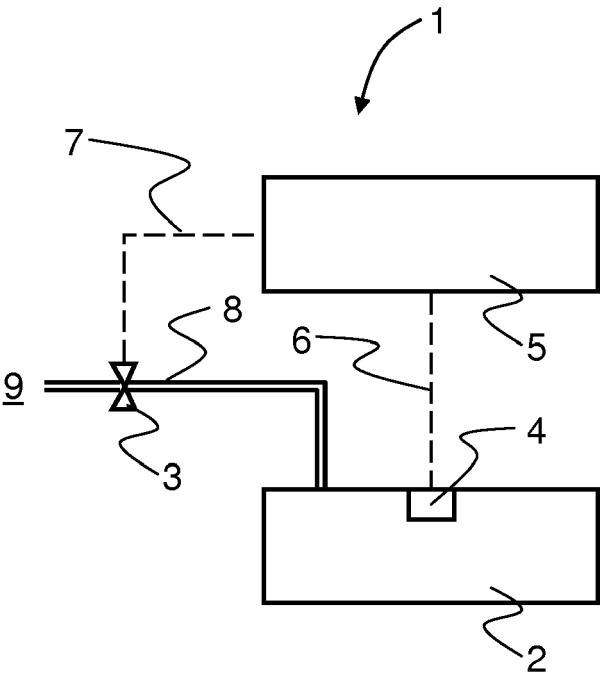


Fig. 1

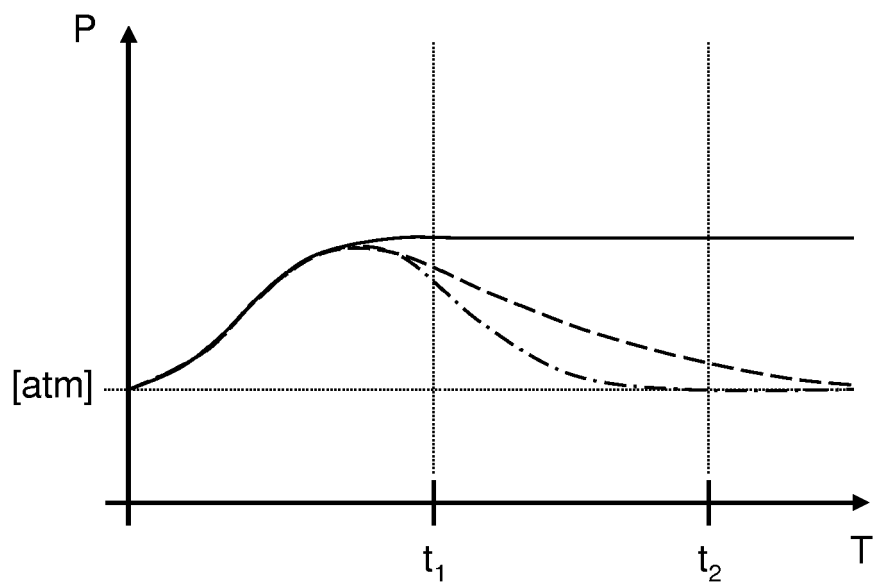


Fig. 2



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Application Number  
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| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                       |                                                 |
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| The present search report has been drawn up for all claims                                                                                                                                                                                             |                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                       |                                                 |
| Place of search<br>The Hague                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                      | Date of completion of the search<br>31 March 2010                                                                                                                                                                                                                                     | Examiner<br>Döring, Marcus                      |
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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT  
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