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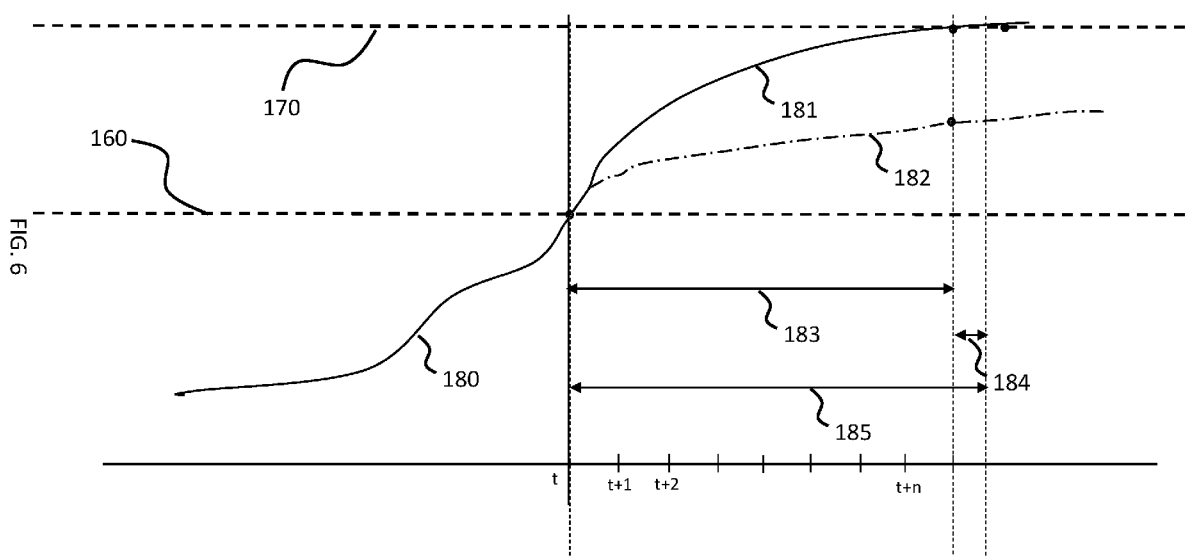
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(54) Title: HYBRID DRIVING ENHANCEMENT WITH EARLY E-DRIVE SHIFT



(57) Abstract: A control system (200) for controlling operation of a hybrid powertrain (110) for a vehicle (1), wherein the hybrid powertrain (110) comprises a first operating mode (120) in which an internal combustion engine (112) is in an activated state and operable to output drive torque, and comprises a second operating mode (130) in which an electric machine (114) is in an activated state and operable to output drive torque while the internal combustion engine (112) is in a deactivated state, the control system (200) comprising one or more controllers (201), wherein the control system (200) is configured to: receive a request (140) to switch from the first operating mode (120) to the second operating mode (130), the request (140) requiring deactivation of the internal combustion engine (112); determine that at least one engine system diagnostic check (150) is required; delay the requested deactivation of the internal combustion engine (112), in dependence on the determination and on a prediction of a time period (183) to complete the at least one engine system diagnostic check (150); and enable the requested deactivation of the internal combustion engine (112), in dependence on expiry of the predicted time period (183) of the at least one engine system diagnostic check (150).

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HYBRID DRIVING ENHANCEMENT WITH EARLY E-DRIVE SHIFT

TECHNICAL FIELD

The present disclosure relates to a hybrid driving enhancement with early e-drive shift. In particular, but not exclusively it relates to a hybrid driving enhancement with early e-drive shift of a vehicle when transitioning from a first operating mode comprising an internal combustion engine to a second operating mode that does not comprise an internal combustion engine.

BACKGROUND

Legislation requires that engine system diagnostic checks are performed on vehicles equipped with internal combustion engines. On vehicles equipped with a hybrid powertrain, it is desirable that these engine system diagnostic checks be performed with reduced disruption to the user of the vehicle.

SUMMARY OF THE INVENTION

It is an aim of the present invention to address one or more of the disadvantages associated with the prior art.

Aspects and embodiments of the invention provide a control system for controlling operation of a hybrid powertrain for a vehicle, a method of controlling operation of a hybrid powertrain for a vehicle, a vehicle and computer software as claimed in the appended claims.

According to an aspect of the invention there is provided a control system for controlling operation of a hybrid powertrain for a vehicle. The hybrid powertrain comprises a first operating mode in which an internal combustion engine is in an activated state and operable to output drive torque, and comprises a second operating mode in which an electric machine is in an activated state and operable to output drive torque while the internal combustion engine is in a deactivated state. The control system comprises one or more controllers. The control system is configured to: receive a request to switch from the first operating mode to the second operating mode, the request requiring deactivation of the internal combustion engine; determine that at least one engine system diagnostic check is required; delay the requested deactivation of the internal combustion engine, in dependence on the determination and on a prediction of a time period to complete the at least one engine system diagnostic check; and enable the requested deactivation of the internal combustion engine, in dependence on expiry of the predicted time period of the at least one engine system diagnostic check.

An advantage is that vehicle fuel consumption and emissions may be reduced. This is because an engine system diagnostic check is only run if it is determined that the check is required (for example, the test has not been performed in a current drive cycle), while engine deactivation is only delayed for a time period that is predicted to be sufficient for the check to be completed.

Delaying the requested deactivation may comprise causing disconnection of the engine from one or more vehicle wheels and also controlling an operating point of the engine to either a predetermined value or to a target value required by the engine system diagnostic check.

- 5 An advantage is that the reliability of the engine system diagnostic check may be improved, because as the operating point for the check is now known and independent of output drive torque requirements, the accuracy of the predicted time taken to complete the diagnostic check is improved.

The predetermined value may be an internal combustion engine idle operating point.

- 10 An advantage is that noise, vibration and harshness (NVH) may be improved, as the engine is operating at an idle condition. A further advantage is that fuel consumption and internal combustion engine emissions are reduced during the diagnostic check time period.

The control system may be configured to activate the electric machine to output drive torque, while the requested deactivation of the internal combustion engine is delayed.

An advantage is that as the output drive torque required by a user of the vehicle is provided independently by the electric machine, vehicle responsiveness is maintained whilst the engine system diagnostic check is in progress.

- 15 The at least one engine system diagnostic check may comprise at least one from the group comprising: a particulate filter status check; a lambda sensor response check; a lambda sensor range check; and a lambda sensor air:fuel ratio transition check; a fuel system purge valve check; an aftertreatment system oxygen storage capacity check; a particulate filter regeneration status check; a flywheel adaptation check; and an exhaust system catalyst predictive regeneration check.

- 20 An advantage is that different types of diagnostic check may be performed, enabling different aspects of the engine system to be checked.

Determination that at least one engine system diagnostic check is required may be based on whether the at least one engine system diagnostic check has been completed in a current drive cycle.

- 25 An advantage is that the engine system diagnostic checks are performed with sufficient regularity so as to satisfy regulatory requirements, but are not performed when not required, as this would unnecessarily increase fuel consumption and emissions.

The request to switch from the first operating mode to the second operating mode may be based at least in part on at least one of the following: a requested load falling below a first threshold while electrical energy stored in an

energy storage means is above a second threshold; manual user mode selection; a change of driving dynamics mode; or a change of terrain response mode.

An advantage is that the switch from the first operating mode to the second operating mode is only made when it is determined that such a switch is both desirable (for example to reduce vehicle emissions) and possible (for example, based upon there being sufficient electrical energy stored to support operation in the second operating mode).

Prediction of the time period to complete the at least one engine system diagnostic check may be based at least in part on a predicted trajectory of at least one engine parameter and may be based at least in part on comparison of the projected trajectory with a diagnostic release threshold associated with the at least one engine system diagnostic check.

An advantage is that the success rate of successfully performing an engine system diagnostic check is increased without unnecessarily delaying engine shutdown, leading to increased vehicle emissions.

The at least one engine parameter may be dependent on an integrated internal combustion engine exhaust gas mass and / or an integrated internal combustion engine intake air mass.

An advantage is that the probability of successfully completing an engine system diagnostic check is increased because the predicted period for completing the engine system diagnostic check is based upon at least one engine parameter that correlates with the type of check to be performed.

According to an aspect of the invention there is provided a vehicle comprising the control system.

An advantage is that the vehicle is able to meet legislative requirements, enabling it to be sold.

According to an aspect of the invention, there is provided a method of controlling operation of a hybrid powertrain for a vehicle, wherein the hybrid powertrain comprises a first operating mode in which an internal combustion engine is in an activated state and operable to output drive torque, and comprises a second operating mode in which an electric machine is in an activated state and operable to output drive torque while the internal combustion engine is in a deactivated state. The method comprises: receiving a request to switch from the first operating mode to the second operating mode, the request requiring deactivation of the internal combustion engine; determining that at least one engine system diagnostic check is required; delaying the requested deactivation of the internal combustion engine, in dependence on the determination and on a prediction of a time period to complete the at least one engine system diagnostic check; and enabling the requested deactivation of the internal combustion engine, in dependence on expiry of the predicted time period of the at least one engine system diagnostic check

According to an aspect of the invention there is provided computer software that, when executed, is arranged to perform a method of controlling operation of a hybrid powertrain for a vehicle.

Within the scope of this application, it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination that falls within the scope of the appended claims. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination that falls within the scope of the appended claims, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1 illustrates an example of a vehicle;

FIG. 2 illustrates an example of a control system for a vehicle;

FIG. 3 illustrates an example of a non-transitory computer-readable storage medium 300 comprising the instructions (computer software);

FIG. 4 illustrates an example of a hybrid powertrain;

FIG. 5 illustrates an example of a predictive method;

FIG. 6 illustrates an example of the implementation of the predictive method; and

FIG. 7 illustrates an example of the implementation of the predictive method over a drive cycle.

DETAILED DESCRIPTION

FIG. 1 illustrates an example of a vehicle 1 in which embodiments of the invention can be implemented. In some, but not necessarily all examples, the vehicle 1 is a passenger vehicle, also referred to as a passenger car or as an automobile. In other examples, embodiments of the invention can be implemented for other applications, such as commercial vehicles.

FIG. 1 is a front perspective view and illustrates a longitudinal x-axis between the front and rear of the vehicle representing a centreline, an orthogonal lateral y-axis between left and right lateral sides of the vehicle 1, and a

vertical z-axis. A forward/fore direction typically faced by a driver's seat is in the negative x-direction; rearward/aft is +x. A rightward direction as seen from the driver's seat is in the positive y-direction; leftward is -y. These are a first lateral direction and a second lateral direction.

FIG. 2 illustrates an example control system 200 configured to implement one or more aspects of the invention.

- 5 The control system 200 of FIG. 2 comprises a controller 201. In other examples, the control system 200 may comprise a plurality of controllers on-board and/or off-board the vehicle 1.

- The controller 201 of FIG. 2 includes at least one processor 204; and at least one memory device 206 electrically coupled to the electronic processor 204 and having instructions (e.g., a computer program 208) stored therein, the at least one memory device 206 and the instructions configured to, with the at least one processor 204, cause any
10 one or more of the methods described herein to be performed. The processor 204 may have an interface 202 such as an electrical input/output I/O or electrical input for receiving information and interacting with external components.

FIG. 3 illustrates a non-transitory computer-readable storage medium 300 comprising the instructions (computer software).

- 15 FIG. 4 shows the vehicle 1 comprising a hybrid powertrain 110.

FIG. 4 illustrates that the hybrid powertrain 110 comprises an internal combustion engine 112 and at least one electric machine 114. The hybrid powertrain may be operated in a plurality of modes, comprising a first operating mode 120, and a second operating mode 130 (as illustrated in FIG. 7).

- The hybrid powertrain 110 may be a parallel hybrid powertrain, in that any of the internal combustion engine 112,
20 or the at least one electric machine 114 or both the internal combustion engine 112 and the at least one electric machine 114 may provide output torque for the vehicle, depending on mode. The hybrid powertrain may comprise at least one clutch, configured to cause disconnection of the internal combustion engine 112 from one or more vehicle wheels 111 of the vehicle 1.

- In a first operating mode 120 of the hybrid powertrain 110, the internal combustion engine 112 is in an activated state and operable to output drive torque. In the first operating mode 120 of the hybrid powertrain, the at least one electric machine 114 may be in an activated state and operable to output drive torque 115. Alternatively, in the first operating mode 120 of the hybrid powertrain 110, the at least one electric machine 114 may be in a deactivated state, and not operable to output drive torque 115.
25

- In a second operating mode 130 of the hybrid powertrain 110, the at least one electric machine 114 is in an activated state and operable to output drive torque 115 while the internal combustion engine 112 is in a deactivated state not operable to output drive torque.
30

As is discussed with reference to FIGS 2-7, a control system 200, and method 500 of operating the control system 200 is required to control switching from the first operating mode 120 to the second operating mode 130.

Switching from the first operating mode 120 to the second operating mode 130 may be desirable when the output drive torque required by the vehicle 1 alters. For example, switching from the first mode 120 the second mode 130 may be desirable when the total output drive torque required by the vehicle 1 falls below a first threshold (not shown) while electrical energy stored in an energy storage means 113 is above a second threshold (not shown). The first threshold (not shown) may be set such that it is less than or equal to the maximum output drive torque that may be output by the at least one electric machine 114. Alternatively, or additionally, switching from the first mode 120 to the second mode 130 may be based upon a manual user mode selection, a change of a driving dynamics mode; and/or a change of terrain response mode.

The manner in which switching is made between operating modes may also be based upon legislative and / or environmental considerations.

Emissions legislation operating in the jurisdiction in which the vehicle 1 is used, may require that engine system diagnostic checks are performed on the operating behaviour of the internal combustion engine 112 and / or an aftertreatment system (such as an exhaust catalyst) fitted to the vehicle 1.

These diagnostic checks require that the internal combustion engine is activated – i.e., the diagnostic checks may be performed when the hybrid powertrain 110 is operating in the first operating mode 120, but cannot be performed when the hybrid powertrain 110 is operating in the second operating mode 130.

Examples of the diagnostic checks comprise:

- a particulate filter status check;
- a lambda sensor response check;
- a lambda sensor range check;
- a lambda sensor air:fuel ratio transition check;
- a fuel system purge valve check;
- an aftertreatment system oxygen storage capacity check;
- a particulate filter regeneration status check; and
- an exhaust system catalyst predictive regeneration check.

It will be appreciated that the engine system diagnostic check may additionally comprise other checks – for example, checks that are performed once or infrequently, such as calibration checks performed during manufacture, or following overhaul of the hybrid powertrain 110. For example, the engine system diagnostic check may additionally comprise a flywheel adaptation check.

The vehicle 1 may comprise on-board diagnostics (OBD) to control the diagnostic checks 150.

The on-board diagnostics may comprise an In-Use Monitor Performance Ratio (IUMPR). The IUMPR monitors a cumulative ratio of how many times a diagnostic check has been successfully completed versus how many times the diagnostic check has been demanded to be completed. The IUMPR is monitored and updated over the life of the vehicle 1.

Legal approval of the vehicle type of the vehicle 1 for sale within a jurisdiction may be dependent on an IUMPR ratio being above a certain value. For example, the required IUMPR ratio may be at least 0.336.

It is appreciated that although the control system 200 could immediately deactivate the internal combustion engine 112 when switching from the first operating mode 120 of the hybrid powertrain 110 to the second operating mode 130 of the hybrid powertrain 110, this may have a detrimental effect on meeting the IUMPR ratio required for legal compliance.

Similarly, it may be also be appreciated that although the control system 200 could improve the achieved IUMPR ratio by providing an automatic, fixed delay on switching from the first mode 120 to the second mode 130, to enable diagnostic checks to complete, this may unnecessarily delay the deactivation of the internal combustion engine 110. This would increase vehicle fuel consumption and exhaust emissions, and could be a potential irritation to the owner or user of the vehicle 1.

Furthermore, as the time taken to perform diagnostic checks may increase as the driven mileage on the vehicle increases, use of a fixed delay period set to increase for an older / higher mileage vehicle would be likely to result in an unnecessary delay for a lower mileage vehicle.

The below-described invention addresses these problems.

FIGS. 5 and 7 illustrate a method 500, and an example illustrated drive cycle for enhancing hybrid driving by predicting a time period to complete the at least one engine diagnostic check.

The predicted time period for different types of diagnostic check may be different. For example, the predicted time period for performing the particulate filter status check may be different to the predicted time period for performing the lambda sensor range check etc.

The predicted time period may determine the time at which the hybrid powertrain 110 switches from the first operating mode 120 to the second operating mode 130.

The time taken to complete each/at least some diagnostic checks depends on various engine parameters 180 (as illustrated in FIG. 6). These engine parameters 180 may include the cumulative mass flow rate of intake air to the

engine and/or the cumulative mass flow rate of engine exhaust gas. This is because the engine system diagnostic checks need the engine 112 to be active (operational) and at or above a particular operating point for a particular duration of time.

The cumulative mass flow rate of intake air to the engine 112 may also referred to as an integrated intake air mass 180. The cumulative mass flow rate of engine exhaust gas may also be referred to as an integrated exhaust gas mass 180.

As illustrated in FIG. 6, therefore, the invention predicts the time required to complete a check, based on the predicted integrated intake air and/or exhaust gas mass. Integration of the predicted intake air and/or predicted exhaust gas mass is initiated at the start of engine operation (the first operating mode 120) within the drive cycle 700. The intake air mass and exhaust gas mass integrators are reset to zero following shutdown of the control system 200 (for example, following completion of the drive cycle 700) or following completion of the engine system diagnostic check within the drive cycle 700.

If the predicted air mass (within an acceptable time period) is sufficient - e.g. is predicted to reach a diagnostic release threshold 170 to enable the check to complete, then engine deactivation is delayed to enable the operational check to proceed. Thus, switching from the first operational mode 120 to the second operational mode 130 is delayed from a time, t , at which the request to switch is made.

If the predicted air mass is insufficient (within this period), then engine deactivation is not delayed, and the engine 112 is deactivated immediately. In this circumstance, the diagnostic check is deferred to the next available opportunity.

From FIG. 6, it may be appreciated that the lower the value of the integrated engine parameter 180 at the time of making a prediction relative to the diagnostic release threshold 170, the more difficult it becomes to make an accurate prediction. This is because less data is available to make the prediction, while more time is available for the actual integrated engine parameter 182 to diverge from the predicted integrated engine parameter 181. To address this, a predictive horizon release threshold 160 is established for each diagnostic check.

A prediction concerning the time taken to complete the at least one diagnostic check is only made if the integrated engine parameter is greater than or equal to the predictive horizon release threshold 160 at the time that engine deactivation is requested – i.e., a prediction is only made when there is a reasonable likelihood that the prediction will be accurate.

If the integrated engine parameter 180 is less than the predictive horizon release threshold 160 at the time that engine deactivation is requested, then no prediction is made and the engine system diagnostic check is deferred to a later time.

The predictive horizon release threshold 160 and diagnostic release threshold 170 are established for each respective engine system diagnostic check 150. The predictive horizon release threshold 160 and /or diagnostic release threshold 170 may be different for the different types of diagnostic check.

5 Each engine system diagnostic check 150 therefore has two associated thresholds associated with it. For example, particulate filter status check has both an associate predictive horizon release threshold 160, and a diagnostic release threshold 170.

The predictive horizon release threshold 160 and diagnostic release threshold 170 may be determined by analysis of engine test results performed by the manufacturer of the vehicle 1 or an associate of the manufacturer of the vehicle, during the development of the vehicle 1.

10 The values of the predictive horizon release threshold 160 and diagnostic release threshold 170 of each check are stored in the at least one memory device 206, prior to performance of method 500.

The engine parameter 180 required by the engine diagnostic checks increments in time when the internal combustion engine 112 is activated (operational). For the checks to be successfully completed, the checks require the cumulative (integrated) flow of intake air and/or exhaust gas is greater than or equal to a threshold (the diagnostic release threshold 170). It may be appreciated that as the checks may relate to different components of the hybrid powertrain 110 (for example, in some cases the lambda sensor, in other cases the particulate filter), the flow of intake air / and/or exhaust gas may be different for different diagnostic checks. For this reason, the diagnostic release threshold 170 may be different for different engine system diagnostic checks 150.

20 The mass of engine intake air may be determined by the controller 201, using control system inputs to the internal combustion engine. For example, from measurement of intake massflow, made by a hot film mass airflow sensor, intake manifold pressure and / or intake valve opening timing. The mass of engine exhaust gas may be determined by the controller 201 from the mass of engine intake air and an exhaust system air:fuel ratio sensor (lambda sensor). Instantaneous mass flow rates so obtained may be integrated with respect to time to obtained integrated intake air mass and /or integrated exhaust gas mass 180.

25 The engine system diagnostic checks may require a minimum integrated mass of engine exhaust gas and/or intake air to be successfully completed. Integration of the engine parameter 180 (for example, exhaust gas mass and/or intake air mass) is initiated at the start of engine operation (first operating mode 120) within the drive cycle 700. The intake air mass and/or exhaust gas mass integrators are reset to zero following shutdown of the control system 200 (for example, following completion of the drive cycle 700) or following completion of the engine system diagnostic check within the drive cycle 700.

FIG. 7 illustrate an internal combustion engine operating point (for example, an engine speed in revolutions / minute) plotted as a y axis, against time, plotted as an x-axis. Trace 706 therefore represents the history of the engine operating point (for example, comprising engine speed) against time. In Fig. 7, the illustrated time period represents the time for a journey, for example, the time of a drive cycle 700.

- 5 As is illustrated by FIG. 7, it may be appreciated that during the drive cycle 700, representing the journey undertaken by the vehicle 1, there may be multiple periods of first operating mode operation 701, 703, 705 and multiple periods of second operating mode operation 702, 704 of the hybrid powertrain 110. For example, the journey may start in a city, in which the second operating mode (electric machine only) is used, before the vehicle joins a fast road such as a motorway, where operation of the second mode may no longer possible, causing the
- 10 hybrid powertrain 110 to switch to the first operating mode 120.

The hybrid powertrain may then switch back and forth between the first and second operating modes depending upon the vehicle output torque demand, and other factors such as the remaining electrical energy stored in the energy storage means 113 used to provide electrical energy to the electric machine 114. For example, FIG. 7 illustrates two periods of first mode operation, 702, 704 (internal combustion engine 112 activated).

- 15 FIG. 7 also illustrates that at time t , there is a sudden change in engine operating point to a lower, but non-zero, engine operating point. This is based on receipt of a request 140 to switch engine operating mode from the first engine operating mode 120 to the second engine operating mode 130 (transition from time period 702 to time period 703).

- However, FIG. 7 also illustrates that at a subsequent switch in engine operating mode from first operating mode
- 20 130 to second operating mode 120 (period 704 to 705), there is no comparable reduction in engine operating point. This is because the diagnostic check was successfully completed prior to switching engine operating mode from the first engine operating mode 120 to the second engine operating mode 130 at the transition from time period 702 to time period 703.

- As is subsequently disclosed, if the diagnostic check had not completed at the transition from time period 702 to
- 25 time period 703, the diagnostic check may be reattempted.

The individual blocks of method 500 are now discussed.

At block 502 a change in demanded vehicle output torque causes a request 140 to switch from the first operating mode 120 to the second operating mode 130. The request 140 requires deactivation of the internal combustion engine 112. The request 140 occurs at a time, t , as illustrated in FIG. 7

- 30 Following receipt of the request 140, the method progresses from block 502 to block 504.

At block 504, the controller 201 determines whether at least one engine diagnostic engine system check is required. An engine diagnostic system check is required if the engine diagnostic system check has not completed during the current drive cycle 700. An engine diagnostic check is not required if the engine diagnostic system check has completed during the current drive cycle 700.

- 5 For example, in FIG. 7, period 702 corresponds to the first time period during the current drive cycle when hybrid powertrain 110 operates in the first mode 120. When a request 140 is received in period 702 to switch from the first operating mode 120 to the second operating mode 130, the engine diagnostic check has not completed, and so, is required.

- 10 Conversely, period 704 of FIG.7 corresponds to a second time period during the current drive cycle 700 when the hybrid powertrain 110 is operating in the first operating mode 120. In this case, as the diagnostic check was previously completed in the drive cycle 700 following time period 702, a diagnostic check is not required. Hence, there is no delay in switching from the first operating mode 120 to the second operating mode 130, following receipt of a request 140 to do so,

If an engine system diagnostic check is required, the method progresses from block 504 to block 506.

- 15 If an engine system diagnostic check is not required, the method progresses from block 504 to block 508. At block 508, the required deactivation of the internal combustion engine is initiated.

- At block 506, the controller 201 determines whether to delay the requested deactivation of the internal combustion engine 110, in dependence on the determination that at least one engine system diagnostic check is required. The determination is based at least in part on a prediction of a time period to complete the at least one engine system
20 diagnostic check.

The prediction of the time period to complete that at least on engine system diagnostic check is performed as follows.

- Previously, following initiation of first operating mode operation (before time, t), the controller 201 has commenced integration of a measured engine parameter such as exhaust gas mass and/or intake air mass. The intake air
25 mass and / or exhaust as mass integrators may have been reset prior to this point, for example, following completion of the diagnostic checks within a preceding drive cycle 700, or following powering on of control system 200 at the start of current drive cycle 700. From initiation of the first operating mode 120, the integrators integrate these engine parameters, updating them in real-time based on instantaneous exhaust gas massflow and / or intake air massflow. The integrated exhaust gas mass 180 and / or integrated intake air mass 180 therefore increases
30 with time when the internal combustion engine 112 is activated. Different engine system diagnostic checks may use different integrated engine parameters 180. For example, engine system diagnostic checks which relate to an

intake air mass flow may use the integrated intake air mass 180. Conversely engine system diagnostic checks which relate to components of the exhaust system may use the integrated exhaust gas mass. In some embodiments, an engine system diagnostic check may use both the integrated intake air mass 180 and the integrated exhaust gas mass 180. This may be desirable where a correlation exists between the integrated intake
5 air mass 180 and the integrated exhaust gas mass 180, as using both parameters may improve the robustness of the engine system diagnostic check.

It may be appreciated that the update in integrated intake air mass and /or exhaust gas mass may occur at discrete points in time, for example, corresponding to successive clock-cycles of the controller 201.

10 In block 506, at the time t , (the time the request 140 to switch from the first operating mode 120 to the second operating mode 130 is received), the value of the at least one engine parameter is compared with the predictive horizon release thresholds 160 for diagnostic checks 150.

For each engine system diagnostic check 150, if the integrated engine parameter 180 is greater than or equal to the predictive horizon release threshold 160 associated with that check, then the switch from the first engine operating mode 120 to the second operating mode 130 is demanded to be delayed. The delay is based at least
15 in part on the predicted time 183 for the check to complete. Progression of the method from block 506 to 508 only occurs once the delay has expired, enabling the diagnostic check to complete.

Conversely, if at time t , the integrated engine parameter 180 is less than the predictive horizon release threshold 160 associated with that engine system diagnostic check 150, then no demanded delay is imposed, and the method 500 immediately progresses from block 506 to block 508, at which block the engine 112 is deactivated. In this
20 case, the engine system diagnostic check is deferred until a later time. This is done because the lower value of the integrated parameter 180 relative to the predictive horizon release threshold 160 is indicative of the fact that the check would take a longer than desirable time to complete.

It may be appreciated that at the time t that the request 140 to switch from the first operating mode 120 to the second operating mode 130 is received, multiple engine operating diagnostic checks may demand a delay to
25 switching from the first operating mode 120 to the second operating mode 130. In this case, the delay in switching from operating in the first mode 120 to operating in the second mode 130 is based upon the engine system diagnostic check 150 which is predicted to take the longest time to complete (a "highest wins" gate).

For example, if the predicted time to complete the particulate filter status check is greater than the predicted time to complete the fuel system purge valve check, the predicted time delay to progress from block 506 to block 508
30 is based upon the longer time of the particulate filter status check 150, and not the shorter time of the fuel system purge valve check.

The predicted time period 183 for completing each engine system diagnostic check is based upon a trajectory 181 of the integrated engine parameter 180.

The trajectory 181 of the integrated engine parameter 180 is determined by a rate of increase (slope) in intake and/or exhaust mass flow data established from data collected during certification cycle testing. Examples of certification cycles include: WLTC, FTP and / or NEDC. A tolerance band is also established from data obtained engine bench testing and/or on road vehicle testing. Data from multiple engine bench tests and multiple vehicles may be used to establish the tolerance band. The controller 201 determines whether the actual trajectory 182 (as shown in FIG. 6) is within the tolerance range of the predicted trajectory 181.

The actual engine parameter trajectory during a drive cycle 700 may differ from expectations based upon prior certification cycle testing, engine bench testing and / or on road vehicle testing conducted during the development of the hybrid powertrain 110. For example, the actual engine parameter trajectory 182 may differ from expectations due to the driving style of the user of the vehicle and/or aging of the hybrid powertrain 110. The controller 201 may therefore vary the predicted trajectory 181 over time to accommodate this. For example, a Kalman filter may be used to adapt the predicted trajectory 181 based upon the completion of successful engine systems diagnostic checks learned over the life of the vehicle and/or component on which the diagnostic check is performed.

When determining whether to start a diagnostic check, the previous evolution of the integrated engine parameter 180 from the initiation of integrator to time t is used to predict the trajectory 181 of integrated engine parameter 180. The trajectory is extrapolated forward in time until it is predicted that the diagnostic release threshold 170 for the associated check is reached. The predicted time period 183 determines in part the predicted time delay 185 of the at least one engine system diagnostic check 150.

In some but not necessarily all embodiments, an additional time period, for example, a debounce time 184, may be added to the predicted time period 183 to reach the diagnostic release threshold 170. This additional time period may account for error handling, by allowing a confirmation time to confirm that an error is real.

In some but not necessarily all embodiments, an event-based debounce may additionally be used to confirm, an error over successive drive cycles (for example, two drive cycles).

The sum of the time predicted 183 to reach the diagnostic release threshold and the optional debounce time 184 determine the delay period 185 from receipt of the request for engine deactivation, to engine deactivation.

Once time 185 is reached, the method progresses from block 506 to block 508, and the internal combustion engine 112 is deactivated, following the delay.

The time at which this progression occurs is dependent upon the delay period calculated for the at least one engine diagnostic check 150.

It may be appreciated that the ongoing actual trajectory 182 of the engine parameter 180 may differ from the predicted trajectory 181. This means that not all engine system diagnostic checks that are predicted to complete are actually complete when the internal combustion engine is deactivated.

5 However, following expiry of the predicted time period 183 to reach the diagnostic release threshold 170, the controller 201 does not apply a further time delay, if the threshold 170 has not been reached.

Instead, following expiry of the predicted time period 183, The control system 200 verifies whether the engine system diagnostic check has been completed, and updates the OBD and IUMPR.

10 Although switching from the first operating mode 120 to the second operating mode 130 may delay the deactivation of the internal combustion engine 112, the control system may take some action following receiving a request 140 to switch from the first operating mode to the second operating mode but before deactivating the internal combustion engine 112.

For example, at method block 502, the control system 200 may disconnect the internal combustion engine 112 from the at least one vehicle wheels 111, with vehicle drive torque solely provided by the at least one electric machine 114.

15 As the internal combustion engine is no longer providing drive torque, the control system 200 may control an operating point of the engine to either a predetermined value or to a target value required by the engine system diagnostic check 150. For example, the internal combustion engine operating point may be an idle setting. This may have the advantage that vehicle refinement is improved, due to the change in operating point. The change in operating point may additionally reduce fuel consumed following receipt of the engine deactivation request, with a
20 related reduction in vehicle emissions.

Changing the operating point may have an additional advantage in that the accuracy of the predicted time period to complete the engine system diagnostic check is increased, because a source of variability in the prediction (ongoing change in engine operating point) is removed.

25 Adjustments made by the controller 201 to the internal combustion engine operating point are accommodated in block 506, when predicting the time period to complete an engine system diagnostic check.

For purposes of this disclosure, it is to be understood that the controller(s) described herein can each comprise a control unit or computational device having one or more electronic processors. A vehicle and/or a system thereof may comprise a single control unit or electronic controller or alternatively different functions of the controller(s) may be embodied in, or hosted in, different control units or controllers. A set of instructions could be provided which,
30 when executed, cause said controller(s) or control unit(s) to implement the control techniques described herein (including the described method(s)). The set of instructions may be embedded in one or more electronic

processors, or alternatively, the set of instructions could be provided as software to be executed by one or more electronic processor(s). For example, a first controller may be implemented in software run on one or more electronic processors, and one or more other controllers may also be implemented in software run on one or more electronic processors, optionally the same one or more processors as the first controller. It will be appreciated, however, that other arrangements are also useful, and therefore, the present disclosure is not intended to be limited to any particular arrangement. In any event, the set of instructions described above may be embedded in a computer-readable storage medium (e.g., a non-transitory computer-readable storage medium) that may comprise any mechanism for storing information in a form readable by a machine or electronic processors/computational device, including, without limitation: a magnetic storage medium (e.g., floppy diskette); optical storage medium (e.g., CD-ROM); magneto optical storage medium; read only memory (ROM); random access memory (RAM); erasable programmable memory (e.g., EPROM and EEPROM); flash memory; or electrical or other types of medium for storing such information/instructions.

It will be appreciated that various changes and modifications can be made to the present invention without departing from the scope of the present application.

The blocks illustrated in FIG. 5 may represent steps in a method and/or sections of code in the computer program 300. The illustration of a particular order to the blocks does not necessarily imply that there is a required or preferred order for the blocks and the order and arrangement of the block may be varied. Furthermore, it may be possible for some steps to be omitted.

Although embodiments of the present invention have been described in the preceding paragraphs with reference to various examples, it should be appreciated that modifications to the examples given can be made without departing from the scope of the invention as claimed.

Features described in the preceding description may be used in combinations other than the combinations explicitly described.

Although functions have been described with reference to certain features, those functions may be performable by other features whether described or not.

Although features have been described with reference to certain embodiments, those features may also be present in other embodiments whether described or not.

Whilst endeavouring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance it should be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

CLAIMS

1. A control system for controlling operation of a hybrid powertrain for a vehicle, wherein the hybrid powertrain comprises:

5 a first operating mode in which an internal combustion engine is in an activated state and operable to output drive torque, and

a second operating mode in which an electric machine is in an activated state and operable to output drive torque while the internal combustion engine is in a deactivated state,

the control system comprising one or more controllers, wherein the control system is configured to:

10 receive a request to switch from the first operating mode to the second operating mode, the request requiring deactivation of the internal combustion engine;

determine that at least one engine system diagnostic check is required;

delay the requested deactivation of the internal combustion engine, in dependence on the determination and on a prediction of a time period to complete the at least one engine system diagnostic check; and

15 enable the requested deactivation of the internal combustion engine, in dependence on expiry of the predicted time period of the at least one engine system diagnostic check.

2. A control system for controlling operation of a hybrid powertrain for a vehicle as claimed in claim 1, wherein delaying the requested deactivation comprises causing disconnection of the engine from one or more vehicle
20 wheels and also controlling an operating point of the engine to either a predetermined value or to a target value required by the engine system diagnostic check.

3. A control system for controlling operation of a hybrid powertrain for a vehicle as claimed in claim 2, wherein the predetermined value is an internal combustion engine idle operating point.

4. A control system for controlling operation of a hybrid powertrain for a vehicle as claimed in any preceding claim, wherein the control system is configured to activate the electric machine to output drive torque, while the requested deactivation of the internal combustion engine is delayed.

5. A control system for controlling operation of a hybrid powertrain for a vehicle as claimed in any preceding claim, wherein the at least one engine system diagnostic check comprises at least one from the group comprising:

a particulate filter status check;

a lambda sensor response check;

a lambda sensor range check;

35 a lambda sensor air:fuel ratio transition check;

a fuel system purge valve check;
 an aftertreatment system oxygen storage capacity check; and
 a particulate filter regeneration status check.

- 5 6. A control system for controlling operation of a hybrid powertrain for a vehicle as claimed in any preceding claim, wherein the determination that at least one engine system diagnostic check is required is based on whether the diagnostic check has been completed in a current drive cycle.
7. A control system for controlling operation of a hybrid powertrain for a vehicle as claimed in any preceding claim, wherein the request to switch from the first operating mode to the second operating mode is based at least in part on at least one of the following:
 - a requested load falling below a first threshold while electrical energy stored in an energy storage means is above a second threshold;
 - manual user mode selection;
 - 15 a change of driving dynamics mode; or
 - a change of terrain response mode.
8. A control system for controlling operation of a hybrid powertrain for a vehicle as claimed in any preceding claim wherein prediction of the time period to complete the at least one engine system diagnostic check is based at least in part on a predicted trajectory of at least one engine parameter and is based at least in part on comparison of the projected trajectory with a diagnostic release threshold associated with the at least one engine system diagnostic check.
9. A control system for controlling operation of a hybrid powertrain for a vehicle as claimed in claim 8, wherein the at least one engine parameter is dependent on an integrated internal combustion engine exhaust gas mass and / or is dependent on an integrated internal combustion engine intake air mass.
10. A vehicle comprising the control system as claimed in any preceding claim.
11. A method of controlling operation of a hybrid powertrain for a vehicle, wherein the hybrid powertrain comprises:
 - a first operating mode in which an internal combustion engine is in an activated state and operable to output drive torque; and
 - a second operating mode in which an electric machine is in an activated state and operable to output drive torque while the internal combustion engine is in a deactivated state,

the method comprising:

receiving a request to switch from the first operating mode to the second operating mode, the request requiring deactivation of the internal combustion engine;

determining that at least one engine system diagnostic check is required;

5 delaying the requested deactivation of the internal combustion engine, in dependence on the determination and on a prediction of a time period to complete the at least one engine system diagnostic check; and

enabling the requested deactivation of the internal combustion engine, in dependence on expiry of the predicted time period of the at least one engine system diagnostic check.

10

12. Computer software that, when executed, is arranged to perform a method according to claim 11.

15

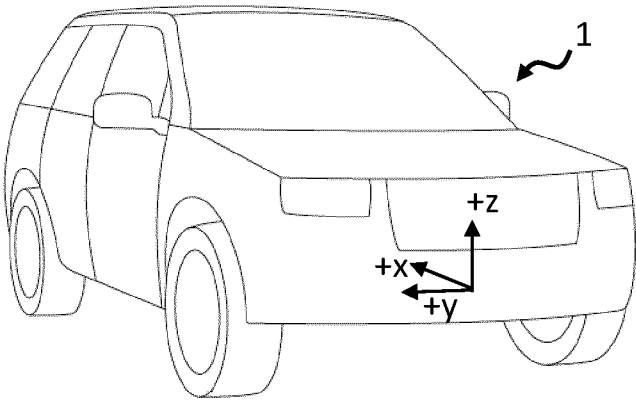


FIG. 1

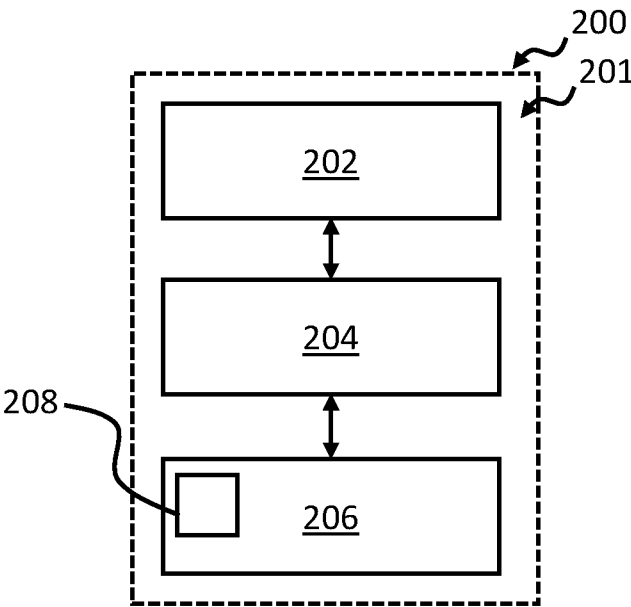


FIG. 2

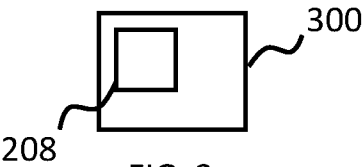


FIG. 3

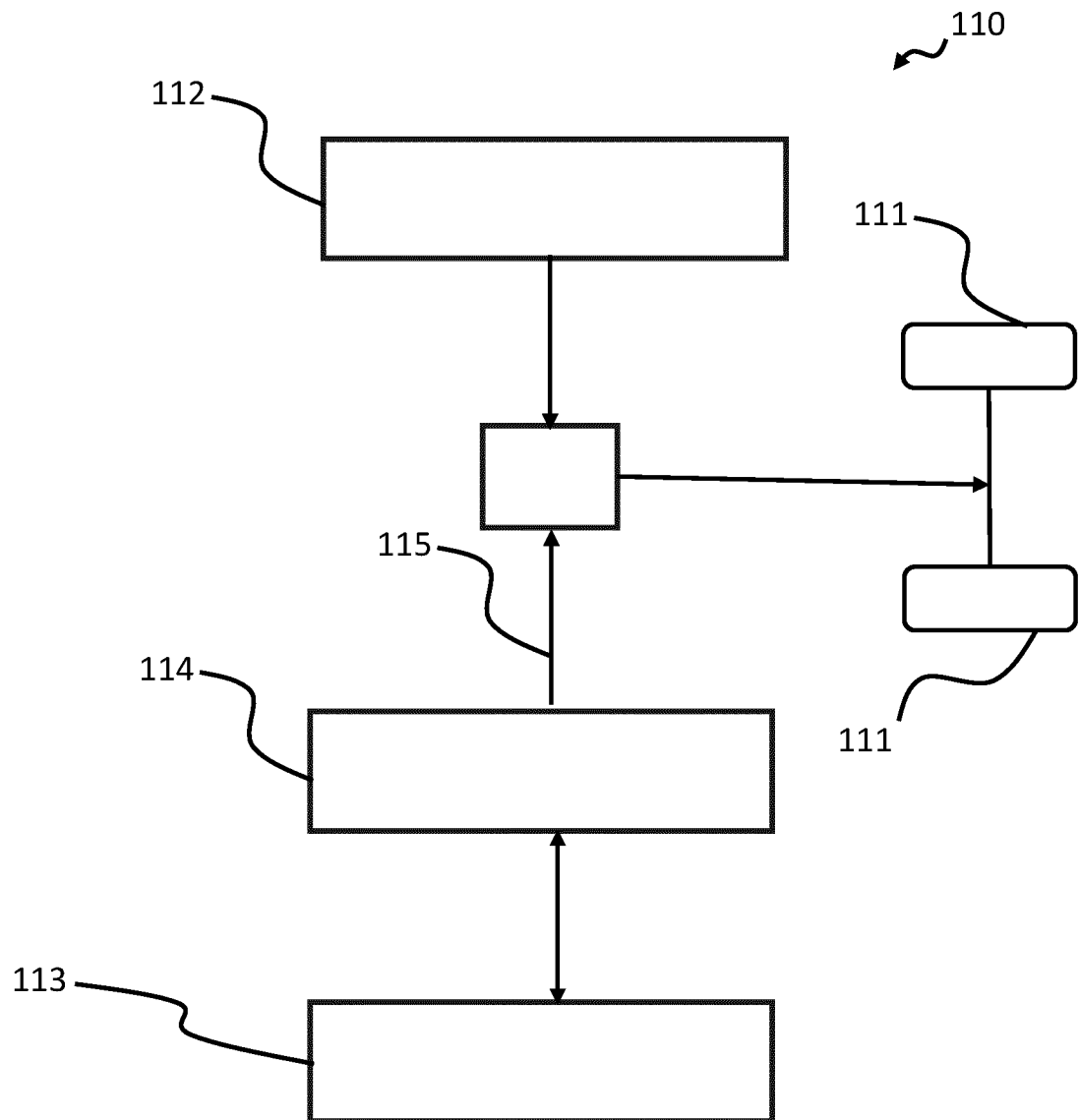


FIG. 4

3/5

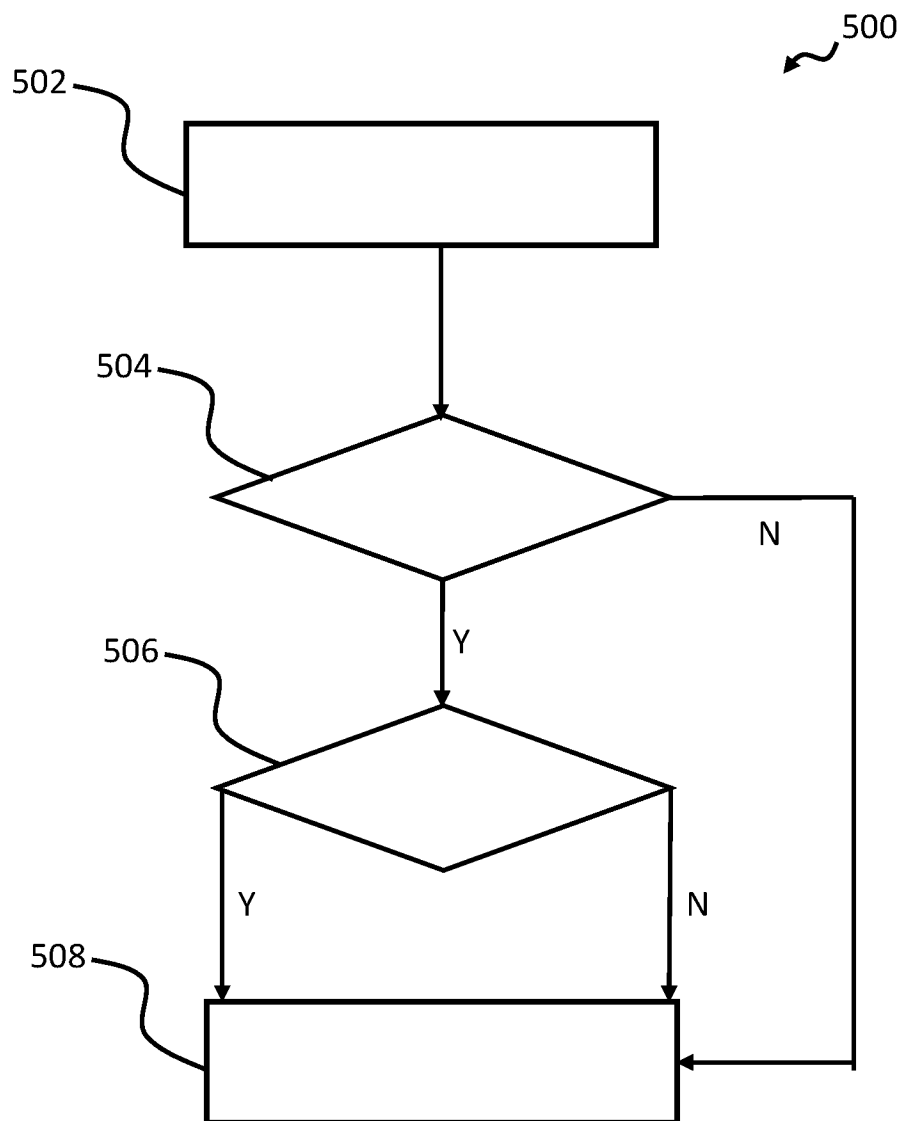


FIG. 5

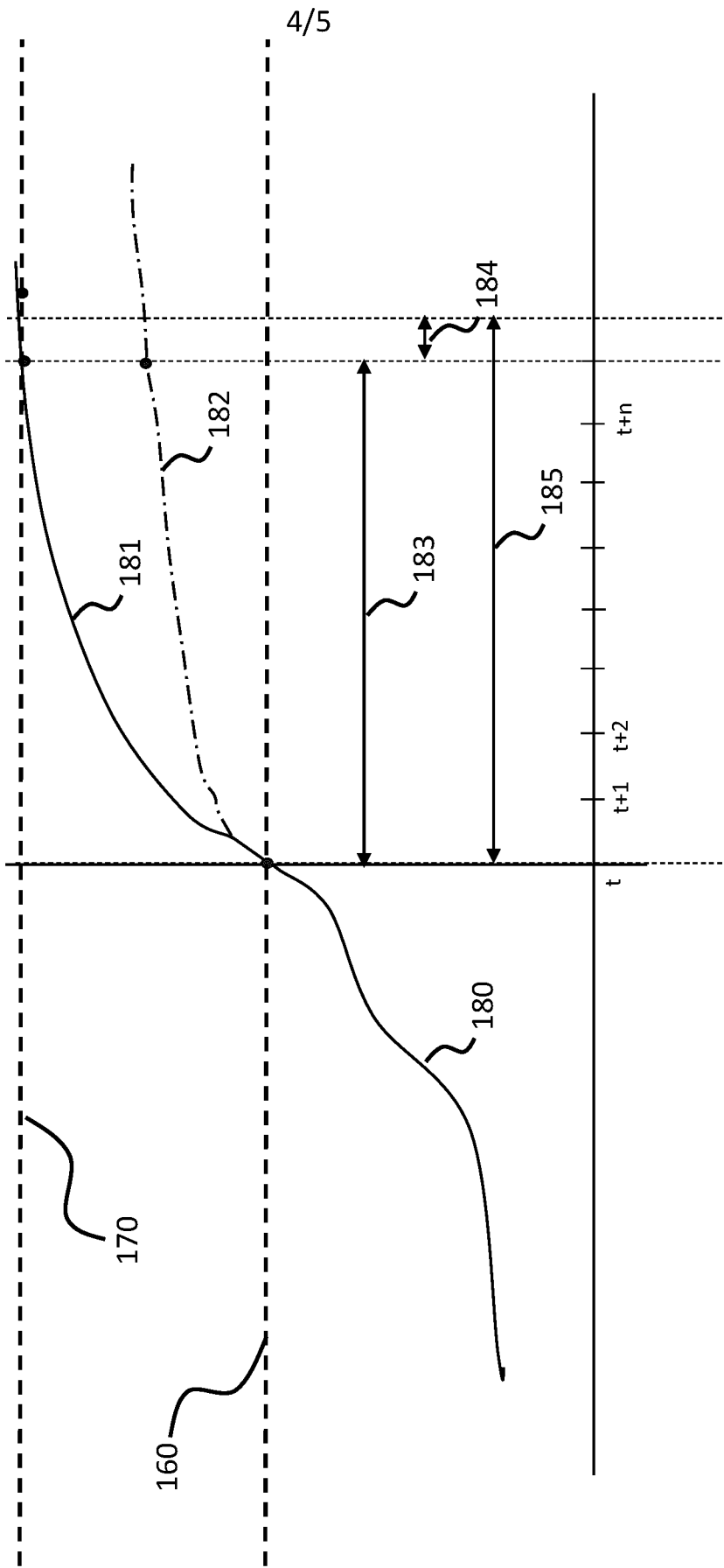


FIG. 6

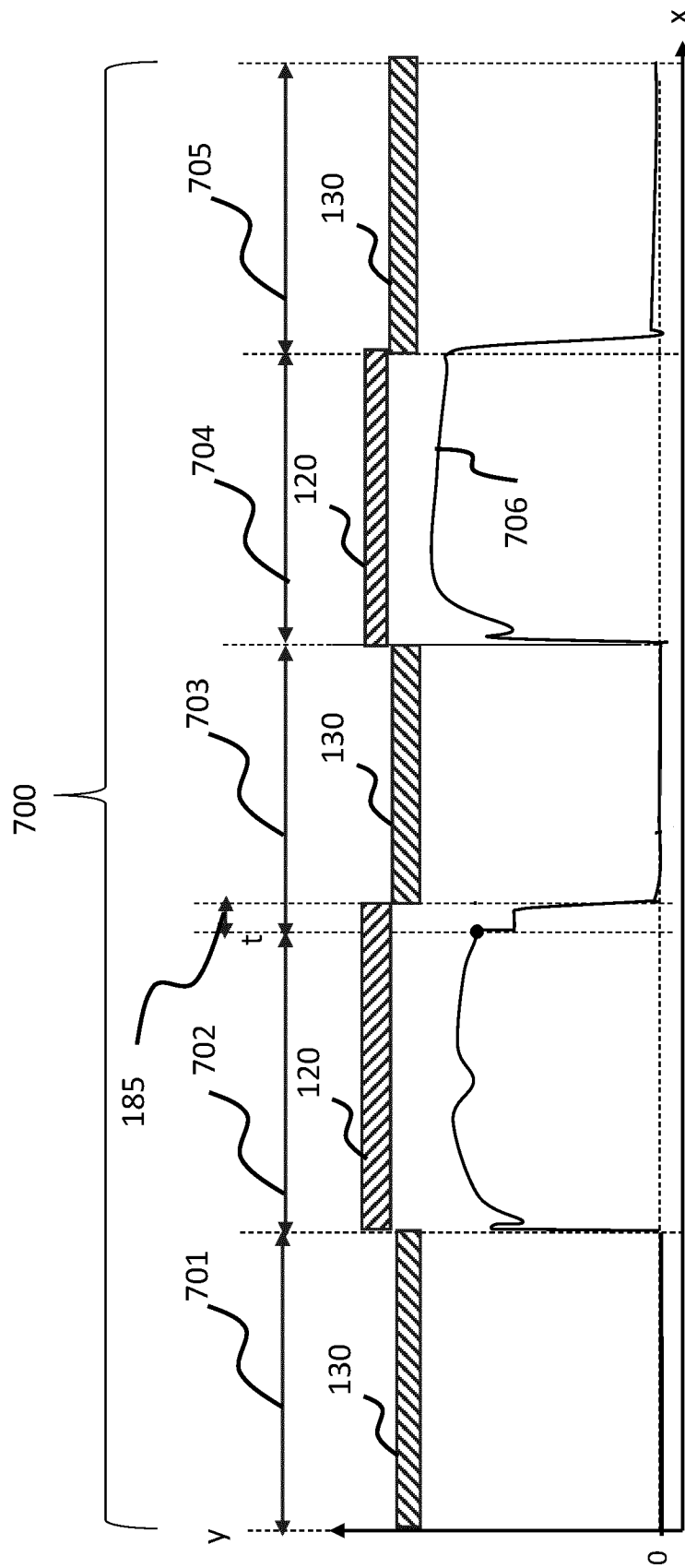


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/061686

A. CLASSIFICATION OF SUBJECT MATTER		
INV.	B60K6/387	B60K6/48
	B60W20/11	B60W20/13
	B60W30/182	B60W30/188
	B60W10/02	B60W10/06
	B60W20/16	B60W20/40
	B60W20/17	B60W30/192
	B60W10/08	B60W20/50
	B60W50/08	
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) B60K B60W		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2019/375395 A1 (JENTZ ROBERT [US] ET AL) 12 December 2019 (2019-12-12) paragraphs [0002] - [0007], [0031], [0045], [0034], [0054] - [0059], [0082] - [0089], [0097] - [0099], [0105] - [0113]; figures 1, 5, 7, 9A-9B, 10 -----	1-12
X	US 2014/277998 A1 (MARTIN DOUGLAS RAYMOND [US] ET AL) 18 September 2014 (2014-09-18) paragraphs [0013] - [0022], [0040] - [0069]; figures 3, 4 -----	1, 4, 5, 7, 10-12
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 7 August 2023		Date of mailing of the international search report 17/08/2023
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Vena, Gianpiero

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2023/061686

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2019375395 A1	12-12-2019	CN 110578630 A	17-12-2019
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		DE 102014204229 A1	18-09-2014
		US 2014277998 A1	18-09-2014