



(51) International Patent Classification:

F02N 11/08 (2006.01) *F02N 11/04* (2006.01)
F02N 19/00 (2010.01) *B60W 10/06* (2006.01)
B60W 30/18 (2012.01)

(21) International Application Number:

PCT/EP2017/079182

(22) International Filing Date:

14 November 2017 (14.11.2017)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

1619294.0 15 November 2016 (15.11.2016) GB

(71) Applicant: **JAGUAR LAND ROVER LIMITED**
[GB/GB]; Abbey Road Whitley, Coventry Warwickshire
CV3 4LF (GB).

(72) Inventors: **GREEN, Christopher**; c/o Jaguar Land Rover,
Patents Department W/1/073 Abbey Road, Whitley, Coventry
Warwickshire CV3 4LF (GB). **BALDER, Scott**; c/o
Jaguar Land Rover, Patents Department W/1/073 Abbey
Road, Whitley, Coventry Warwickshire CV3 4LF (GB).
BRUNETTI, Gianmarco; c/o Jaguar Land Rover, Patents

Department W/1/073 Abbey Road, Whitley, Coventry War-
wickshire CV3 4LF (GB). **MOURRE, Thomas**; c/o Jaguar
Land Rover, Patents Department W/1/073 Abbey Road,
Whitley, Coventry Warwickshire CV3 4LF (GB).

(74) Agent: **ELLIS, Richard**; Jaguar Land Rover, Patents De-
partment W/1/073 Abbey Road, Whitley, Coventry War-
wickshire CV3 4LF (GB).

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP,
KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,

(54) Title: AN APPARATUS, METHOD AND COMPUTER PROGRAM FOR CONTROLLING AN ELECTRIC MACHINE FOR
RESTARTING AN ENGINE WITHIN A VEHICLE

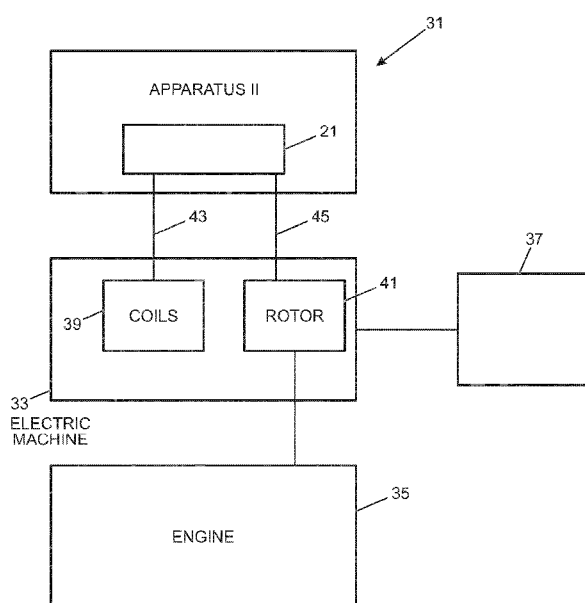


FIG. 3

(57) Abstract: An apparatus, method, computer program and non-transitory computer readable medium for controlling an electric machine for restarting an engine within a vehicle, the apparatus comprising: means for providing a first control signal, in response to a determination that the engine is entering an off condition, to cause a first level of current to be supplied to the coils; and means for providing a second control signal to cause a second level of current to be supplied to the coils; wherein the first level of current is below a minimum level of current required to enable the coils to cause the rotor to rotate and the second level of current is above the minimum level of current.

EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

AN APPARATUS, METHOD AND COMPUTER PROGRAM FOR CONTROLLING AN ELECTRIC MACHINE FOR RESTARTING AN ENGINE WITHIN A VEHICLE

TECHNICAL FIELD

5

The present disclosure relates to an apparatus, method, computer program and non-transitory computer readable medium for controlling an electric machine for restarting an engine within a vehicle. In particular, but not exclusively it relates to an apparatus, method, computer program and non-transitory computer readable medium for controlling an electric machine for restarting an engine within a vehicle when the engine exits an off condition.

10

Aspects of the invention relate to an apparatus, method, computer program and non-transitory computer readable medium.

BACKGROUND

15

In order to increase fuel efficiency of a vehicle the engine of the vehicle may be arranged into an off condition, in which the engine is stopped, while the vehicle is still moving. This may be known as a stop on the move (SOTM) state. This may increase the fuel efficiency of the vehicle.

20

An SOTM state may be used if the vehicle is travelling below a threshold speed and the brake pedal is actuated by the driver. This may cause the engine to be stopped. The engine may be restarted and the off condition may be exited if the driver releases the brake pedal and/or actuates the accelerator pedal.

25

It is an aim of the present invention to improve the transition from an off condition to a driving state.

SUMMARY OF THE INVENTION

30

Aspects and embodiments of the invention provide an apparatus, method, computer program and non-transitory computer readable medium as claimed in the appended claims.

According to an aspect of the invention there is provided an apparatus for controlling an electric machine for restarting an engine within a vehicle, the electric machine comprising coils and a rotor, the apparatus comprising means for providing a first control signal, in response to a determination that the engine is entering an off condition, to cause a first level of current to be supplied to the coils; and means for providing a second control signal to cause a second level of current to be supplied to the coils; wherein the first level of current is below a minimum level of current required to enable the coils to cause the rotor to rotate and the second level of current is above the minimum level of current.

This provides the advantage that it enables an engine to be restarted quickly. The first and second control signals are provided separately. This enables the coils to be maintained in an energised state without having to operate or cause the electric machine to provide power. Also as the coils of the electric machine are maintained in an energised state this maintains the motor in a magnetised state so that when the engine needs to be restarted there is minimal delay in magnetising the motor. This may enable the electric machine to be restarted quickly which may enable the off condition to be exited quickly.

Further, according to the aspect of the invention the determination that the engine is entering an off condition is capable of being made while the vehicle is moving and without driver actuation of a brake pedal.

The determination that the engine is entering an off condition may be capable of being made regardless of the speed of the vehicle.

The determination that the engine is entering an off condition may be dependent on a decision that the engine should enter the off condition, the decision being dependent on a context outside the vehicle. Therefore, the determination that the engine is entering an off condition may be dependent on context information associated with a context outside the vehicle.

The determination that the engine is entering an off condition may be dependent on a decision that the engine should enter the off condition, the decision being dependent on machine learning. Therefore, the determination that the engine is entering an off condition may be dependent on machine learning.

The determination that the engine is entering an off condition may be dependent on a decision that the engine should enter the off condition, the decision being dependent on a selected operating mode of the vehicle. Therefore, the determination that the engine is entering an off condition may be dependent on a selected operating mode of the vehicle.

5

The determination that the engine is entering an off condition may be dependent on a decision that the engine should enter the off condition, the decision being dependent on detection of overrun while the vehicle is in cruise control and/or during autonomous driving. Therefore, the determination that the engine is entering an off condition may be dependent on detection of
10 overrun while the vehicle is in cruise control and/or during autonomous driving.

This may also ensure that the electric motor can be maintained in a magnetised state whenever the off condition is entered. This may also enable the first control signal and the second control signal to be provided at different times.

15

The second control signal may be provided in response to a determination that the engine is to exit the off condition.

This enables the rotor to be restarted as soon as it is determined that the engine of the vehicle
20 is exiting the off condition. This may ensure that the engine can be restarted quickly once it is determined that the engine of the vehicle is to exit the off condition.

The determination that the engine is to exit an off condition may be dependent on a decision whether the engine should exit the off condition, the decision being dependent on detection of
25 a torque demand while the vehicle is in cruise control and/or during autonomous driving. Therefore, the determination that the engine is to exit the off condition may be dependent on detection of a torque demand while the vehicle is in cruise control and/or during autonomous driving.

30 The first control signal may maintain the coils in an energised state while the engine is in the off condition.

This may ensure that the coils are maintained in the energised state for as long as the engine of the vehicle is in the off condition. As the second control signal is provided at a different time

to the first control signal this enables the coils to be maintained in the energised state without actuating the rotor.

The off condition may be entered and exited while the vehicle is moving.

5

This provides the advantage that it enables a driver to control a vehicle to quickly restart an engine and exit a stop on the move state. This may provide for an improved driver experience as it reduces any perceived lag in the time taken for the engine to restart.

10 The apparatus may comprise means for providing a control signal to de-energise the coils after a predetermined time period.

This may provide the advantage that it prevents the coils from overheating if the engine of the vehicle remains in the off condition for longer than the predetermined time. This may prevent
15 any damage from being caused to the coils and the other parts of the electric machine.

The respective means may be provided by one or more controllers. For example, the means for providing the first control signal can be the same or separate means as the means for providing the second control signal.

20

According to an aspect of the invention there is provided a vehicle comprising an apparatus as described above.

According to an aspect of the invention there is provided a method of controlling an electric
25 machine for restarting an engine within a vehicle, the method comprising: providing a first control signal in response to a determination that the engine is entering an off condition, to cause a first level of current to be supplied to the coils, wherein the determination that the engine is entering an off condition is capable of being made while the vehicle is moving and without driver actuation of a brake pedal; and providing a second control signal to cause a
30 second level of current to be supplied to the coils; wherein the first level of current is below a minimum level of current required to enable the coils to cause the rotor to rotate and the second level of current is above the minimum level of current.

The engine may enter the off condition in dependence on one or more conditions as described above, including but not limited to a context outside the vehicle, machine learning, a selected operating mode of the vehicle, or detection of overrun while the vehicle is in cruise control and/or during autonomous driving.

5

According to an aspect of the invention there is provided a computer program for providing restarting of an engine within a vehicle, the computer program comprising instructions that, when executed by one or more processors, cause an apparatus to perform, at least: providing a first control signal in response to a determination that the engine is entering an off condition, to cause a first level of current to be supplied to the coils, wherein the determination that the engine is entering an off condition is capable of being made while the vehicle is moving and without driver actuation of a brake pedal; and providing a second control signal to cause a second level of current to be supplied to the coils; wherein the first level of current is below a minimum level of current required to enable the coils to cause the rotor to rotate and the second level of current is above the minimum level of current.

According to an aspect of the invention there is provided a non-transitory computer readable medium comprising a computer program as described above.

According to an aspect of the invention there is provided an apparatus for controlling an electric machine for restarting an engine within a vehicle, the apparatus comprising; means for maintaining the electric machine in an energised state.

According to an aspect of the invention there is provided a system for controlling an electric machine for restarting an engine within a vehicle, the system comprising:

means for receiving one or more signals indicating that the engine of the vehicle is entering an off condition, wherein a determination that the engine is entering an off condition is capable of being made while the vehicle is moving and without driver actuation of a brake pedal;

means to maintain the electric machine in an energized state by providing a first control signal to energise coils within the electric machine when the engine is in an off condition;

means for receiving one or more signals indicating that the engine of the vehicle is to exit an off condition; and

means to cause a rotor within the electric machine to rotate by providing a second control signal.

According to an aspect of the invention there is provided a system for controlling an electric machine for restarting an engine within a vehicle as described above, wherein:

said means for receiving one or more signals comprises an electronic processor having an electrical input for receiving said one or more signals; and

an electronic memory device electrically coupled to the electronic processor and having instructions stored therein,

said means to maintain the electric machine in an energized state by providing a first control signal to energise coils within the electric machine when the engine is in an off condition, and said means to cause a rotor within the electric machine to rotate by providing a second control signal comprises the processor being configured to access the memory device and execute the instructions stored therein such that it is operable to detect that the engine of the vehicle is entering or exiting an off condition based on the received signals; and command the first control signal or the second control signal to be provided.

According to some, but not necessarily all embodiments of the disclosure there is provided an apparatus for controlling an electric machine for restarting an engine within a vehicle, the electric machine comprising coils and a rotor, the apparatus comprising means for providing a first control signal, in response to a determination that the engine is entering an off condition, to cause a first level of current to be supplied to the coils; and means for providing a second control signal to cause a second level of current to be supplied to the coils; wherein the first level of current is below a minimum level of current required to enable the coils to cause the rotor to rotate and the second level of current is above the minimum level of current.

According some, but not necessarily all embodiments of the disclosure there is provided a method of controlling an electric machine for restarting an engine within a vehicle, the method comprising: providing a first control signal in response to a determination that the engine is entering an off condition, to cause a first level of current to be supplied to the coils; and providing a second control signal to cause a second level of current to be supplied to the coils; wherein the first level of current is below a minimum level of current required to enable the coils to cause the rotor to rotate and the second level of current is above the minimum level of current.

According to some, but not necessarily all embodiments of the disclosure there is provided a computer program for providing restarting of an engine within a vehicle, the computer program comprising instructions that, when executed by one or more processors, cause an apparatus to perform, at least: providing a first control signal in response to a determination that the engine is entering an off condition, to cause a first level of current to be supplied to the coils; and providing a second control signal to cause a second level of current to be supplied to the coils; wherein the first level of current is below a minimum level of current required to enable the coils to cause the rotor to rotate and the second level of current is above the minimum level of current.

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 is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, 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 a vehicle;

Fig 2 illustrates an apparatus;

Fig 3 illustrates a system;

Fig 4 illustrates an example method;

Fig 5 illustrates the status of components of the system during an example method; and

Fig 6 illustrates the status of components of the system during an example method.

DETAILED DESCRIPTION

The Figures illustrate an apparatus 11 for controlling an electric machine 33 for restarting an engine 35 within a vehicle 1, the apparatus 11 comprising: means 21 for providing a first control signal 43 to energise coils 39 within the electric machine 33 when the engine 35 is in an off condition; and means 21 for providing a second control signal 45 to cause a rotor 41 within the electric machine 33 to rotate to enable the engine 35 to exit the off condition.

Fig 1 illustrates an example vehicle 1 which may comprise an apparatus 11 according to embodiments of the invention. The vehicle 1 may be a hybrid electric vehicle 1 or any other suitable type of vehicle 1. The vehicle 1 may comprise an engine 35 such as combustion engine. The vehicle 1 may comprise an electric machine 33 which may be arranged to start the combustion engine.

In embodiments of the invention the engine 35 of the vehicle 1 may be arranged into an off condition in which the engine 35 is stopped. The engine 35 of the vehicle 1 may be arranged into an off condition while the vehicle is moving, known as a stop on the move (SOTM) state, or during any other suitable state. The SOTM state may be entered if the vehicle 1 is travelling below a threshold speed and the brake pedal is actuated by the driver. The SOTM state may be exited if the brake pedal is released and/or if the driver actuates the accelerator pedal.

The vehicle 1 may also comprise an apparatus 11 which may be used to control the electric machine 33 for restarting the engine 35. Examples of the apparatus 11 are described below in relation to Figs 2 and 3. Examples of methods that may be performed by the apparatus 11 are described below in relation to Figs 4 to 5.

Fig 2 illustrates an apparatus 11 which may be provided within the vehicle 1. The apparatus 11 may be arranged to control an electric machine 33 for restarting the engine 35 within the vehicle 1.

The apparatus 11 comprises a controller 21. The controller 21 may be a chip or a chip set. The controller 21 may form part of one or more systems comprised in the vehicle 1. The controller 21 may be arranged to control any suitable functions or applications within the vehicle 1.

The controller 21 comprises at least one processor 23, at least one memory 25 and at least one computer program 27.

5 Implementation of a controller 21 may be as controller circuitry. The controller 21 may be implemented in hardware alone, may have certain aspects in software including firmware alone or may be a combination of hardware and software (including firmware).

As illustrated in Fig 2 the controller 21 may be implemented using instructions that enable hardware functionality, for example, by using executable instructions of a computer program 10 27 in a general-purpose or special-purpose processor 23 that may be stored on a computer readable storage medium (disk, memory etc) to be executed by such a processor 23.

The processor 23 may be arranged to read from and write to the memory 25. The processor 23 may also comprise an output interface via which data and/or commands are output by the 15 processor 23 and an input interface via which data and/or commands are input to the processor 23.

The memory 25 may be arranged to store a computer program 27 comprising computer program instructions 29 (computer program code) that controls the operation of the controller 20 21 when loaded into the processor 23. The computer program instructions 29, of the computer program 27, provide the logic and routines that enables the controller 21 to detect that the engine 35 of the vehicle 1 is in an off condition and control the provision of one or more control signals. The controller 21 may also be arranged to detect that the engine 35 of the vehicle 1 is exiting an off condition and control the provision of one or more control signals in response 25 to the exiting of the off condition. The processor 23 by reading the memory 25 is able to load and execute the computer program 27.

As illustrated in Fig 2, the computer program 27 may arrive at the controller 21 via any suitable delivery mechanism 31. The delivery mechanism 31 may be, for example, a non-transitory 30 computer-readable storage medium, a computer program product, a memory device, a record medium such as a compact disc read-only memory (CD-ROM) or digital versatile disc (DVD), an article of manufacture that tangibly embodies the computer program 27. The delivery mechanism may be a signal arranged to reliably transfer the computer program 27. The controller 21 may propagate or transmit the computer program 27 as a computer data signal.

Although the memory 25 is illustrated as a single component/circuitry it may be implemented as one or more separate components/circuitry some or all of which may be integrated/removable and/or may provide permanent/semi-permanent, dynamic/cached storage.

Although the processor 23 is illustrated as a single component/circuitry it may be implemented as one or more separate components/circuitry some or all of which may be integrated/removable. The processor 23 may be a single core or multi-core processor.

Fig 3 schematically illustrates an example system 31 which comprises an apparatus 11 as described above. The system 31 may be provided within vehicles 1 as described above.

The example system 31 of Fig 3 comprises an apparatus 11, an electric machine 33, an engine 35 and a power source 37. It is to be appreciated that only components relevant to the following description have been shown in Fig 3. Other components may be provided in other embodiments of the invention.

The apparatus 11 may be as described above in relation to Fig 2. The apparatus 11 may comprise one or more controllers 21. The controller 21 may be as described above. In some examples the controller 21 may be dedicated to controlling the electric machine 33 and may solely control functions relating to the electric machine 33. In other examples the controller 21 may be arranged to control functions of the other systems of the vehicle 1. This may enable the same controller 21 to be used for different systems. This may reduce the number of controllers 21 needed within the vehicle 1.

The system 31 is arranged so that the apparatus 21 is coupled to the electric machine 33. The apparatus 11 may be coupled to the electric machine 33 so that the controller 21 can provide control signals 43, 45 to the electric machine 33.

The electric machine 33 may comprise any means which may be used to start and restart the engine 35. The electric machine 33 may be coupled to a power source 37. The power source 37 may comprise any suitable means such as a battery. The electric machine 33 may comprise

means for converting the electrical energy from the battery into rotary motion that can be used to start the engine 35.

In the example of Fig 3 the electric machine 33 comprises one or more coils 39 and a rotor 41. It is to be appreciated that the electric machine may also comprise other components that are not illustrated in Fig 3.

The one or more coils 39 may comprise conductive windings. The coils 39 may be connected to the power source 37 so that electric current provided by the power source 37 may be used to energise the coils 39. When the coils 39 are energised an electromagnetic field is provided by the coils 39.

In the example of Fig 3 the electric machine 33 also comprise one or more rotors 41. The rotors may comprise any means which may be arranged to rotate to convert the electrical energy from the coils 39 into rotational motion. The rotors 41 may be positioned relative to the coils 39 so that an alternating current provided to the coils 39 causes the rotation of the rotor 41. In some embodiments of the invention the one or more coils 39 may be wound around the rotor 41.

The rotor 41 may be coupled to the engine 35 so that rotation of the rotor 41 enables cranking of the engine 35. The rotor 41 may be coupled to the engine 35 by a belt or any other suitable means. The engine 35 may be an internal combustion or any other suitable type of engine.

The apparatus 11 is arranged to control the system 31. The controller 21 of the apparatus 11 is arranged to provide control signals 43, 45 to the electric machine 33. The controller 21 may also be arranged to provide control signals 43, 45 to other parts of the system 31.

In the example system 31 of Fig 3 the controller 21 is arranged to provide a first control signal 43 and a second control signal 45 to the electric machine 33. The first control signal 43 and the second control signal 45 may be provided at different times. The first control signal 43 and the second control signal 45 may be provided in response to different trigger events.

The first control signal 43 may be provided in response to a determination that the engine 35 is entering an off condition such as an SOTM state. The controller 21 may be arranged to

determine that the engine 35 is entering an off condition. The controller 21 may determine that the engine 35 is entering the off condition if the vehicle 1 is travelling below a threshold speed and the brake pedal is pressed by the driver.

5 The first control signal 43 may cause the coils 39 within the electric machine 33 to become energised. In response to receiving the first control signal 43 the electric machine 33 may be arranged to provide power from the power source 37 to the coils 39 to energise the coils 39. The power that is provided to the coils 39 may be sufficient to enable the electric coils 39 to be energised but might not be sufficient to enable the rotor 41 to rotate.

10

The second control signal 45 may be provided in response to a determination that the engine 35 is exiting an off condition such as an SOTM state. The controller 21 may be arranged to determine that the engine 35 is exiting an off condition. The controller 21 may determine that the engine 35 is exiting the off condition if the driver releases the brake pedal and/or if the
15 driver actuates an accelerator pedal.

15

The second control signal 45 may cause the rotor 41 within the electric machine 33 to start rotating. In some embodiments of the invention the electric machine 33 may be arranged so that, in response to receiving the second control signal 45, the electric machine 33 may be
20 arranged to increase the power provided from the power source 37 to the coils 39. The power provided to the coils 39 may be increased to a level which enables the rotor 41 to start rotating.

20

The rotation of the rotor 41 may cause the rotation of a belt or any other suitable means which may enable the cranking of the engine 35. This enables the electric machine 33 to be used to
25 start the engine 35.

25

Fig 4 illustrates an example method which may be implemented using the example apparatus 11 and systems 31 as described above. In some examples the method may be implemented by a controller 21 provided within an apparatus 11.

30

At block 51 the method comprises providing a first control signal 43 to energise coils 39 within an electric machine 33 when the engine 35 of the vehicle 1 is in an off condition. The off condition could be a SOTM state or any other suitable off condition.

The first control signal 43 may be provided in response to a determination that the engine 35 is entering an off condition. For example the first control signal 43 could be provided if it is determined that the vehicle 1 is travelling below a threshold speed and the driver has actuated the brake pedal. The first control signal 43 may ensure that the coils 39 are kept in an energised state when the engine 35 is the off condition.

At block 53 the method comprises providing a second control signal 45 to cause a rotor 41 within the electric machine 33 to rotate to enable the engine 35 to exit the off condition.

The second control signal 45 may be provided in response to a determination that the engine 35 is exiting an off condition. For example, the first control signal 43 could be provided if it is determined that the driver has stopped actuating the brake pedal and/or if it is determined that the driver has actuated the accelerator pedal. The second control signal 45 may be provided after the first control signal 43.

As the coils 39 are maintained in an energized state while the engine 35 is the off condition the rotor 41 can begin to rotate as soon as the second control signal 45 is received. There is minimal delay incurred waiting for the coils 39 to become energized before the rotor 41 begins to rotate. This may reduce the amount of time it takes for the engine 35 to be restated when exiting an idle mode. In some examples this may reduce the time taken to restart the engine 35 by 80ms or more. This may reduce any lag the driver perceives when exiting the off condition.

Figs 5 and 6 illustrate the status of components of the system 31 when embodiments of the invention are implemented. The system 31 may be as shown in Fig 3. Figs 5 and 6 show the status of the engine 35, the status of the coils 39 within the electric machine 33, the status of the rotor 41 within the electric machine 33 and the torque within the belt between the rotor 41 and the engine 35. In the example system 31 the coils 39 are provided around the rotor 41.

At time t_1 it is determined that the engine 35 is entering an off condition. In the examples of Figs 5 and 6 the off condition is a SOTM state. Other off conditions may be used in other examples of the disclosure. Prior to time t_1 the engine 39 is powered on. When the engine 35 enters the off condition the engine 35 is turned off. When the engine 35 is turned off no power is provided from the engine 35 to the drive train of the vehicle 1.

At time t_1 the engine 35 is turned off and a first control signal 43 is sent from the controller 21 to the electric machine 33 to energise the coils 39 within the electric machine 33. In the examples of Figs 5 and 6 the control signal 43 is sent at the same time as the engine 35 is turned off. This may minimize any delays in energising the coils 39. In other examples the control signal 43 is sent after the engine 35 is turned off. This may allow the coils 39 to de-energise temporarily. This saves energy in scenarios in which the controller 21 anticipates that an engine restart will not be required for a long time period.

At time t_2 a current is provided to the coils 39 in response to the first control signal 43. The current which is provided to the coils 39 may be sufficient to enable the coils 39 to be maintained in a magnetised state. As shown in Fig 6, the current which is provided to the coils 39 may be lower than the current which is provided before time t_2 when the electric machine 33 is being used to provide rotary motion. In other examples, such as the example shown in Fig 5, the current which is provided to the coils 39 may be higher than the current which is provided before time t_2 . In the examples of Figs 5 and 6 the current that is provided to the coils 39 may be 3A. Other levels of current may be used in other embodiments of the invention.

At time t_3 the energising of the coils 39 is completed. The energising of the coils 39 may be completed once the current provided to the coils reaches a threshold level. In the example of Figs 5 and 6 the threshold level is 3A. Other thresholds may be used in other embodiments of the invention. In some examples the energising of the coils 39 may be completed once the magnetic field generated by the coils 39 reaches a predetermined level.

In embodiments of the invention the coils 39 are not energised instantaneously so there is some time delay between the receipt of the first control signal 43 and the coils 39 becoming energised. In the examples of Figs 5 and 6 the time taken to energise the coils 39 could be between 50 and 90ms. Other ranges of times may be taken in other systems 31 and embodiments of the invention.

Once the energising of the coils 39 has been completed the coils 39 are maintained in the energised state. The energised state may last for the duration of time period t_4 . During time period t_4 the current to the coils 39 may be maintained so that the coils 39 are kept in a magnetized state. In the examples of Figs 5 and 6 the control signal 43 is provided to the

electric machine 33 for the duration of time period t_4 to ensure that coils 39 are maintained in the energised state.

In the examples of Figs 5 and 6 the time period t_4 lasts until it is determined that the engine 35 is exiting the off condition. In the examples of Figs 5 and 6 it may be determined that the engine 35 is exiting the off condition when the driver releases the brake pedal at time t_5 .

Once it has been determined that the engine 35 is to exit the off condition the second control signal 45 is provided from the controller 21 to the electric machine 33. The second control signal 45 enables the rotor 41 to rotate within the electric machine 33. In embodiments of the invention the second control signal 45 may cause the current provided to the coils 39 to be increased so as to cause rotation of the rotor 41. In the examples of Figs 5 and 6 the current provided to the coils 39 has increased from 3A to 10A. It is to be appreciated that other increases in current may be used in other embodiments of the invention.

Once the rotor 41 begins to rotate this increases the torque in the belt between the rotor and the engine 35 and enables the engine 35 to be cranked. At time t_6 the engine 35 is cranked and can be restarted so that the engine 35 has exited the off condition.

In the examples of Figs 5 and 6 the time taken to crank the engine 35 is 50ms. This is the time between the driver releasing the brake pedal and the engine 35 restarting. The time taken to energise the coils is between 50ms and 90ms. As the energising of the coils 39 occurs before the driver releases the brake pedal this does not form part of the delay in the restart of the engine 35. Therefore the time to restart the engine 35 is reduced. This may provide an improved driving experience for the driver.

The time period t_4 may last for a maximum pre-determined time period. If it is not determined that the engine 35 is exiting the off condition before the end of the maximum pre-determined time period then the controller 21 may be arranged to send a further control signal to the electric machine 33 to de-energise the coils 39. In response to the further control signals the coils 39 may be disconnected from the power source 37 so that no energy is provided from the power source 37 to the coils 39.

The further control signal may ensure that the coils 39 are de-energised before they overheat or before any damage is caused to the coils 39 or other components of the electric machine 33. In the examples of Figs 5 and 6 the maximum predetermined time period may be between 6 to 10s. Other predetermined time periods may be used in other embodiments of the invention. The duration of the predetermined time periods may depend on factors such as the size and shape of the coils 39, the materials used for the coils 39 and any other suitable factors.

Braking to a halt as described above is an example of an 'overrun' scenario suitable for implementing (entering) SOTM. An overrun occurs when the combustion engine enters fuel cut-off due to a lack of demand for torque from the engine/powertrain at least for maintaining or increasing vehicle speed. In an overrun state, fuelling of the engine is stopped so that only un-burnt air is passed through the engine. While no driver request for torque from the engine for maintaining or increasing vehicle speed is detected, for example via an accelerator pedal or cruise control/autonomous driving interface (if installed), the engine may be operated in overrun.

SOTM may be used in a variety of overrun scenarios, not limited to the vehicle travelling below a threshold speed and the brake pedal being actuated by the driver. Another overrun scenario could arise while the vehicle is traversing a long downhill section of a route in which no engine torque is required to maintain a desired vehicle speed or accelerate the vehicle. SOTM could be used in such a scenario to provide a form of 'glide mode' (also referred to as 'coasting' or 'sailing' mode).

In some, but not necessarily all examples implementing SOTM comprises opening the clutch of known type (not shown) separating the engine from the transmission during overrun to reduce pumping losses.

The determination that the engine is entering an off condition may be dependent on a decision that the engine should enter the off condition, in other words a decision whether to enter SOTM. The decision could be made by the apparatus or could be made by another controller, the result being obtained by the apparatus. The decision may be dependent on one or more conditions. A similar decision may be employed as to whether to exit SOTM.

In some, but not necessarily all examples a condition for entering SOTM could comprise detecting vehicle overrun (no driver request for torque from the engine for maintaining or increasing vehicle speed).

5 In some, but not necessarily all examples SOTM could be entered during glide mode while the vehicle is moving and without driver actuation of a brake pedal. The determination that the engine is entering an off condition may be capable of being made regardless of (independently of) the speed of the vehicle. In some examples, the determination that the engine is entering an off condition may be capable of being made regardless of the speed of the vehicle at least
10 up to 50kph or at least up to 100kph or at least up to 160kph. In other words, there may be no threshold speed or the threshold speed may be higher than these speeds. In some, but not necessarily all examples SOTM could be entered and then deactivated while the vehicle is still moving. Control of the electric machine in accordance with aspects of the present invention to control engine restart while the vehicle is still moving allows a smooth engine restart. This
15 reduces the likelihood of an engine restart causing sudden and/or unexpected engine braking that could destabilise the fast-moving vehicle.

An optional further condition for entering SOTM could require detecting that a driver request for torque has not been received for a threshold time, for example a few seconds.

20

An optional further condition(s) for entering SOTM could be dependent on context information associated with a context outside the vehicle. In some examples, context information may indicate one or more of terrain information or traffic information, indicative of terrain or traffic ahead of the vehicle. Terrain information may include information indicative of a gradient.
25 Traffic information may include information indicative of a traffic speed and/or a queue ahead of the vehicle. The context information could be obtained from a navigation system of the vehicle such as a Global Positioning System module, and/or could be obtained from one or more sensors on the vehicle such as a forward-facing camera or a lidar sensor. In some example implementations, the context information could be used to predict an overrun. In
30 some example implementations, the context information could be used to predict how long a detected/predicted overrun is likely to last for, and SOTM could be inhibited if the prediction indicates that a minimum threshold duration of the overrun will not occur. In some example implementations, the terrain information could be used to predict whether a vehicle cruising speed will be maintained and/or will not increase during SOTM implementation, despite the

reduction in pumping loss associated with de-clutching the engine, and SOTM may be inhibited if a gradient is too shallow or steep.

Alternatively or in addition to context information, satisfaction of the further condition(s) could be dependent on machine learning. For example, stored machine learning data indicating when overrun has previously been used at which locations or times in similar past journeys can be interrogated to predict information about an overrun.

An optional condition for SOTM could be dependent on a selected operating mode of the vehicle. In particular, a condition for inhibiting SOTM could be dependent on the selected operating mode. For example, SOTM functionality may be inhibited if the vehicle is in an 'off-road' mode. Examples of such modes include 'off road', and/or more specific modes such as 'rock crawl', 'sand', or 'wading' modes. Vehicle operating modes define one or more of the following parameters: steering response; accelerator pedal response; engine mapping; brake mapping; output torque; differential settings; four-wheel drive settings; anti-lock braking control; wheel slip parameters.

Conditions for exiting SOTM and therefore sending the second control signal to restart the engine may be dependent on, for example, at least one of: torque demand (via accelerator pedal, cruise control or autonomous driving module); brake pedal use; increasing vehicle speed; or decreasing vehicle speed. In other words, SOTM could be interrupted if additional acceleration or engine braking is required.

The blocks illustrated in Fig 4 may represent steps in a method and/or sections of code in the computer program 27. 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.

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

Whilst endeavoring 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
10 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.

15

CLAIMS

1. An apparatus for controlling an electric machine for restarting an engine within a vehicle, the electric machine comprising coils and a rotor, the apparatus comprising:
- 5 means for providing a first control signal, in response to a determination that the engine is entering an off condition, to cause a first level of current to be supplied to the coils, wherein the determination that the engine is entering an off condition is capable of being made while the vehicle is moving and without driver actuation of a brake pedal; and
- means for providing a second control signal to cause a second level of current to be
- 10 supplied to the coils; wherein
- the first level of current is below a minimum level of current required to enable the coils to cause the rotor to rotate and the second level of current is above the minimum level of current.
- 15 2. An apparatus as claimed in claim 1 wherein the determination that the engine is entering an off condition is capable of being made regardless of the speed of the vehicle.
3. An apparatus as claimed in claim 1 or 2 wherein the determination that the engine is entering an off condition is dependent on context information associated with a context outside
- 20 the vehicle.
4. An apparatus as claimed in any preceding claim, wherein the determination that the engine is entering an off condition is dependent on machine learning.
- 25 5. An apparatus as claimed in any preceding claim, wherein the determination that the engine is entering an off condition is dependent on a selected operating mode of the vehicle.
6. An apparatus as claimed in any preceding claim, wherein the determination that the engine is entering an off condition is dependent on detection of overrun while the vehicle is in
- 30 cruise control and/or during autonomous driving.
7. An apparatus as claimed in any preceding claim wherein the second control signal is provided in response to a determination that the engine is to exit the off condition.

8. An apparatus as claimed in claim 7, wherein the determination that the engine is to exit the off condition is dependent on detection of a torque demand while the vehicle is in cruise control and/or during autonomous driving.

5 9. An apparatus as claimed in any preceding claim wherein the first control signal maintains the coils in an energised state while the engine is in the off condition.

10. An apparatus as claimed in any preceding claim wherein the off condition is exited while the vehicle is moving.

10

11. An apparatus as claimed in any preceding claim wherein the apparatus comprises means for providing a control signal to de-energise the coils after a predetermined time period.

12. A vehicle comprising an apparatus as claimed in any of claims 1 to 11.

15

13. A method of controlling an electric machine for restarting an engine within a vehicle, the method comprising:

providing a first control signal in response to a determination that the engine is entering an off condition, to cause a first level of current to be supplied to the coils, wherein the determination that the engine is entering an off condition is capable of being made while the vehicle is moving and without driver actuation of a brake pedal; and

20

providing a second control signal to cause a second level of current to be supplied to the coils; wherein

the first level of current is below a minimum level of current required to enable the coils to cause the rotor to rotate and the second level of current is above the minimum level of current.

25

14. A method as claimed in claim 13 wherein the determination that the engine is entering an off condition is capable of being made regardless of the speed of the vehicle.

30

15. A method as claimed in claim 13 or 14 wherein the determination that the engine is entering an off condition is dependent on context information associated with a context outside the vehicle;

16. A method as claimed in claim 13, 14 or 15, wherein the determination that the engine is entering an off condition is dependent on machine learning

17. A method as claimed in any of claims 13 to 16, wherein the determination that the engine is entering an off condition is dependent on a selected operating mode of the vehicle.

18. A method as claimed in any of claims 13 to 17, wherein the determination that the engine is entering an off condition is dependent on detection of overrun while the vehicle is in cruise control and/or during autonomous driving.

19. A method as claimed in any of claims 13 to 18 wherein the second control signal is provided in response to a determination that the engine is to exit the off condition.

20. An apparatus as claimed in claim 19, wherein the determination that the engine is to exit the off condition is dependent on detection of a torque demand while the vehicle is in cruise control and/or during autonomous driving.

21. A method as claimed in any of claims 13 to 20 wherein the first control signal maintains the coils in an energised state while the engine is in the off condition.

22. A method as claimed in any of claims 13 to 21 wherein the off condition is exited while the vehicle is moving.

23. A method as claimed in any of claims 13 to 22 wherein the method comprises providing a control signal to de-energise the coils after a predetermined time period.

24. A computer program for providing restarting of an engine within a vehicle, the computer program comprising instructions that, when executed by one or more processors, cause an apparatus to perform, at least:

providing a first control signal in response to a determination that the engine is entering an off condition, to cause a first level of current to be supplied to the coils, wherein the determination that the engine is entering an off condition is capable of being made while the vehicle is moving and without driver actuation of a brake pedal; and

providing a second control signal to cause a second level of current to be supplied to the coils; wherein

the first level of current is below a minimum level of current required to enable the coils to cause the rotor to rotate and the second level of current is above the minimum level of current.

25. A non-transitory computer readable medium comprising a computer program as claimed in claim 24.

26. A method and/or apparatus and/or vehicle and/or computer program and/or non-transitory computer readable medium substantially as described herein with reference to the accompanying drawings and/or as illustrated in the accompanying drawings.

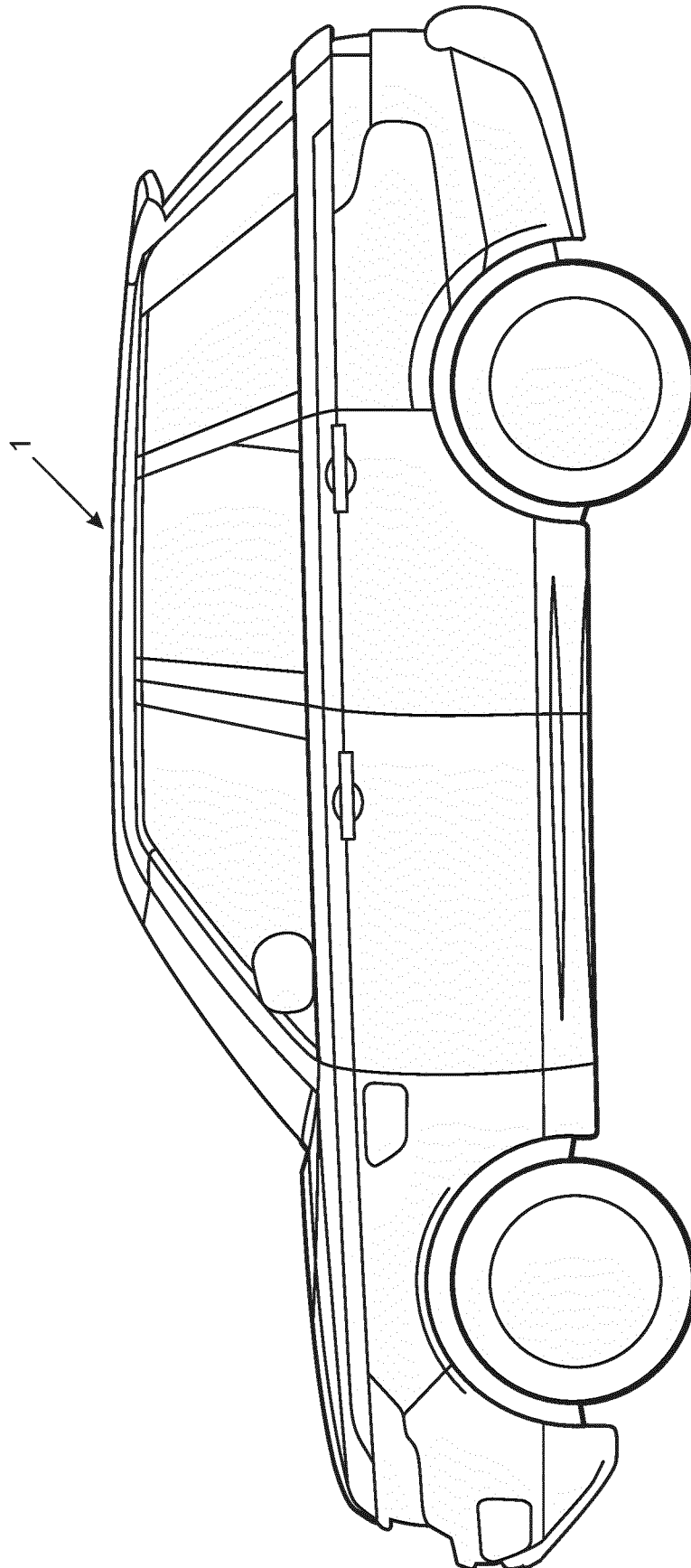


FIG. 1

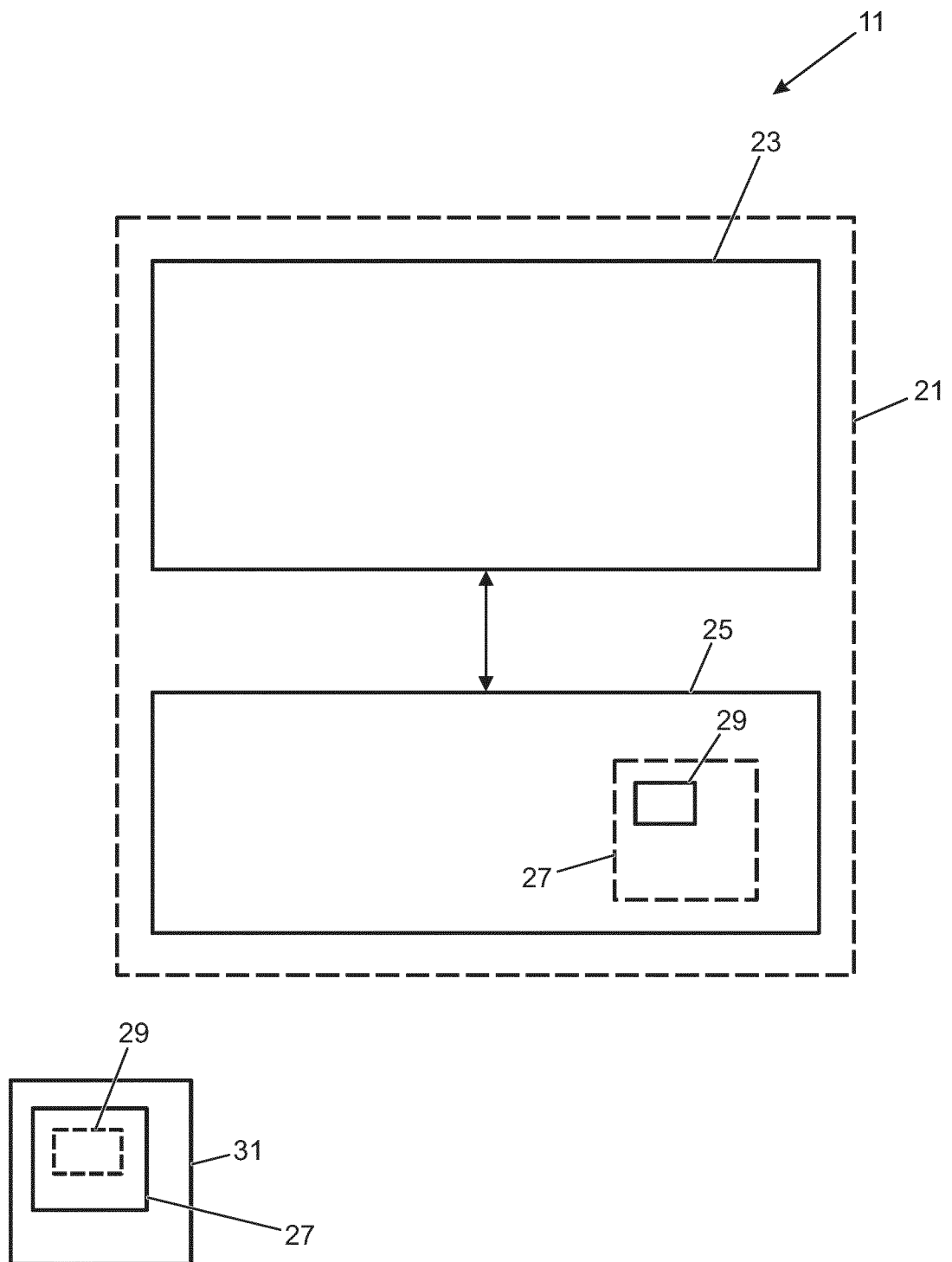


FIG. 2

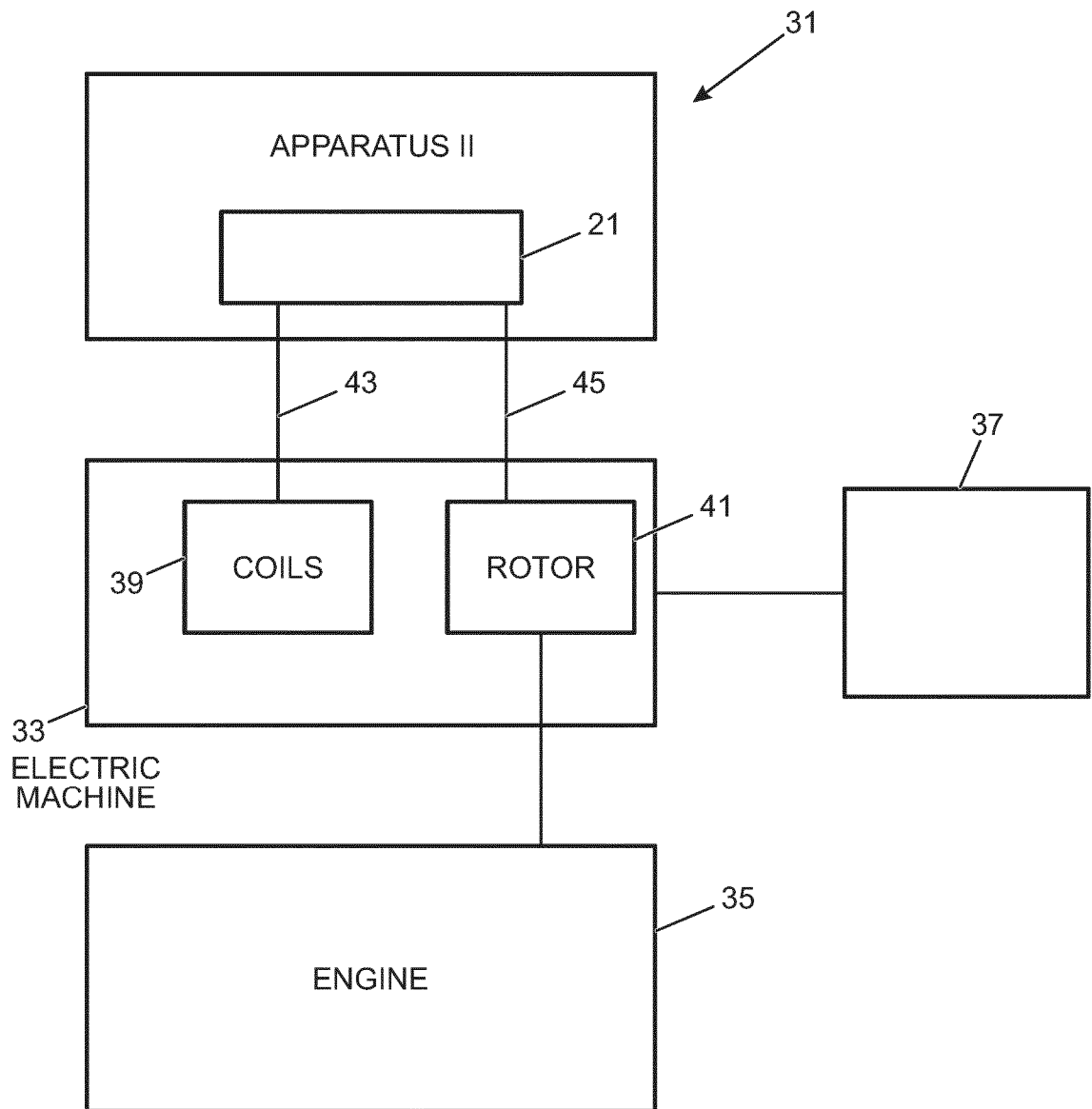


FIG. 3

4/6

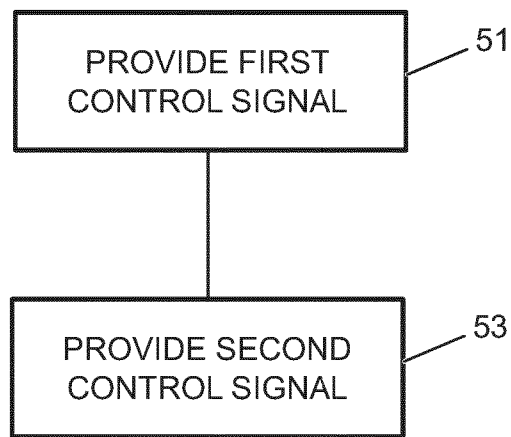


FIG. 4

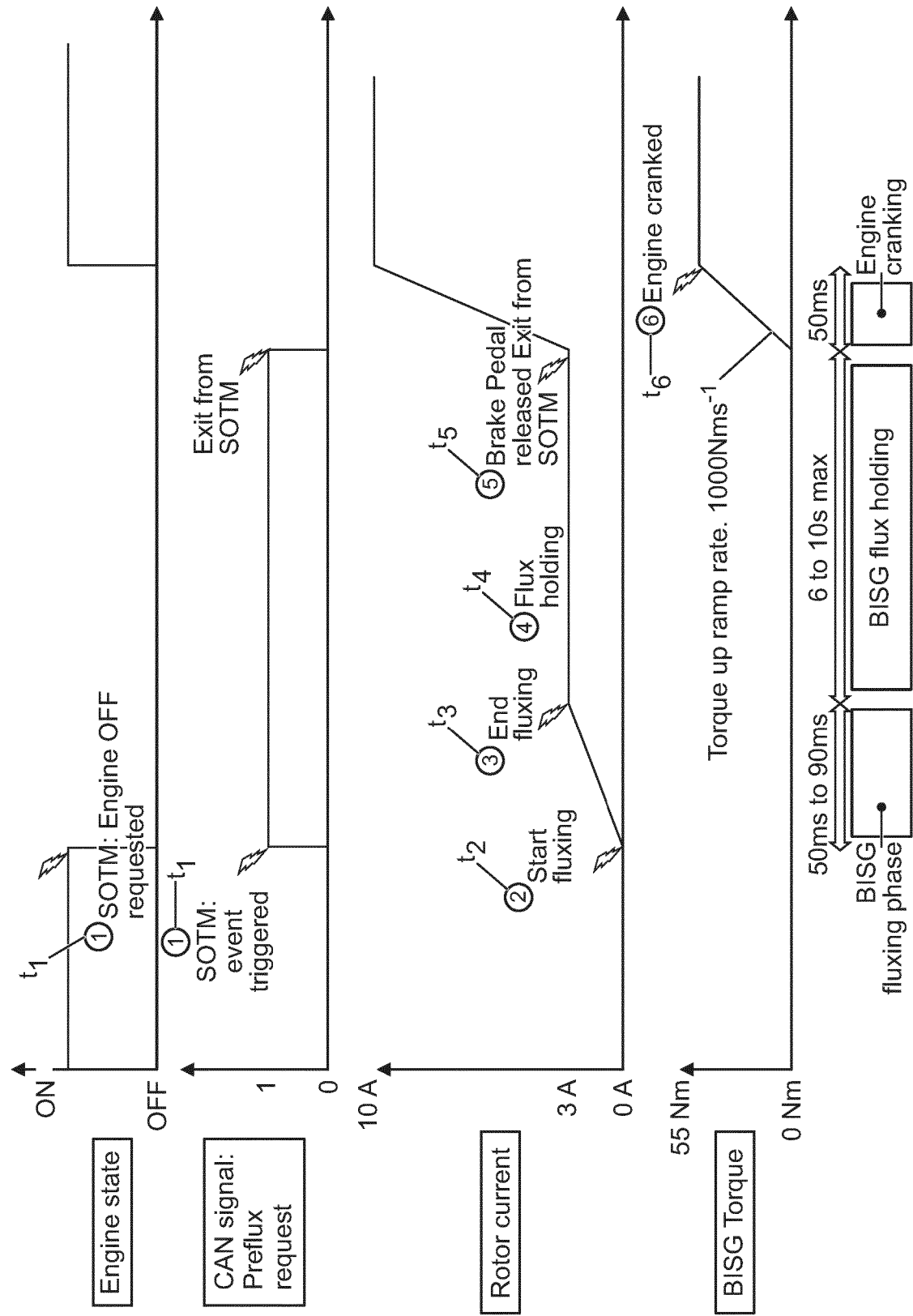


FIG. 5

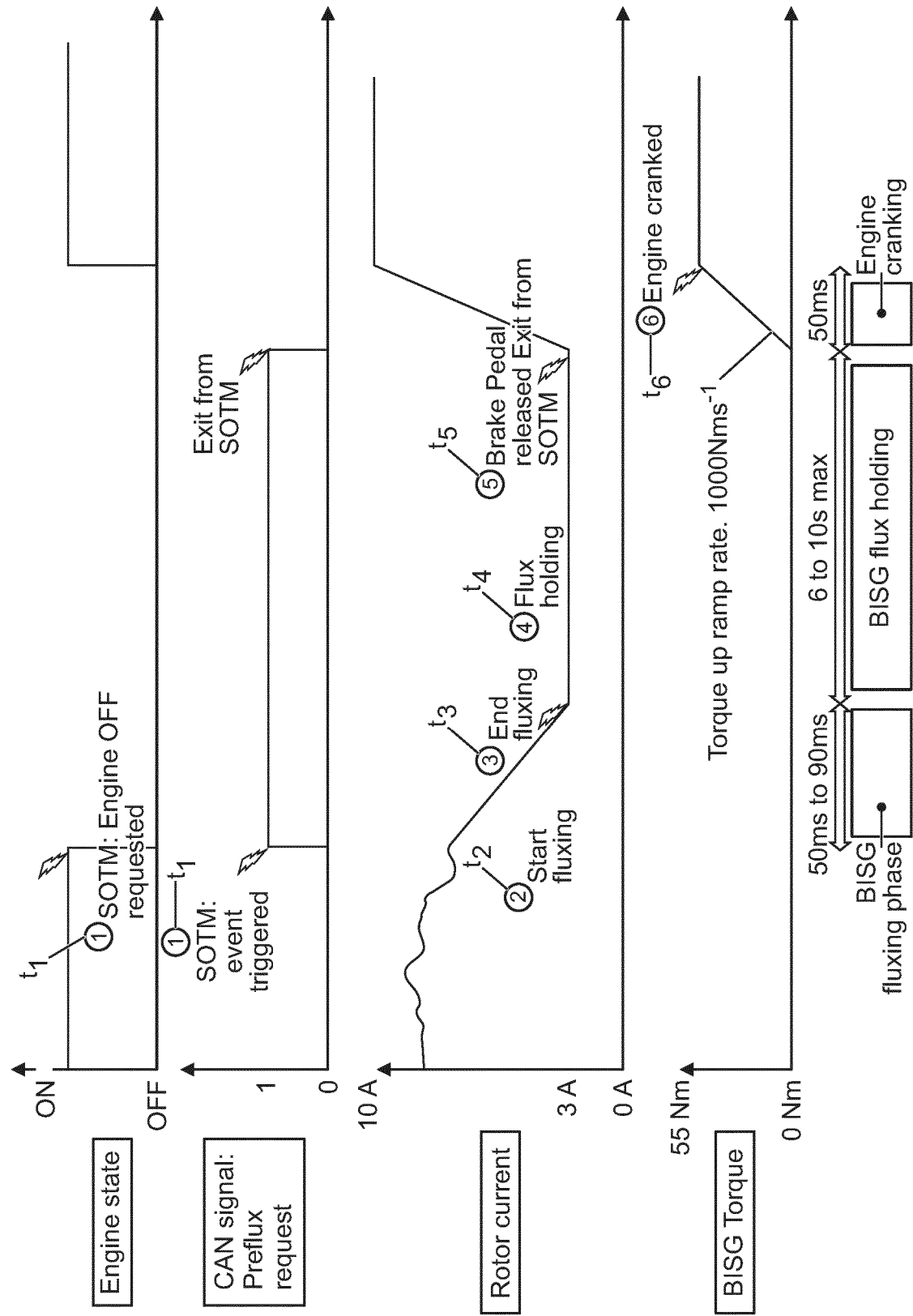


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/079182

A. CLASSIFICATION OF SUBJECT MATTER INV. F02N11/08 F02N19/00 B60W30/18 ADD. F02N11/04 B60W10/06		
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) F02N 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 2012/259535 A1 (JAROS ROLF [DE] ET AL) 11 October 2012 (2012-10-11) paragraph [0016]; figure 1 -----	1-26
Y	US 2009/206786 A1 (LECOLE BRICE [FR] ET AL) 20 August 2009 (2009-08-20) paragraph [0044]; figure 2 paragraph [0044] -----	1-26
Y	US 2012/179357 A1 (PHILLIPS ANTHONY MARK [US]) 12 July 2012 (2012-07-12) figure 6 -----	1-26
Y	US 2012/016573 A1 (ELLIS NATHANIEL [US]) 19 January 2012 (2012-01-19) figures 6,9 -----	1,3-13, 15-26
☐ 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 20 February 2018		Date of mailing of the international search report 05/03/2018
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 Ulivieri, Enrico

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2017/079182

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2012259535	A1	11-10-2012	CN 102575631 A 11-07-2012
			DE 102009045886 A1 28-04-2011
			EP 2491240 A1 29-08-2012
			US 2012259535 A1 11-10-2012
			WO 2011047916 A1 28-04-2011

US 2009206786	A1	20-08-2009	BR PI0514919 A 24-06-2008
			CN 101044315 A 26-09-2007
			EP 1800001 A1 27-06-2007
			FR 2875556 A1 24-03-2006
			JP 4746624 B2 10-08-2011
			JP 2008513667 A 01-05-2008
			US 2009206786 A1 20-08-2009
			WO 2006032796 A1 30-03-2006

US 2012179357	A1	12-07-2012	NONE

US 2012016573	A1	19-01-2012	NONE
