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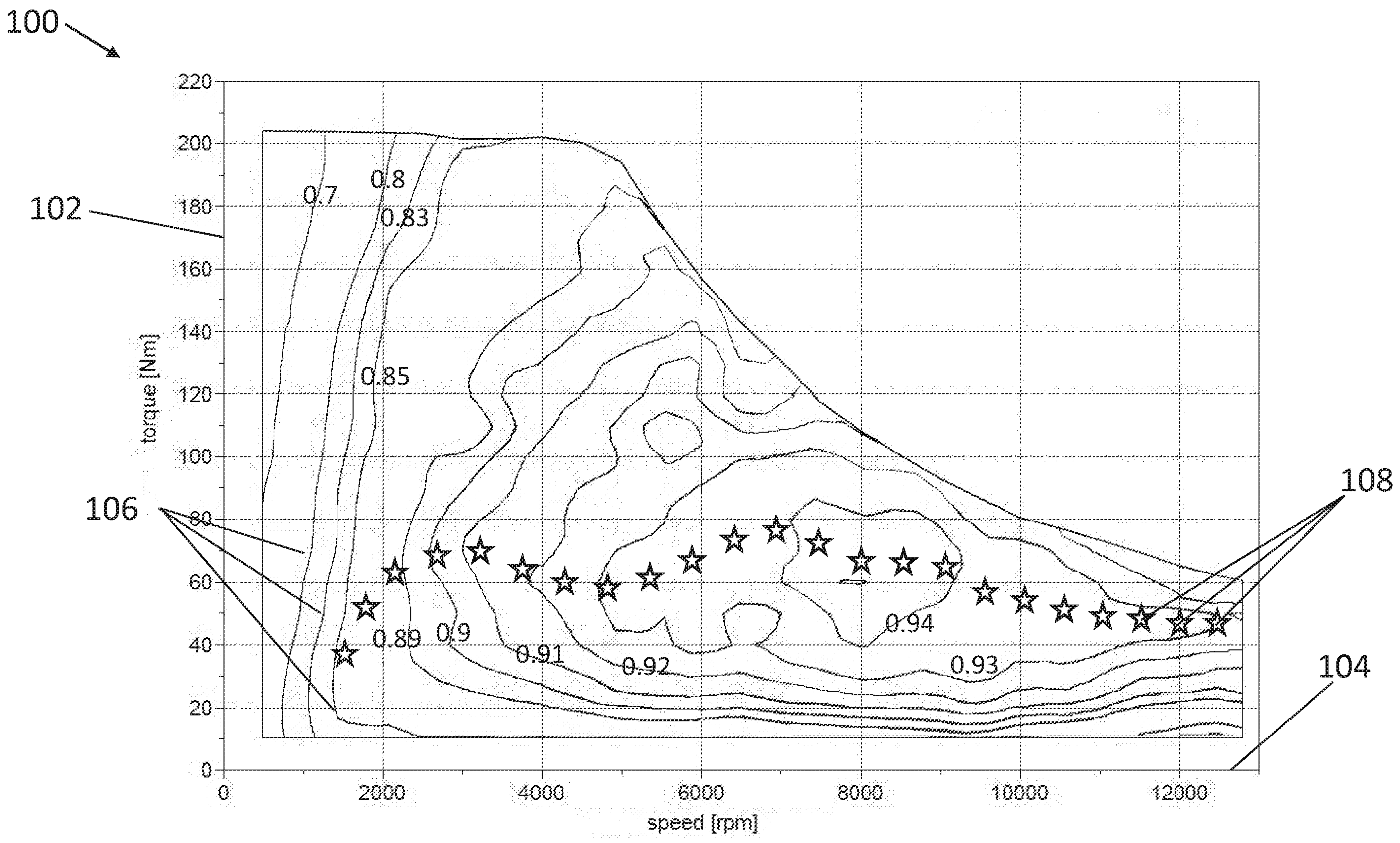
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102
104
106
108
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speed [rpm]
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200
220
0
2000
4000
6000
8000
10000
12000
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0.83
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0.89
0.9
0.91
0.92
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0.94

Figure 1

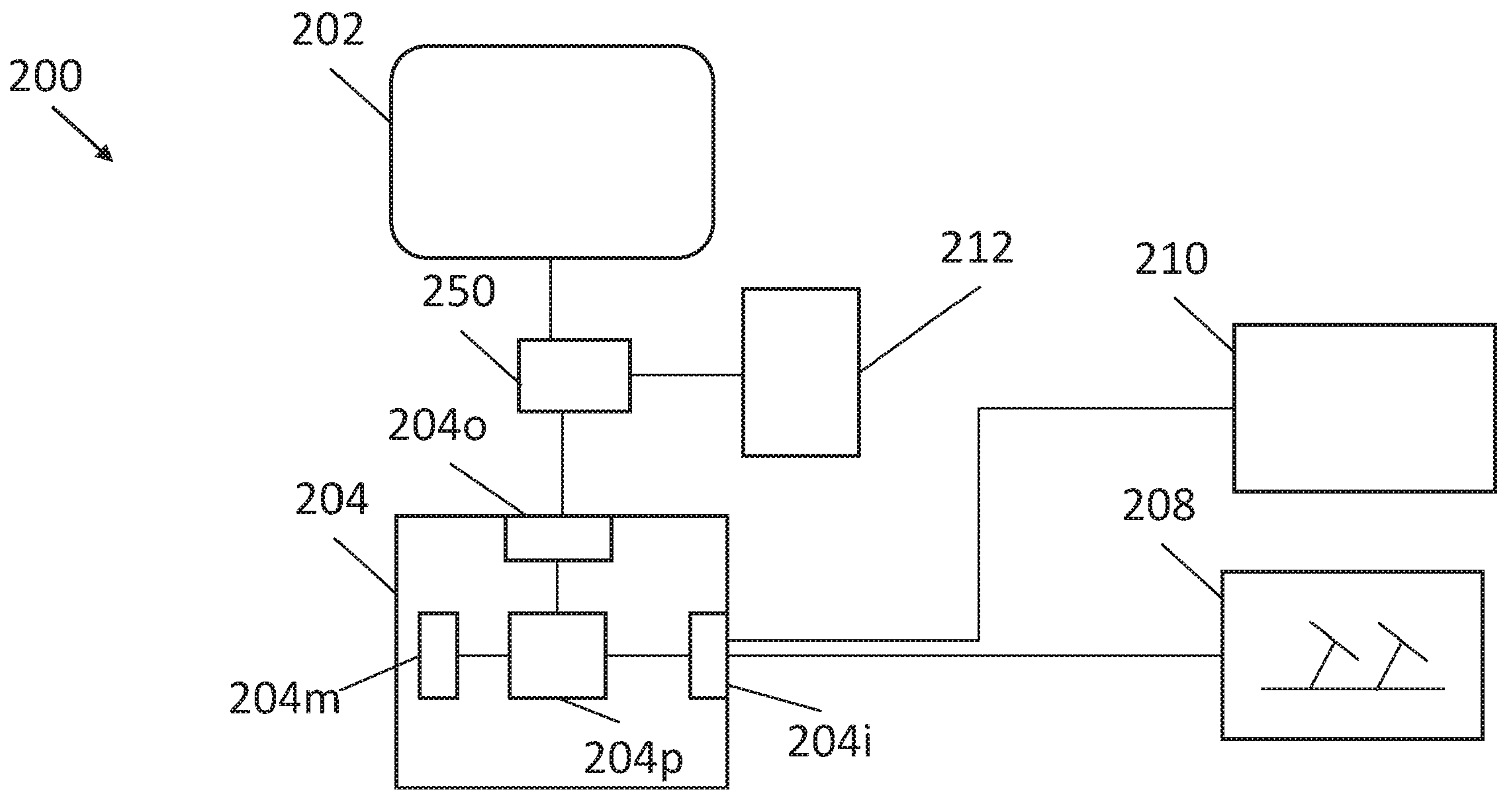

Figure 2

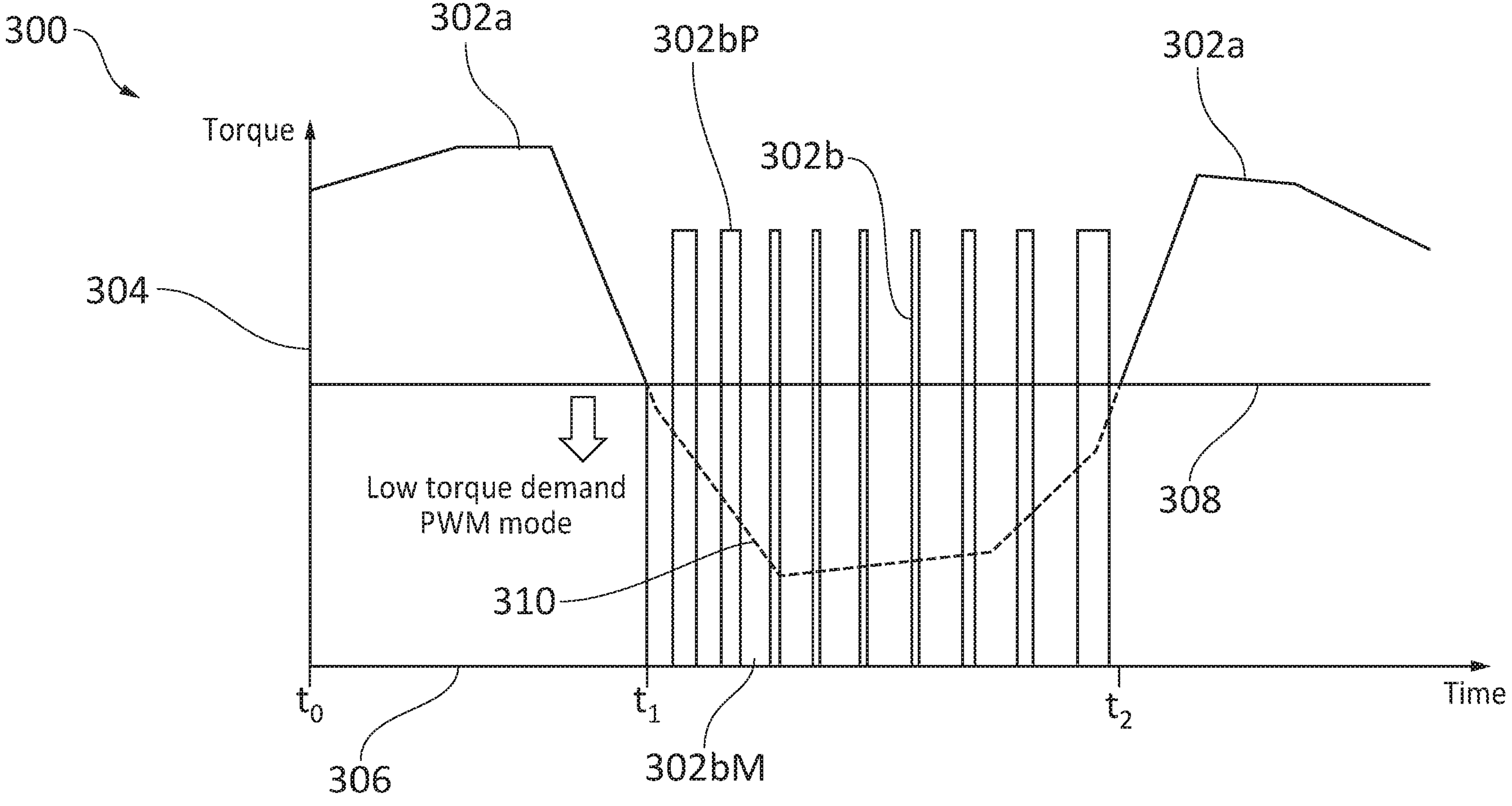
300
302a
302bP
302b
302a
Torque
304
Low torque demand
PWM mode
308
310
t0
t1
t2
Time
306
302bM

Figure 3

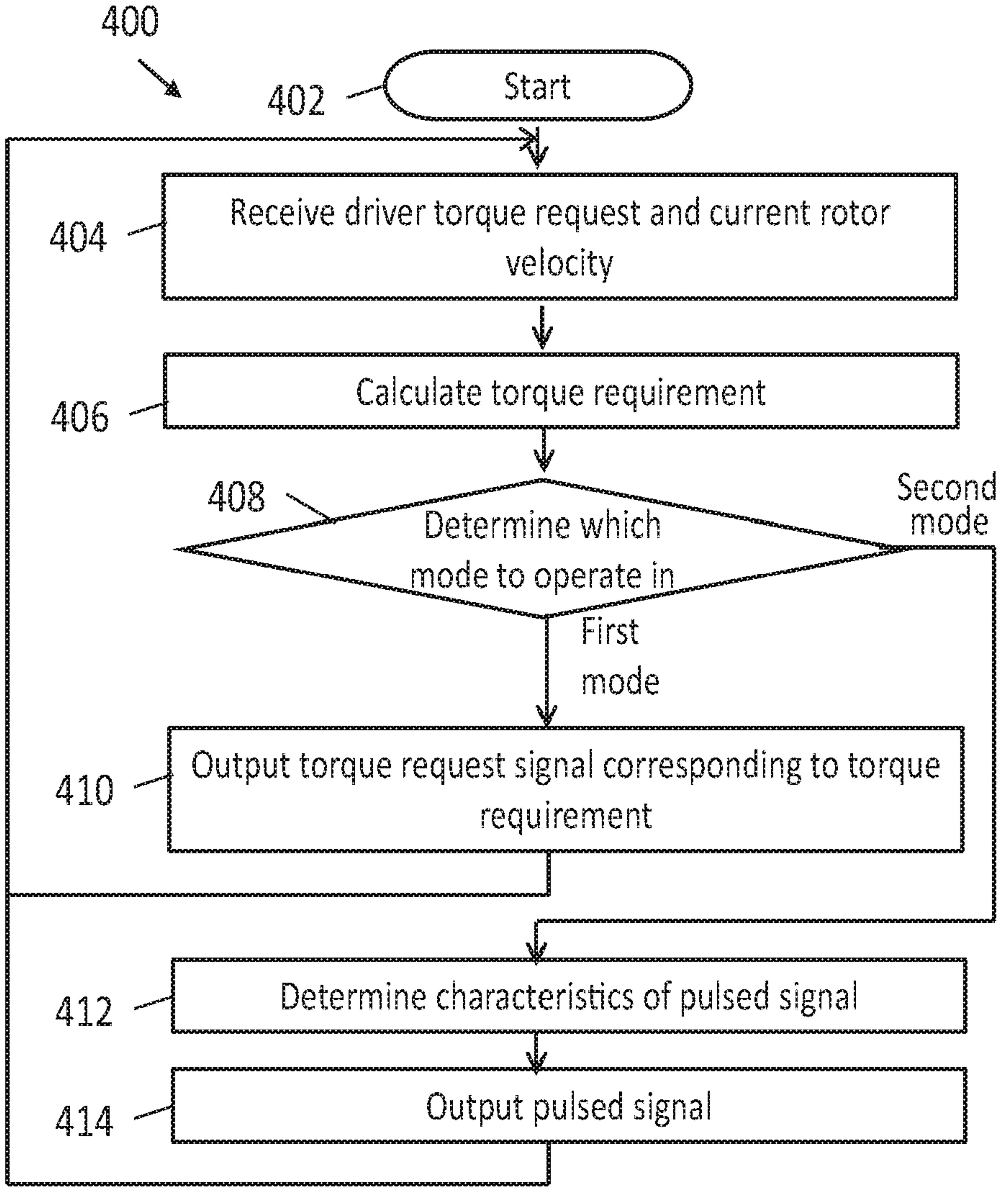

Figure 4

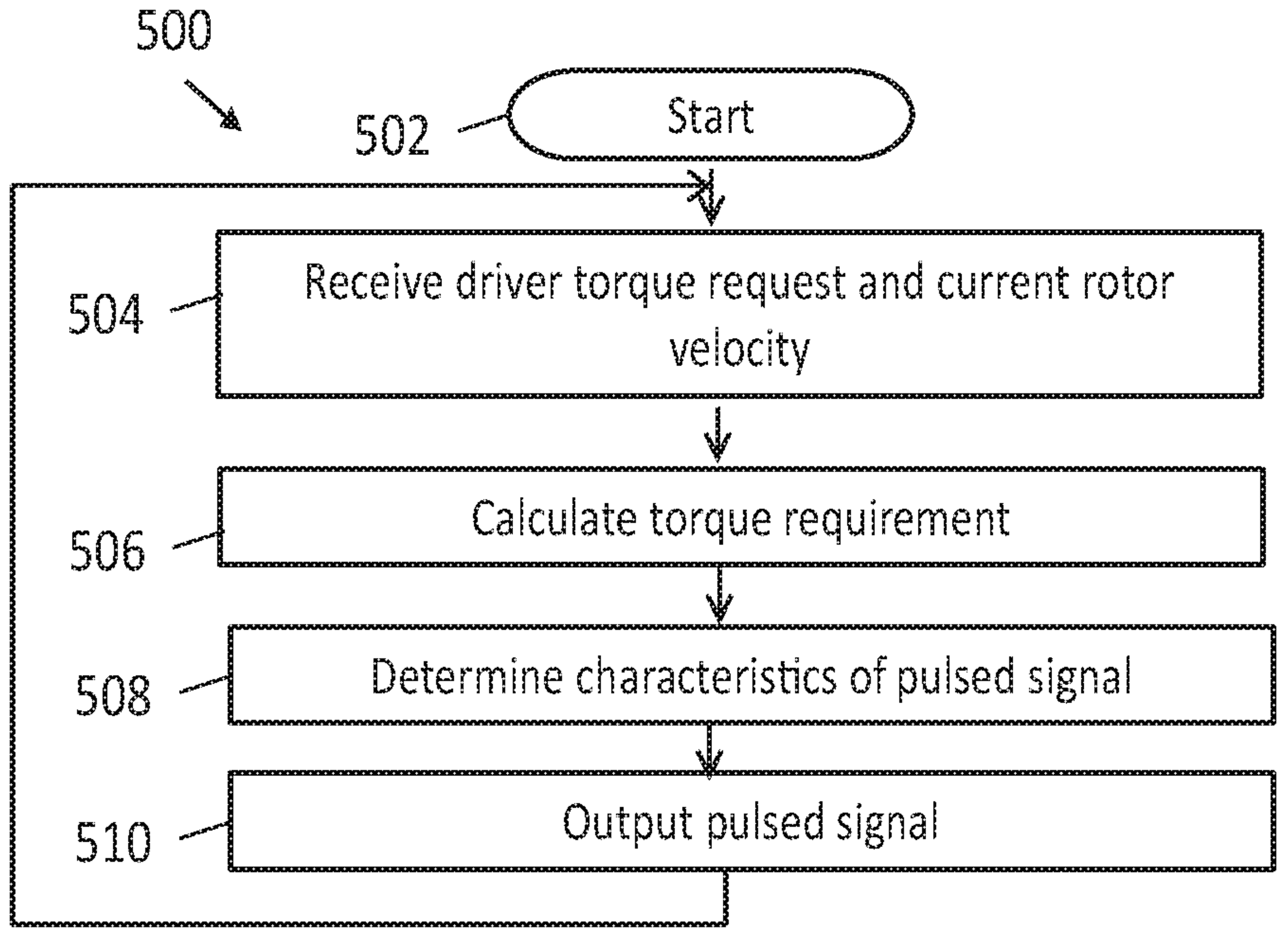

Figure 5

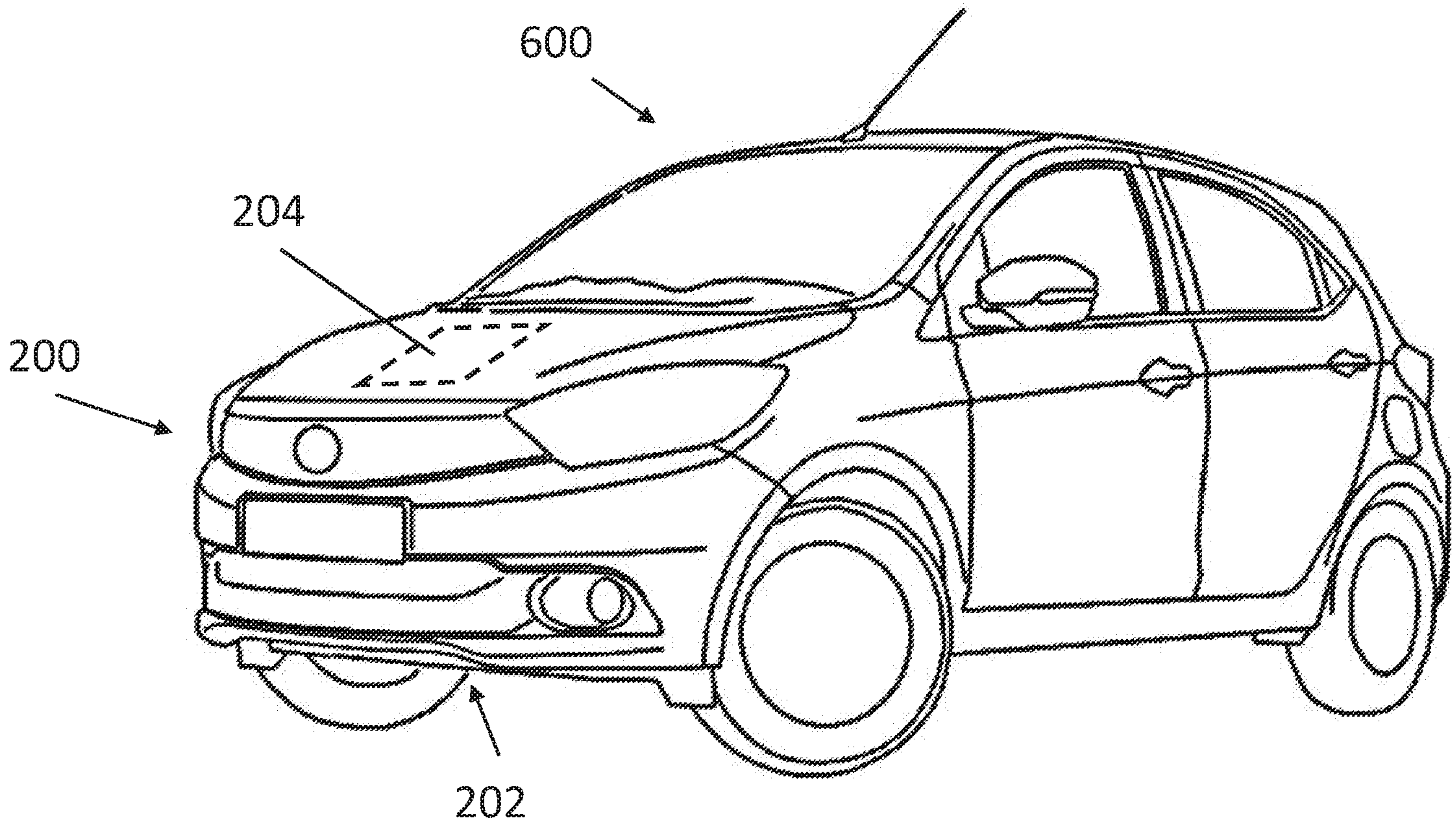

Figure 6

Control System and Method

TECHNICAL FIELD

The present invention relates to a control system and method, particularly, but not exclusively, the present invention relates to a control system and method for controlling a traction motor of a vehicle.

BACKGROUND

It is increasingly common for motor vehicles to be powered by one or more electric machines, either alone or in combination with a combustion engine. Although electric machines are capable of achieving significantly higher energy efficiency than combustion engines, it is known that the energy efficiency of an electric machine can be heavily dependent on the instantaneous power output and rotational velocity of the rotor. Accordingly, an electric machine sized to provide a relatively high power output to give acceptable peak acceleration performance for a vehicle may perform at sub-optimal efficiency when the power output required is much lower than the maximum power output that the machine is capable of providing. This may cause the range that an electric vehicle is capable of driving under real-world conditions to be much lower than the vehicle would theoretically be capable of achieving if it could operate at or near maximum efficiency.

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It is an object of at least certain embodiments of the invention to at least mitigate one or more of the problems of the prior art.

SUMMARY OF THE INVENTION

Aspects and embodiments of the invention provide a controller, a method, an electric machine, a computer program, and a vehicle as claimed in the appended claims.

According to an aspect of the invention for which protection is sought there is provided a controller for a traction motor of a vehicle according to claim 1.

Advantageously, such a controller is operable to improve efficiency of the traction motor by operating in the second mode when the operating conditions are such that the traction motor would operate at low efficiency if a continuous torque demand signal was provided.

The input indicative of a torque request may be indicative of a torque request from a driver, or it may be indicative of a torque request from an autonomous vehicle system, which may be equivalent to an input indicative of accelerator pedal position. It will be understood that in some applications, for example applications in autonomous vehicles, the torque requirement may be calculated by a physically separate controller. Accordingly, a controller within the scope of the present application may in fact comprise one or more separate controllers operable in combination.

In an embodiment the one or more inputs further comprise a second input indicative of a speed of the vehicle, and the determination of whether to operate in the first mode or the second mode is made in dependence on the first input and the second input. Advantageously, this may allow the controller to make a more accurate determination as to when it would be advantageous to operate in the second mode. This is because the efficiency of the electric machine may be a function of the vehicle speed (which is directly proportional to the speed of the rotor of the traction motor for an electric machine with a fixed gear ratio), as well as the torque output. Furthermore, this may allow the controller to prioritise operation in the second mode when the vehicle speed is high and so any increase in noise, vibration and harshness (NVH) that may be associate with operation in the second mode may be less noticeable to vehicle occupants.

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Optionally, the pulsed signal comprises a signal switching between a peak torque request corresponding to a torque greater than the torque requirement and a minimum torque request corresponding to a torque less than the torque requirement. Advantageously, this may allow the time-averaged value of the torque request signal to be substantially equal to the torque requirement. Further optionally, the peak torque request may be selected in dependence on said second input. This may allow the peak torque request to correspond to a torque value at which the traction motor operates with maximum efficiency at the current rotor velocity.

In an embodiment, the switching frequency of the pulsed signal is selected in dependence on the torque requirement. Optionally, the switching frequency is selected in dependence on the second input.

In an embodiment, the minimum torque request comprises a request for substantially zero torque.

In an embodiment, the processing means is configured to operate in the second mode if the torque requirement is less than a threshold value. Advantageously, this provides a simple way of determining whether or not to operate in the second mode.

Optionally, the threshold value is adjusted in dependence on the vehicle speed.

In an embodiment, the pulsed torque request signal has a switching frequency in the range of 1-100Hz. Optionally, the switching frequency may be in the range 10-50Hz. The switching frequency of the pulsed torque request signal may be lower than the frequency of the output provided by the inverter to drive the electric machine.

Optionally, the input indicative of a torque demand comprises an input indicative of an accelerator pedal position.

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In some embodiments, the frequency of the torque request signal may be higher when the second input indicates that the vehicle speed is low, and the frequency may decrease when the vehicle speed is high. That is to say, there may be an inverse relationship between the vehicle speed and the frequency of the pulsed signal. Such an inverse relationship may reduce a likelihood that the pulsed signal will cause discomfort to a vehicle occupant. This is because other sources of NVH may be more significant at higher speeds, so any additional NVH introduced by a low-frequency pulsed signal is unlikely to be noticeable. At low speed it may be desirable to use a high-frequency pulsed signal, as such a signal is less likely to introduce additional NVH, although the efficiency gain that can be made by using a pulsed signal may be somewhat lower than could be made using a low-frequency pulsed signal.

In an embodiment, the frequency is in the range of 1-100Hz. Optionally, the frequency may be in the range of 10-50Hz. Use of such frequencies may allow an efficiency gain to be obtained, without a driver of the vehicle noticing a disturbance in the torque provided by the traction motor.

In an embodiment, the pulsed signal comprises a signal switching between a peak torque request corresponding to a torque greater than the torque requirement and a minimum torque request corresponding to a torque less than the torque requirement. Optionally, the minimum torque request comprises a request for substantially zero torque.

According to another aspect of the invention for which protection is sought there is provided an electric machine in combination with a controller as described above.

According to another aspect of the invention for which protection is sought there is provided a method of controlling a vehicle according to claim 12.

Optionally, the one or more inputs further comprise a second input indicative of a speed of the vehicle, and wherein the determination of which of the first and second modes to operate is made in dependence on the first input and the second input.

In an embodiment, the pulsed signal comprises a signal switching between a peak torque request corresponding to a torque greater than the torque requirement and a minimum torque request corresponding to a torque less than the torque requirement. Optionally, the peak torque request is selected in dependence on said second input. Further optionally, the peak torque request is selected in dependence on the first input. The switching frequency of the pulsed signal may be selected in dependence on the torque requirement and/or the first input. Optionally, the switching frequency may be selected in dependence on the second input.

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Optionally, the method comprises operating in the second mode if the torque requirement is less than a threshold value.

In an embodiment, the threshold value is adjusted in dependence on the vehicle speed.

In an embodiment the switching frequency is in the range of 1-100Hz, optionally 10-50Hz.

In an embodiment, the first input comprises an input indicative of an accelerator pedal position.

The processing means may comprise an electronic processor.

According to another aspect of the invention there is provided a computer program comprising instructions which, when the program is executed by a computer, cause the computer to carry out one or more of the methods described hereinbefore.

The computer program may be stored on a computer-readable storage medium, optionally on a non-transitory computer-readable storage medium.

According to a further aspect of the invention, there is provided a vehicle comprising a controller, an electric machine in combination a controller, or a computer readable storage medium as described hereinbefore.

The input means may be an input portion of the controller, for example an electrical input or an input board and the output means may be an output portion of the controller, for example an electrical output or an output board. In some embodiments a combined input and output means may be provided, for example in the form of an electrical input/output (I/O) interface or an I/O board. The control means may be a controller having a processor and an electronic memory.

It will be understood that the term "traction motor" refers to an electric machine that is arranged to drive the wheels of a vehicle so as to provide traction to move the vehicle. Such a traction motor may form part of a driveline in a fully electric vehicle powered solely by one or more traction motors, or it may form part of a hybrid vehicle that is powered by a combination of a combustion engine and one or more electric machines.

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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 figures, in which:

Figure 1 shows a representative contour plot of efficiency against torque output and rotational velocity for a vehicle traction motor;

Figure 2 shows a schematic diagram of a control system in an embodiment of the present invention;

Figure 3 shows a graph illustrating torque output against time for an electric machine controlled by a control system in an embodiment of the present invention;

Figure 4 shows a flow chart illustrating operation of a control system according to an embodiment of the present invention;

Figure 5 shows a flow chart illustrating operation of a control system according to another embodiment of the present invention; and

Figure 6 shows a vehicle in an embodiment of the present invention.

DETAILED DESCRIPTION

Figure 1 illustrates a representative contour plot 100 having a plurality of contour lines 106 illustrating lines of constant energy efficiency for different combinations of electric machine torque output (shown on axis 102) and rotor rotational velocity (shown on axis 104). Each of the contour lines 106 is labelled with the proportional energy efficiency for that line. As shown in figure 1, motor efficiency is typically relatively low for low rotor velocities. At higher rotor velocities higher efficiencies, potentially up to 0.95 (i.e. 95%) can be achieved. However, it should be noted that at higher rotational velocities the motor efficiency is a strong function of the output torque. As can be seen from figure 1, electric machines may operate at relatively low efficiency if either the rotational velocity of the rotor or the torque output from the electric machine is low. Although figure 1 shows an efficiency map for a particular known electric machine, the skilled person will understand that a generally similar map would be observed for other electric machines.

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The present inventors have recognised that, when operated as traction motors in vehicles, electric machines may spend a considerable proportion of their operational life working at sub-optimal efficiency. This is because the electric machine in a fully electric vehicle or a series hybrid is typically connected to the road wheels with a fixed gear ratio. Accordingly, the rotational velocity and torque are likely to be determined by the road speed and the torque request, respectively. Furthermore, as an electric machine in an electric vehicle must be capable of providing sufficient power output to give acceptable peak acceleration, it may be the case that only a relatively small proportion of the torque that the machine could theoretically produce is output during normal driving conditions. This can lead to the machine operating in regions of low efficiency as illustrated in figure 1.

Figure 2 illustrates a control system 200 for an electric machine 202, which may operate as a traction motor in an electric vehicle 600 as illustrated in figure 6. Control system 200 comprises a controller 204 having an input means 204i arranged to receive a first input indicative of a driver torque demand from an input means such as an accelerator pedal 208 and a second input indicative of a speed of the vehicle from an input means such as a vehicle speed sensor 210. In some embodiments the input indicative of vehicle speed may be indicative of the electrical machine rotor velocity, which is directly proportional to the vehicle speed for an electric vehicle having the rotor of the electric machine connected to the road wheels by a fixed gear ratio.

The input means 204i is arranged to communicate signals indicative of the driver torque request and the speed of the vehicle to a processing means 204p, which is coupled to an electronic memory 204m. The processing means is configured, in dependence on the received signals indicative of the driver torque request and the speed of the vehicle, to calculate a required amount of torque to be supplied by the electric machine 202. When the required amount of torque has been calculated the processing means 204p is arranged to send a signal to output means 204o instructing the output means to output a torque request signal corresponding to the required amount of torque. The output signal from the output means 2040 is received by a power controller 250, which is an inverter in the illustrated embodiment.

The inverter 250 is arranged to receive DC power from a traction battery 212 and to supply an alternating current of the required number of phases to the electric machine 202. Although the DC battery is arranged to supply power at a constant voltage (400V in the illustrated embodiment, although the skilled person will understand that other voltages may be used in different embodiments) the power controller 250 or another controller is arranged to modify the voltage supplied by the power controller 250 to the coils of the electric machine 202. This may be performed by high-frequency pulse-width modulation (PWM) of the DC current supplied by the battery. The switching frequency of such PWM may be in the region of 20kHz, and in any event will be significantly greater than the frequency of the AC power output from the inverter. Use of PWM allows the effective voltage supplied to be reduced without wasting electrical energy, which could otherwise occur for example by introducing a variable resistance between the battery and the power controller and/or the electric machine. Furthermore, because the PWM is performed at high frequency, the inductance of the coils of the electric machine 202 causes the high-frequency switching of the current supplied by the inverter to be smoothed out to a substantial degree. Accordingly, pulsations as a result of the PWM switching to reduce the voltage supplied from the traction battery 212 do not cause significant or noticeable pulsation of the torque output by the electric machine 202.

The processing means 204p is arranged to operate in two different modes. In a first one of the two modes the processing means 204p is arranged to output a substantially constant torque request signal corresponding to the torque requirement. That is to say that, if the combination of inputs received via the input means 204i is constant with respect to time, then the processing means is arranged to output a torque request signal that is also constant with respect to time. Accordingly, the operation of the controller 204 when the processing means is in the first mode is similar to the operation of a conventional controller for determining a torque request signal.

In the second one of said modes the controller is arranged to output a pulsed torque request signal. When operating in the second mode the controller is arranged to switch between a peak torque request corresponding to a torque greater than the torque requirement and a minimum torque request corresponding to a torque of lower than the torque requirement. Typically, the minimum torque request corresponds to a request for zero torque. The pulse frequency and the ratio of time spent at the peak torque request relative to that spent at the minimum torque request are determined by the processing means 204p in dependence on the inputs received via input means 204i, as will be described in more detail below.

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Although figure 2 illustrates an embodiment in which the vehicle is controlled by a human driver, it will be understood that the invention is equally applicable to autonomous vehicles. Accordingly, the driver torque request may be replaced by a torque request from an autonomous vehicle system.

Figure 3 illustrates a graph 300 showing a representative torque request signal 302 output by the output means 2040 of the controller 204i in a particular driving scenario. As can be seen in figure 3, between t_0 and t_1 the torque request signal varies in a substantially continuous manner. The variations in the torque request signal between t_0 and t_1, illustrated by line 302a, are a result of changing inputs to the controller 204, which change the torque requirement calculated by the processing means 204p. At time t_1 the driver torque request falls below the threshold value illustrated by line 308. This causes the processing means to transition from the first mode to the second mode, in which the processing means operates until time point t2.

When operating in the second mode (i.e. between t1 and t2 as illustrated in figure 3) the torque request signal 302b pulses between a peak torque request 302bP and a minimum torque request 302bM. Operation in the second mode is advantageous when the torque requirement is low, because the efficiency of the electric machine 202 is reduced when the torque requirement is low. Accordingly, switching of the torque requirement when operating in the second mode allows the controller 204 to operate the electric machine 202 intermittently in a high torque, high efficiency condition as opposed to operating the electric machine 202 constantly in a low torque, relatively low efficiency condition. As can be seen in figure 3, the duration of the pulses at which the electric machine is operated at the peak torque 302bP vary in dependence on the torque requirement 310 (it will be noted that when the controller 204 is operating in the first mode the torque request given by the output means 204o is substantially equivalent to the torque request signal 302a, so a separate torque requirement is not visible when the controller 204 is operating in the first mode (i.e. between t_0 and t_1 and after t_2). The duration of the pulses may be selected so as to provide a torque that is substantially equal to the calculated torque requirement 310 when averaged over a suitable time period. Accordingly, the vehicle dynamic performance when operating in the second mode may not be significantly affected by the pulsations in the torque provided by the electric machine 202.

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When operating the second mode, the processing means 204p substantially continuously evaluates the vehicle operating conditions to determine whether or not it is appropriate to transition back into the first mode. As shown in figure 3, at time point t_2 the torque requirement increases above the threshold torque value 308, causing the processing means to transition back into the first mode. Accordingly, after t_2 the torque request signal 302a corresponds to a substantially continuous request for an amount of torque corresponding to the calculated torque requirement.

Although figure 3 illustrates an embodiment in which the processing means 204p is configured to operate in the first mode when the calculated torque requirement is above the threshold value 308 and to operate in the second mode when the torque requirement is below the threshold value 308, it will be understood that other conditions may be appropriate in other embodiments. Indeed, in some embodiments the processing means 204p may determine a required operating mode by referring to a map relating various input conditions to a required mode for the processing means 204p to operate in. Such a map may be stored on the electronic memory 204m.

Advantageously, the map may return an instruction to operate in the second mode when the input conditions are such that the efficiency of the motor when operating in the first mode is likely to be significantly worse than the efficiency when operating in the second mode. As will be understood by the skilled person, for an electric machine that is connected to the road wheels by a fixed gear ratio, the velocity of the rotor is directly proportional to the vehicle road speed. Accordingly, the maximum efficiency of an electric machine of a vehicle travelling at a given road speed may be considered to be the efficiency when the electric machine is producing an amount of torque that results in the highest efficiency operation for the required rotor velocity. Referring to figure 1, stars 108 illustrate torque outputs that result in operation of the electric machine at maximum efficiency for different rotor velocities. The map may return an instruction to operate in the second mode if the efficiency when operating at the torque output that provides maximum efficiency is higher than the efficiency when producing the calculated torque requirement by more than a threshold amount, and the torque requirement is less than the torque at which maximum efficiency may be obtained. Under these circumstances a gain in efficiency may be made by operating in the second mode rather than the first mode. This may be achieved by outputting a pulsed torque signal that alternates between a high torque request corresponding to the amount of torque at which the maximum efficiency is achieved and a minimum torque request corresponding to approximately zero torque. The lengths of the high and minimum torque requests may be selected to ensure that the torque output averaged over a suitable time period substantially corresponds to the torque requirement.

In some embodiments the map may only provide an instruction to operate in the second mode when one or more further criteria are met. For example, when a vehicle is travelling at relatively high speed there may be an increased amount of road and wind noise and vibration in the cabin, as compared to a vehicle travelling at low speed. Accordingly, the map may only output an instruction to operate in the second mode when the vehicle speed is above a threshold value, so that any increase in noise, vibration and harshness (NVH) introduced by operation in the second mode is not perceptible by the vehicle occupants. In some embodiments a plurality of different maps may be provided for use in different operational modes of the vehicle. For example, a map for use in an "Eco" mode may begin to instruct operation in the second mode at a lower speed and/or when the efficiency gains by operating in the second mode are smaller than a map for use in a "Comfort" mode. In this way, when the vehicle is operating in the "Eco" mode it may operate in the second mode for a greater proportion of a given drivecycle than it would if operating in the "Comfort" mode. Conversely, when operating in the "Comfort" mode any increase in NVH that may accompany operation in the second mode may be reduced.

When the processing means 204p is operating in the second mode it is operable to determine the value of peak torque request and the durations of the peak and minimum torque requests. It will be understood that the combined durations of the peak torque request 302bP and the minimum torque request 302bM is equivalent to the period of one cycle of the pulsed torque request signal. The frequency of the pulsed torque request signal is equal to the reciprocal of the period of the pulsed signal.

As discussed above, the value of the peak torque request may be substantially equal to the torque value that produces maximum efficiency of the electric machine 202 at the current rotor velocity. The duration of the peak torque request 302bP relative to that of the minimum torque request (i.e. the proportion of time spend requesting the peak torque) may therefore be selected to ensure that the time-averaged torque request is substantially equal to the current torque requirement. Although the frequency of the pulsed signal can be selected somewhat arbitrarily, it will be understood that it may be desirable to avoid the pulsed torque signal introducing vibrations that are at a resonant frequency of any of the components of the driveline. Accordingly, the optimal frequency of the pulsed signal may be determined empirically be assessing the NVH performance of the vehicle when pulsed torque request signals of different frequency are used. It will be understood that the optimum frequency may depend on various factors including, but not limited to, the current vehicle speed, the magnitude of the peak torque requests and the driving mode in which the vehicle is currently operating. Accordingly, the processing means 204p may be arranged to access a map or look-up table stored in the electronic memory 204m that is arranged to output the frequency at which the pulsed signal should be output for a given set of input conditions. The present inventors have recognised that frequencies in the range of 10-50Hz provide a good improvement in efficiency without introducing significant additional NVH.

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In some embodiments, the frequency of the torque request signal may be higher when the second input indicates that the vehicle speed is low, and the frequency may decrease when the vehicle speed is high. That is to say, there may be an inverse relationship between the vehicle speed and the frequency of the pulsed signal. Such an inverse relationship may reduce a likelihood that the pulsed signal will cause discomfort to a vehicle occupant. This is because other sources of NVH may be more significant at higher speeds, so any additional NVH introduced by a low-frequency pulsed signal is unlikely to be noticeable. At low speed it may be desirable to use a high-frequency pulsed signal, as such a signal is less likely to introduce additional NVH, although the efficiency gain that can be made by using a pulsed signal may be somewhat lower than could be made using a low-frequency pulsed signal.

Operation of the control system 200 will now be described with reference to the flow chart 400 shown in figure 4. As shown in figure 4, the method 400 starts at step 402 (which may occur when the vehicle is switched on), and proceeds immediately to step 404. At step 404 the processing means 204p receives inputs indicative of the driver torque request and the vehicle speed from the input means 204i, which receives a signal indicative of the driver torque request from the driver input means 208 and a signal indicative of the vehicle speed and/or rotor velocity from the vehicle speed sensor 210.

The method then progresses to step 406, in which the processing means 204p calculates a torque requirement based on the driver torque request and the velocity of the rotor. The torque requirement may be calculated in the conventional way, for example by reference to a map or look-up table relating the torque requirement to the driver torque request and the rotor velocity. It will be understood that in some embodiments the calculation of the torque requirement may also take account of various other inputs, such as a current driving mode, the rate of change of the driver torque request or the temperature of the electric machine.

Once the torque requirement has been calculated by the processing means 204p, the method proceeds to step 408, in which it is determined which of the first and second modes to operate in. As described above, the determination as to which of the first and second modes to operate in is made at least in dependence on the driver torque request. In the present embodiment, the processing means 204p is arranged to refer to a map or look-up table stored in the electronic memory 204m that relates the rotor velocity and the torque requirement (which requirement is calculated based on the driver torque request and other inputs) to an instruction as to which of the first and second modes to operate in. Although the precise features of the map may be determined empirically to optimise vehicle efficiency and performance (including NVH performance), it will be understood that an instruction to operate in the second mode may be provided when the operating conditions are such that the electric machine 202 could operate at higher efficiency if the torque output was increased.

If a determination to operate in the first mode is made in step 408 then the method proceeds to step 410, in which the processing means 204p instructs the output means 204o to output a substantially continuous torque request signal corresponding to the torque requirement to the power controller 250. The method then returns to step 404, thereby allowing the torque requirement and determination of which mode to operate in to be updated based on any changes to the inputs to the controller 204.

In the event that a determination to operate in the second mode is made in step 408, the method proceeds to step 412, in which the characteristics of the pulsed torque signal are calculated. Specifically, the processing means 204p calculates the magnitudes and the durations of the peak torque requests 302bP and the minimum torque requests 302bM respectively. Optionally, the magnitude of the minimum torque requests may be set to zero, in which case the processing means 204p calculates the magnitude of the peak torque requests 302bP and the durations of the peak torque requests 302bP and the minimum torque requests 302bM. The magnitude of the peak torque requests may correspond to a torque at which the efficiency of the electric machine 202 is maximised for the current rotor velocity. The relative durations of the peak and minimum torque request signals may be selected to ensure that, when averaged over the period of the pulsed signal, the torque output from the electric machine 202 substantially corresponds to the torque requirement calculated in step 406. The absolute lengths of the peak and minimum torque requests may be selected so that the frequency of the pulsed signal does not correspond to a resonant frequency of any of the other components of the driveline.

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Optimisation of the frequency of the pulsed signal may be performed empirically for a given vehicle, and a map or look-up table containing instructions as to what frequency of pulsed signal to use under different operating conditions may be stored in the electronic memory 204m and referred to by the processing means 204p to determine the frequency of the pulsed signal. The frequency of the pulsed signal may be in the range of 20-50Hz, although it will be understood that other frequencies may also be appropriate in other embodiments.

Once the characteristics of the pulsed torque signal have been calculated, the method proceeds to step 414, in which the processing means 204p instructs the output means 204o to output a pulsed signal having the determined characteristics.

The method then returns to step 404, in which updated inputs are received by the processing means. In step 414 the processing means 204p may instruct the output means 204o to output the pulsed signal for a single period (i.e. the duration of one peak torque request and one minimum torque request). In this way, an updated torque request signal based on updated inputs to the controller 204 may be outputted when the period of the pulsed signal ends. This may be another pulsed signal if a determination that the processing means 204p should operate in the second mode is made when the method next reaches step 408, or it could be a substantially continuous signal if the processing means determines that operation in the second mode is no longer appropriate when the method next reaches step 408.

Although an embodiment in which the processing means 204p is operable in both the first mode and the second mode has been described above, it will be understood that in some embodiments the processing means 204p may operate continuously in the second mode. Figure 5 shows a method of operating a vehicle in such an embodiment.

Method 500 commences with step 502 (which may occur when the vehicle is switched on), and proceeds immediately to step 504. At step 504 the processing means 204p receives inputs indicative of the driver torque request and the vehicle speed from the input means 204i, which receives a signal indicative of the driver torque request from the driver input means 208 and a signal indicative of the vehicle speed and/or rotor velocity from the vehicle speed sensor 210.

The method then progresses to step 506, in which the processing means 204p calculates a torque requirement based on the driver torque request and the velocity of the rotor. The torque requirement may be calculated in the conventional way, for example by reference to a map or look-up table relating the torque requirement to the driver torque request and the rotor velocity. It will be understood that in some embodiments the calculation of the torque requirement may also take account of various other inputs, such as a current driving mode or the rate of change of the driver torque request.

Next, the method proceeds to step 508, in which the characteristics of the pulsed torque signal are calculated. Specifically, the processing means 204p calculates the magnitudes and the durations of the peak torque requests 302bP and the minimum torque requests 302bM respectively. Optionally, the magnitude of the minimum torque requests may be set to zero, in which case the processing means 204p calculates the magnitude of the peak torque requests 302bP and the durations of the peak torque requests 302bP and the minimum torque requests 302bM. The magnitude of the peak torque requests may correspond to a torque at which the efficiency of the electric machine 202 is maximised for the current rotor velocity. The relative durations of the peak and minimum torque request signals may be selected to ensure that, when averaged over the period of the pulsed signal, the torque output from the electric machine 202 substantially corresponds to the torque requirement calculated in step 506. The absolute lengths of the peak and minimum torque requests may be selected so that the frequency of the pulsed signal does not correspond to a resonant frequency of any of the other components of the driveline.

Optimisation of the frequency of the pulsed signal may be performed empirically for a given vehicle, and a map or look-up table containing instructions as to what frequency of pulsed signal to use under different operating conditions may be stored in the electronic memory 204m and referred to by the processing means 204p to determine the frequency of the pulsed signal. The frequency of the pulsed signal may be in the range of 20-50Hz, although it will be understood that other frequencies may also be appropriate in other embodiments.

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Once the characteristics of the pulsed torque signal have been calculated, the method proceeds to step 510, in which the processing means 204p instructs the output means 2040 to output a pulsed signal having the determined characteristics. The method then returns to step 504, in which updated inputs are received by the processing means. In step 510 the processing means 204p may instruct the output means 2040 to output the pulsed signal for a single period (i.e. the duration of one peak torque request and one minimum torque request). In this way, an updated torque request signal based on updated inputs to the controller 204 may be outputted when the period of the pulsed signal ends.

Figure 6 illustrates a vehicle 600 of one embodiment of the present invention comprising the control system 200 of the embodiment of Figure 2, specifically showing the controller 204 configured to operate the electric machine 202 as a traction motor in the electric vehicle 600.

It will be appreciated that embodiments of the present invention can be realised in the form of hardware, software or a combination of hardware and software. Any such software may be stored in the form of volatile or non-volatile storage such as, for example, a storage device like a ROM, whether erasable or rewritable or not, or in the form of memory such as, for example, RAM, memory chips, device or integrated circuits or on an optically or magnetically readable medium such as, for example, a CD, DVD, magnetic disk or magnetic tape. It will be appreciated that the storage devices and storage media are embodiments of machine-readable storage that are suitable for storing a program or programs that, when executed, implement embodiments of the present invention. Accordingly, embodiments provide a program comprising code for implementing a system or method as claimed in any preceding claim and a machine-readable storage storing such a program. Still further, embodiments of the present invention may be conveyed electronically via any medium such as a communication signal carried over a wired or wireless connection and embodiments suitably encompass the same.

The claims should not be construed to cover merely the foregoing embodiments, but also any embodiments which fall within the scope of the claims.

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CLAIMS

1. A controller for a traction motor of a vehicle, the controller comprising:

input means arranged to receive one or more inputs including a first input indicative of a torque demand;

output means configured to output a torque request signal for a power controller of the traction motor; and

processing means communicably coupled to the input means and the output means,

wherein the processing means is configured to determine a torque requirement in dependence on the one or more inputs and to control the output means to output the torque request signal in dependence on the determined torque requirement,

the processing means being configured to operate in a first mode in which the output means is controlled to output a substantially constant torque request signal corresponding to the torque requirement and a second mode in which the output means is controlled to output a pulsed torque request signal,

the processing means being configured to determine whether to operate in the first mode or the second mode in dependence on the first input.

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2. A controller as claimed in claim 1, wherein the one or more inputs further comprise a second input indicative of a speed of the vehicle, and wherein the determination of whether to operate in the first mode or the second mode is made in dependence on the first input and the second input.

3. A controller as claimed in claim 1 or claim 2, wherein the pulsed signal comprises a signal switching between a peak torque request corresponding to a torque greater than the torque requirement and a minimum torque request corresponding to a torque less than the torque requirement; optionally, when dependent on claim 2, wherein the peak torque request is selected in dependence on said second input.

4. A controller as claimed in claim 3 when dependent on claim 2, wherein the peak torque request is selected in dependence on said second input.

5. A controller as claimed in claim 3 or 4, wherein the switching frequency of the pulsed signal is selected in dependence on the torque requirement.

6. A controller as claimed in any one of claims 3-5 where directly or indirectly dependent on claim 2, wherein the switching frequency is selected in dependence on the second input.

7. A controller as claimed in claim 3, or any one of claims 4-6 where dependent on claim 3, wherein the minimum torque request comprises a request for substantially zero torque.

8. A controller as claimed in any preceding claim, wherein the processing means is configured to operate in the second mode if the torque requirement is less than a threshold value.

9. A controller as claimed in claim 8, wherein the processing means is configured to adjust the threshold value in dependence on the vehicle speed.

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10. A controller as claimed in any preceding claim, wherein the pulsed torque request signal has a switching frequency in the range of 10-50Hz.

11. A controller as claimed in any preceding claim, wherein the input indicative of a torque demand comprises an input indicative of an accelerator pedal position.

12. A method of controlling a vehicle comprising:

receiving one or more inputs including a first input indicative of a torque demand;

determining a torque requirement in dependence on the one or more inputs;

determining whether to operate in a first mode or a second mode in dependence on the first input; and

outputting a torque request signal to a power controller of the traction motor in dependence on the determined torque requirement,

wherein when operating in the first mode outputting a torque request signal comprises outputting a substantially constant torque request signal corresponding to the torque requirement and when operating in the second mode outputting a torque request signal comprises outputting a pulsed torque request signal.

13. A method as claimed in claim 12, wherein the one or more inputs further comprise a second input indicative of a speed of the vehicle, and wherein the determination of

which of the first and second modes to operate in is made in dependence on the first input and the second input.

14. A method as claimed in claim 12 or claim 13, wherein the pulsed torque request signal comprises a signal switching between a peak torque request corresponding to a torque greater than the torque requirement and a minimum torque request corresponding to a torque less than the torque requirement.

15. A method as claimed in claim 14 when dependent on claim 13, wherein the peak torque request is selected in dependence on said second input.

16. A method as claimed in claim 14 or 15, wherein the switching frequency of the pulsed torque request signal is selected in dependence on the torque requirement.

17. A method as claimed in any one of claims 12-16, wherein the method comprises operating in the second mode if the torque requirement is less than a threshold value.

18. A method as claimed in claim 17, wherein the threshold value is adjusted in dependence on the vehicle speed.

19. A method as claimed in any one of claims 12-18, wherein the switching frequency is in the range of 10-50Hz.

20. A method as claimed in any one of claims 12-19, wherein the first input comprises an input indicative of an accelerator pedal position.

21. A computer program comprising instructions which, when the program is executed by a computer, cause the computer to carry out the method of any of claims 12-20.

22. A computer-readable storage medium having stored thereon the computer program of claim 21.

23. An electric machine in combination with the controller of any of claims 1-11.

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24. A vehicle comprising a controller as claimed in any one of claims 1-11 or a computer-readable storage medium as claimed in claim 22 or an electric machine in combination with the controller as claimed in claim 23.

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