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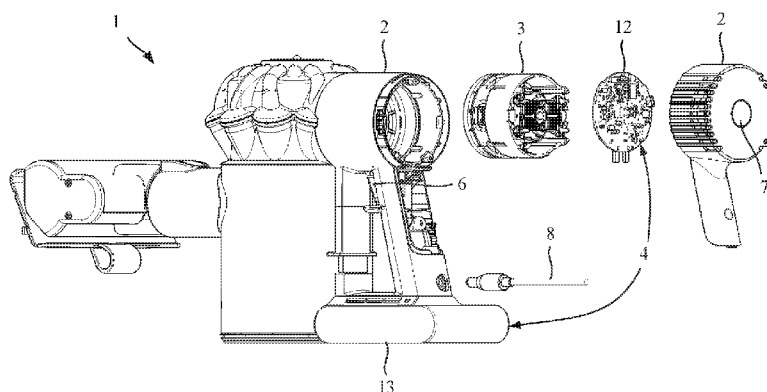


Fig. 1

(57) Abstract: A vacuum cleaner comprising a vacuum motor and a power supply. The power supply comprises input terminals for connection to an AC source, output terminals connected to the vacuum motor, an AC-to-DC stage, and a battery. The AC-to-DC stage converts alternating current drawn from the AC source into direct current that is supplied to the battery and the vacuum motor. The power supply operates in a first mode when disconnected from the AC source and a second mode when connected to the AC source. When the power supply operates in the second mode, the vacuum motor operates in either a low-power state or a high-power state. When the vacuum motor operates in the low-power state, the vacuum motor and the battery each draw power from the AC source such that the battery charges. When the vacuum motor operates in the high-power state, the vacuum motor draws power from both the AC source and the battery such that battery discharges.



Vacuum Cleaner having a Dual Power Supply

The present invention relates to a vacuum cleaner having a power supply that supplies a vacuum motor with power drawn from a battery or an AC source, such as a mains power supply.

WO2008/146988 describes a vacuum cleaner having a dual power supply and a vacuum motor that can be driven using AC or DC power. The power supply comprises a power cord, a battery, a charging device, and a control unit. When the power cord is connected to the mains power supply, the control unit transmits a driving signal to the vacuum motor such that the motor is driven with AC power supplied by the mains power supply. Additionally, the charging device uses the AC power to simultaneously charge the battery. When the power cord is subsequently disconnected from the mains power supply, the control unit transmits a driving signal to the vacuum motor such that the motor is driven with DC power supplied by the battery.

The present invention provides a vacuum cleaner comprising a vacuum motor and a power supply, wherein: the power supply comprises input terminals for connection to an AC source, output terminals connected to the vacuum motor, an AC-to-DC stage, and a battery; the AC-to-DC stage converts alternating current drawn from the AC source into direct current that is supplied to the battery and the vacuum motor; the power supply operates in a first mode when disconnected from the AC source and a second mode when connected to the AC source; when the power supply operates in the first mode, the vacuum motor draws power from the battery only; and when the power supply operates in the second mode: the vacuum motor operates in one of a low-power state and a high-power state; the vacuum motor and the battery each draw power from the AC source when the vacuum motor operates in the low-power state such that the battery charges; and the vacuum motor draws power from both the AC source and the battery when the vacuum motor operates in the high-power state such that battery discharges.

The AC-to-DC stage may be used to generate a DC voltage that is used to both recharge the battery and power the vacuum motor. It is not therefore necessary to provide a vacuum motor that is capable of being driven by both DC power and AC power.

5 When connected to the AC source, the power supply operates differently depending on the operating state of the vacuum motor. When the vacuum motor is in the low-power state, the power drawn from the AC source by the AC-to-DC stage is shared between the vacuum motor and the battery. As a result, the battery charges during operation of the vacuum motor. When the vacuum motor is in the high-power state, the power
10 drawn from the AC source by the AC-to-DC stage is supplied entirely to the vacuum motor. The battery additionally supplies power to the vacuum motor so as to boost the power drawn from the AC source. As a result, the battery discharges during operation of the vacuum motor. The vacuum motor therefore draws power simultaneously from the AC source and the battery when in the high-power state. The advantage of this
15 arrangement is that the AC-to-DC stage may employ electrical components having a lower power rating. As a result, a cheaper, smaller and lighter power supply may be realised. In spite of the lower power rating, the power supply is nevertheless able to supply the vacuum motor with higher power by using the battery to boost the power drawn from the AC source.

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The power drawn by the vacuum motor when the power supply operates in the second mode may be no less than the power drawn by the vacuum motor when the power supply operates in the first mode. Accordingly, the performance of the vacuum motor when the power supply is connected to the AC source is no worse than that when the
25 power supply is disconnected from the AC source. More particularly, when operating in the low-power state, the power drawn by the vacuum motor when the power supply operates in the first mode may be the same as that when the power supply operates in the second mode. A user would therefore discern no noticeable difference in performance when the power supply is connected and disconnected from the AC source,

and yet the battery would be charged when the power supply is connected to the AC source.

The power drawn by the vacuum motor may be M when the power supply operates in the first mode, the power drawn by the vacuum motor may be N when the power supply operates in the second mode and the vacuum motor operates in the low-power state, and the power drawn by the vacuum motor may be P when the power supply operates in the second mode and the vacuum motor operates in the high-power state. P is then greater than both M and N . As a result, the power drawn by the vacuum motor when operating in the high-power state is greater than that when operating in the low-power state and greater than that when the power supply is disconnected from the AC source. Since the vacuum motor draws power from the battery when operating in high-power state, the battery discharges. High-power state may therefore be employed where increased suction is required momentarily, e.g. in order to remove particularly stubborn dirt. Additionally, N may be greater than or equal to M . As a result, the performance of the vacuum motor when charging the battery is no worse than that when the power supply is disconnected from the AC source.

The power drawn from the battery when the power supply operates in the first mode may be at least 200 W. Accordingly, when the power supply is disconnected from the AC source, the power supplied to the vacuum motor is relatively high and thus relatively good suction may be achieved.

The AC-to-DC stage and the battery may be connected in parallel between the input terminals and the output terminals. This then has the advantage that the battery may act as a storage device for the AC-to-DC stage when the power supply operates in the second mode. As a result, the AC-to-DC stage may have little or no storage capacitance, thereby reducing the size and cost of the AC-to-DC stage and thus the power supply. As a consequence of the low storage capacitance, the current output by the AC-to-DC stage may have a relatively high ripple. In particular, the AC-to-DC

stage may output a current having a ripple of at least 50%. There are then first periods during which the current drawn by the vacuum motor is greater than that output by the AC-to-DC stage, and there are second periods during which the current drawn by the vacuum motor is less than that output by the AC-to-DC stage. During each first period, the vacuum motor draws the deficit current from the battery, which in turn causes the battery to discharge. During each second period, the surplus current not drawn by the vacuum motor is instead drawn by the battery, thereby causing the battery to charge. As a result, the battery acts as a storage device for the AC-to-DC stage. Consequently, in spite of the ripple in the current output by the AC-to-DC stage, the power supply is able to meet continuously the power demands of the vacuum motor.

The term 'ripple' is expressed herein as a peak-to-peak percentage of the maximum value, i.e. $\text{ripple} = (I_{\text{max}} - I_{\text{min}})/I_{\text{max}} * 100\%$, where I_{max} and I_{min} are respectively the maximum and minimum values of the current over each cycle.

The AC-to-DC stage may adjust the power drawn from the AC source in response to changes in the voltage of the battery. For example, the AC-to-DC stage may monitor the voltage of the battery and then use this information to avoid over-voltage and/or under-voltage. Additionally or alternatively, the AC-to-DC stage may use this information to control the charge rate of the battery. For example, as the battery voltage increases, the AC-to-DC stage may increase the power drawn from the AC source such that the battery is charged with a constant current. Once the battery is fully charged, the AC-to-DC stage may adjust the power drawn from the AC source in order to hold the battery at a voltage close to full charge. For example, when the voltage of the battery is below a threshold corresponding to full charge, the AC-to-DC stage may set the power drawn from the AC source to a level greater than that drawn by the vacuum motor. As a result, the battery experiences net charging. When the voltage of the battery subsequently rises above the threshold, the AC-to-DC stage may set the power drawn from the AC source to a level less than that drawn by the vacuum motor. As a result, the battery experiences net discharging. Discharging of the battery then continues until

the voltage of the battery drops below a further threshold, at which point the AC-to-DC stage sets the power drawn from the AC source to its previous value such that the battery again experiences net charging.

- 5 The AC-to-DC stage may comprise an AC-to-DC converter for rectifying the current drawn from the AC source, a PFC circuit for regulating the rectified current drawn from the AC source, and a step-down DC-to-DC converter for lowering the voltage of the rectified current. The voltage-conversion ratio of the DC-to-DC converter may then be defined such that the peak voltage of the rectified current, when stepped down, is lower
10 than the battery voltage. This then has the advantage that the PFC circuit is able to operate in boost mode to provide continuous current control.

In order that the present invention may be more readily understood, an embodiment of the invention will now be described, by way of example, with reference to the
15 accompanying drawings, in which:

Figure 1 is a partially exploded view of a vacuum cleaner in accordance with the present invention;

20 Figure 2 is a block diagram of the vacuum cleaner;

Figure 3 is a block diagram of a power supply forming part of the vacuum cleaner;

Figure 4 is a circuit diagram of the vacuum cleaner;
25

Figure 5 illustrates the current output by an AC-to-DC stage of the power supply, and the current demand of a vacuum motor of the vacuum cleaner; and

Figure 6 illustrates the same waveforms as that of Figure 5, wherein the total charge drawn from (region A) and by (region B) a battery of the power supply is shown.
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The vacuum cleaner 1 of Figures 1 and 2 comprises a main body 2, a vacuum motor 3, a power supply 4, a system controller 5, an on-off switch 6, a power-mode switch 7, and a power cord 8.

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The vacuum motor 3 is housed within the main body 2 and has three operating states: standby, low power, and high power. When in the standby state, the vacuum motor 3 does not generate any suction and instead draws only that power required by the internal controller of the vacuum motor 3. When in the low-power and high-power states, the vacuum motor 3 generates suction and draws respectively 200 W and 400 W from the power supply 4. Greater suction is therefore generated by the vacuum motor 3 when operating in the high-power state.

The power supply 4 is likewise housed within the main body 2 and comprises input terminals 10, output terminals 11, an AC-to-DC stage 12, and a battery 13. The input terminals 10 are connectable to an AC source 14, such as a mains power supply, via the power cord 8. The output terminals 11 are connected to the vacuum motor 3. The AC-to-DC stage 12 and the battery 13, which are housed respectively in an upper part and a lower part of the main body 2, are connected in parallel between the input terminals 10 and the output terminals 11.

The power supply 4 operates in one of two modes depending on whether or not the power supply 4 is connected to the AC source 14. When disconnected from the AC source 14, the power supply 4 operates in a first mode or battery mode. When connected to the AC source 14, the power supply 4 operates in a second mode or mains mode. The term ‘mains mode’ is used here since the AC source 14 is typically a mains power supply.

The system controller 5 monitors the output voltage of the power supply 4 and the states of the on-off switch 6 and the power-mode switch 7. The system controller 5 then uses

this information to control the operating state of the vacuum motor 3. More specifically, the system controller 5 monitors the input signals: V_BAT, S_PWR and S_HILO. V_BAT provides a measure of the voltage of the battery 13 and thus the output voltage of the power supply 4. S_PWR and S_HILO are digital signals that are pulled logically high when the on-off switch 6 and the power-mode switch 7 respectively have been actuated. In response to these three signals, the system controller 5 outputs the signal OP_STATE to the vacuum motor 3. OP_STATE has three possible values corresponding to STBY, LO and HI. In response, the vacuum motor 3 operates respectively in the standby, low-power and high-power state. Different values for OP_STATE may be achieved in a number of ways. For example, the voltage of OP_STATE may be 0 V (STBY), 2.5 V (LO) or 5 V (HI). Alternatively, OP_STATE may be a PWM signal having a duty cycle of 0% (STBY), 50% (LO) or 100% (HI).

The on-off switch 6 is a trigger switch that is located on a handle of the main body 2. The switch 6 is operated by a user to power on and off the vacuum cleaner 1. The switch 6 outputs the signal S_PWR to the system controller 5. When the on-off switch 6 is actuated, S_PWR is pulled high.

The power-mode switch 7 is a momentary push-button switch that is located at the rear of the main body 2. The switch 7 is operated by the user to switch the vacuum motor 3 between the low-power state and the high-power state. The power-mode switch 7 outputs the signal S_HILO to the system controller 5. When the power-mode switch 7 is actuated, the signal S_HILO is pulled high momentarily.

The power cord 8 is used to connect the power supply 4 to the AC source 14. The power cord 8 is detachable from the power supply 4 so that the power cord 8 can be discarded when operating in battery mode.

Referring now to Figures 3 and 4, the AC-to-DC stage 12 comprises an electromagnetic interference (EMI) filter 20, an AC-to-DC converter 21, a power factor correction (PFC) circuit 22, and a DC-to-DC converter 23.

- 5 The EMI filter 20 is used to attenuate high-frequency harmonics in the input current drawn from the AC source 14.

The AC-to-DC converter 21 comprises a bridge rectifier D1-D4 providing full-wave rectification.

10

- The PFC circuit 22 comprises a boost converter located between the AC-to-DC converter 21 and the DC-to-DC converter 23. The boost converter comprises an inductor L1, a capacitor C1, a diode D5, a switch S1 and a control circuit. The inductor, capacitor, diode and switch are arranged in a conventional arrangement. Consequently, 15 the inductor L1 is energised when the switch S1 is closed, and energy from the inductor L1 is transferred to the capacitor C1 when the switch S1 is opened. Opening and closing of the switch S1 is then controlled by the control circuit.

- The control circuit comprises a current sensor R1, a voltage sensor R2,R3, and a PFC 20 controller 25. The current sensor R1 outputs the signal I_IN, which provides a measure of the input current drawn from the AC source 14. The voltage sensor R2,R3 outputs the signal V_IN, which provides a measure of the input voltage of the AC source 14. The current sensor R1 and the voltage sensor R2,R3 are located on the DC side of the AC-to-DC converter 21. Consequently, I_IN and V_IN are rectified forms of the input 25 current and the input voltage. Both signals are output to the PFC controller 25. The PFC controller 25 scales V_IN in order to generate a current reference. The PFC controller 25 then uses the current reference to regulate the input current I_IN. There are various control schemes that the PFC controller 25 might employ in order to regulate the input current. For example, the PFC controller 25 might employ peak, 30 average or hysteresis current control. Such control schemes are well known and it is not

therefore the intention here to describe a particular scheme in any detail. The PFC controller 25 also receives the signal V_{BAT} , which provides a measure of the voltage of the battery 13 and is output by a further voltage sensor R4,R5. As described below, the PFC controller 25 regulates the input current in response to changes in the battery voltage. This is achieved by adjusting the amplitude of the current reference (i.e. by scaling V_{IN}) in response to changes in V_{BAT} .

The DC-to-DC converter 23 comprises a half-bridge LLC series resonant converter that comprises a pair of primary-side switches S2,S3, a primary-side controller (not shown) for controlling the primary-side switches, a resonant network Cr,Lr, a transformer Tx, a pair of secondary-side switches S4,S5, a secondary-side controller (not shown) for controlling the secondary-side switches, and a low-pass filter C2,L2. The primary-side controller switches the primary-side switches S2,S3 at a fixed frequency defined by the resonance of Cr and Lr. Similarly, the secondary-side controller switches the secondary-side switches S4,S5 at the same fixed frequency so as to achieve synchronous rectification. The low-pass filter C2,L2 then removes the high-frequency current ripple that arises from the switching frequency of the converter 23.

The impedance of the DC-to-DC converter 23 is relatively low. As a consequence, the voltage at the output of the PFC circuit 22 is held at a level defined by the voltage of the battery 13. More specifically, the voltage at the output of the PFC circuit 22 is held at the battery voltage multiplied by the turns ratio of the DC-to-DC converter 23. In order to simplify the following discussion, the term 'stepped battery voltage' will be used when referring to the battery voltage, V_{BAT} , multiplied by the turns ratio, N_p/N_s .

On opening the switch S1 of the PFC circuit 22, energy from the inductor L1 is transferred to the capacitor C1, causing the capacitor voltage to rise. As soon as the capacitor voltage reaches the stepped battery voltage, energy from the inductor L1 is transferred to the battery 13. Owing to the relatively low impedance of the DC-to-DC converter 23, the voltage of the capacitor C1 does not rise any further but is instead held

at the stepped battery voltage. On closing the switch S1 of the PFC circuit 22, the capacitor C1 discharges only when there is a difference between the capacitor voltage and the stepped battery voltage. As a result, the capacitor C1 continues to be held at the stepped battery voltage after the switch S1 has been closed. The voltage of the battery 13 is therefore reflected back to the PFC circuit 22.

In order that the PFC circuit 22 is able to control continuously the input current drawn from the AC source 14, it is necessary to maintain the capacitor voltage at a level greater than the peak value of the input voltage of the AC source 14. Since the capacitor C1 is held at the stepped battery voltage, it is necessary to maintain the stepped battery voltage at a level greater than the peak value of the input voltage. Moreover, this condition must be met over the full voltage range of the battery 13. Consequently, the turns ratio of the DC-to-DC converter 23 may be defined as:

$$N_p/N_s > V_{IN(peak)} / V_{BAT(min)}.$$

where N_p/N_s is the turns ratio, $V_{IN(peak)}$ is the peak value of the input voltage of the AC source 14, and $V_{BAT(min)}$ is the minimum voltage of the battery 13.

The PFC circuit 22 ensures that the input current drawn from the AC source 14 is substantially sinusoidal. Since the input voltage of the AC source 14 is sinusoidal, the input power drawn from the AC source 14 by the AC-to-DC stage 12 has a sine-squared waveform. Since the AC-to-DC stage 12 has very little storage capacity, the output power of the AC-to-DC stage 12 has substantially the same shape as the input power, i.e. the output power also has a sine-squared waveform. The output voltage of the AC-to-DC stage 12 is held at the battery voltage. Consequently, the AC-to-DC stage 12 acts as a current source that outputs an output current having a sine-squared waveform. The waveform of the output current is therefore periodic with a frequency twice that of the input current and a ripple of 100%.

Owing to the ripple in the output current of the AC-to-DC stage 12, there are periods during which the current demanded by the vacuum motor 13 is greater than the output current, and there are periods during which the current demanded by the vacuum motor 3 is less than the output current. Hereafter these periods will be referred to as discharge periods and charge periods.

Figure 5 illustrates the current demand of the vacuum motor 3 and the output current of the AC-to-DC stage 12 over a couple of cycles. In order to simplify the illustration, the output current is shown as a smooth waveform. However, it will be appreciated that the output current will have some high-frequency ripple at the switching frequencies of the PFC circuit 22 and the DC-to-DC converter 23. As can be seen in Figure 5, there are discharge periods during which the current demand of the vacuum motor 3 is greater than the output current of the AC-to-DC stage 12. The deficit in current is then made up by the battery 13. The vacuum motor 3 therefore draws current from both the AC-to-DC stage 12 and the battery 13 during each discharge period. Needless to say, since current is drawn from the battery 13, the battery 5 discharges during each discharge period. It can also be seen that there are charge periods during which the current demand of the vacuum motor 3 is less than the output current of the AC-to-DC stage 12. The surplus current is then used to charge the battery 13. The vacuum motor 3 and the battery 13 therefore draw current from the AC-to-DC stage 12 during each charge period. As a result, the battery 13 acts as a smoothing capacitor for the AC-to-DC stage 12 when the power supply 4 operates in mains mode.

Figure 6 illustrates the same waveforms as that of Figure 5. The area of the region labelled A is representative of the total charge drawn from the battery 13 during each discharge period. The area of the region labelled B is representative of the total charge drawn by the battery 13 during each charge period. When the area of region A is greater than that of region B, there is net discharging of the battery 13. Conversely, when the area of region A is less than that of region B, there is net charging of the

battery 13. There is then neither net charging nor net discharging of the battery 13 when the areas of the two regions are the same.

As is apparent from Figure 6, the areas of regions A and B depend on the magnitude of the current demand of the vacuum motor 3 and the amplitude of the output current of the AC-to-DC stage 12. The amplitude of the output current is defined by the amplitude of the input current drawn from the AC source 14, which in turn is defined by the current reference employed by the PFC circuit 22. Accordingly, by adjusting the current reference, the amplitude of the current output by the AC-to-DC stage 12, and thus the areas of regions A and B, may be adjusted.

Operation of the vacuum cleaner 1 will now be described.

BATTERY MODE

When the power supply 4 is disconnected from the AC source 14, the power supply 4 operates in battery mode. Power to the vacuum motor 3 and the system controller 5 is then supplied solely by the battery 13. The controller of the vacuum motor 3 and the system controller 5 are continuously powered on.

Standby State

When the on-off switch 6 is open, S_PWR is logically low. In response, the system controller 5 sets OP_STATE to STBY and thus the vacuum motor 3 operates in the standby state.

Low-Power State

When the on-off switch 6 is closed, S_PWR is pulled logically high. In response, the system controller 5 compares the voltage of battery 13, as provided by V_BAT, against a fully-discharged threshold. If the voltage of the battery 13 is less than the threshold, the battery 13 is regarded as fully discharged. The system controller 5 therefore continues to set OP_STATE to STBY such that the vacuum motor 3 remains in the

standby state. Conceivably, the system controller 5 may additionally provide the user with an indication that the battery 13 is fully discharged. For example, the vacuum cleaner 1 may include an LED which the system controller 5 turns on momentarily. If the voltage of the battery 13 is greater than the fully-discharged threshold, the system controller 5 sets OP_STATE to LO. The vacuum motor 3 then operates in the low-power state and draws 200 W from the power supply 4. As the vacuum motor 3 draws power from the power supply 4, the battery 13 naturally discharges. When the system controller 5 determines that the voltage of the battery 13 has dropped below the fully-discharged threshold, the system controller 5 sets OP_STATE to STBY, thereby causing the vacuum motor 3 to switch to the standby state.

Although the vacuum motor 3 has a low-power state and a high-power state, the high-power state is disabled when the power supply 4 operates in battery mode. To this end, the system controller 5 ignores the S_HILO signal when the power supply 4 operates in battery mode.

MAINS MODE

When the power supply 4 is connected to the AC source 14, the power supply 4 operates in mains mode. The controller of the vacuum motor 3 and the system controller 5 are again continuously powered on.

Standby State

When the on-off switch 6 is open, S_PWR is logically low and the system controller 5 sets OP_STATE to STBY. The PFC controller 25 monitors the voltage of the battery 13 via the V_BAT signal. If the voltage of the battery 13 is less than a fully-charged threshold, the PFC controller 25 sets the amplitude of the current reference to a non-zero value. As a result, power is drawn from the AC source 14 and output by the AC-to-DC stage 12. Since the vacuum motor 3 is in the standby state, all power output by the AC-to-DC stage 12 is drawn by the battery 13. The system controller 5 and the controller of the vacuum motor 3 will draw some power from the AC-to-DC stage 12

and thus it is not strictly correct to say that all power output by the AC-to-DC stage 12 is drawn by the battery 13. However, the power drawn by the controllers is so small relative to the total power output by the AC-to-DC stage 12 that, for the purposes of the present discussion, the battery 13 may be said to draw all power from the AC-to-DC stage 12. Since the battery 13 draws power from the AC-to-DC stage 12, the battery 13 experiences net charging.

When charging the battery 13 (i.e. when the voltage of the battery 13 is less than the fully-charged threshold), the PFC controller 25 sets the amplitude of the current reference such that the battery 13 is charged with a constant average current. That is to say that the magnitude of the current output by the AC-to-DC stage 12, when averaged over each cycle of the waveform, is constant. The PFC controller 25 therefore sets the amplitude of the current reference to a value that depends on the voltage of the battery 13. In particular, as the voltage of the battery 13 increases, the PFC controller 25 increases the amplitude of the current reference.

When the voltage of the battery 13 subsequently exceeds the fully-charged threshold, the PFC controller 25 sets the amplitude of the current reference to zero such that no power is drawn from the AC source 14, and thus no power is output by the AC-to-DC stage 12. The PFC controller 25 employs a further threshold which is set just below the fully-charged threshold. This further threshold will hereafter be referred to as the top-up threshold, for reasons that will shortly become apparent. Should the voltage of the battery 13 drop below the top-up threshold (e.g. due to ionic relaxation within the battery 13), the PFC controller 25 sets the amplitude of the current reference to a non-zero value such that power is again drawn from the AC source 14 and output by the AC-to-DC stage 12. As a result, the battery 13 again experiences net charging. When the voltage of the battery 13 subsequently exceeds the fully-charged threshold, the PFC controller 25 sets the amplitude of the current reference to zero. The voltage of the battery 13 is therefore topped up whenever the voltage drops below the top-up threshold.

The maximum power drawn from the AC source 14 by the power supply 4 is 300 W. The PFC controller 25 therefore sets the amplitude of the current reference such that, at the fully-charged threshold, the power drawn from the AC source 14 does not exceed 300 W.

Low-Power State

Upon closing the on-off switch 6, S_PWR is pulled logically high. In response, the system controller 5 sets OP_STATE to LO. The vacuum motor 3 then operates in the low-power state and draws 200 W from the power supply 4.

The PFC controller 25 monitors the voltage of the battery 13 via the V_BAT signal. If the voltage of the battery 13 is less than the fully-charged threshold, the PFC controller 25 sets the amplitude of the current reference to a non-zero value such that a power of between 200 W and 300 W is drawn from the AC source 14 and output by the AC-to-DC stage 12. Since the vacuum motor 3 draws only 200 W, the additional power output by the AC-to-DC stage 12 is drawn by the battery 13, which experiences net charging. As in the standby state, the PFC controller 25 sets the amplitude of the current reference such that the battery 13 is charged with a constant average current. It is for this reason that the power drawn from the AC source 14 is not constant but instead varies between 200 W and 300 W. For example, as the voltage of the battery 13 increases, the PFC controller 25 increases the amplitude of the current reference such that the power drawn from the AC source 14 increases and thus a constant average current is output by the AC-to-DC stage 12.

When the voltage of the battery 13 subsequently exceeds the fully-charged threshold, the PFC controller 25 decreases the amplitude of the current reference such that the power drawn from the AC source 14 is less than 200 W. For example, the power drawn from the AC source 14 may be 180 W. The power demanded by the vacuum motor 3, however, continues to be 200 W. The deficit power is then supplied by the battery 13,

i.e. the vacuum motor 3 draws 180 W from the AC source 14 and 20 W from the battery 13. As a result, the battery 13 experiences net discharging. When the voltage of the battery 13 subsequently drops below a top-up threshold (this may be the same or a different top-up threshold to that used in the standby state), the PFC controller 25 increases the amplitude of the current reference such that the power drawn from the AC source 14 is again between 200 W and 300 W. As a result, the battery 13 again experiences net charging and thus the voltage of the battery 13 is chopped between the fully-charged threshold and the top-up threshold.

10 High-Power State

When the power-mode switch 7 is actuated, S_HILO is pulled high momentarily. In response, the system controller 5 sets OP_MODE to HI. The vacuum motor 3 then operates in high-power state and draws 400 W from the power supply 4. Additionally, the PFC controller 25 sets the amplitude of the current reference such that a power of 300 W is drawn from the AC source 14 and output by the AC-to-DC stage 12. The deficit power is then supplied by the battery 13, i.e. the vacuum motor 3 draws 300 W from the AC source 14 and 100 W from the battery 13. As a result, the battery 13 experiences net discharging.

20 When the voltage of the battery 13 subsequently drops below the fully-discharged threshold, the system controller 5 sets OP_STATE to LO. As a result, the vacuum motor 3 switches to the low-power state and the battery 13 experiences net charging. The system controller 5 may disable the high-power state (i.e. ignore the S_HILO signal) until such time as the voltage of the battery 13 has recovered to a particular value.

If the power-mode switch 7 is actuated whilst OP_STATE is set to HI, the system controller 5 may set OP_STATE to LO. The power-mode switch 7 may then be used to switch between the low-power and the high-power states.

When operating in mains mode, the power supply 4 draws a maximum of 300 W from the AC source 14. In particular, the PFC controller 25 sets the amplitude of the current reference such that the power drawn from the AC source 14 is no greater than 300 W, irrespective of the operating state of the vacuum motor 3. Rather than drawing a maximum of 300 W, the power supply 4 could conceivably draw a maximum of 500 W. This would then have the advantage that the battery 13 may be charged when the vacuum motor 3 operates in the high-power state. However, by lowering the maximum power draw to 300 W, the AC-to-DC stage 12 is able to employ components having a lower power rating. As a result, a cheaper, smaller and/or lighter power supply 4 may be realised. Reducing the size and weight of the power supply 4 is particularly advantageous in this application since the power supply 4 is housed within the main body 2 of the vacuum cleaner 1. Although the AC-to-DC stage 12 is rated for 300 W, the power supply 4 is nevertheless able to supply the vacuum motor 3 with 400 W by using the battery 13 to boost the power drawn from the AC source 14 by the AC-to-DC stage 12.

The vacuum motor 3 has a power demand of 400 W when operating in the high-power state. However, the vacuum motor 3 may be rated for lower power. In particular, the vacuum motor 3 may be rated for just 200 W. Consequently, if the vacuum motor 3 were to operate in the high-power state for long periods, the resulting temperature rise within the vacuum motor 3 may damage the motor 3. The power supply 4 may therefore be configured such that the high-power state is enabled for short periods only. For example, when S_HILO is pulled high, the system controller 5 may start a timer in addition to setting OP_STATE to HI. After a predetermined period of time has elapsed, the system controller 5 may set OP_STATE to LO. The system controller 5 may then disable the high-power state (i.e. ignore the S_HILO signal) for a set period of time so as to allow the temperature within the vacuum motor 3 to decrease. Additionally or alternatively, the system controller 5 may monitor the temperature within the vacuum motor 3 (e.g. by means of a thermistor) and disable the high-power state in the event that the temperature within the vacuum motor 3 exceeds a threshold. By employing a

vacuum motor 3 that is rated for just 200 W and by enabling the high-power state for relatively short periods only, a cheaper vacuum motor 3 (i.e. one rated for lower power) may be employed and yet a higher power of 400 W may be achieved temporarily.

5 Although specific values have been provided for the powers drawn by the vacuum motor 3 and the power supply 4, it will be appreciated that these values are provided by way of example only. In a more general sense, the power drawn by the vacuum motor 3 may be said to be M when operating in the low-power state and N when operating in the high-power state, where M is less than N . The maximum power drawn by the power
10 supply 4 from the AC source 14 may be said to be P when the vacuum motor 3 operates in the low-power state and Q when the vacuum motor 3 operates in the high-power state. M is then less than P such that the battery 13 is charged when the vacuum motor 3 operates in the low-power state. Additionally, N is greater than Q such that the power drawn from the AC source 14 is boosted by the battery 13 when the vacuum
15 motor operates in the high-power state. In the embodiment described above, P and Q are equal such that the maximum power drawn from the AC source 14 is the same irrespective of whether the vacuum motor 3 operates in the low-power state or the high-power state. Alternatively, however, P may be less than Q . This may be desirable, for example, should it transpire that the rate at which the battery 13 charges is excessively
20 high when drawing a maximum power of Q from the AC source 14 in the low-power state.

When operating in the low-power state, the power demand of the vacuum motor 3 is the same irrespective of whether the power supply 4 is in battery mode or mains mode. As
25 a result, a user will discern no noticeable difference in the performance of the vacuum cleaner 1 when the power supply 4 is connected and disconnected from the AC source 14. Conceivably, however, the power demand of the vacuum motor 3 may be different. For example, the power demand of the vacuum motor 3 may be lower when the power supply 4 is in battery mode such that the vacuum cleaner 1 has a longer run
30 time.

Whilst a particular embodiment for the power supply 4 has thus far been described, it will be apparent to those skilled in the art that various modifications are possible without departing from the scope of the invention as defined by the claims. For example, whilst the provision of the EMI filter 20 has particular benefits and may indeed be required for regulatory compliance, it will be apparent that the EMI filter 20 is not essential to the claimed invention and may be omitted. Additionally, although the PFC circuit 22 comprises a boost converter located on the primary side of the DC-to-DC converter 23, alternative configurations are possible. By way of example only, the PFC circuit 22 may comprise a buck converter or the PFC circuit 22 may be located on the secondary side of the DC-to-DC converter 23. Where the PFC circuit 22 is located on the primary side of the DC-to-DC converter 23, the AC-to-DC converter 21 and the PFC circuit 22 could conceivably be replaced with a single bridgeless PFC circuit. Similarly, although the DC-to-DC converter 13 comprises an LLC resonant converter, alternative configurations are possible, such as an LC series or parallel resonant converter.

The AC-to-DC stage 12 acts as a current source that outputs a current having a ripple of 100%. The battery 13 then acts as a smoothing capacitor for the AC-to-DC stage 12. This then has the advantage that the PFC circuit 22 may employ a capacitor C1 of relatively low capacitance. Indeed, the capacitor C1 of the PFC circuit 22 need only provide short-term storage of charge flowing between the PFC circuit 22 and the DC-to-DC converter 23. As a result, a smaller and cheaper PFC circuit 22, and thus a smaller and cheaper power supply 4, may be realised. In spite of the aforementioned advantages, the AC-to-DC stage 12 may be configured to output a current having a smaller ripple. This may be desirable for at least two reasons. First, the rates at which the battery 13 charges and discharges during each charge and discharge period would be slower, and the total charge drawn by and from the battery 13 during each charge and discharge period would be smaller. One or both of these factors may help prolong the life of the battery 13. Second, for the same average output power of the AC-to-DC

stage 12, the peak value of the output current will be smaller and thus a smaller and/or cheaper filter inductor L2, having a lower current rating, may be used. Decreasing the ripple in the output current may be achieved by operating the DC-to-DC converter 23 at a frequency higher than resonance. This then increases the impedance of the DC-to-DC
5 converter 23, thereby allowing a voltage differential to arise between the PFC circuit 22 and the battery 13. This voltage differential may then be used to shape the current output by the AC-to-DC stage 12 such that it has a ripple less than 100%. However, any reduction in ripple will require additional capacitance. Accordingly, the AC-to-DC stage 12 is preferably configured such that the output current has a ripple of least 50%.

CLAIMS

1. A vacuum cleaner comprising a vacuum motor and a power supply, wherein:
the power supply comprises input terminals for connection to an AC source,
5 output terminals connected to the vacuum motor, an AC-to-DC stage, and a battery;
the AC-to-DC stage converts alternating current drawn from the AC source into
direct current that is supplied to the battery and the vacuum motor;

the power supply operates in a first mode when disconnected from the AC
source and a second mode when connected to the AC source;

10 when the power supply operates in the first mode, the vacuum motor draws
power from the battery only; and

when the power supply operates in the second mode:

the vacuum motor operates in one of a low-power state and a high-power
state;

15 the vacuum motor and the battery each draw power from the AC source
when the vacuum motor operates in the low-power state such that the battery
charges; and

the vacuum motor draws power from both the AC source and the battery
when the vacuum motor operates in the high-power state such that battery
20 discharges.

2. A vacuum cleaner as claimed in claim 1, wherein the power drawn by the
vacuum motor when the power supply operates in the second mode is no less than the
power drawn by the vacuum motor when the power supply operates in the first mode.

25

3. A vacuum cleaner as claimed in claim 1 or 2, wherein the power drawn by the
vacuum motor is M when the power supply operates in the first mode, the power drawn
by the vacuum motor is N when the power supply operates in the second mode and the
vacuum motor operates in the low-power state, the power drawn by the vacuum motor
30 is P when the power supply operates in the second mode and the vacuum motor operates

in the high-power state, P is greater than both M and N, and N is greater than or equal to M.

4. A vacuum cleaner as claimed in any one of the preceding claims, wherein the power drawn from the battery when the power supply operates in the first mode is at least 200 W.

5. A vacuum cleaner as claimed in any one of the preceding claims, wherein the AC-to-DC stage and the battery are connected in parallel between the input terminals and the output terminals.

6. A vacuum cleaner as claimed in claim 5, wherein the AC-to-DC stage outputs a current having a periodic waveform with a ripple of at least 50%.

7. A vacuum cleaner as claimed in any one of the preceding claims, wherein the AC-to-DC stage adjusts the power drawn from the AC source in response to changes in the voltage of the battery.

8. A vacuum cleaner as claimed in claim 7, wherein, when the voltage of the battery exceeds a threshold, the AC-to-DC stage decreases the power drawn from the AC source such that the power drawn from the AC source by the AC-to-DC stage is less than the power drawn from the power supply by the vacuum motor.

9. A vacuum cleaner as claimed in claim 8, wherein, when the voltage of the battery drops below a further threshold, the AC-to-DC stage increases the power drawn from the AC source such that the power drawn from the AC source by the AC-to-DC stage is greater than the power drawn from the power supply by the vacuum motor.

10. A vacuum cleaner as claimed in any one of the preceding claims, wherein the AC-to-DC stage comprises an AC-to-DC converter for rectifying the current drawn

from the AC source, a PFC circuit for regulating the rectified current drawn from the AC source, and a step-down DC-to-DC converter for lowering the voltage of the rectified current.

1/4

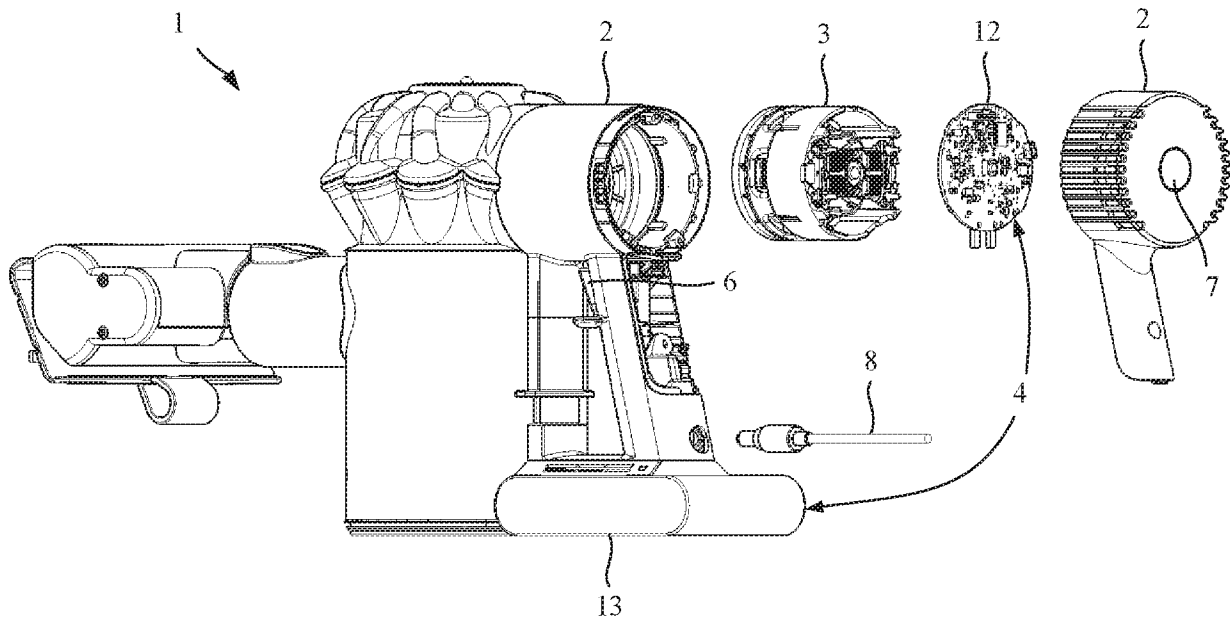


Fig. 1

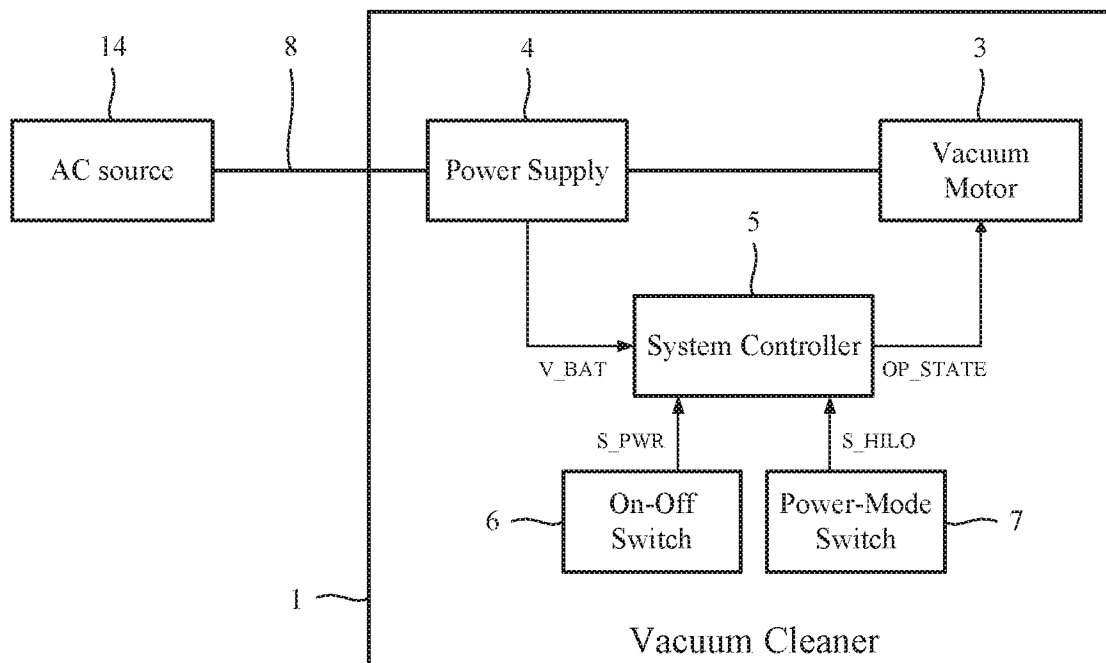


Fig. 2

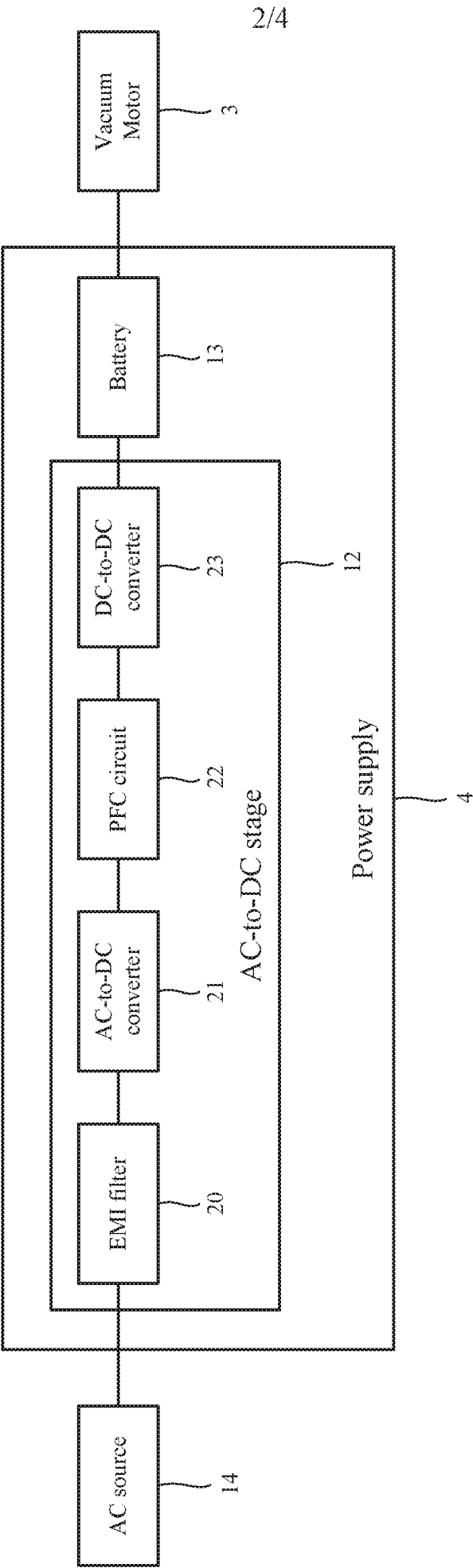


Fig. 3

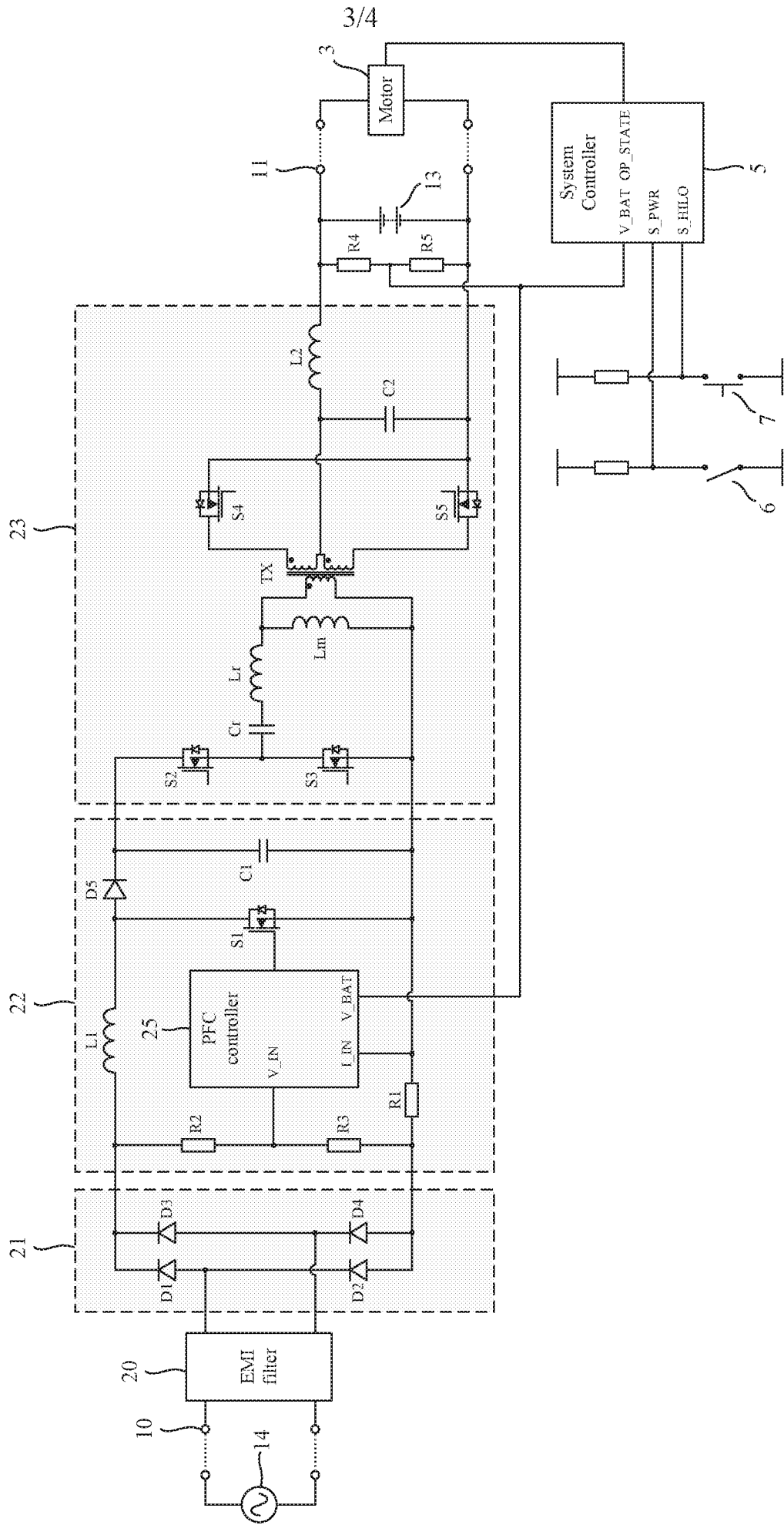


Fig. 4

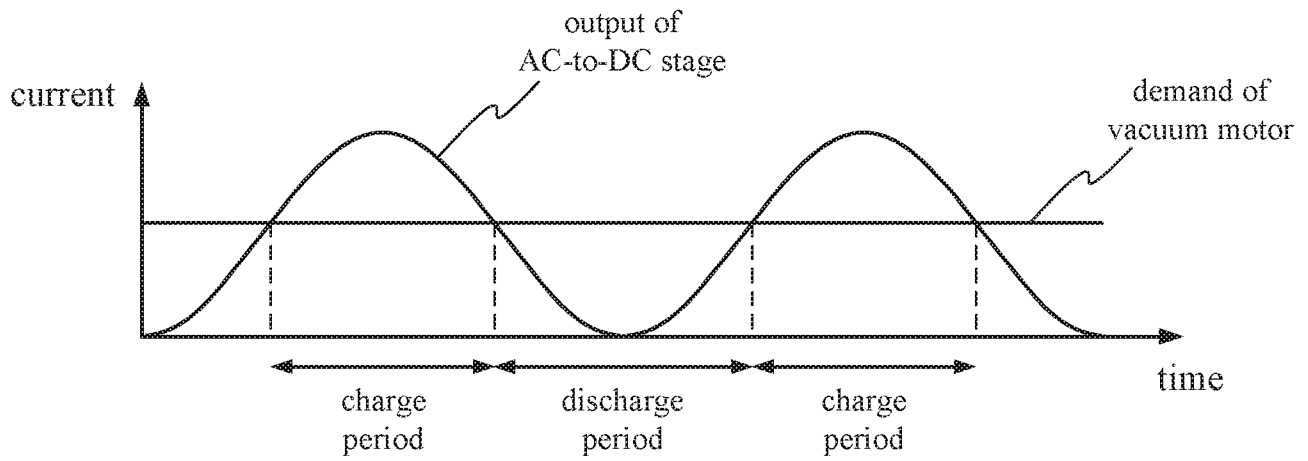


Fig. 5

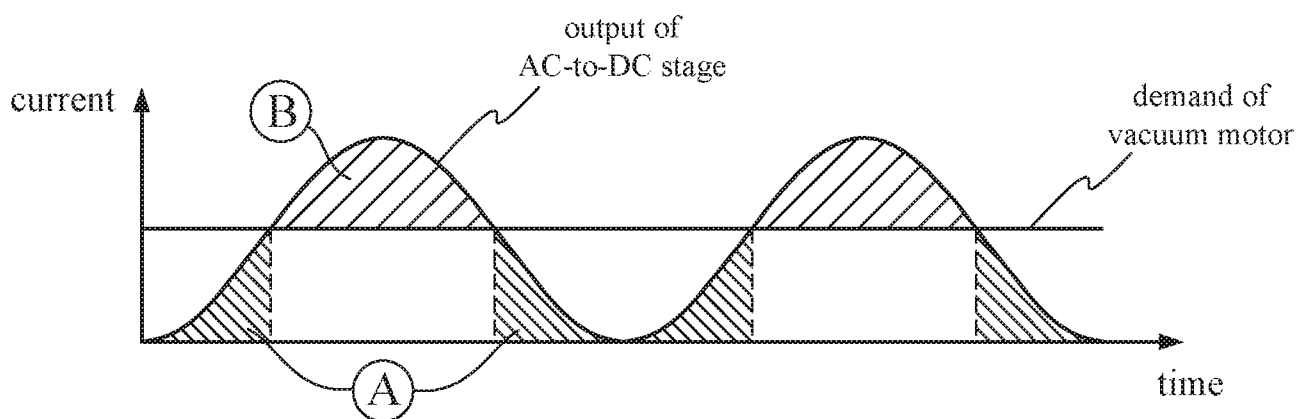


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2016/051979

A. CLASSIFICATION OF SUBJECT MATTER
INV. A47L9/28
ADD.

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)
A47L

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.
A	WO 2008/146988 A1 (LG ELECTRONICS INC [KR]; YOO MYUNG-KEUN [KR]; KIM SANG-YOUNG [KR]; AHN) 4 December 2008 (2008-12-04) figure 5	1-10
A	US 2008/284363 A1 (LUCAS DELBERT E [US] ET AL) 20 November 2008 (2008-11-20) paragraph [0079]; figure 11	1-10



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

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"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

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"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

22 September 2016

Date of mailing of the international search report

06/10/2016

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2016/051979

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2008146988	A1	04-12-2008	
		CN 101677734 A	24-03-2010
		EP 2162043 A1	17-03-2010
		KR 20080105847 A	04-12-2008
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US 2008284363	A1	20-11-2008	NONE
