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PWM HVAC Blower Controller and BLDC Motor Controller Efficiency Assessment

RATIONALE

Legislation has been introduced that provides credits for the use of emission reduction technologies. One such technology is the use of a Pulse Width Modulated (PWM) HVAC Blower Controller (together with a brushed DC motor) or a Brushless DC controller (with Brushless DC motor) in place of traditional HVAC Blower Controllers such as resistors or Linear Power Modules. A uniform standard does not exist to evaluate the efficiency of such controllers and estimate the impact towards emissions and qualify for credit with the legislative bodies.

Latest revision includes minor corrections and clarifications.

1. SCOPE

The intention of this standard is to establish a framework to measure the efficiency of PWM HVAC Blower Controllers and Brushless DC Motor Controllers and define a usage based overall efficiency. This result can then be used by vehicle OEMs to demonstrate compliance towards requirements or benchmarks established by regulatory agencies.

2. REFERENCES

2.1   Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

EPA-HQ-OAR-2010-799; FRL-9706-5; NHTSA-2010-0131: 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards

3. DEFINITIONS

All physical dimensions and units are expressed in SI units and all voltage is assumed to be in Direct Current (DC) unless otherwise noted.

3.1   PULSE WIDTH MODULATION (PWM)

Pulse-width modulation (PWM) is a modulation process or technique used to control output power supplied to electrical devices, especially to inductive loads such as motor, by means of switching between supply and load on and off at a high frequency. In this document, PWM will also be used to describe an HVAC blower controller using this control method.

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3.2   LINEAR POWER MODULE (LPM)

An HVAC blower controller which operates a transistor in a linear mode to control output voltage to an HVAC blower motor.

3.3   VARIABLE BLOWER CONTROLLER (VBC)

Another name for a Linear Power Module.

3.4   BRUSHLESS DC MOTOR (BLDC)

A motor that is commutated via electronic switching rather than a brush and commutator.

4.   EQUIPMENT

4.1   DC Power Supply (Regulated): 0 to 20 V and 0 to 40 A

4.2   Signal generator or LIN-BUS Master device to provide set point to LIN-based controllers

4.3   For PWM and Brush DC motor

4.3.1   All voltage measurement equipment shall be accurate to within 0.05% of reading at 20 KHz square wave signal with average measurement.

4.3.2   Current shunt: 100 A/100 mV at ±0.1%

4.4   For BLDC Controller

4.4.1   Oscilloscope (One Needed)

- High-end oscilloscope for advanced math functions and deep memory

- Minimum of four channels

- ≥20 MHz bandwidth, sampling rate ≥10 MS/s, ≥8-bit resolution

- Sample memory depth ≥10 MS

4.4.2   Current Probes (Minimum of Two Needed)

- Bandwidth ≥1 MHz

- Range 30 to 50 A

- Note: Rogowski coils and current transformers cannot be used. Only DC-capable probes can be used.

4.4.3   Differential Voltage Probes (Minimum of Two Needed)

- Bandwidth: ≥20 MHz

- Range: ≥20 V, but ≤100 V

5.   PWM CONTROLLER WITH BRUSHED DC MOTOR

5.1   Test Set-Up

5.1.1   Load

The load shall be set with 13.5 V at the power input of the PWM Controller and the set point input to the controller (duty cycle or LIN) shall be adjusted to provide 12.5 V_{avg} output to the load.

5.1.1.1   Using HVAC Blower

With the electrical input to the PWM Controller adjusted as described in 5.1, restrict the inlet or outlet of the HVAC blower such that the current draw is in accordance with the current listed in Table 2.

5.1.1.2   Using Load Simulator

With the electrical input to the PWM adjusted as described in 5.1, select an inductive-resistive load to draw the currents listed at the respective voltages in Table 2. The inductance shall be 70 to 200 μH. The resistance can be adjusted by use of different values of resistors set in parallel or series, or a sufficiently sized variable resistor, in order to obtain the targeted current draw.

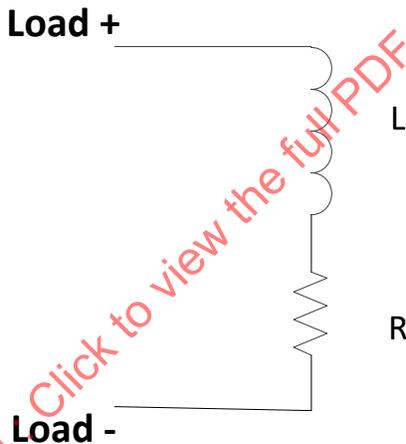**Load +**

L

R

Load -

Figure 1 - Example of load simulator

5.1.1.3   Wire Connection

3.0 mm^2 or 12 AWG wire of a length of 150 mm ± 10 mm from connector to connector (wire insertion side) shall be used to connect the power module to the blower motor or resistive load.

5.1.1.4   Test Diagram

Components and instrumentation shall be set-up in accordance with the following diagrams:
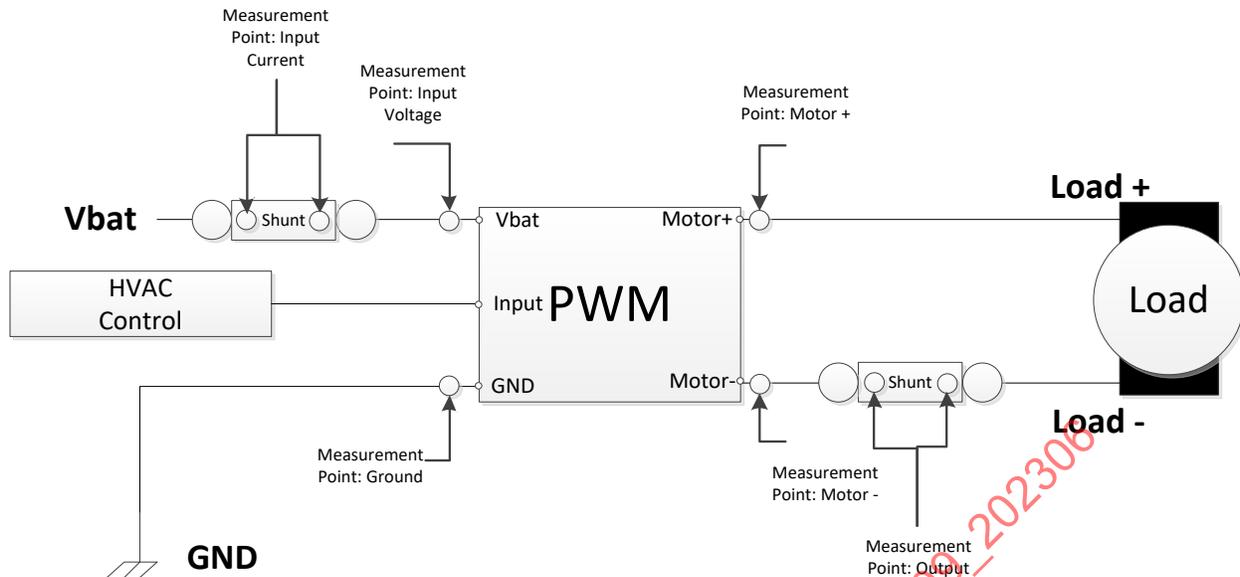
Measurement
Point: Input
Current

Measurement
Point: Input
Voltage

Measurement
Point: Motor +

Load +

Vbat   Shunt   Vbat   PWM   Motor+   **Load**

HVAC
Control   Input   PWM

GND   Motor-   Shunt   **Load -**

Measurement
Point: Ground

GND

Measurement
Point: Motor -

Measurement
Point: Output
Current

Figure 2 - Test set-up for PWM with high-side switch

Measurement
Point: Input
Current

Measurement
Point: Input
Voltage

Measurement
Point: Output
Current

Measurement
Point: Motor +

Load +

Vbat   Shunt   Vbat   PWM   Motor+   Shunt   **Motor**

HVAC
Control   Input   PWM

GND   Motor-   **Load -**

Measurement
Point: Ground
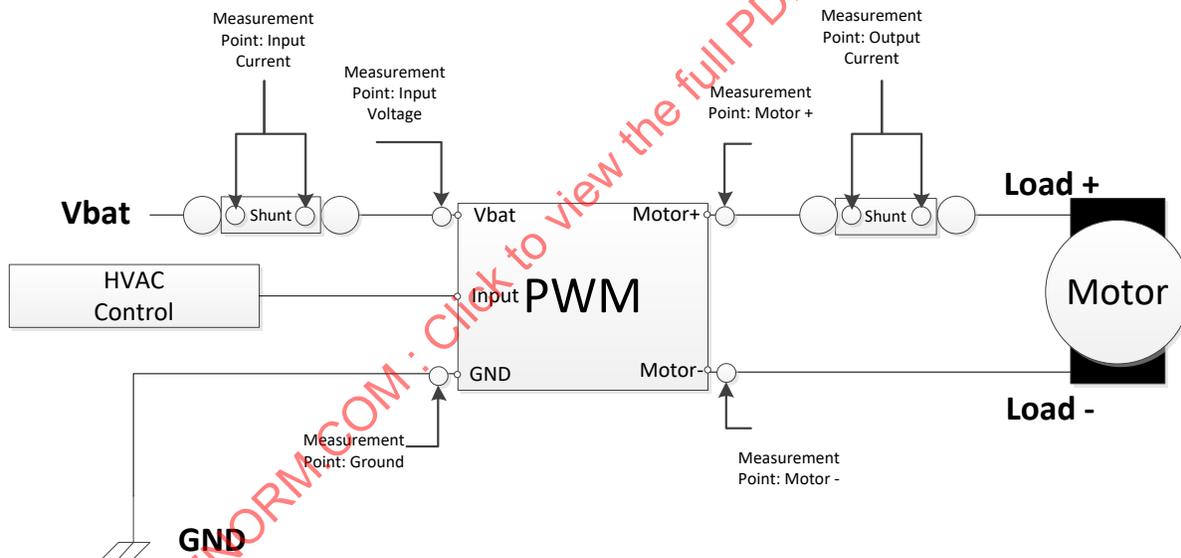
GND

Measurement
Point: Motor -

Figure 3 - Test set-up for PWM with low-side switch

The manufacturer shall use a harness in good condition in order to remove variability of the contact losses of the terminals due to assembly and dis-assembly. The sense wires should be connected to wires near the connector.

The voltage drop across the shunt should be read according to a 4-wire measurement technique as shown on Figures 2 and 3.

5.1.1.5   Ambient Conditions

Test should be run in ambient temperatures of 25 °C ± 5 °C. Cooling airflow for the PWM module should be representative of a production HVAC environment to cool the PWM controller to required levels.

5.1.2   Test Procedure

5.1.2.1   Control the power supply output such that the input voltage to the PWM controller is 13.5 V ± 0.05 V.

5.1.2.2   Adjust the input control signal to the PWM controller such that the target output voltage, ±2% of reading, is achieved.

5.1.2.3   Hold this condition for 10 minutes and record the following listed in Table 1.

Table 1 - Required data

Characteristic	Unit
PWM Controller Input Voltage	VDC
PWM Controller Output Voltage (avg)	VDC (avg)
PWM Controller Input Current	A
PWM Controller Output Current (avg)	A
Input Setpoint (Duty Cycle or LIN)	%

5.1.2.4   Repeat until all required voltages are tested. The required voltages are listed in Table 2:

Table 2 - Required test voltages and currents

Condition	Voltage [V$_{avg}$]	Current [I$_{avg}$]
Low	4.00	23% x Hi
Medium Low	6.00	35% x Hi
Medium	8.25	54% x Hi
Medium High	10.50	75% x Hi
High	12.50	Hi*

*   Hi is defined as 1 A beneath the lower tolerance of the rated current. For example, if the component is listed as having a current rating of 28 A ± 3 A, the "Hi" current used for this test would be 24 A.

5.1.3   Reporting And Calculation

5.1.3.1   Reporting format shall follow the documentation in Table 3:

Table 3 - Test reporting

Condition	Duty Cycle [%]	PWM Controller Input Voltage [VDC]	PWM Controller Input Current [A]	PWM Controller Input Power [W]	PWM Controller Output Voltage [VDC$_{avg}$]	PWM Controller Output Current [A]	PWM Controller Output Power [W]	Efficiency [%]	Weighting Factor [%]
Low									35%
Medium Low									22%
Medium									21%
Medium High									12%
High									10%
Weighted Average Efficiency:			-						

5.1.3.1.1   The Efficiency is calculated as the PWM Controller Output Power divided by the PWM Controller Input Power. See Equation 1:

$$\text{Efficiency} = \frac{PWM\ Controller\ Output\ Voltage\ x\ PWM\ Controller\ Output\ Current}{PWM\ Controller\ Input\ Voltage\ x\ PWM\ Controller\ Input\ Current} = \frac{PWM\ Controller\ Output\ Power}{PWM\ Controller\ Input\ Power} \qquad \text{(Eq. 1)}$$

5.1.4   Weighting factors are based on an estimate of percent usage at different blower voltages in the field.

5.1.5   Weighted Average Efficiency is the measure that will be assessed for credits qualification. The weighted average efficiency shall be calculated as shown in Equation 2:

Weighted Average Efficiency = $0.35*\text{Efficiency}_{Low} + 0.22*\text{Efficiency}_{MedLow} + 0.20*\text{Efficiency}_{Med} + 0.12*\text{Efficiency}_{MedHigh} + 0.10*\text{Efficiency}_{High}$ (Eq. 2)

6.   CONTROLLER FOR BRUSHLESS DC MOTOR (BLDC)

6.1   Test Set-Up

6.1.1   Establishing Appropriate Load

The load shall be set with 13.5 V at the power input to the BLDC controller and the set point shall be varied to achieve the targeted current draw (when using HVAC Blower described in 6.1.2) or targeted motor speed (when using dynamometer described in 6.1.3).

6.1.2   Using HVAC Blower

With the electrical input to the BLDC controller established according to 6.1.1., restrict the inlet or the outlet of the HVAC blower such that the current draw is 1 A below the maximum current limit of the device. For subsequent measures, the input set point shall be adjusted such that the targeted BLDC controller input power is reached, ±2% of reading.

6.1.3   Using Dynamometer

With the electrical input to the BLDC controller established according to 6.1.1, adjust the torque of the dynamometer such that the current draw is 1 A below the maximum current limit of the device. Record the speed at this point. For subsequent measurements, adjust the duty cycle input to the BLDC controller to target the scaled speed according to Table 5. Then adjust the torque of the dynamometer to achieve the targeted input power in Table 5. Two examples are described below.

For the first example, at maximum input set point and no load, the no load speed is hypothetically 4200 rpm. However, with the addition of torque to reach the target current, the resultant speed is 3800 rpm as the torque is beyond the speed plateau. Thus, the "Maximum" speed is 3800 rpm and the next subsequent point (63% of High Input Power) will have the input set point adjusted to achieve 88% x 3800 rpm = 3300 rpm and the torque adjusted to achieve 63% of the "Hi" input power.

In a second example, if at maximum input set point and no load, the no load motor speed is 4200 rpm. With the addition of torque to reach the target current, the resultant speed is still on the plateau (torque where the speed versus torque relationship is flat) at 4200 rpm. Thus, the "Maximum" speed would be 4200 rpm and the next subsequent point (63% of High Input Power) will have the input set point adjusted to achieve 88% x 4200 = 3696 rpm and the torque adjusted to reach 63% of "Hi" input power.

The supplier may use an external supply of air to cool the motor and controller to levels representative of an HVAC module.

6.1.4 Example Test Diagram
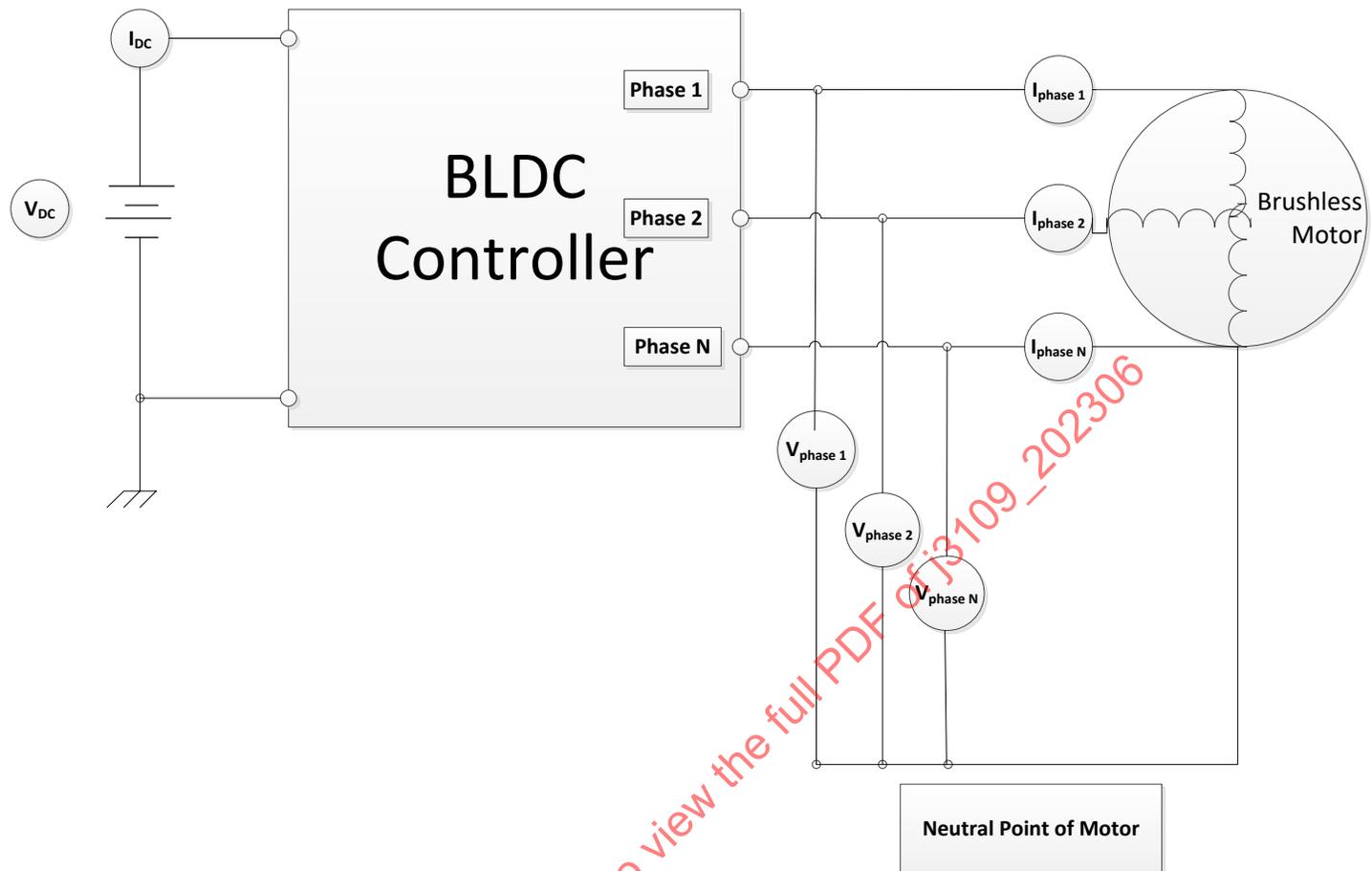
Output Power = V_{Phase1} x I_{Phase1} + V_{Phase2} x I_{Phase2} +...+V_{PhaseN} x I_{PhaseN} (all instantaneous values, not average nor RMS)

For other motor topologies, a different set-up may be required if the neutral point of the motor is not accessible or not present.

The manufacturer shall make modifications as necessary to install the instrumentation such that it does not interfere with the operation of the BLDC.

6.2 TEST PROCEDURE

6.2.1 It is imperative to check "known zero," use the degauss/autozero function, and recompensate after temperature stabilization in order to minimize offset errors. If needed, the use of a math channel can be used to subtract known offsets. In order to minimize gain errors, the gains of the input and output measuring instruments should be matched. A math channel for gain adjustment, or fine-graine attenuation setting on a per-channel basis can be used (after offset compensation).

6.2.2 Control the power supply output such that the input voltage to the BLDC controller is 13.5 V ± 0.05 V.

6.2.3 Adjust the input control signal to the BLDC controller such that the target input power, ±2% of reading, is achieved.

6.2.4 The oscilloscope shall utilize a math function to calculate input power, as well as the output power of each phase. If the oscilloscope does not have enough channels to capture output power of all phases and the input power simultaneously, then an alternative approach is required. For each test condition, the output power for a single phase and the input power shall be measured simultaneously, and then repeated for each phase. The input power shall be measured at all times in order to ensure that no changes to the test condition occurs.