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Date: December 15, 2020

Mr. Linc Wehrly
Director, Light Duty Vehicle Center
Compliance Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency
2000 Traverwood Drive
Ann Arbor, Michigan 48105

Subject: Request for GHG Off-Cycle Credit for HVAC Brushless Motor Technology in 2020 Model Year and later HMC vehicles

Dear Mr. Wehrly:

Pursuant to the provisions of 40 CFR § 86.1869-12(d) and 49 CFR § 531.6(b), Hyundai Motor Company (HMC), represented by Hyundai America Technical Center, Inc. (HATCI), requests greenhouse gas (GHG) off-cycle credit for the use of Pulse Width Modulated (PWM) HVAC Brushless Motor (BLM) Power Controller Technology. Based on test results and analysis provided in Attachment A and B, Hyundai Motor Company (HMC) requests credits equal to 0.4 grams CO_2 per mile for 2020 and later model year passenger cars equipped with HVAC brushless motor technology. This credit value can be separated by A/C on and off credits as shown in Table 1 below.

Table 1. HVAC Brushless Motor Credit Request

[unit: gCO2/mi]	Total Credit	A/C On Credit	A/C Off Credit
Manual A/C	0.4	0.2	0.2
Automatic A/C	0.4	0.3	0.1

In accordance with 40 CFR 86.1869-12(d)(1), HATCI previously informed EPA of intent to pursue off-cycle credit for HVAC brushless motor technology by alternative method. HATCI also met with EPA in September 2020 to review the proposed methodology and plan, of which EPA was agreeable. Therefore, HATCI is proceeding with an official application to EPA requesting GHG off-cycle credits for HVAC Brushless Motor technology. HMC also intends to pursue similar credit request to NHTSA for off-cycle CAFE credits for use of HVAC brushless motor technology.

Background and Rationale for Alternative Methodology

Greenhouse gas emission standards through 2025 represent a major initiative in US energy and climate policy. EPA and DOT have issued a joint rulemaking that set greenhouse gas emissions and fuel economy standards for the largest sources of greenhouse gases from transportation, including cars, light trucks, and heavy-duty trucks. Over the course of the program, light-duty GHG regulations are projected to: cut 6 billion metric tons of GHG emissions, nearly double vehicle fuel efficiency while protecting consumer choice, reduce America's dependence on oil and provide significant savings for consumers at the fuel pump. To achieve these worthy goals, a key regulatory element is the ability for manufacturers to have a variety of options and flexibilities in meeting the standards.

A key flexibility is the off-cycle credits provision; off-cycle credits are an opportunity for manufacturers to generate credits for technologies that provide CO_2 reductions not captured by the traditional 2-cycle (FTP, HWFET) emissions tests conducted on a chassis dynamometer. There are three pathways by which a manufacturer may accrue off-cycle credits. The first is a pre-determined menu of credit values for specific off-cycle technologies. In cases where additional lab testing can demonstrate emission benefits of a technology, a second pathway allows manufacturers to use a broader array of emission tests known

as 5-cycle testing, which captures more elements of real-world driving, including high speeds and hard acceleration (US06), solar loads, high temperature, and A/C use (SC03), and cold temperatures (cold FTP). The third pathway allows manufacturers to seek EPA approval to use an alternative methodology for determining the off-cycle credits.

The Pulse Width Modulated HVAC Brushless Motor Power Controller Technology is not included in the EPA's pre-determined menu credit. Additionally, the 5-cycle test option would not adequately measure the real-world GHG reduction benefits of the technology. Only one of the five tests is conducted with the A/C switched on. Since it is conducted at a high ambient temperature of 95F, high solar load of 850 W/m^2, and high relative humidity of 40%, the demanding climatic conditions result in the air conditioning systems being operated at maximum capacity throughout the test. Therefore, 5-cycle testing does not sufficiently represent the wide range of customer usage of the HVAC brushless motors. Also, benefit of HVAC brushless motor technology is relatively small and it is difficult to see the benefit in vehicle-level testing. For these reasons, HATCI is pursuing additional off-cycle credits via the alternative methodology pathway.

Technology Description

HVAC brushed motor uses mechanical switching while the BLM uses circuit switching. A brushed motor uses brushes to deliver current to the motor windings on the rotor. However, the BLM technology removes brushes and uses a magnet on a rotor with an electromagnetic stator. Without consumable brush and physical contact between the stator and commutator, the BLM technology reduces frictional losses and the amount of power needed to produce airflow in the HVAC unit.

Alternative Methodology to evaluate GHG off-cycle benefit

The evaluation methodology used to quantify the technology benefit consists of 3 steps:

1. System Selection – Select a HVAC system to remove the impact of additional factors except motor type
2. Bench Testing (SAE J3109) – Measure average power saving of BLM from 3 tests
3. Benefit Calculation – Convert power saving to emission reduction by using SAE J3174 and calculate A/C On and Off credit by using Motor & Equipment Manufacturers Association (MEMA) US A/C usage profile

① System Selection

2020 model year Sonata hybrid is the first vehicle model with HVAC brushless motor, and the technology is planned to be applied to future models. Bench testing was conducted for 2020 and 2021 model year vehicles. Same HVAC module and same blower case were used for both brushed motor and brushless motor to remove the impact of additional factors except motor type. With this system selection, HMG compared the amount of power consumed to heat for the PWM Brushed motor and PWM Brushless motor through the procedure outlined in SAE J3109.

② Bench Testing (SAE J3109)

Blower motor controls, which reduce wasted electrical energy (e.g. pulse width modulated power controller), are one of the pre-determined A/C efficiency menu credit technologies. SAE J3109 is the standard which was established as a framework to demonstrate compliance to this menu, including test procedures and required equipment for determining the weighted power saving of a HVAC blower motor. CO_2 reduction benefit of the BLM was evaluated using this standard. Table 2 below summarizes the J3109 criteria: test conditions, fixed values by the standard, measured data in the test and calculated values from test results.

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Table 2. PWM Test Matrix Showing J3109 Criteria

Condition	Brushed Motor								Brushless Motor					Power saving		
	A:	B:	C:	D:	E:	F:	G:	H:	I:	J:	K:	L:	M:	N:	O:	P:
	Duty Cycle	Voltage Input	Current Input	Power Input	Voltage Output	Current Output	Power Output	Rotor Speed	Rotor Speed	Duty Cycle	Voltage Input	Current Input	Power Input	Power saving	Weighiting factor	Weighted power saving
	[%]	[VDC]	[A]	[W]	[VDC_{avg}]	[A]	[W]	[rpm]	[rpm]	[%]	[VDC]	[A]	[W]	[W]	[%]	[W]
Low		13.5		0.000	4	23%xHi	0.000				13.5		0.000	0.00	35	0.000
Medium Low		13.5		0.000	6	35%xHi	0.000				13.5		0.000	0.00	22	0.000
Medium		13.5		0.000	8.3	54%xHi	0.000				13.5		0.000	0.00	20	0.000
Medium High		13.5		0.000	10.5	75%xHi	0.000				13.5		0.000	0.00	12	0.000
High		13.5		0.000	12.5	HI	0.000				13.5		0.000	0.00	10	0.000
															Total saving	**0.000**

*Shaded area indicates J3109 constants

The brushed motor was tested first to capture its power consumption as a baseline using the SAE J3109 methodology. The input voltage is controlled at 13.5V, and duty cycle was adjusted to reach the required output voltage. The inlet and outlet of the HVAC module were blocked to match the specified output current by J3109. According to SAE J3109, "High is defined as 1 amp beneath the lower tolerance of the rated current.", 20 amps was determined to be output current for high condition. The input current and rotor speed were recorded with this condition.

Three tests were conducted on the brushed motor and were repeated with the brushless motor. While maintaining same load, the duty cycle was adjusted to reach the brushed motor's recorded rotor speed. The input current was recorded after reaching that rpm, then the BLM input power was calculated using the input current.

As a result, weighted power saving for each condition was calculated using the J3109 weighting factor. The final power saving value was used to estimate the GHG off-cycle credit amount of PWM BLM technology.

Each test was conducted three times to confirm repeatability, and the result can be found in the Attachment A. Tables 3 shows the results of average of three tests. The average power saving of BLM technology was 15.64 W.

Table 3. J3109 Bench Test Result for 20MY Sonata HEV AC (Average of 3 Tests)

Condition	Brushed Motor								Brushless Motor					Power Saving		
	A:	B:	C:	D:	E:	F:	G:	H:	I:	J:	K:	L:	M:	N:	O:	P:
	Duty Cycle	Voltage Input	Current Input	Power Input	Voltage Output	Current Output	Power Output	Rotor Speed	Rotor Speed	Duty Cycle	Voltage Input	Current Input	Power Input	Power saving	Weighiting factor	Weighted power saving
	[%]	[VDC]	[A]	[W]	[VDC_{avg}]	[A]	[W]	[rpm]	[rpm]	[%]	[VDC]	[A]	[W]	[W]	[%]	[W]
Low	28.0	13.5	1.8	23.7	4	4.6	18.3	1103	1112	25.6	13.5	1.3	18.1	5.6	35	1.953
Medium Low	44.0	13.5	3.7	50.0	6	7.2	43.1	1618	1624	38.6	13.5	3.1	41.8	8.2	22	1.812
Medium	61.9	13.5	7.6	102.7	8.3	11.1	91.4	2151	2153	52.8	13.5	6.1	82.8	19.9	20	3.987
Medium High	76.7	13.5	13.4	180.9	10.5	15.4	161.6	2669	2670	65.6	13.5	10.9	147.5	33.5	12	4.018
High	83.8	13.5	20.6	277.4	12.5	20.5	256.1	3023	3030	74.6	13.5	17.7	238.7	38.7	10	3.874
															Total Saving	15.644

③ *Benefit Calculation*

To estimate the GHG emission reduction from the power saving of PWM BLMs, HATCI utilized SAE J3174. SAE J3174 is the supporting standard for calculating emissions reductions. The calculation accounts for the blower usage, alternator efficiency, engine efficiency, vehicle lifetime mileage, vehicle CO_2 emissions, gasoline heating value, and calculated power saving from the bench test. The values used in the standard are based on the 2009 MEMA's response to NHTSA 2009-0059 and EPA-HQ-OAR-2009-0472, the EPA final ruling, and other industry accepted values. The final CO_2 emission reduction can be calculated as follows by using values from MEMA's response.

CO_2 emission reduction for passenger car

$$= \frac{Gallons\ of\ Saving\ Fuel\ per\ Life * 8887\ \frac{gCO_2}{gal}}{Travel\ Mile\ per\ Life}$$

$$= \frac{\frac{Blower\ usage\ hours * power\ saving\ W}{Alternator\ Efficiency * Engine\ Efficiency * Gasoline\ Heating\ Value \frac{W}{gal}} * 8887\ \frac{gCO_2}{gal}}{195{,}264\ miles}$$

$$= \frac{\frac{6151.6 * power\ saving\ W}{80\% * 42\% * 33410 \frac{W}{gal}} * 8887\ \frac{gCO_2}{gal}}{195{,}264\ miles}$$

$$= 0.025 * power\ saving\ \frac{gCO_2}{mile} \qquad = 0.025 * 15.64\ \frac{gCO_2}{mile} \qquad = 0.39\ \mathrm{gCO_2/mile}$$

Where:
Blower Usage (Passenger Car) = 6151.6 hours
Blower Usage (Light Truck) = 7115.7 hours
gasoline heating value =33410 $\frac{W}{gal}$
CO_2 emission per gallon gasoline = 8887$\frac{gCO_2}{gal}$
Alternator Efficiency = 80%
Engine Efficiency = 42%
Vehicle Lifetime Mileage for Passenger Car = 195,264 mile
Vehicle Lifetime Mileage for Light Truck = 225,865 mile

Based on J3174, the brushless motor implemented in HMC vehicle yields 0.4 gCO_2/mi benefit.

Total 0.4 gCO_2/mi credit can be separated between time when the blower is used with the A/C On and Off by utilizing MEMA US Air Conditioning Usage Profile (Table 4).

Table 4. Air Conditioning Usage Rate

	Ignition On Time (Hours)	A/C On Time (Hours, %)	A/C Off Time (Hours, %)	Driving Distance per Year (mile)	Fleet Composition (%)
Manual A/C	393.8	175.6 (44.6%)	218.2 (55.4%)	12500	65
Automatic A/C	393.8	276.8 (70.3%)	117 (29.7%)	12500	35

The A/C On and A/C Off credit application can be determined as below (Table 5) by using above blower usage rate.

Table 5. PWM BLM GHG Off-Cycle Credit Breakdown

	Total Credit	A/C On Time	A/C Off Time
Manual A/C	0.4 g CO_2/mile	0.4 * 44.6% = 0.18 = 0.2 g CO_2/mile	0.4 * 55.4% = 0.22 = 0.2 g CO_2/mile
Automatic A/C	0.4 g CO_2/mile	0.4 * 70.3% = 0.28 = 0.3 g CO_2/mile	0.4 * 29.7% = 0.12 = 0.1 g CO_2/mile

The credit amount per each HVAC type that utilizes PWM BLMs is summarized in Table 6, below. The A/C efficiency cap is applied to the A/C On credit which is A/C usage portion of the total saving. The CO_2 reduction outside of A/C usage (i.e. heater) is not limited by the A/C efficiency cap.

Table 6. HVAC Brushless Motor Credit by System Type and A/C On/Off

[unit: gCO_2/mi]	Total Credit	A/C On Credit	A/C Off Credit
Manual A/C	0.4	0.2	0.2
Automatic A/C	0.4	0.3	0.1

Durability

Durability of the Pulse Width Modulated HVAC Brushless Motor Power Controller has been thoroughly tested to meet Hyundai Motor Company specifications. The HVAC brushless motor technology is applied on HMC vehicles from 2020 model year and are expected to meet all the durability requirements of 40 CFR §86.1869-12(d). The durability evaluation does not predict any expected in-use emission deterioration rate over the full useful life of the vehicle.

Conclusion

Based on the bench test data presented in this application, Hyundai Motor Company, represented by HATCI, hereby requests that the EPA approve an off-cycle following GHG off-cycle credit for 2020 and later model year passenger cars equipped with Pulse Width Modulated HVAC Brushless Motor Power Controller Technology.

Table 7. HVAC Brushless Motor Credit Request

[unit: gCO_2/mi]	Total Credit	A/C On Credit	A/C Off Credit
Manual A/C	0.4	0.2	0.2
Automatic A/C	0.4	0.3	0.1

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Thank you for your consideration of this application for off-cycle GHG credits.

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Attachments:

Attachment A: Bench testing results [CBI]

Attachment B: Confidential listing of 2020 and later HMC Vehicles with HVAC Brushless Motor technology, Sales Volumes and Credits [CBI]