

Development of the Ultra-thin DC Brushless Motor for a Hybrid Car – INSIGHT

Akiyoshi SHIMADA*

Hirohisa OGAWA*

Minoru NAKAJIMA*

Hiroo SHIMADA*

ABSTRACT

We developed an ultra-thin DC brushless motor for use as the auxiliary drive of the ultra-low-fuel-consumption hybrid car, “INSIGHT”.

Use of an ultra-thin design for this motor overcomes restrictions of the layout construction between the engine and the transmission. The ultra-thin design was achieved using a concentrated winding for the salient-pole of the split stator and a centralized distribution bus ring. Utilization of these technologies resulted in a maximum output performance of 10 kW at a maximum torque of 83.3 N-m while keeping the width of the electromagnetic motor circuits to a mere 60 mm. In addition, since the use of this arrangement for the motor subjects it to the effects of water and dirt just as with the clutch compartment, a joint chamber and labyrinth construction is used to form a drain. Meanwhile a stator cover and disk sensor are employed to prevent foreign matter from entering. This design achieves a motor capable of withstanding a harsh ambient environment.

1. Introduction

With the growing importance of environmental issues involving air quality, the INSIGHT ultra-low-fuel-consumption hybrid car offering a fuel consumption of 35 km/liter (10-15 mode) has been developed as one solution to these problems. The Integrated Motor Assist (IMA) system installed in this vehicle employs a parallel hybrid system which uses the engine as the main power source and an electric motor as an auxiliary power source, making it possible to reduce the size and weight of the entire system, including the electric motor⁽¹⁾.

The objectives that were set for the development of this motor involved reducing its thickness to allow transverse mounting of the power train of the IMA system in the engine compartment of a 1.5-liter class vehicle while satisfying required vehicle performance, and ensuring environmental resistance equivalent to that of the engine. This report describes how these objectives were met.

2. Motor Functions and Objectives

Fig.1 shows the engine and electric motor of the IMA system, while Fig.2 shows the system configuration. Since this system is of the parallel hybrid type, the motor has the functions of assisting the engine that serves as the main power source according to the performance being demanded, regenerating braking energy in the form of electrical power, and generating the 12 V load component. In addition, the motor also restarts the engine after it has stopped idling⁽²⁾.



Fig.1 IMA power unit

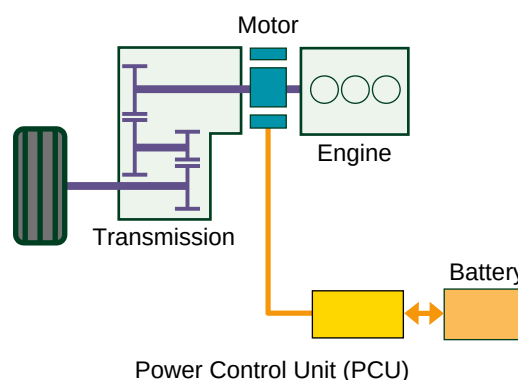


Fig.2 IMA system construction

* Tochigi R&D Center

It was necessary to reduce the size and weight of the entire power train to realize a vehicle capable of fulfilling these functions and of achieving a fuel consumption of 35 km/liter (10-15 mode). In order to accomplish this, the motor is coupled directly to the engine and positioned between the engine and transmission. During the course of motor development, emphasis was placed on a thin design that would provide good resistance to the operating environment, leading to the following technical objectives.

- (1) Compact size, requiring the development of a thin motor that allows the power train to be installed transversely in the engine compartment of a 1.5-liter class vehicle.
- (2) Environmental resistance that ensures durability in the operating position between the engine and transmission.

3. Technology for Developing the Ultra-thin Motor

Fig.3 shows the construction of the stator. The stator is a salient-pole, concentrated-winding split type, incorporating a centralized distribution bus ring and stator holder, and this construction formed the technological basis for developing the ultra-thin motor.

Fig.4 shows examples of a conventional type of winding and the newly developed type of winding. Generally, there are many cases in which the stator is formed into an integrated unit, and wave winding or salient-pole concentrated winding is typically used. There are problems

associated with developing an ultra-thin motor incorporating either of these types of winding.

Wave winding requires an unacceptably wide area for the winding transfer portion and a long time for the winding process. In the case of an integrated stator with salient-pole concentrated winding, it is necessary to ensure adequate space for the winding nozzle to move as shown in Fig.5, otherwise the range over which windings can be provided is limited. This problem was solved by the construction described next.

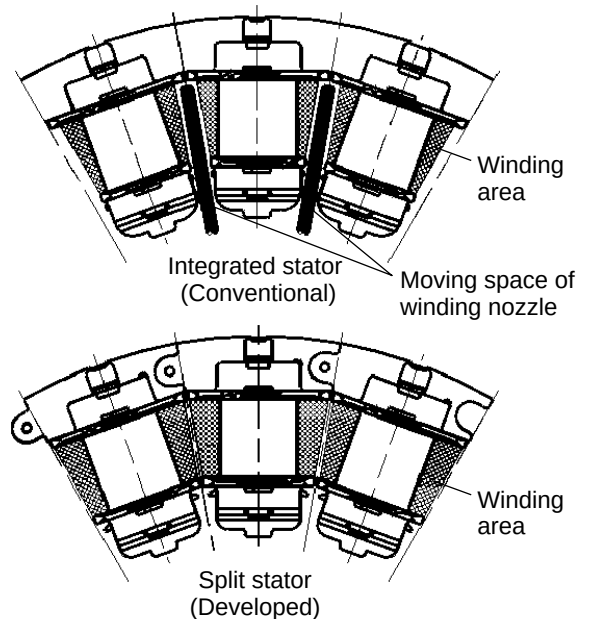


Fig.5 Comparison of winding area

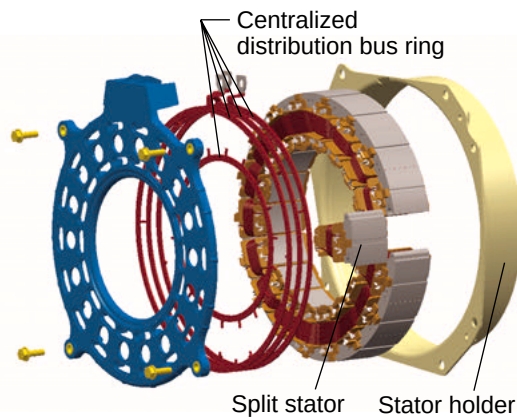


Fig.3 Stator construction

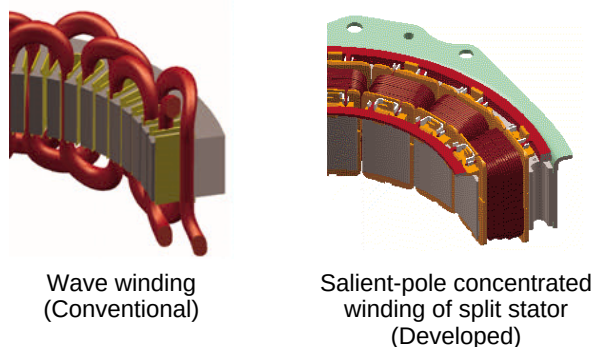


Fig.4 Comparison of winding

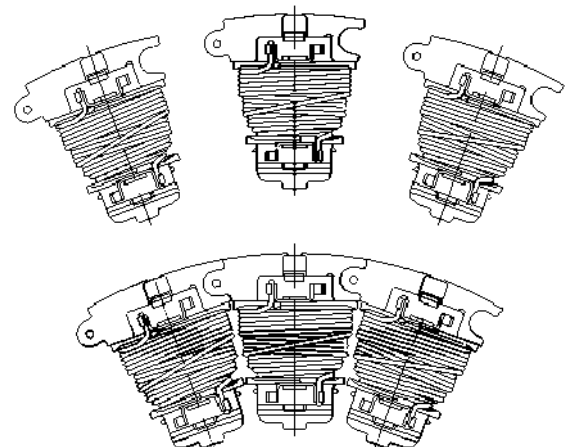


Fig.6 State of winding with split stator

that of an integrated stator. Moreover, by maintaining the alignment with salient-pole concentrated winding, increasing the space factor of the windings and combining with a centralized distribution bus ring, the width of the electromagnetic motor circuits could be reduced without compromising the vehicle torque demand.

This type of stator also offers better manufacturability than an integrated stator, starting with the yield of the silicon steel plate. In order to improve the yield, the stator was split and blanked as shown in Fig.7. The lamination and fixing processes are also relatively simple due to the use of internal die caulking. In addition, since the split stator allows winding work to be done for each pole, the size of the equipment can be minimized.

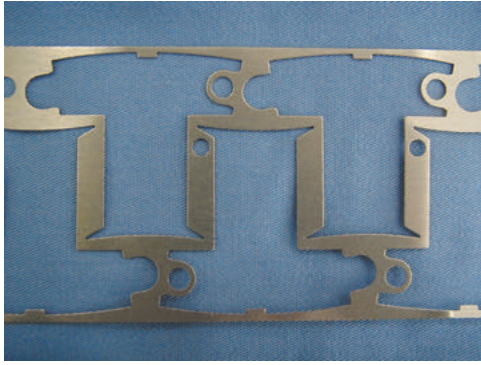


Fig.7 Blanking of flat rolled silicon steel

3.2. Centralized Distribution Bus Ring

This 3-phase motor uses six windings connected in parallel for each phase as shown by the equivalent circuit in Fig.8. The red portion of this figure corresponds to the centralized distribution bus ring. This component is stamped from a copper plate, and each winding is then connected. Since the six windings would need to be fixed with the wiring in the form of a crossover for each phase in a conventional motor, this would result in manufacturing difficulties. However, the use of a centralized distribution bus ring enables the work to be simplified by fusing only at the terminal portion. Fig.9 shows a comparison of these wiring diagrams with and without a centralized distribution bus ring.

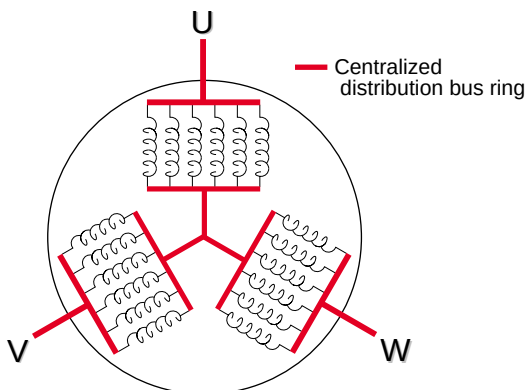


Fig.8 Equivalent circuit of the motor

The crossover portions can be seen to be much simpler as a result of employing the centralized distribution bus ring.

The three-phase centralized distribution bus ring is stacked as shown in Fig.10 to minimize the thickness. Although insulation between the phases could present a problem with this stacked structure, the required level of resistance in the operating environment in terms of heat, vibration and dust required fluorine to be selected for the insulation coating material. The thickness of the fluorine coating was determined from the results of durability and reliability tests, using the data in Fig.11 as the evaluation criteria. The results of these tests under the harsh conditions of hot and cold, vibration and dust clearly proved that the fluorine coating would be optimally suitable. These technological solutions made it possible to reduce the

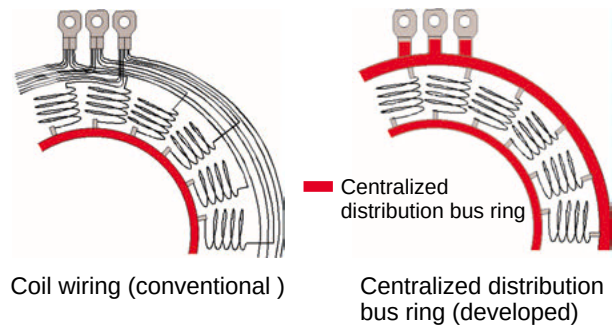


Fig.9 Comparison of wiring

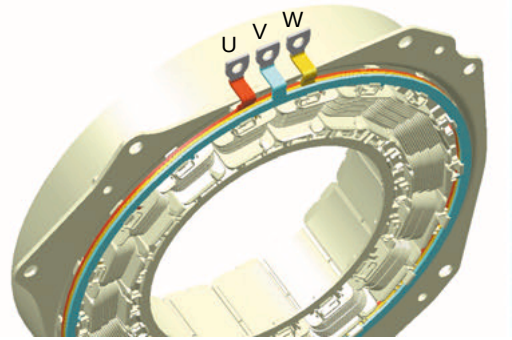


Fig.10 Layout of centralized distribution bus ring

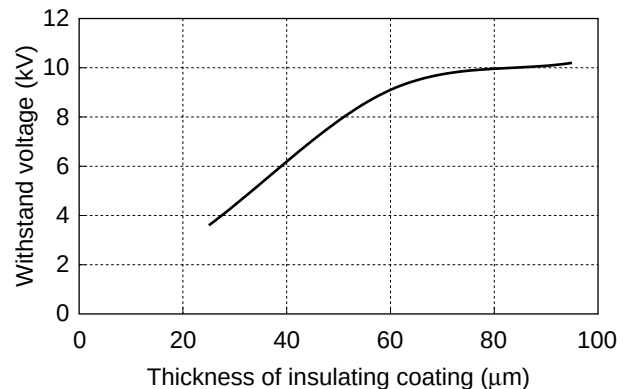


Fig.11 Isolation performance curve

thickness of a conventional motor by approximately 40% to produce an ultra-thin motor having a thickness of only 60 mm. Fig.12 shows the hybrid power train featuring this new electric motor, while Table 1 and Fig.13 show the motor specifications.

4. Durability in a Harsh Operating Environment

Since the motor is located inside the clutch housing between the engine and transmission, it is difficult to create a watertight operating environment. Thus, a design was

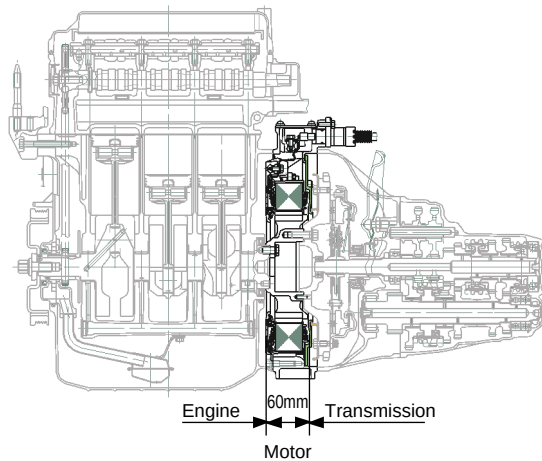


Fig.12 Cross section of hybrid power train

Table 1 Specifications of motor

Motor type	DC brushless	
Number of phase	3 phases	
Number of pole	12 poles	
Number of slot	18 slots	
Weight	18.6kg	
Maximum output power	Starter	83.3N-m/2kW
	Assist	49.0N-m/10kW
	Regeneration	83.3N-m/10kW

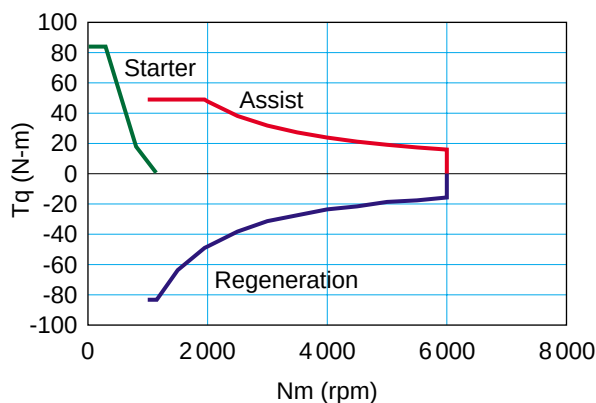


Fig.13 Motor power performance curve

developed to make it difficult for water, oil, etc. to enter this housing, while also allowing rapid drainage in the case of ingress. It was also necessary to prevent any contamination of the motor electromagnetic circuits by foreign matter, despite the fact that the motor would need to tolerate clutch lining dust and other magnetic substances. These problems were solved in the manner described next.

4.1. Water Sealing and Drainage

The motor is provided with a drain and breather to minimize the effect of water and oil ingress. Particular attention was focused on drainage, since the bottom of the motor is at nearly the lowest point of the vehicle in its mounted position. In the case of traveling in wet conditions, water is sprayed from the tires on to the motor housing. This spray will penetrate into the motor if drainage is provided simply through holes in the motor housing.

Fig.14 shows the drainage method employed in the early stages of development. Although a pipe was inserted into the motor housing and this pipe discharged away from the direction of vehicle travel, the high-pressure water spray penetrated the motor through this drain pipe. The design shown in Fig.15 resolved this problem by incorporating a baffled plenum chamber between the drain outlet and the hole leading into the motor.

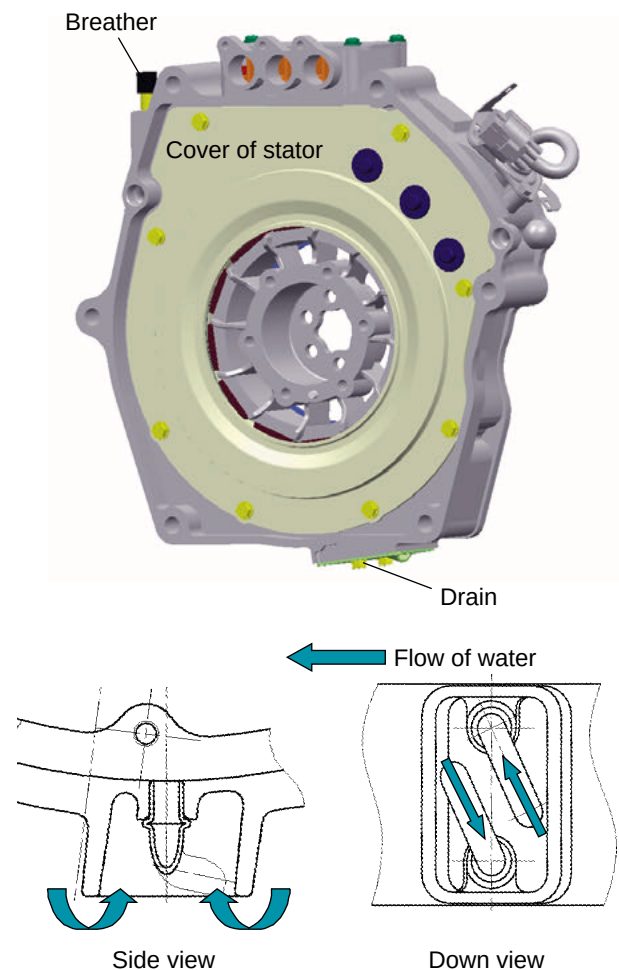


Fig.14 Prototype of drain construction

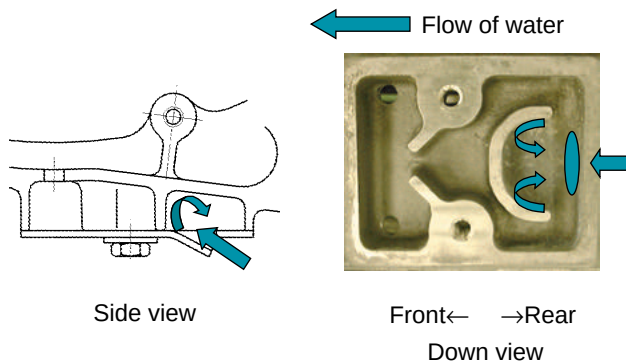


Fig.15 Production model of drain construction

4.2. Sealing Against Clutch Lining Dust, Metallic Particles and Other Foreign Matter

The clutch housing in which the motor is located is basically open to the atmosphere. Accordingly, external dust and other foreign matter is able to enter the clutch chamber. In addition, routine operation of the clutch generates clutch lining dust and metallic particles within the clutch housing. Any substantial amount of this dust and foreign matter accumulating on the windings and magnets of the motor would have a detrimental effect on its performance. A labyrinth seal is therefore provided between the stator cover and commutation sensor disk as shown in Fig.16 to inhibit the entry of dust and foreign matter from the clutch housing. This sealing system has been rigorously tested over the service life of the vehicle.

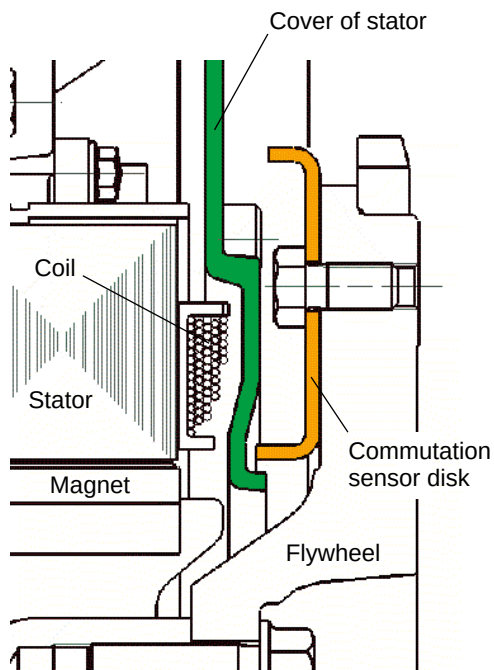


Fig.16 Enlarged cross section of motor & transmission

5. Conclusion

Novel approaches were taken to develop an ultra-thin motor that would operate reliably under harsh conditions to produce a compact hybrid power train.

(1) Salient-pole, concentrated-winding, split stator

The use of this split stator results in an approximately 70% increase in winding range when compared to a conventional integrated stator.

(2) Centralized distribution bus ring

The conventional wiring and anchoring processes used for winding crossovers have been simplified by only needing to perform fusing work.

(3) Effective water sealing and drainage

The use of a chamber structure and labyrinth structure are combined.

(4) Sealing against clutch lining dust and foreign matter

A labyrinth seal is provided between the stator cover and commutation sensor disk.

References

- (1) Fukuo,K., Fujimura,A., Saito,M., Tsunoda,K., Takiguchi,S.: Development of the Ultra-Low-Fuel-Consumption Hybrid Car - INSIGHT, HONDA R&D Technical Review, Vol.11, No2, p.1-8(1999) (Written in Japanese)
- (2) Ochiai,S., Uchibori,K., Hara,K., Tsurumi,T., Suzuki,M.: Development of the Motor Assist System for a Hybrid Car - INSIGHT, HONDA R&D Technical Review, Vol.12, No1, p.7-14(2000) (Written in Japanese)

■ author ■



Akiyoshi SHIMADA



Hirohisa OGAWA



Minoru NAKAJIMA



Hiroo SHIMADA