

Development of High Induction Stator Core

Takehiro MIYOSHI*

ABSTRACT

Stator core iron loss was reduced by 60% by optimizing the thickness and microstructure of iron-cobalt alloy, which shows a high induction, and by developing a new adhesive and surface treatment technology. A manufacturing process was developed that satisfies the required magnetic characteristics and dimensional accuracy, and a new production system was constructed for laminated parts. The newly developed stator enabled a 20% reduction in the motor size.

1. Introduction

Application of hybrid systems to Formula One racing cars was planned from 2009, and the increased weight and effects on aerodynamics of adding motor-related parts was an issue. Reducing the size and weight of motor parts is essential for maintaining competitiveness, and the aim was to reduce the stator core size by applying a high induction permendur (Fe 49%, Co 49%, V 2%, hereafter “FeCo materials”). FeCo materials are used in the military, aerospace and other fields, but the steel type specifications are limited and there is also a long manufacturing lead time. Higher induction and lower iron loss were pursued for racing use, and efforts were also made to establish material specifications and a stator core manufacturing method that satisfy the required dimensional accuracy and productivity.

2. Developed Technologies

2.1. Material Development

Figure 1 shows the target material property values. Compared to Fe-Si (“Base”), existing FeCo materials (“original”) have high iron loss, so the target was set at an iron loss equal to or less than that of Fe-Si. Iron loss is classified into the two types of eddy current loss and hysteresis loss, and eddy current loss is proportional to the square of the thickness, so eddy current loss can be reduced by reducing the thickness⁽¹⁾. However, reducing the thickness raises the issues of a lower lamination factor, lower rolling and pressing quality, and lower productivity due to an increased number of layers. The iron loss values of cold rolled materials with a thickness of 10 μm to 150 μm were measured under conditions of 1.0 T and 400 Hz. The magnetic characteristics were measured using a toroidal-shaped laminated ring with an

outer diameter of 25 mm and an inner diameter of 15 mm. Figure 2 shows the structure after rolling, and Fig. 3 shows the magnetic characteristics. The lowest iron loss value occurred at a thickness of 50 μm . Reducing the thickness lowers the eddy current loss, but at the same time the structure becomes finer, resulting in an increased hysteresis loss. This is thought to be why the total iron loss is not reduced at a thickness of 50 μm or less. The lamination factor drops when lamination is performed with a thickness of 50 μm , so the thickness was set at 100 μm in consideration of the balance between the lamination factor and iron loss.

An insulation layer is needed between the steel sheet layers to reduce eddy current loss, so thinness, insulation performance, and productivity are demanded. It was difficult to coat thin plates with a zinc phosphate insulating film for Fe-Si, and the required insulation performance could not be obtained. Various insulation treatments were evaluated, and the results showed that eddy current loss was most reduced by the oxide film. This film was formed by adding a heat treatment process after magnetic annealing.

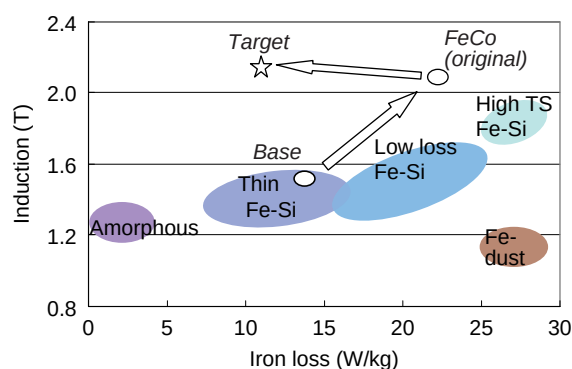


Fig. 1 Target properties

* Automobile R&D Center

Calking and welding produce strain that leads to a rise in iron loss, so the laminated materials were fixed using adhesive. This adhesive required adhesive strength, thinness, heat resistance and oil resistance, so a newly developed heat resistant adhesive with low viscosity was applied. Figure 4 shows the insulation film layers. The adhesive layer together with the insulation layers on both sides have a combined thickness of just 3 μm , which enabled a stator lamination factor of 97% or more.

2.2. Heat Treatment and Lamination Process

The heat produced by magnetic annealing causes the fixing jig to adhere and deform, so deformation was suppressed by adding a permeable ceramic. This work method enabled simultaneous heat treatment of multiple stators.

FeCo materials show order-disorder transformation by magnetic annealing, resulting in different dimensions before and after treatment. Press accuracy was achieved by using a die that is adjusted for heat deformation.

Securing flatness of the edge surfaces after adhesive bonding was difficult, but parts accuracy was achieved by increasing the jig accuracy, use of vacuum debubbling, and optimizing the core-turning and lamination procedure.

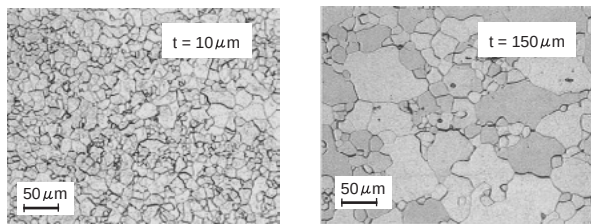


Fig. 2 Microstructure

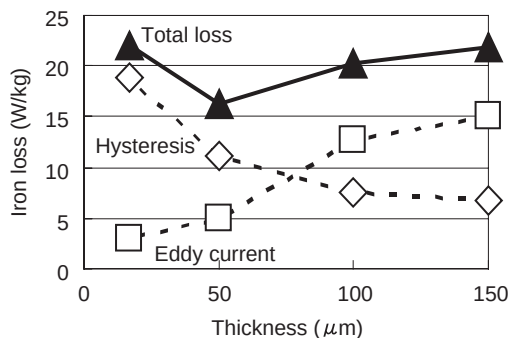


Fig. 3 Iron loss and thickness

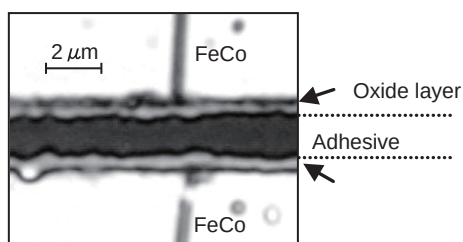


Fig. 4 Surface treatment and adhesive layer

3. Effects on Performance

Copper wire was wrapped around a core yoke, and the DC BH characteristics and iron loss value were measured to confirm the magnetic characteristics of an actual stator core. Figure 5 shows an exterior view of the test sample. The induction B50 was 2.0 T or more, and iron loss was 12 W/kg or less at W10/400, which met the targets. A motor using the newly developed materials achieved 15% higher torque with a size 20% smaller than that of a motor using Fe-Si materials.

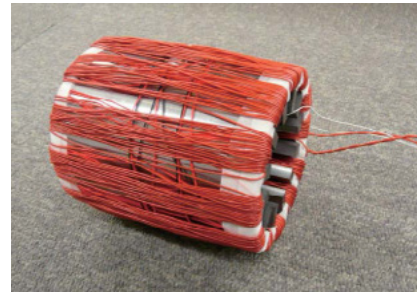


Fig. 5 BH measurement sample

4. Conclusion

- (1) Using existing FeCo materials as a base, the thickness and structure were optimized and a new surface treatment was developed. This simultaneously achieved high induction and low iron loss.
- (2) A machining process for ultra-thin laminated materials was developed that both satisfies dimensional accuracy and has high productivity.
- (3) The motor size was reduced by 20%.

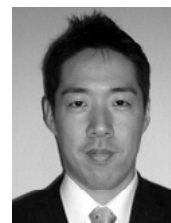
Acknowledgments

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Reference

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Author



Takehiro MIYOSHI