REDUCTION OF IRON LOSS ON LAMINATED STATOR CORES BY SECONDARY CURRENT HEATING METHOD

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Abstract. In this paper, the "secondary current heating method," which has been proposed in the previous reports, was used to heat-treat the laminated stator cores of actual motors to reduce iron loss. To evaluate the magnetic properties of the laminated stator cores including the teeth, an inner core was installed inside the stator to form a closed magnetic path. The air gap between the stator and the inner core causes the B-H loops to be tilted compared to the one of the back yoke, though, it was found that the iron loss was reduced by about 30% in the laminated stator core after heat treatment.

1. Introduction

Residual stresses generated in the manufacturing processes of motor cores, such as punching, laminating, caulking, welding, winding, and press-fitting, are factors that degrade the magnetic properties of electrical steel sheets [1]. For this reason, all industrial motor cores used to undergo heat treatment (strain relief annealing) in a large electric furnace. In large electric furnaces, the heat treatment time is long (about 12 hours) and the running cost is high because of the atmosphere heating (indirect heating). Therefore, heat treatment is not currently used for industrial motors in Japan. However, it is an important issue to reduce the iron loss of industrial motor cores and achieve higher efficiency by some kind of treatment in order to realize a carbon neutral society.

Therefore, we have proposed a new heat treatment method for ring-shaped laminated cores of electrical steel sheets that are to be heated in a much shorter time than in a conventional large electric furnace to reduce the iron loss [2]. The new heat treatment method is named "Secondary Current Heating method," and it has been shown that the iron loss of ring-shaped laminated cores can be reduced by up to 14% in about 10 minutes [2]. The principle diagram of the Secondary Current Heating method is shown in Fig. 1. The magnetic flux change chained around the centre of the ring-shaped laminated cores generates a secondary current (induced current) in the object to be heated, enabling direct heating using the object itself as the heat source. This enables heat treatment in a shorter time than indirect heating in an electric furnace.

In this paper, we examine to apply the Secondary Current Heating method into heating actual motor laminated stator cores to reduce iron loss.

2. Secondary Current Heating Method

As shown in Fig. 1, the Secondary Current Heating device consists of a main yoke, an excitation coil, an auxiliary yoke, and a laminated stator core as the object to be heated. The auxiliary yoke and laminated stator cores are removable for installation in the actual manufacturing process. The excitation coil generates magnetic flux in the main yoke and the auxiliary yoke. Due to the alternating magnetic flux, time-varying magnetic fluxes intersect in the laminated stator cores surrounding the auxiliary yoke, generating an induced electromotive force. Since the back yoke section of the laminated stator cores is electrically short-circuited, a secondary current (induced current) flows. Fig. 2 shows the laminated stator core used in this paper. The stator core has an outer diameter of approximately 50 mm, an inner diameter of the teeth of approximately 30 mm, and a lamination thickness of approximately 26.5 mm. The number of teeth is 6. The stator cores are made from non-oriented electrical steel sheets with the 0.5 mm-thickness, laminated by punching and caulking. For the ring-shaped specimens reported so far, the target temperature was set at around 600 °C to minimize the heating time, but for the laminated stator cores, we aimed at a shorter heat treatment time above the recommended strain relief annealing temperature to further reduce the iron losses in the cores.

3. Magnetic properties of laminated stator cores and reduction of iron loss

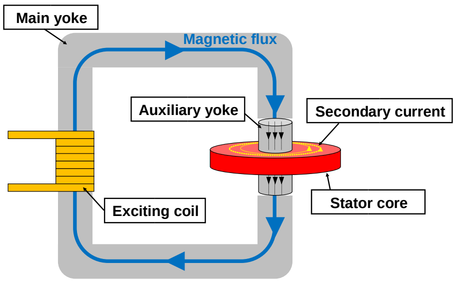

Fig. 1 Secondary Current Heating method

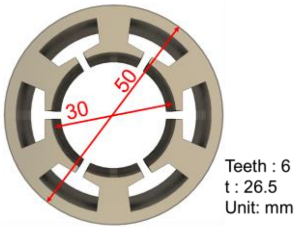

Fig. 2 Laminated stator core

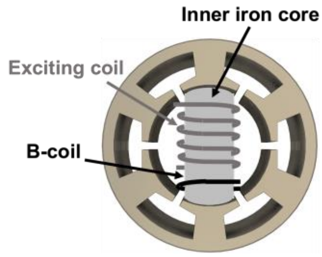

Fig. 3 Allocation of exciting coil and B-coil of stator cores

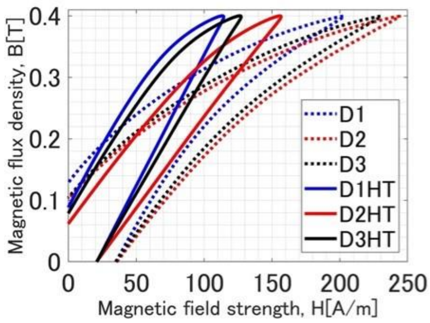

Fig. 4 B-H loops of stator core at frequency, 50 Hz at 0.4 T.

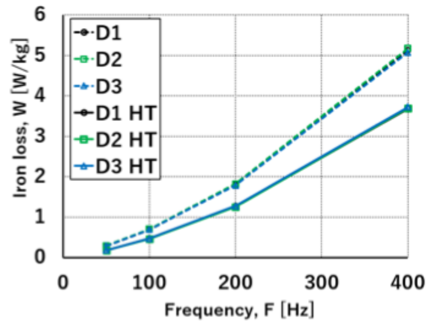

Fig. 5 Iron distribution of stator cores

In the measurement system on magnetic properties, the magnetic flux density B of the laminated stator cores is feedback-controlled by a PC to set the target value so that the magnetic properties and iron loss, which are different due to heat treatment, can be compared and evaluated under the same magnetic conditions. The B-H loops were derived from the excitation coil and B coil, and they were compared and evaluated. The iron losses were calculated from the B-H loops, and the usefulness of heat treatment using the Secondary Current Heating method was discussed.

Since the magnetic properties of the teeth contribute greatly to motor performance, the magnetic properties of the stator cores, including the teeth, were evaluated. As shown in Fig. 3, the excitation coil and B coil are wound around the inner core so that it can be easily installed in any pair of teeth. In our preliminary experiment, the B-H loops varied depending on the position where the inner core was installed. We investigated the reason, and found that the laminated stator cores used in this paper were for small power motors, so rolling direction was not taken into account during laminating, and the effect of magnetic anisotropy was found. Therefore, to ensure that the rolling direction of the laminated stator cores and the direction of the inner core installation were unique, measurements were performed by installing the inner core in three different ways: PositionD1, Position-D2, and Position-D3. The B-H loops measured with the inner core is shown in Fig. 4. The magnetic flux condition is 0.4 T. The dotted line is before heat treatment and the solid line is after heat treatment. Compared to the B-H loops measured on the back yokes, these B-H loops are significantly tilted. This is due to the gap between the stator cores and the inner core. However, the B-H loops including the teeth are also improved after proposed heat treatment, and it is possible to evaluate the magnetic properties of the entire laminated stator cores including the teeth by using the inner core. Fig. 5 shows the iron loss distributions. Compared to the back yoke section, the iron losses increase. Since the iron losses remain almost the same even when there is a gap in the magnetic path, the iron losses of the entire laminated stator cores, including the teeth section, is considered to be larger than that of the back yoke section. In any case, the iron losses of the entire laminated stator cores were found to be reduced by about 30% after heat treatment. Details and further discussions are to be presented in the full paper.

References:

[1] Schoppa A., et al., Influence of the manufacturing process on the magnetic properties of non-oriented electrical steels, *Journal of Magnetism and Magnetic Materials*, 2000, **215-216**, 74-78.

[2] Tsuchida Y., Yoshino N., and Enokizono M., Reduction of Iron Loss on Laminated Electrical Steel Sheet Cores by means of Secondary Current Heating Method, *IEEE Transactions on Magnetics*, 2017, **53**, 4 pages.