An Improved Method for Predicting Iron Losses in SMC Electrical Machines

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Abstract. This paper presents an improved method for predicting iron losses in electrical machines with soft magnetic composite (SMC) cores. Different formulations are used for iron loss prediction with purely alternating, purely circular rotating, and elliptically rotating flux density vectors, respectively. A series of three-dimensional finite element analyses is conducted to determine the flux density locus in each element in a claw pole permanent magnet SMC electrical machine when the rotor rotates. The predicted results are compared with the experimental data of the prototype.

1 Introduction

The local flux density patterns within a three-dimensional (3D) flux electrical machine are quite complex. The flux density locus at one position can be alternating (1D) with or without harmonics, 2D or even 3D rotating with purely circular or elliptical patterns. Experiments on samples revealed significant difference between the core losses caused by alternating and by rotating magnetic fields.

This paper outlines the core loss calculation in a claw pole SMC machine by using a 3D finite element analysis of magnetic field. The total core loss is computed by summing up the core loss of each element, which can be obtained by calculating separately the hysteresis (alternating and rotational, both purely circular and elliptical), eddy current, and anomalous losses, when the rotor rotates. The coefficients for each loss component are determined by a loss separation procedure and the experimental data obtained by using a single-sheet two-dimensional core loss testing system [1].

2 Modelling of Iron Losses

For alternating core loss modelling, a standard practice is to separate the loss into three components: hysteresis, eddy current and anomalous losses, i.e. $P_a=C_{ha}fB^h+C_{ea}(fB)^2+C_{aa}(fB)^{1.5}$, where B is the peak value of flux density, f the frequency, and C_{ha}, h, C_{ea}, and C_{aa} are the loss coefficients.

Similarly, the specific core loss with a circular rotating flux vector $\boldsymbol{B}$ can also be

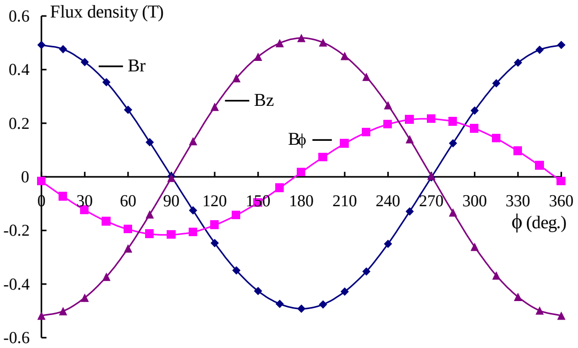

Figure 1: Time variation of flux density at a typical point in the claw poles

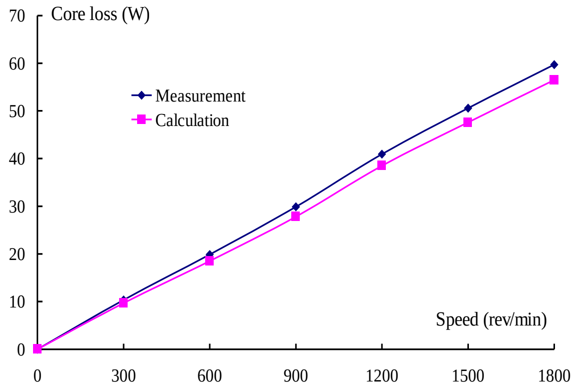

Figure 2: Core loss calculation and measurement

separated into three components as $P_r=P_{hr}+C_{er}(fB)^2+C_{ar}(fB)^{1.5}$, where P_{hr} is the rotational hysteresis loss, and C_{er} and C_{ar} are coefficients for the rotational eddy current and anomalous loss components. The rotational hysteresis loss behaves very differently from its alternating counterpart. To model the rotational hysteresis loss, a novel formulation was proposed in [2]. It is postulated that the specific rotational hysteresis loss per cycle can be expressed in terms of four parameters, a_1, a_2, a_3, and B_s, by

$$\frac{P_{hr}}{f}=a_1\left[\frac{1/s}{(a_2+1/s)^2+a_3^2}-\frac{1/(2-s)}{[a_2+1/(2-s)]^2+a_3^2}\right],\text{ where } s=1-\frac{B}{B_s}\sqrt{1-\frac{1}{a_2^2+a_3^2}} \quad (1)$$

The core loss with an elliptical rotating flux density can be predicted from the alternating and purely circular formulations as [2]: $P_t=R_BP_r+(1-R_B)^2P_a$, where $R_B=B_{min}/B_{maj}$ is the axis ratio, and B_{maj} and B_{min} are the major and minor axes of the elliptical $\boldsymbol{B}$ locus.

3 Magnetic Field Analysis and Core Loss Calculation

Figure 1 shows the calculated time variations of the corresponding flux density at a typical element in the claw poles. The flux density is really 3D and further analysis shows the locus of $\boldsymbol{B}$ rotates (elliptically) in a plane, which is not parallel to any coordinate axis. Figure 2 shows the core loss calculation for different frequencies or rotor speeds.

4 Core Loss Measurement

To measure the core loss of the claw pole permanent magnet (PM) machine, a calibrated dc motor is used as a prime mover. At no-load and connected to the tested machine, the power fed into the dc motor is measured. The difference gives the sum of the core loss and mechanical loss of the tested machine.

The mechanical loss of the PM machine is measured by replacing the SMC stator with a wood tube (to imitate the windage) and then repeating the previous procedure. The core loss is obtained by subtracting the mechanical loss from the sum of the core loss and mechanical loss. The measured core losses at different speeds are also plotted in Figure 2.

5 Conclusions

The comparison between the calculated and measured core loss in a claw pole permanent magnet SMC machine shows that the proposed core loss models and calculation method are practical. The calculation core loss is about 6% lower than the measured. This may be due to that there is some core loss in the stator shaft and other iron parts. More details will be presented in the extended full paper.

References

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[2] J.G. Zhu and V.S. Ramsden, Improved Formulations for Rotational Core Losses in Rotating Electrical Machines, *IEEE Transactions on Magnetics*, Vol.34, No.4, July 1998, pp. 2234-2242.