Core Loss Calculation of Permanent Magnet Machines Using Analytical Method

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Abstract
The core losses are caused by the changing flux densities in various parts of the iron structures in the permanent magnet (PM) machine. Some of these core losses can be significant during high-frequency operations. It is imperative to consider the core losses during the design stage. The purpose of this paper is to analytically predict the core loss of the PM machine at the design stage. The core loss obtained by the analytical method is compared with those obtained using the finite element method and experiments. In order to verify this, the core loss results obtained using the proposed method, an experimental system was implemented with a commercial PM machine, power analyzer, and the manufactured test PM machine.

Process of proposed core loss calculation method

- As shown in Fig. 1, the process followed in the proposed analytical method is given below.
- Step 1: Rearrangement of the core loss data
- Step 2: Deduction of the core loss coefficient by curve fitting
- Step 3: Analytical modeling with a search coil for calculating the flux density
- Step 4: Calculation of the core loss using the obtained core loss coefficients and flux density.

For core loss modeling, a standard practice is to separate the loss into the following three components: hysteresis (P_h), eddy current loss (P_e), and anomalous loss (P_a), i.e., the core loss considering the anomalous loss is expressed as follows:

\[ P_{core} = P_h + P_e + P_a \]

The function for the frequency of each core loss coefficient can be obtained as follows:

\[ k_1 = 3.721\exp(-f/5) + 0.00592 \]
\[ k_2 = \exp(-0.474\log(f) - 7.002) \]
\[ k_3 = \exp(-0.0075 \times 7.22) \]
\[ n = 1.115^{f/10} - 0.0067 < f/105 \]

Core loss calculation

From V x A = B, the normal and the tangential component of the flux density can be expressed as

\[ P_{core} = B_{\parallel} I_{\parallel} + B_{\perp} I_{\perp} \]

The magnetic vector potential A

\[ A_{\parallel} = k_0 B_{\parallel} \ln \left( \frac{L}{r} \right) \]
\[ A_{\perp} = k_0 B_{\perp} \ln \left( \frac{L}{r} \right) \]

As in this paper, an analytical method for computing the core loss in PM machine was presented.

- The stator core loss can be calculated from the loss factor calculated by curve fitting of the original core loss data and the magnetic flux density of the stator calculated by the analytical method.
- At this time, the behavior of the magnetic field was referred to the existing study.
- In order to have a good precision in the analytical results, the number of harmonic terms used in the computations was equal to N=70 (air-gap and PM stator calculated by the analytical method).
- In order to verify the core loss results predicted by curve fitting method and magnetic behavior analysis, the experimental system has been implemented with commercial DC motor, power analyzer (PM3300-Voltèch) and manufactured test motor.
- For the case when the PM machine is driven at rated speed 450 rpm, the analytical predictions, FE analysis and measurements for the core loss have a result of 8.64 W, 9.2 W and 10.26 W, respectively.

Conclusion

- In this paper, an analytical method for computing the core loss in PM machine was presented.
- The stator core loss can be calculated from the loss factor calculated by curve fitting of the original core loss data and the magnetic flux density of the stator calculated by the analytical method.
- For a given rotor position, the computation time is approximately 10 s with the analytical model, whereas the nonlinear FE analysis takes approximately 100 s for a mesh of 26510 elements.
- The analytical method presented in this paper is very convenient for comprehensive studies and incorporation into optimization.