A Study on the Simulated Torque Table With Nonlinear Datasets of IPMSM for HEV

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Abstract — This paper supposes a method for setting up the simulation of operation performance in consideration of non-linearity of IPMSM. For this, it makes datasets of various parameters with non-linearity through FEM and an interpolation method. It simulates MTPA control and FW control accurately using the datasets, moreover it embodies the efficiency-map of IPMSM accurately on the basis of the simulation. Last, it verifies the validity of simulation through tests.

I. Introduction

Recently, a hybrid electric vehicle has attracted public attention, so it emphasizes the necessity of traction motor with a high input current and wide driving range. Among them, various researches have been regarding IPMSM with high power density and mechanical solidity. [1] However, due to complexity of parameters with non-linear characteristics of a motor and current vector control, actually it is so difficult to estimate a base speed within an actual driving range or a voltage limit accurately. Moreover, it is impossible to embody the construction of efficiency-map because of the efficiency that is different according to control modes.

First, IPMSM used in the present paper is designed for 5ton series-type hybrid truck, that shows high armature reaction due to a high current of 535A and high-speed operation of 10000rpm in an instantaneous driving condition performs maximum power control. Specifications of IPMSM are shown in TABLE I and Fig.1 shows the flux-density distribution of model on the condition of 535A and 3000rpm.

II. Calculation of NonLinear Dataset using FEM

In case of the traction motor, a current phase angle is changed according to speed by performance of flux-weakening control for high-speed operation. Parameters showing nonlinear characteristic according to changes of current phase angles are inductance, core loss and input voltage to embody driving simulation of IPMSM. The inductance is a parameter used for calculation of torque, and the core loss is also a parameter used for calculation of efficiency and shaft torque. Lastly, the input voltage is an important parameter in flux-weakening control in consideration of voltage limits. For example, Fig. 2 shows the nonlinear loss datasets.

III. Torque Table Considering the Control Mode

The majority of IPMSM use the maximum power control that gains the maximum power while satisfying current and voltage limit. [2] In this time, they use the maximum torque-per-ampere (MTPA) control only in consideration of current limit, up to base speed at which the input voltage reaches the voltage limit. In areas showing more than base speed, they use flux-weakening (FW) control to reduce the induced voltage by the increase of d-axis current. The flowchart of the driving simulation supposed by the present paper is shown in Fig.3.

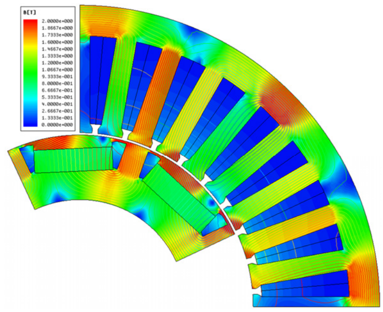
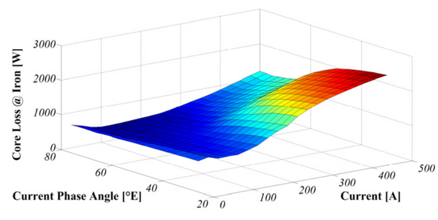


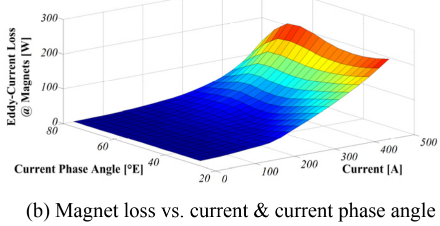
Fig. 1. IPMSM flux-density distribution @ 535A, 3000RPM

TABLE I
SPECIFICATIONS FOR THE IPMSM

Item	Specification
Instantaneous Power / Torque	120 [kW] / 403 [Nm]
Continuous Power / Torque	65 [kW] / 224 [Nm]
Maximum Rotating Speed	10,000 [RPM]
Battery Voltage / PWM method	600 [V] / Space Vector PWM
Poles / Slots	8 / 36 (Distributed Winding)
Current Density	15 [A/mm^2] (Water Cooling)
Outer Diameter / Stack Length	250 [mm] / 230 [mm]



(a) Iron loss vs. current & current phase angle



(b) Magnet loss vs. current & current phase angle
Fig. 2. Nonlinear Characteristics of the Core Loss dataset

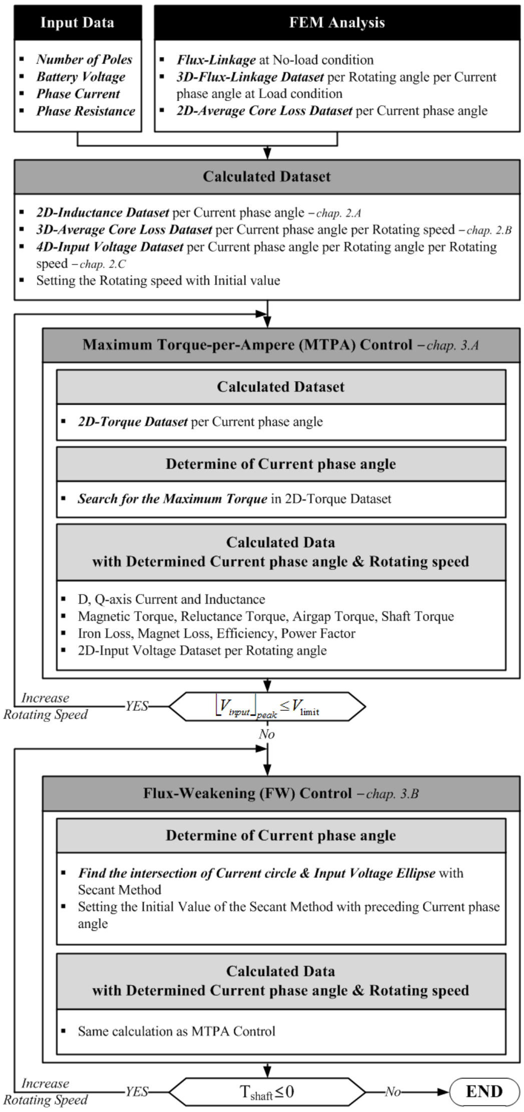


Fig. 3. Process of Torque Table Simulation for IPMSM

IV. Verification Through Test

The performance test was performed by using a motor made to verify the validity of the present paper. Fig.4 shows the setup of the motor and test equipments and Fig.5 is the efficiency-map of the IPMSM. TABLE II shows the comparison between characteristics in torque and efficiency of a test value and an analyzed value, and it is found as proper according as an error rate is below 5%.

TABLE II
COMPARISON OF THE DRIVING SIMULATION AND TEST @ CONTINUOUS POWER

Speed / Current	Torque [Nm] /Efficiency [%] [sim. vs Exp.]	Error Ratio [%] [Tor. / Eff.]
1000RPM / 168A	218 / 93.6 vs 221 / 94.3	98.6 / 99.3
2843RPM / 168A	217 / 95.8 vs 221 / 95.7	98.2 / 100.1
5000RPM / 108A	132 / 96.2 vs 123 / 94.6	107.3 / 101.7
7000RPM / 84A	90 / 95.9 vs 94 / 94.6	95.7 / 101.4

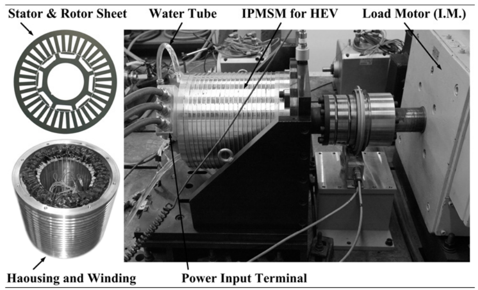


Fig. 4. Manufactured IPMSM and experiment equipments

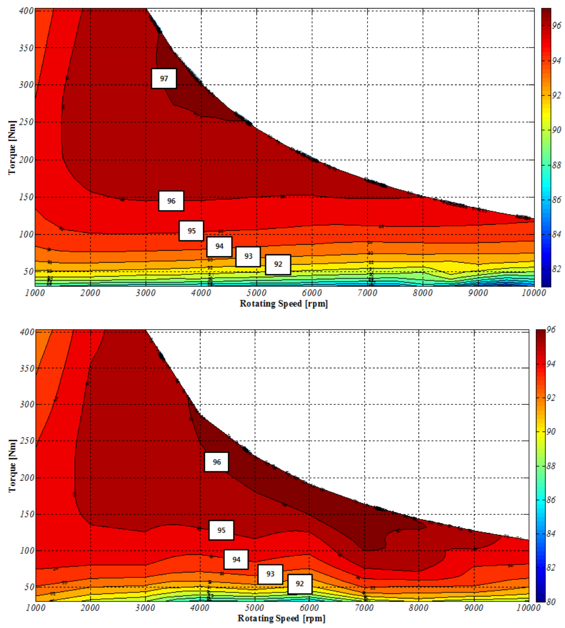


Fig. 5. Comparison of Efficiency-Map with Sim. & Exp.

V. Conclusion

It reduces the number of FEM analysis to the minimum, and proposes the torque table simulation of IPMSM considering all nonlinear characteristics. Moreover, it calculates the efficiency map using the simulation and verifies the validity through tests.

VI. Acknowledgment

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VII. References

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