EVTeC 2025
7th International Electric Vehicle Technology Conference 2025
20259024

Developing IPMSM control that achieve high precision with short calibration time

Kentaro Matsuo [1)] **Shun Taniguchi** [2)] **Hiroaki Inaba** [3)]
1) Astemo Ltd., 2520, Takaba, Hitachinaka, Ibaraki 312-8503, Japan
E-mail: kentaro.matsuo.xb@hitachiastemo.com
2) Astemo Ltd., 2520, Takaba, Hitachinaka, Ibaraki 312-8503, Japan
E-mail: shun.taniguchi.xt@hitachiastemo.com
3) Astemo Ltd., 2520, Takaba, Hitachinaka, Ibaraki 312-8503, Japan
E-mail: hiroaki.inaba.vu@hitachiastemo.com

ABSTRACT: In recent years, motor-powered vehicles (xEVs) such as hybrid vehicles, plug-in hybrid vehicles, and electric vehicles have attracted attention due to growing interest in environmental issues. E-motor control of inverter/e-motor systems for xEVs requires the following characteristics. High requirements for torque accuracy and torque response, necessity to adjust (calibrate) control parameters using the actual machine, and presence of many models. Therefore, e-motor control is required to realize high precision in short calibration time. Therefore, we developed new calibration methods and evaluated it with a 200kW-class EV motor.

KEY WORDS: xEV, IPMSM, Torque control, Torque accuracy, Calibration

1. INTRODUCTION

In recent years, motor-powered vehicles (xEVs) such as hybrid vehicles, plug-in hybrid vehicles, and electric vehicles have attracted attention due to growing interest in environmental issues. Hitachi Astemo Ltd. is aiming to expand its market share of electric products and is focusing on the development of inverters for xEVs.

Inverter/e-motor systems for xEVs generally use IPMSM, which is compact and lightweight. IPMSM(Interior Permanent Magnet Synchronous Motor) control for xEVs requires the following characteristics.

(1) High requirements for torque accuracy and torque response.

(2) Necessity to adjust (calibrate) control parameters using the actual machine.

(3) Presence of many models.

Therefore, IPMSM control is required to realize high-precision controllability in a short calibration time. Therefore, we improved the calibration method and introduced it into product development. As a result, the torque accuracy/response calibration time, which used to take about half a year, was shortened to about 2~4 weeks. In this paper, we show the method of shortening the calibration time and the evaluation results of the torque accuracy by conducting it.

2. ISSUES OF CALIBRATION FOR MOTOR CONTROL

IPMSM control has two main functions: one is the current command calculation to determine torque accuracy, and the other is the current control (Auto current regulator) to determine dynamic characteristics. The current command calculation calculates the d-axis and q-axis current command values with respect to the torque command value given by the upper controller. The d-axis and q-axis current command values with respect to the torque command value have nonlinear relationships and have many influencing factors. The current control is a control for following the actual current to a given d-axis and q-axis current command values. It is necessary to design and calibrate the response and stability considering magnetic saturation. When high-precision controllability is realized while considering these characteristics, the control parameters become a multidimensional lookup table. As a result, a huge amount of data is required for calibration. It takes about 20 weeks to calibrate the current command calculation, and shortening the process was required.

Copyright © 2025 Society of Automotive Engineers of Japan, Inc.

3. HOW TO IMPROVE CALIBRATION EFFICIENCY

In response to the above issues, we improved the calibration method by improving the controller, applying model-based calibration, and test bench automation.

3.1. Improvement of controller

Fig. 1 shows the configuration of the current command calculation conventionally used in Hitachi Astemo Ltd. The d-axis and q-axis current command values (i_d^*, i_q^*) are calculated from the torque command, DC voltage, and rotor angular velocity using a 3D lookup table. Then, the calculated d-axis and q-axis current command values are corrected by the rotor temperature (rotor magnet temperature). It is necessary to calibrate the d-axis and q-axis current command values for each grid of the lookup table, which takes an enormous amount of time.

Fig. 2 shows the proposed current command calculation. The torque T of IPMSM is expressed by the following equation.

$$T = p(\phi + (L_d - L_q)i_d)i_q = p\{\phi i_q + \Delta L i_d i_q\} \quad (1)$$

(p: pole pair, ϕ: magnet flux, L_d: d-axis inductance, L_q: q-axis inductance, ΔL: $(L_d - L_q)$, i_d: d-axis current, i_q: q-axis current)

ϕ varies with magnet temperature and iq, and ΔL varies with id and iq (independent of rotor angular velocity and DC voltage) [(1)(2)]. Therefore, the parameters for calculating the d-axis and q-axis current command values were reduced to three 2D lookup tables, and the number of calibration points were reduced. However, Equation (1) does not include mechanical loss and iron loss (drag torque). Therefore, the drag torque is corrected based on rotor angular velocity and DC voltage to torque command value. With this controller, it was possible to focus on the physical quantities that affect each lookup table, and the number of measurement points could be reduced.

3.2. Model-based calibration

In the conventional calibration method, actual machine data was required for each controller, and the measurement and calculation must be repeated as shown in Fig. 3. As a result, there was a waiting time for measurement and calculation.

Basically, IPMSM can be modeled by the relationship between d-axis and q-axis magnetic flux and torque with respect to d-axis and q-axis current. Therefore, we introduced a fitting method for acquiring these characteristics and generating a motor model.

Fig. 4 shows the flow of model-based calibration. First, the data for calibration is automatically measured on a test bench, and then a motor model is generated based on that data. The model is used to calculate the control parameters. The post-process is only a

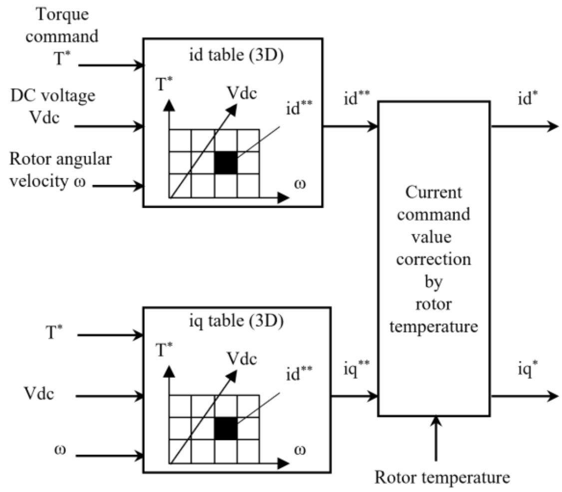

Fig. 1 Conventional current command calculation

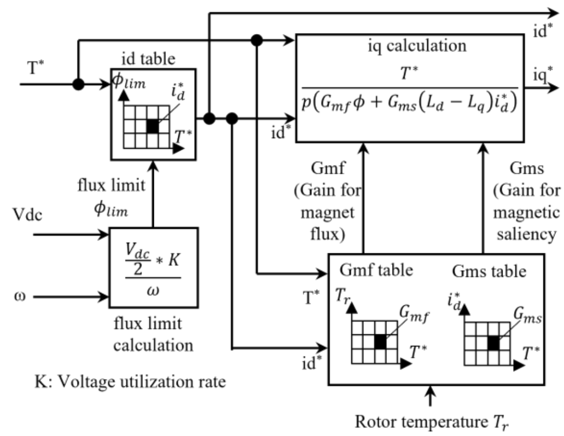

Fig. 2 Proposed current command calculation

verification test, reducing the waiting time for measurement and calculation. As a measurement method, as shown in Fig. 5, id and iq are comprehensively set at a certain rotation speed, and torque, Vd, and Vq are measured [(3)]. From this result, modeling is performed using equations (1), (2) and (3).

$$V_d = Ri_d - \omega\phi_q \quad (2)$$

$$V_q = Ri_q + \omega\phi_d \quad (3)$$

(R: Stator winding resistance, ω: angular velocity, ϕ_d: d-axis flux ($L_d i_d + \phi$), ϕ_q: q-axis flux($L_q i_q$), Excluding differential terms)

3.2. Test bench automation

In model-based calibration, the data measurement conditions are required to be uniform. Therefore, it is desirable to have an environment in which the test bench automatically manages the measurement conditions and conducts the test. Therefore, we introduced test bench automation using AVL's automation tool. In addition to the suppression, the effects of this include shortening

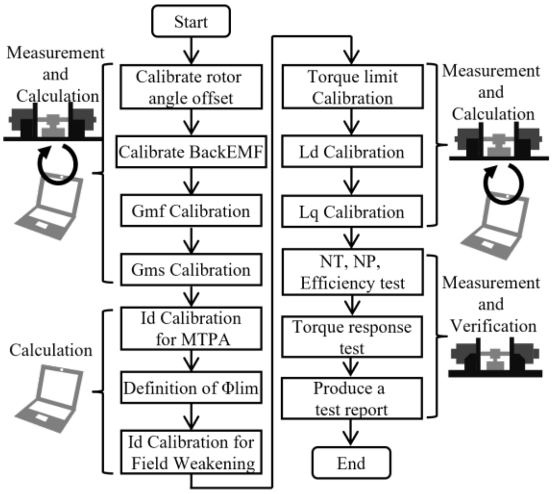

Fig. 3 Flowchart for conventional calibration method

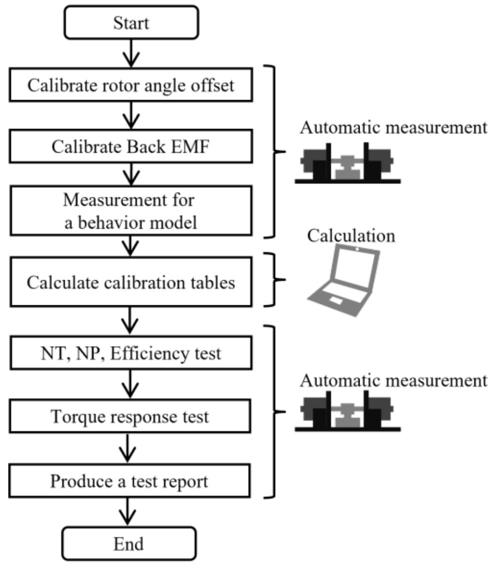

Fig. 4 Flowchart for Model-Based calibration

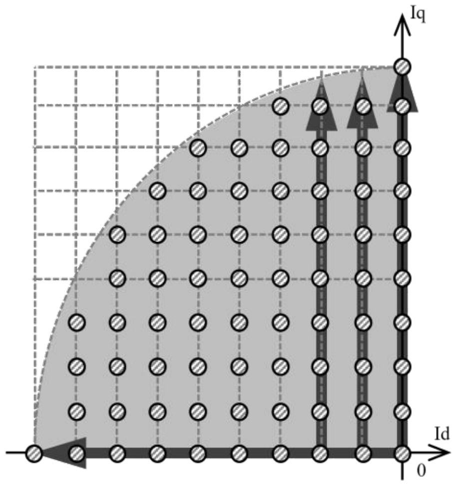

Fig. 5 Measurement for Model-Based calibration

the conformance time by night operation and improving the traceability of conformance results. As an effect, in addition to the above-described measurement condition management, there are effects such as shortening the calibration time by night operation and improving the traceability of the calibration result.

4. EXPERIMENTAL RESULTS

Fig. 6 shows the evaluation results of torque accuracy calibrated to the proposed controller and calibration method using a 200kW-class IPMSM for EVs. The vertical axis is the torque command, and the horizontal axis is the angular velocity, each normalized by the maximum value. In addition, regards to the accuracy evaluation method, the figure displays the ratio of actual torque to the command value. Overall, the results show almost 100%, indicating that the torque accuracy is sufficient. It takes about one week from calibration to measurement of torque accuracy, and high torque accuracy can be achieved in a short calibration time.

5. CONCLUSION

Regarding the calibration of IPMSM control, we improved the efficiency of calibration time by improving the controller, model-based calibration, and applying test bench automation. Torque accuracy was verified using a 200kW-class motor for EVs, and it was confirmed that high accuracy can be achieved in a short calibration time. The calibration time of the current command calculation was shortened from 20 weeks to 1 week, and the overall calibration time was also shortened from half a year to about 2~4 weeks.

Torque accuracy [%]		Rotational speed [p.u.]							
		0.02	0.15	0.31	0.46	0.62	0.77	0.92	1.00
Torque command [p.u.]	1.00	101.0	100.6	100.2					
	0.94	100.9	100.6	100.3					
	0.80	100.9	100.5	100.0					
	0.67	100.5	100.4	100.0	100.3				
	0.54	100.5	100.4	100.2	100.2				
	0.40	100.9	100.3	100.1	100.6	99.9	99.2		
	0.27	100.8	100.1	99.9	99.7	100.2	100.3	99.7	99.5
	0.13	100.9	99.9	99.7	99.5	100.3	101.1	101.6	101.5

Fig. 6 Result of torque accuracy evaluation

Copyright © 2025 Society of Automotive Engineers of Japan, Inc.

REFERENCES

(1) J.Nakatsugawa, Y.Iwaji: and Y.Enomoto, "Extension of Mathematical Models Taking Temperature Variation in Permanent Magnet Synchronous Motors into Consideration" *IEEJ Trans. IA*, Vol.136, No.4, pp.263-269 (2016) (in Japanese)

(2) S. Shinnaka, "New Dynamic Self-Consistent Mathematical Model and Torque Characteristics of Permanent-Magnet Synchronous Motors with Magnetic Cross-Coupling" *IEEJ Trans. IA*, Vol.132, No.1, pp.109-120 (2012) (in Japanese)

(3) S.Taniguchi, K.Matsuo, K.Tobari, T.Ajima, K.Yoshida, and E.Kishimoto "Flux-based Cascade Vector Control" *IEEJ Trans. IA*, Vol.143, No.5, pp.365-372 (2023) (in Japanese)

Copyright © 2025 Society of Automotive Engineers of Japan, Inc.