Loss Calculation and Thermal Analysis for High-Speed Permanent Magnet Synchronous Machines

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ABSTRACT The small size of high-speed permanent magnet synchronous machines (PMSMs) makes the increase of loss density and the difficulty of heat dissipation. PMSMs are sensitive to temperature, especially the permanent magnet (PM), which is likely to suffer irreversible demagnetization due to the excessively high temperature. This paper investigates the loss and thermal analysis of high-speed PMSMs with amorphous alloy stator core and interior permanent magnet (IPM) rotor. First, the trajectory of magnetic flux density in typical parts of high-speed PMSM with sinusoidal and pulsewidth modulation (PWM) inverter power supply is analyzed. The core loss characteristics based on the proposed field-circuit coupled method is obtained. Then, an electromagnetic-thermal iteration calculation method is proposed to analyze the temperature distribution. The effect of different parameters on thermal behavior is investigated, which provide references for the suppression of temperature rise. Finally, the theoretical analysis is verified through the experiments based on a high-speed PMSM prototype.

INDEX TERMS High-speed permanent magnet synchronous machine, magnetic field, loss distribution, temperature distribution.

I. INTRODUCTION

In recent years, due to the advantages of high power density, high efficiency and small size, high-speed PMSMs have been widely used in a range of applications, including new energy vehicles, aerospace, high-performance servos and distributed power generation [1]–[4]. However, high speed and high frequency also lead to various design challenges. Due to the high frequency characteristic of the magnetic flux density in the stator and rotor core, iron loss increases significantly with the frequency, especially the influence of time harmonics caused by the inverter power supply. At the same time, the time harmonics will also cause a significant increase of PM eddy current loss [5]. Also, the compact size results in a considerable loss density, which increases the difficulty of heat dissipation [6]. Therefore, the research on the loss and the temperature characteristic of the high-speed PMSMs is an urgent problem in the design of the high-speed PMSMs.

The basis of the temperature calculation is the accurate calculation of loss. The loss distribution of high-speed PMSMs is different from conventional electric machines. In addition to iron loss and eddy current loss, air friction loss is an important part of the high-speed PMSMs [7]. In [8], [9], Bertotti iron loss separation model is used to evaluate the iron loss of high-speed PMSMs. In order to consider the impact of rotational magnetization on the iron loss, an orthogonal decomposition model is obtained in [10], and the analysis results show that the iron loss increased by 20% compared with the classical Bertotti model. However, the experimental current is used as the excitation in the calculation. In the PMSM design stage, it is unable to obtain the experimental current. Besides due to the influence of space harmonics caused by the stator slotting and time harmonics produced by the inverter power supply [11], the PM eddy current loss increase significantly, which leads to the rise of PM temperature. In [12], an analytical model is deduced to predict the PM eddy current loss. The time harmonics are taken into account in the analytical model, but the influence of stator slotting is ignored. In [13], an accurate analytical model is proposed to
calculate the rotor eddy current loss resulted from the slotting effect. Based on the proposed analytical model, the influence of slot-opening to slot-pitch ratio, retaining sleeve material and retaining sleeve thickness on the rotor eddy current loss is investigated. Because the analytical model ignores the effects of the winding end and saturation, the obtained calculation results are not accurate, especially for the IPM rotor. The finite element method (FEM) is beneficial to the PM eddy current loss calculation with complex structure and working conditions. The application of the FEM in the analysis of the rotor eddy current loss is becoming more and more widely used. In [14], three dimensional FEM is obtained to analyze the distribution of the PM eddy current loss. The results show that the time harmonics have a significant effect on the PM eddy current loss. In [15], [16], time-stepping FEM is used to simulate the inverter power supply for the high-speed PMSM and PM eddy current loss is evaluated based on FEM. However, the core saturation effect and leakage inductance at the winding end are ignored. For high-speed PMSMs, the AC resistance is higher than the DC resistance due to the skin effect and proximity effect. For round wires, the effects can be suppressed by using thin wire and the wire diameter should be less than the skin penetration-depth at the operating frequency [17].

The purpose of thermal analysis is to ensure that the PMSMs design is suitable according to temperature rise. Thermal behavior is critical in the design of high-speed PMSMs because it interacts with the electric and magnetic fields. The commonly used methods of thermal analysis for PMSMs include lumped-parameter thermal network (LPTN), FEM and computational fluid dynamics (CFD). An efficient cooling system and accurate thermal calculation are necessary to improve the thermal reliability. In [18], a water-cooled shell structure is used to cool the high-speed generator and an LPTN is utilized to investigate the generator temperature. In [19], air axil ducts are set in the stator slot to cool the rotor directly, an LPTN is created for an air-cooled high-speed PMSM and the influence of different parameters on the rotor PM temperature are investigated. However, the accuracy of LPTN is mainly dependent on the thermal resistance coefficient. In [8], a high-speed PM rotor is supported by active magnetic bearings and the rotor temperature distribution is estimated by FEM. However, the effect of core loss on the rotor temperature is ignored. The thermal of the PMSM is simulated through transient 3D FEM analysis in [20]. However, the convection boundaries are obtained through the empirical algorithm. In order to improve the accuracy of thermal calculation, CFD is used to calculate the temperature distribution in [21]–[23]. However, the effect of the temperature on the material properties is ignored or only the effect of temperature on the resistivity is considered, and CFD computing accounts for plentiful time.

In this paper, the field-circuit coupled method is proposed to simulate the electromagnetic performance. The iron loss is obtained by the orthogonal decomposition model which takes into account the rotational magnetization and harmonics. The PM eddy current loss is estimated with the FEM. Based on the proposed field-circuit coupled method, the loss characteristics with the sinusoidal power and PWM inverter power supply are analyzed. Also, the effect of roughness height on the air friction loss is investigated with the CFD method. Then, the thermal model is established to predict the temperature distribution. The temperature is analyzed based on the electromagnetic-thermal iteration calculation method. The influence of water-cooling channel number, water velocity and power supply type on the temperature distribution is analyzed in detail. In order to verify the calculation accuracy, a high-speed PMSM is prototyped and detailed experiments are performed.

II. HIGH-SPEED PMSM MODEL

In this paper, the main dimension parameters of the high-speed PMSM is shown in Tab.1. In order to reduce the high frequency core loss, the stator core is made of amorphous alloy. Otherwise, limited by the difficulty of processing amorphous alloy, the rotor core is made of silicon steel M270-35A. To disperse the high-speed centrifugal force on the IPM rotor, the PM is divided into two sections and a central rib is added. The stator and rotor structure is shown in Fig.1. In order to reduce the AC resistance, round wire with a diameter of 0.63mm is selected and the winding resistance only increased by 3% at 1000Hz operating frequency.

The designed high-speed PMSM is totally enclosed and the spiral water channel is set in the stator shell to take away the heat generated by the high-speed PMSM, as shown in Fig.2.

| Parameter              | Value     | Parameter              | Value     |
|------------------------|-----------|------------------------|-----------|
| Rated power            | 15kW      | Rated speed            | 20000rpm  |
| Stator outer diameter  | 130mm     | Stator length          | 110mm     |
| Stator slots           | 18        | Pole pairs             | 2         |
| Wire type              | Round wire| Wire size              | 0.63mm    |
| PM material            | NdFeB     | PM width               | 30mm      |
| Stator core material   | Amorphous | Rotor core material    | M270-35A  |

TABLE 1. Main parameters of the 15kW high-speed PMSM.
4) The PWM voltage is taken as the input value and simulated with FEM to get the current, magnetic flux density and loss distribution.

The field-circuit coupled simulation method described above not only considers the effect of local saturation on the performance of the PMSM but also owns the advantages of the fast and easy convergence.

The mathematical model of the field-circuit coupled simulation is shown in equation (1) [24].

\[
\begin{align*}
\nabla \left( \frac{1}{\mu_m} \nabla A_z \right) + J_a &= \frac{1}{\mu_0} \left( \frac{\partial M_x}{\partial x} - \frac{\partial M_y}{\partial y} \right) \\
U &= E_b + RI
\end{align*}
\]

where \(A_z\) is the vector magnetic potential of \(z\) component; \(\mu_m\) is the magnetic permeability; \(J_a\) is the current density; \(M_x\) and \(M_y\) are the magnetization of the PM in the \(x\) and \(y\) directions, respectively; \(U\) is the terminal voltage of PMSM; \(E_b\) is the back EMF; \(I\) is the current; \(R\) is the resistance.

Based on the proposed field-circuit coupled method, the modulating ratio \(M\) is set to 0.75 and the carrier wave ratio \(K\) is set to 15, and obtain the PMSM phase current waveform as shown in Fig.3 (a). Fig.3 (b) shows the current Fourier decomposition. It can be seen from Fig.3 (b) that the orders of the major harmonic components in current are \((2n-1)K\pm2, (2n)K\pm4, (2n)K\pm1, (2n)K\pm5\) \((n = 1, 2, 3, \ldots)\). In the case of \(K = 15\), the orders of the main harmonics are 15±2, 15±4, 30±1, 30±5, etc. Also, as the increases of harmonic order, the current value gradually decreases.

The magnetic flux density trajectory at one-third of the stator teeth height is shown in Fig.4 (a). It is shown that the main magnetization type of the stator teeth is rotational magnetization and the radial magnetic flux density is larger than the tangential magnetic flux density. Compared with the sinusoidal power supply, the magnetic flux density trajectory under the PWM inverter power supply with 10kHz carrier frequency fluctuates significantly. Fig.4 (b) shows the Fourier decomposition of the radial magnetic flux density of the stator teeth with sinusoidal power supply and PWM inverter power supply. At 20000 rpm of the high-speed PMSM, due to the influence of the current time harmonics, the magnetic flux density of the stator teeth contains a lot of high-order harmonics such as 11th, 13th, 17th, 19th, 25th, 29th, and 31th with the PWM inverter power supply.

The magnetic flux density trajectory at half the height of the stator yoke is shown in Fig.5 (a). It is shown that the main magnetization type of the stator yoke is rotational magnetization and the tangential magnetic flux density is larger than the radial magnetic flux density. Fig.5 (b) shows the Fourier decomposition of the tangential magnetic flux density of the stator yoke with sinusoidal power supply and PWM inverter power supply. Similar to the harmonic magnetic flux density of the stator teeth, the harmonic magnetic flux density of the stator yoke with PWM inverter power supply includes 11th, 13th, 17th, 19th, 25th, 29th, and 31th.

The increase of power supply frequency results in the increase of stator iron loss. The conventional classical Bertotti iron loss calculation model under sinusoidal magnetic flux density ignores the effects of rotational magnetization on
the iron loss. From the above analysis results of magnetic flux density in the stator core, it can be seen that the magnetic flux density is not exactly sinusoidal. And the rotational magnetization of the stator yoke is significant. The conventional classical iron loss model only considering the alternating magnetization cannot evaluate the stator iron loss accurately. Therefore, an orthogonal decomposition model which considering the effects of rotational magnetization and magnetic flux density harmonics is used to predict the iron loss. The radial and tangential magnetic flux density in the given element of stator or rotor core is first extracted. The harmonic components of the radial and tangential magnetic flux density are obtained by Fourier decomposition, which is substituted to equation (2) for iron loss calculation [25].

\[
P_{Fe} = P_h + P_e = \int \sum_{k=1}^{\infty} \rho k_h (B_{rk}^2 + B_{\theta k}^2) \, dV + \int \sum_{k=1}^{\infty} \rho k_e (k^2) (B_{rk}^2 + B_{\theta k}^2) \, dV
\]

where \(k_h\) and \(k_e\) are hysteresis loss coefficient and eddy current loss coefficient, respectively; \(f\) and \(k\) are the frequency and harmonic order, respectively; \(V\) and \(\rho\) are the stator core volume and density, respectively; \(B_{rk}\) is the \(k\)th harmonic magnetic flux density in the radial direction; and \(B_{\theta k}\) is the \(k\)th harmonic magnetic flux density in the tangential direction.

Based on the orthogonal decomposition model, the stator iron loss with sinusoidal power supply and PWM inverter power supply is shown in Fig.6. Due to the 25 \(\mu m\) thickness of the amorphous alloy, the eddy current loss of the stator core is less than the hysteresis loss. However, the influence of the PWM inverter power supply on the eddy current loss is greater than that on the hysteresis loss. As shown in Fig.6 (a), the eddy current loss and hysteresis loss of the stator teeth increased by 53.0% and 33.8%, respectively, when the PMSM is powered by the PWM inverter. Fig.6 (b) shows that the eddy current loss and the hysteresis loss of the stator yoke with PWM inverter power supply are increased by 69.2% and 37.6%.

**B. ROTOR LOSS CHARACTERISTICS**

For the IPM rotor core, the orthogonal decomposition model is used to evaluate the IPM rotor core iron loss. For the PM of IPM, FEM is used to calculate the PM eddy current loss. The eddy current density in the PM is shown in formula (3).

\[
J_n = -\sigma \left( \frac{\partial A_n}{\partial t} + C(t) \right) \tag{3}
\]

where \(\sigma\) is the conductivity of the PM; \(C(t)\) is a time function which makes the net current in PM is 0.

The PM eddy current loss is obtained by integrating the eddy current density, as shown in formula (4).

\[
P_m = \sum_{n} \left( \int \frac{J_n^2}{\sigma} \, dV \right) \tag{4}
\]

where \(V_m\) is the PM volume.

In the area of the IPM rotor, two points are selected for magnetic flux density analysis. The location of the two selected points is shown in Fig.7.

The magnetic flux density of point \(P_1\) with the power supply of sinusoidal and PWM inverter are shown in Fig.8 (a). Fig.8 (b) shows the Fourier decomposition of the magnetic flux density of point \(P_1\). Compared with the sinusoidal power supply, affected by the current time harmonics, the magnetic flux density with the PWM inverter power supply includes higher harmonics, such as 12th, 18th, 24th, 30th.

The magnetic flux density of point \(P_2\) with sinusoidal power supply and PWM inverter power supply is shown in Fig.9 (a). The magnetic flux density fluctuates significantly under the PWM inverter power supply. Fig.9 (b) shows the Fourier decomposition of the magnetic flux density at point \(P_2\). Due to the influence of PWM inverter current time harmonics, the magnetic flux density of point \(P_2\) contains 12th, 18th, 24th, 30th higher harmonics.

Fig.10 shows the rotor iron loss and PM eddy current loss with sinusoidal and PWM inverter power supply. For the high-speed IPM rotor, the PWM inverter power supply has a significant effect on the eddy current loss of the rotor core. The eddy current loss of the rotor core with the PWM inverter power supply is increased by 136.6% compared to the sinusoidal power supply. The hysteresis loss of the rotor core with the PWM inverter power supply is only increased by 75%.
C. AIR FRICTION LOSS

Due to the mutual friction between high-speed IPM rotor and air, as the motor speed increases, the air friction loss gradually increases. The air friction loss can be calculated by the following analytical formula:

\[ P_{air} = C_f \pi \rho_a \omega r^4 L_a \]  

(5)

where \( C_f \) is the friction coefficient and it is related to the surface structure of the stator and rotor; \( \rho_a \) is the air density; \( \omega \) is the rotor angular velocity; \( r \) is the rotor radius; \( L_a \) is the rotor axial length.

Although the analytical method can quickly obtain the air friction loss results, the formula based on several empirical coefficients which cause the results to be inaccurate. Thus, CFD is used to calculate the air friction loss more accurately. Fig.12 shows the air gap CFD model. Fig.13 shows the relationship between air friction loss and speed under different roughness heights \( h_r \). At the same roughness height,
the air friction loss increases exponentially with speed. At the same speed, the air friction loss increases as the increase of roughness heights. So, it is necessary to reduce the roughness height of the rotor in the processing of the high-speed IPM rotor.

IV. THERMAL ANALYSIS

A. TEMPERATURE CALCULATION METHOD

Because of the complex structure of the PMSM, in order to improve the thermal calculation accuracy and save the calculation time, the PMSM model needs to be simplified. The PMSM winding is a heterogeneous object which consists of enameled copper wire, impregnated resin, insulation and air. If each conductor is modeled one by one, the thermal calculation will take a long time and is not easy to converge. Therefore, the winding is modeled as upper and lower copper conductors wrapped with equivalent insulation. The equivalent winding model is shown in Fig.14.

The high-speed IPM rotor rotates in the air gap, which will cause airflow in the air gap. The heat exchange between the stator and the rotor is convection. To reduce the calculation time of convection heat transfer, the effective thermal conductivity of a stationary fluid is used to simulate the thermal conductivity of flowing air. The equivalent thermal conductivity of air in the air gap is shown as follows [26]:

$$\lambda_{\text{eff}} = 0.0019\eta_g^{-2.9084} Re^{0.4614 \ln(3.3336\eta_g)}$$  \hspace{1cm} (6)

where $\eta_g$ is the ratio of the outer diameter of the rotor to the inner diameter of the stator; $Re$ is the Reynolds number.

The PMSM temperature is caused by the power loss. Still, the temperature has a significant effect on the material properties, especially the PM and the winding, which in turn affects the power loss. The remanence $B_r$ and coercive force $H_c$ of PM considering the effect of temperature can be calculated by

$$\begin{align*}
B_r &= \left[1 + \frac{(T - T_0)}{100}\right] \left[1 - \frac{IL}{100}\right] B_{r0} \\
H_c &= \left[1 + \frac{(T - T_0)}{100}\right] \left[1 - \frac{IL}{100}\right] H_{c0}
\end{align*}$$  \hspace{1cm} (7)

where $T$ is the working temperature; $T_0$ is the reference temperature; $\alpha_{B_r}$ and $\alpha_{H_c}$ are the reversible temperature coefficient; $IL$ is the irreversible loss rate; $B_{r0}$ is the remanence at the reference temperature $T_0$; $H_{c0}$ is the coercive force at the reference temperature $T_0$.

The resistivity of PM considering the effect of temperature can be obtained by

$$\rho_{\text{pm}} = \rho_{0\text{pm}} \left[\beta_1(T - T_0)^2 + \gamma_1(T - T_0) + 1\right]$$  \hspace{1cm} (8)

where $\rho_{0\text{pm}}$ is the PM resistivity at the reference temperature $T_0$; $\beta_1$ and $\gamma_1$ are the temperature coefficient of PM resistivity.

The winding resistivity has a linear relationship with the temperature, which can be obtained by

$$\rho_w = \rho_{0w} \left[\alpha_w(T - T_0) + 1\right]$$  \hspace{1cm} (9)

where $\rho_{0w}$ is the winding resistivity at the reference temperature $T_0$; $\alpha_w$ is the winding resistivity temperature coefficient.

In order to calculate the temperature distribution accurately, an iterative method of electromagnetic-thermal coupling is proposed, as shown in Fig.15. Firstly, the initial temperature of the PM and the winding is set, and the material properties at the given temperature are calculated according to (7), (8) and (9). Then the coupled field-circuit method is used to obtain the power loss based on the material properties. The air friction loss and the convection conditions are calculated by the CFD method. Based on the loss of high-speed PMSM and the convection conditions, the temperature distribution of the PMSM is obtained by the FEM. And get the difference between the calculated temperature and the set temperature. The iterative calculation of the PMSM temperature is terminated when the temperature difference is less than a preset tolerance.

B. EFFECT OF WATER-COOLING CHANNEL

The number of water-cooling channels is very important for the suppression of high-speed PMSM temperature rise. Also, the number of water-cooling channels has an impact on the cooling water pressure drop in the cooling channels, which will influence the pump selection.

Fig.16 (a) shows the variation of winding maximum temperature rise versus the number of water-cooling channels. Fig.16 (b) shows the variation of cooling water flow pressure drop versus the number of water-cooling channels. As shown
in Fig. 16 (a), the maximum temperature rise of the winding gradually decreases as the number of water-cooling channels increases. When the number of water-cooling channels is increased to 6, the number of water-cooling channels has a weakened impact on the winding maximum temperature rise. However, as shown in Fig. 16 (b), the pressure drop of cooling water flow increases significantly with the number of water-cooling channels, especially after the number of water cooling channels increase to 8. Therefore, an appropriate number of water-cooling channels should be adopted to reduce the maximum temperature rise and the cooling water pressure drop.

C. EFFECT OF COOLING WATER VELOCITY

The cooling water velocity has a significant impact on the temperature rise. The influence of cooling water velocity on the temperature rise is analyzed and the analysis results are shown in Fig. 17.

As shown in Fig. 17, both the winding maximum temperature rise and the PM maximum temperature rise decrease with the increase of cooling water velocity. The cooling water has laminar flow characteristics in the range of water velocity from 0.01 m/s to 0.16 m/s. When the water velocity increases from 0.01 m/s to 0.16 m/s, the winding maximum temperature rise and the PM maximum temperature rise decrease by 11.3% and 11.5%, respectively. The cooling water flow with a velocity between 0.73 m/s and 2 m/s has the turbulent flow characteristics. When the water velocity increases from 0.73 m/s to 2 m/s, the winding maximum temperature rise and the PM maximum temperature rise decrease by 1.6% and 1.7%, respectively. In the transition region from laminar to a turbulent state, as the water velocity increased from 0.16 m/s to 0.73 m/s, the winding maximum temperature rise and the PM maximum temperature rise decreased by 12.9% and 13.3%, respectively. Therefore, the cooling water velocity that just makes the water flow into a turbulent state is a good choice.

D. EFFECT OF POWER SUPPLY

The winding temperature and PM temperature distribution with sinusoidal power supply and PWM inverter power supply are shown in Fig. 18 and Fig. 19. In both power supply models, the maximum temperature of the winding is located at the end of the winding, and the maximum temperature of the PM is located in the middle of the PM.

The winding temperature distribution shows that the power supply mode has a small effect on the winding temperature of high-speed PMSM with amorphous alloy stator core. Compared with the sinusoidal power supply, the maximum winding temperature with the PWM inverter power supply has only increased by 6.8%. However, the PWM inverter power supply has a great impact on the PM temperature. Compared with the sinusoidal power supply, the maximum temperature of the PM has increased by 45.8% with the PWM inverter power supply.
FIGURE 17. Maximum temperature rise versus cooling water velocity. (a) Winding maximum temperature rise. (b) PM maximum temperature rise.

FIGURE 18. Winding temperature distributions. (a) Sinusoidal power supply. (b) PWM inverter power supply.

FIGURE 19. PM temperature distributions. (a) Sinusoidal power supply. (b) PWM inverter power supply.

V. PROTOTYPE AND EXPERIMENTAL TESTS

The proposed high-speed PMSM has been prototyped and the stator and rotor core are shown in Fig.20. A ball bearing is used in the high-speed PMSM. Tab.2 shows the no-load back EMF comparison with different speeds. The test results of the no-load back EMF agree well with the calculations.

An induction machine is driven by the high-speed PMSM as a load through a gearbox. Fig.21 shows the main harmonic current obtained by test and calculation. The calculated harmonic current amplitude is slightly smaller than the experimental value. For the fundamental current, the calculated
The measured and calculated loss under the rated load is compared in Fig.22. Although the experimental results are slightly larger than the calculation results, the calculation accuracy can be considered enough.

Fig.23 shows the temperature rise of the winding end under continuous operating conditions with a speed of 20000 rpm and rated load. The temperature rise of the winding end is stable after 150 minutes. The maximum temperature rise of the winding end obtained by the experiment is 65K, and the maximum temperature rise of the calculated winding end is 61K. It is shown that the error between the calculation result and the experiment result is 6.1%.

VI. CONCLUSION

In this paper, the loss and temperature distribution of a high-speed PMSM with the IPM rotor is analyzed. The field-circuit coupled simulation method is used to analyze the characteristics of the PMSM loss distribution. For the stator core made of amorphous alloy, the hysteresis loss accounts for a large part of the core loss. However, the influence of the PWM inverter power supply on eddy current loss is greater than that on the hysteresis loss. For the IPM rotor core made of silicon steel, the eddy current loss accounts for the large part of the core loss. The eddy current loss of the IPM rotor core with the PWM inverter power supply is increased by 136.6% compared with the sinusoidal power supply. The eddy current loss of the IPM rotor core is 9.6 times its hysteresis loss when the PWM inverter power supply is used. Also, the PM eddy current loss is significantly affected by the PWM inverter power supply. The PM eddy current loss with the PWM inverter power supply is 10.4 times that of the sinusoidal power supply. As the rotational speed increases, the air friction loss increases, and the reduction of the roughness height is beneficial to reduce the air friction loss.

The temperature distribution of the high-speed PMSM is analyzed through an electromagnetic-thermal iteration calculation method. The design of the cooling channels number requires a comprehensive considering of the thermal behavior and the water pressure drop. The reasonable design of water velocity is to make the water flow into turbulent. The PWM inverter power supply has a significant effect on the PM temperature. The effectiveness of the proposed methods for the analysis of the high-speed PMSM has been verified by experiments on a prototype machine.

| Speed/rpm | Back EMF (calculate)/V | Back EMF (test)/V | Error/% |
|-----------|------------------------|------------------|--------|
| 7000      | 106                    | 104              | 1.9    |
| 15000     | 233                    | 227              | 2.6    |
| 20000     | 305                    | 302              | 1.0    |

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