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Self-identification of Key Parameters of Spindle Motor Drives

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Abstract— **This paper will introduce a self-identification method to measure the motor key parameters through its own drive or motor controller. These key parameters include the motor line resistance and inductance at operating frequency as well as back EMF constant or torque constant, which are very important to design motor close-loop control gains. The proposed method does not utilize the special meters or instruments, such as, multimeters, LCR meters or motor testing system, but do apply the phase current and voltage terminal detecting channels of a motor controller. It will provide the bases to the auto-tuning of motor control and motor health online dialogue without extra cost except the bigger size of flash or RAM memory for more codes.**

Index Terms – Permanent magnet motors, motor control and motor parameters.

I. INTRODUCTION

For the optimal dynamical speed control, the spindle motor key parameters consist of back EMF constant, the phase resistances and phase inductance [1], which can be measured offline before a motor is assembled into hard disk drive. But the volume of the spindle motors is quite a big number and these parameters varies with the operating temperature, operating frequency and the motor aging. For example, the phase winding resistance varies with temperature and operating frequency and back EMF constant of a permanent magnet (PM) motor decreases as its permanent magnet temperature increases and ages. Moreover, the terminal inductance changes against rotor position because of the slot effects even for a surface mounted PM motor. This paper explores to utilize the inverter, voltage and current detection channels as well as ADC of a single chip microcontroller to realize the resistance, inductance and back EMF or torque constant detection only with the motor drive or controller without any instruments. Fig. 1 shows a motor and its drive with an inverter, current and voltage detection channels as well as ADC inside the microcontroller.

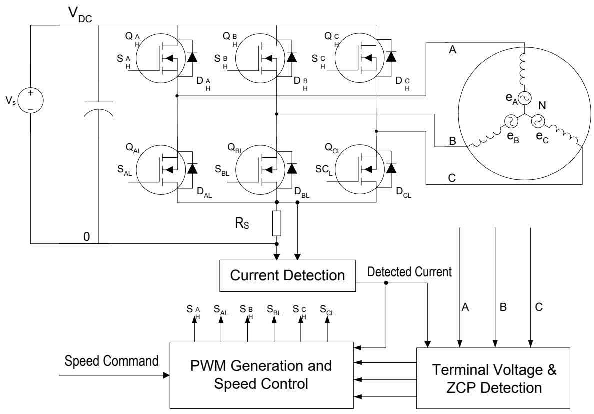
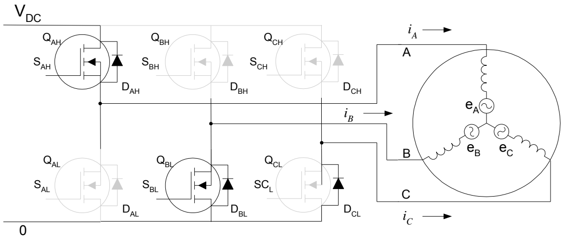
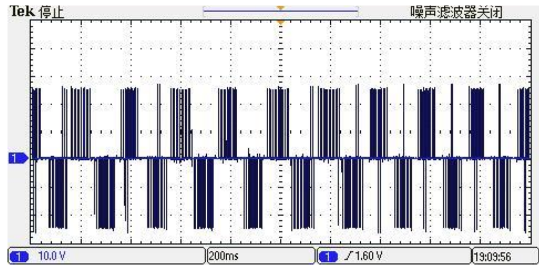


Fig. 1 A PM motor and its controller.



(a) Two excited phases between terminal A and B



(b) SPWM voltage waveform

Fig. 2 SPWM voltage waveform between two terminals.

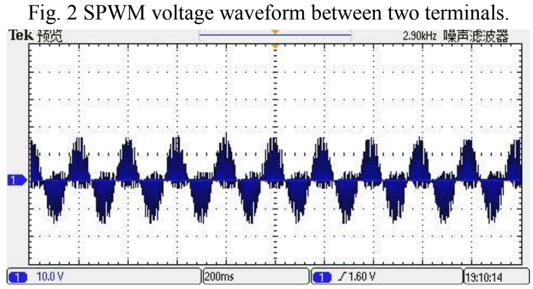


Fig. 3 Exciting current of two phases with the designed SPWM.

II. MEASUREMENT OF LINE RESISTANCES AND INDUCTANCES OF A THREE PM MOTOR

At any moment when the motor controller is powered "ON" but motor is "OFF" or at standstill, any two phases of a three-phase motor or any two terminals can be excited with a small effect amplitude SPWM voltage at a specified fundamental frequency f_s, such as, the operating frequency, 540Hz for a 12-poles spindle motor spinning at 5,400 rpm, the PWM waveform with carrying frequency f_{SPWM} is shown as in Fig. 2. The corresponding current waveform can be detected as shown in Fig. 3.

From Figs. 2 and 3, there are rich harmonic components for the voltages and currents although the similar low pass filters are applied to the SPWM voltage and the current waveforms. A Fourier analysis for the specified frequency of SPWM should be applied as follows:

$$I_{af_s} = \frac{\sqrt{2}f_s}{f_{ADC}}\sum_{k=1}^{N_{ADC}} i(k)\cos\left(2\pi\frac{f_s}{f_{ADC}}k\right) \tag{1}$$

$$I_{bf_s} = \frac{\sqrt{2}f_s}{f_{ADC}}\sum_{k=1}^{N_{ADC}} i(k)\sin\left(2\pi\frac{f_s}{f_{ADC}}k\right) \quad (2)$$

$$I_{f_s} = \sqrt{I_{af_s}^2 + I_{bf_s}^2} \quad (3)$$

$$\varphi_I = \tan^{-1}\frac{I_{bf_s}}{I_{f_s}} \quad (4)$$

where f_{ADC} is the sampling frequency of the ADC and is set to multiple times of the testing signal frequency fs. Similarly, the voltage amplitude and phase between these two terminals can be expressed as follows:

$$V_{af_s} = \frac{\sqrt{2}f_s}{f_{ADC}}\sum_{k=1}^{N_{ADC}} v(k)\cos\left(2\pi\frac{f_s}{f_{ADC}}k\right) \quad (5)$$

$$V_{bf_s} = \frac{\sqrt{2}f_s}{f_{ADC}}\sum_{k=1}^{N_{ADC}} v(k)\sin\left(2\pi\frac{f_s}{f_{ADC}}k\right) \quad (6)$$

$$V_{f_s} = \sqrt{V_{af_s}^2 + V_{bf_s}^2} \quad (7)$$

$$\varphi_V = \tan^{-1}\frac{V_{bf_s}}{V_{af_s}} \quad (8)$$

Therefore, the resistance and inductance between these two terminals is as follows:

$$R_{f_s} = \frac{V_{f_s}}{I_{f_s}}cos(\varphi_V - \varphi_I) \quad (9)$$

$$L_{f_s} = \frac{V_{f_s}}{2\pi f_s I_{f_s}}sin(\varphi_V - \varphi_I) \quad (10)$$

Table I shows the measurement results of a sample motor with the proposed method.

TABLE I
L&R MEASUREMENT BASED ON PROPOSED METHOD

Variables	Values	Units
f_s	540	Hz
$V_{af_s} + jV_{bf_s}$	-0.2657 – j 1.2269	V
$I_{af_s} + jI_{bf_s}$	-0.0464 – j 0.0208	A
R_{f_s}	6.9592	Ω
L_{f_s}	5.8	mH

III. MEASUREMENT OF MOTOR BACK EMF CONSTANT DURING MOTOR FREE-WHEELING

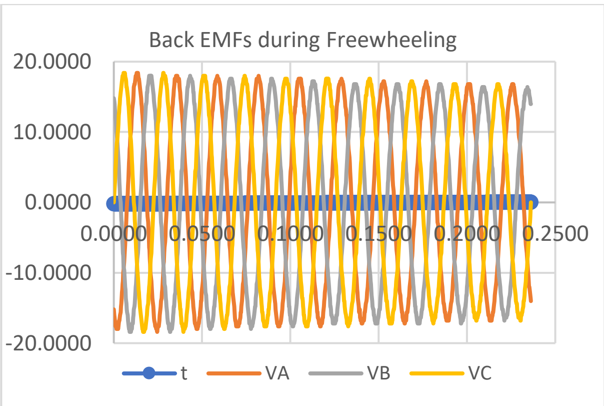


Fig. 4 Phase back EMF during freewheeling.

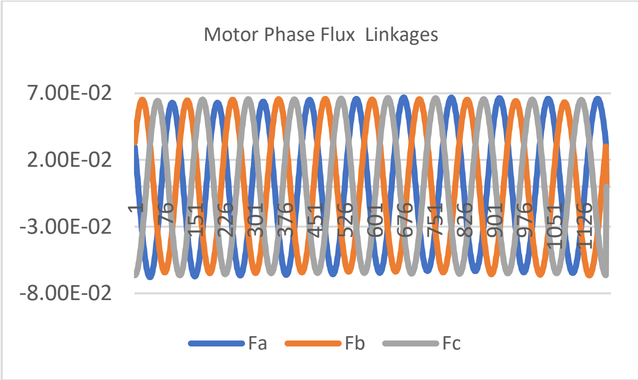


Fig. 5 Phase flux linkage.

During the normal running of the motor, the back EMF is covered by the excited voltage and it cannot be measured directly. However, when the motor is switched off from the inverter, the motor will stop freely and its back EMF can be measured, but its peak is not constant as speed decreases gradually, see Fig. 4. To find the constant back EMF peak value, the motor flux linkages are calculated through Eq (11):

$$\psi_p(\theta_i) = \psi_p(t_0) - \sum_{l=0}^{i} 0.5\times\left[e_{pN}(t_l) + e_{pN}(t_{l+1})\right](t_{l+1} - t_l),$$
$$\text{when } \theta_i = \theta(t_i)\text{, and}$$
$$i = 1, 2, \ldots, i_{end}\text{-1 and } p = A, B, C \quad (11)$$

where i_{end} is the last point of the revolution, i.e., the last ZCP of phase C of the revolution from the 1st ZCP. When i = 0 and i_{end}, the rotor positions are defined as 0 and 2π, respectively, they are the same rotor position in space, as shown in Fig. 5. It can be seen that the flux linkage is independent of the speed.

After the flux linkage peak values are found, the motor back EMF constant can be expressed approximately as:

$$k_e = pp \times |\psi_{peak}(m)|, m = 1,2 \ldots 6 \times pp \quad (12)$$

where pp is the motor pole pairs. The corresponding motor torque constants are:

$$k_T = \frac{3}{2}k_e \ per\ 1A\ peak\ phase\ current\ in\ PMSM\ Mode \quad (13)$$

$$k_T = \frac{3\sqrt{3}}{\pi}k_e \ per\ 1A\ peak\ current\ in\ BLDC\ Mode \quad (14)$$

IV. CONCLUSION

With help of single mixed signal microcontroller, the method of self-identification of motor key parameters has been introduced and verified through experiments.

REFERENCES

[1] Q. Jiang, *et al*, "An effective method to measure back and their harmonics of permanent magnet ac motors," *Journal of Applied Physics*, 99, No. 8, April 15, 2006. Paper 08S309.