An Analysis Method of Vibrations due to Electromagnetic Force in Electric Motor

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***Abstract*—An analysis of radial force is needed to reduce vibrations due to electromagnetic force among the vibrations caused by a motor. This paper proposed a method of separated analysis a radial force by frequency and magnitude for a circumferential mode, and quantitatively and qualitatively analyzed the vibration velocity caused by a stator by using this method. In addition, its reliability was verified by using a coupled analysis of electromagnetic field and vibration.**

***Index Terms*—Electromagnetic forces, vibrations, electric motors, brushless motors, permanent magnet motors.**

I. INTRODUCTION

The vibrations caused by a motor can be divided into two kinds in general. The first is mechanical vibrations caused by bearings and the misalignment of a shaft, and the second is electromagnetic vibrations caused by an electromagnetic force. Of these, the second can be estimated through the analysis of a radial force, a vibration source, during the electromagnetic field design process of a motor.

The existing method analyzed the vibrations in a motor qualitatively by separating a radial force in an air gap at a specific time into harmonic wave components for a space[1,2]. However, this method shows only the circumferential mode and magnitude of a radial force at a specific time, but cannot separate its frequency components. Therefore, it is impossible to estimate the vibration velocity caused by a stator quantitatively.

This paper proposed a method of separating the magnitude and frequency of a radial force by circumferential modes to quantitatively estimate and qualitatively analyze the vibration velocity caused by a stator. This paper also calculated the vibration velocity caused by a stator through a coupled analysis of electromagnetic field and vibration to verify the reliability of the proposed method, and compared it with the estimating results.

II. ANALYSIS METHOD OF A RADIAL FORCE

The radial force in an air gap can be represented as follows:

$$p\left(\theta^m,t\right)=\sum_{r=0}^{\infty}p_r\left(\theta^m,t\right) \tag{1}$$

where $r=0,1,2,3,...$ are the orders of circumferential modes, corresponding to the spatial harmonic wave components of a radial force, and the r th mode component $p_r\left(\theta^m,t\right)$ of a radial force has periodicity with respect to time and space, so it can be represented as Equation (2).

$$\begin{aligned} p_r\left(\theta^m,t\right)&=p_{r1}\left(\theta^m,t\right)+p_{r2}\left(\theta^m,t\right)+...+\\ &=\sum_{n=0}^{\infty}P_{rn}\cos\left(\omega_{rn}t\pm r\left(\theta^m+\theta_{0n}\right)\right)\end{aligned} \tag{2}$$

Where P_{rn} is the magnitude of the n th term of the r th mode, and ω_{rn} is the angular velocity of the n th term of the r th circumferential mode, being the integer multiples of the electric angular velocity ω_e.

The magnitude P_{rn} and angular velocity ω_{rn} of a radial force at the r th mode can be obtained in the following sequence.

1. Sample the period T into quantity N.
2. Perform an FFT analysis for $p\left(\theta^m,t_1\right)\sim p\left(\theta^m,t_N\right)$ with respect to each space θ^m.
3. The order of harmonic waves caused from the No.2 result becomes a spatial harmonic wave, i.e. a circumferential mode.
4. Perform an FFT analysis for a radial force $\left[p_r\left(\theta_0^m,t_1\right),...,p_r\left(\theta_0^m,t_N\right)\right]$ at the same position θ_0^m by considering the phase difference coming from the No.2 result to obtain the order n of an angular velocity and the magnitude P_{rn} of a radial force at this time.
5. Repeat the No.1~4 with respect to all r's.

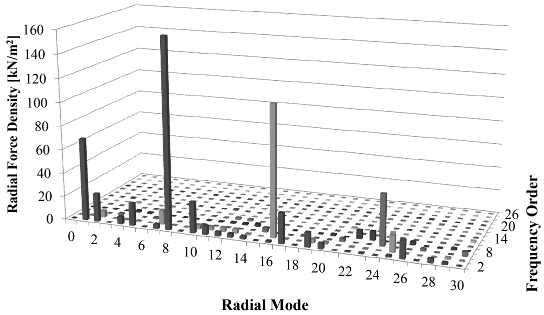


Fig. 1. Radial Force Density

The radial force with respect to a circumferential mode and frequency can be represented as shown in the Fig. 1 by using this method.

III. CALCULATION OF A VIBRATION VELOCITY

A. Natural frequency of a stator

The natural frequency of each vibration mode shall be calculated to estimate the vibrations caused by a stator. In here, the natural frequency was calculated by assuming the shape of a stator as a ring type cylinder. The natural frequency f_{rm} of the r^{th} vibration mode is as follows[3]:

$$f_{rm} = \frac{1}{2\pi}\sqrt{\frac{K_r}{M_r}} \qquad (3)$$

Where K_r is the stiffness of a stator core at the r^{th} mode, M_r is the mass of a stator core at the r^{th} mode.

B. Calculation of a vibration velocity

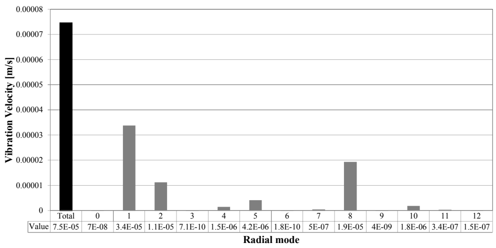
The vibration velocity V_r at the r^{th} vibration mode is as follows[3]:

$$V_r = \sum_{n=1}^{\infty} V_{rn} \qquad (4)$$

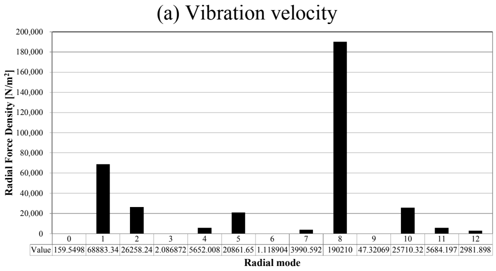
$$V_{rn} = 2\pi f_{rn} \frac{\pi D_{si} L_{stk}}{M_c \omega_{rm}^2} P_{rn} h_m \qquad (5)$$

Where M_c is the mass of a stator core, D_{si} is the inner diameter of a stator, L_{stk} is the stacking length, and h_m is the magnification coefficient, which is the values, determined by the shape of a stator.

Therefore, separating the magnitude and frequency of a radial force in the method proposed in the previous chapter can calculate the vibration velocity caused by a stator. Fig. 2 shows the vibration velocities at the secondary vibration frequency and the magnitude of a radial force separately with respect to the mode r.



(a) Vibration velocity



(b) Magnitude of radial force

Fig. 2. Vibration velocity and magnitude of radial force with respect to vibration mode at 2nd order vibration frequency

IV. A COUPLED ANALYSIS OF ELECTROMAGNETIC FIELD AND VIBRATION

Table I shows the specification of an analysis model. A vibration analysis was also carried out to verify the vibration velocity calculated by using the proposed method. As shown in Fig. 3, a coupled analysis of electromagnetic field and vibration is needed for force mapping.

The Fig. 4 compared the results of the method proposed in the previous chapter with the results of the coupled analysis, whose quantitative and qualitative properties can be confirmed to be very similar to each other.

TABLE I
Specification of 8p 9s SPMSM

Description	Symbol	Value	Unit
Number of poles and slots	N_p	8p 9s	-
Peak value of the phase current	I_{max}	318.2	A_{peak}
Rotation speed	-	3,500	rpm
Stator outer diameter	D_{so}	0.35	m
Stator inner diameter	D_{si}	0.212	m
Rotor outer diameter	D_{ro}	0.21	m
Stacking length	L_{stk}	0.14	m

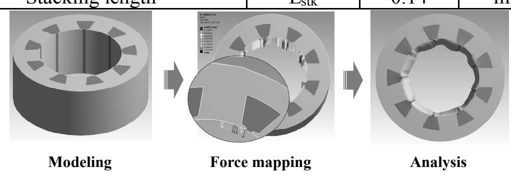


Fig. 3. Vibration analysis procedure

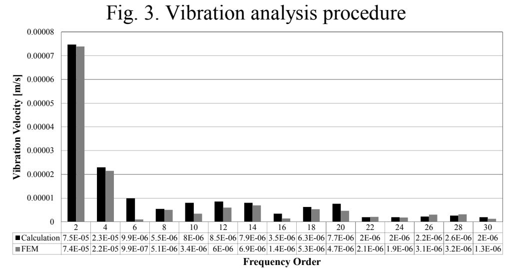


Fig. 4. Vibration characteristics with respect to frequency order

V. CONCLUSION

This paper proposed a technique to estimate an electromagnetic vibration caused by an electromagnetic force, and verified its appropriateness through a coupled analysis of electromagnetic field and vibration. Using the proposed method can perform a quantitative estimate and a qualitative analysis for the caused vibration components depending on vibration frequency, so it can be used in basic design and optimal design considering vibrations as well as the existing electromagnetic field property in designing a motor.

REFERENCES

[1] Y. S. Chen, Z. Q. Zhu, and D. Howe, “Vibration of PM Brushless Machines Having a Fractional Number of Slots Per Pole,” Magnetics, *IEEE Transactions on*, vol. 42, no. 10, pp. 3395-3397, 2006

[2] J. Wang, Z. P. Xia, S. A. Long, and D. Howe, “Radial force density and vibration characteristics of modular permanent magnet brushless ac machine,” Electric Power Applications, *IEE Proceedings* -, vol. 153, no. 6, pp. 793-801, 2006.

[3] J. F. Gieras, J. C. Lai, and C. Wang, *Noise of Polyphase Electric Motors*, no. 10. CRC/Taylor & Francis, 2006.