Design of 8p12s IPMSM for Minimization of Electromagnetic Noise and Vibration

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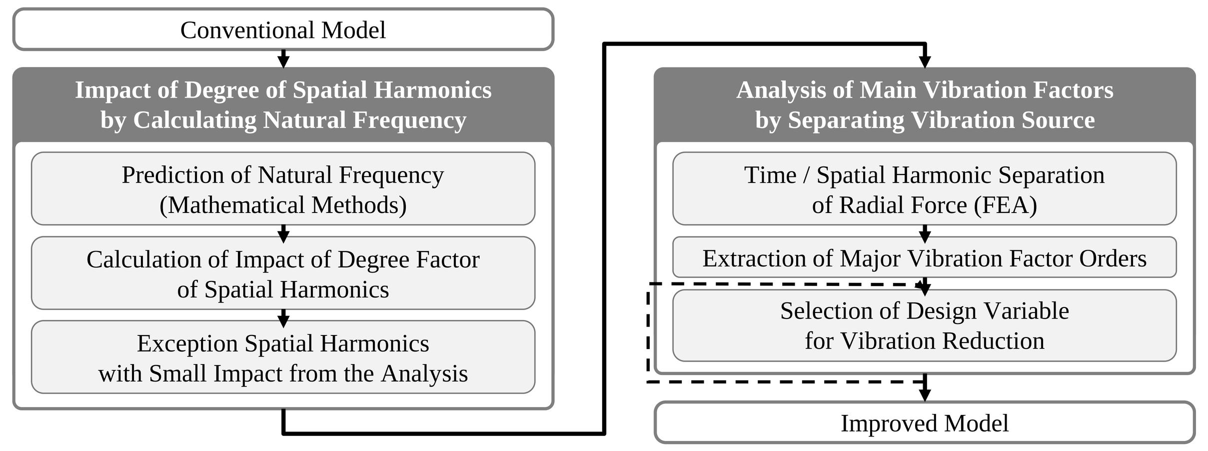
I. Introduction

In this paper, we propose a process of the vibration analysis using spatial harmonics and time harmonics of radial force density as shown in Fig.. For this purpose, this study suggests the impact of degree factor to limit the order of spatial harmonics and deduct the component that has a significant influence on vibration through time, spatial harmonics separation, and calculation of the vibration. Finally, the vibrations of the conventional model and improved model were analyzed, and the validity of the result was verified through the manufactured prototype and vibration test.

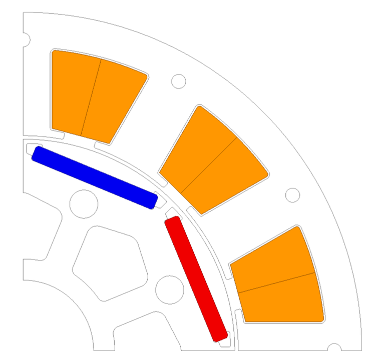


- Process of the vibration analysis using spatial harmonics and time harmonics of radial force density

II. Impact of Degree of Spatial Harmonics by Calculating Natural Frequency

A. Specification of Conventional Model

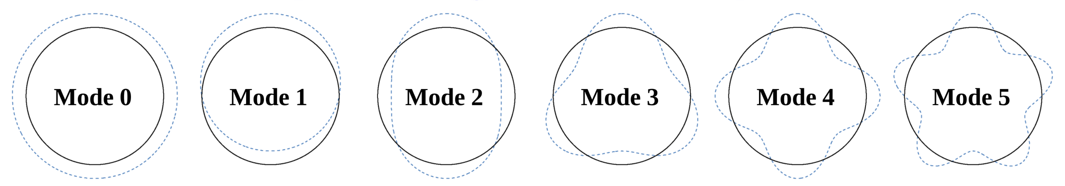
Description	Symbol	Value	Unit
Peak value of the phase current	I_{max}	14.5	A_{pk}
Rotation speed	-	5000	rpm
Stator outer diameter	D_{so}	96	mm
Rotor outer diameter	D_{ro}	60	mm
Airgap length	g	0.5	mm
Stack length	L_{stk}	26.95	mm



- Cross-section of conventional model

B. Prediction of Natural Frequency and Calculation of Impact of Degree Factor of Spatial Harmonics

- Circumferential Mode Shape



- Vibration Velocity for r-th mode

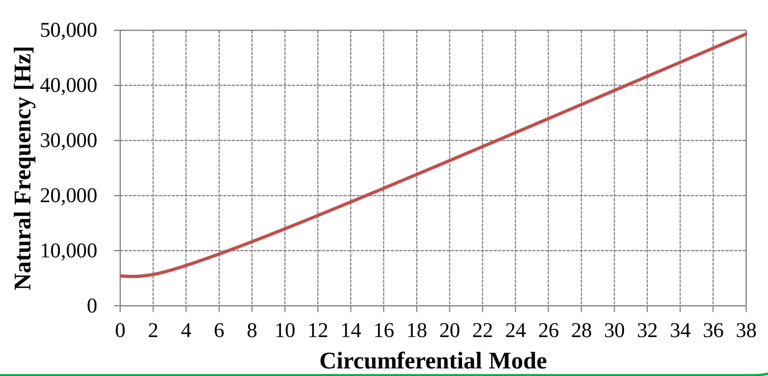
$$V_r = \sum_{n=1}^{\infty} V_{rn}$$

- Vibration Velocity for r-th space harmonics and n-th time harmonics

$$V_{rn} = 2\pi f_{rn} \frac{\pi D_{si} L_{stk}}{M_c \omega_{mr}^2} P_{rn} h_m$$

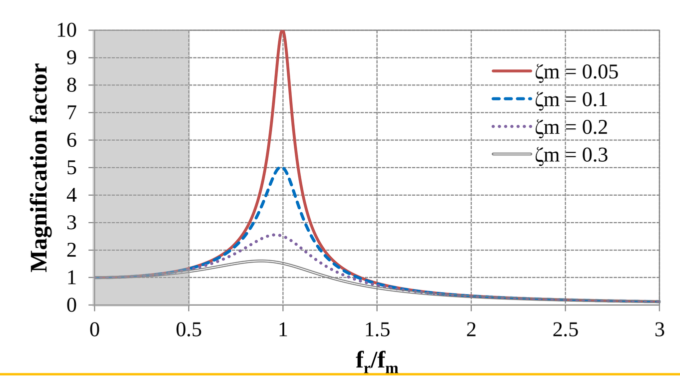
- Natural Frequency in r-th mode

$$f_{mr} = \frac{1}{2\pi}\sqrt{\frac{K_r}{M_c}} = \frac{1}{2\pi}\frac{\Omega_r}{R_c}\sqrt{\frac{E_c}{\rho_c(1-v_c^2)}}$$



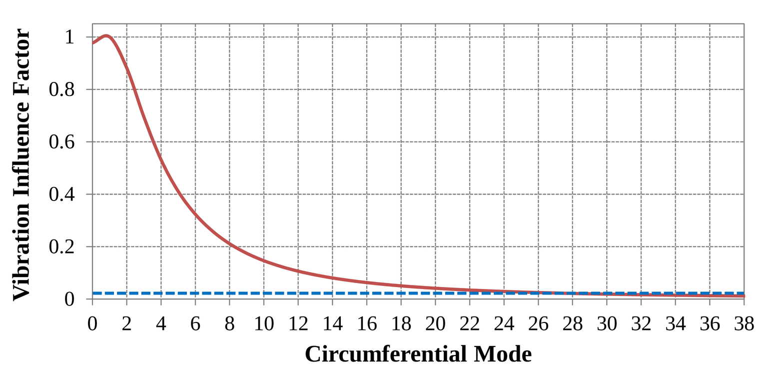
- Magnification Factor

$$h_m = \frac{1}{\sqrt{\left[1-(f_{rn}/f_{mr})^2\right]^2 + \left[2\zeta_m (f_{rn}/f_{mr})\right]^2}}$$



- Vibration Influence Factor

$$k_v = \left(\frac{f_{m1}}{f_{mr}}\right)^2$$



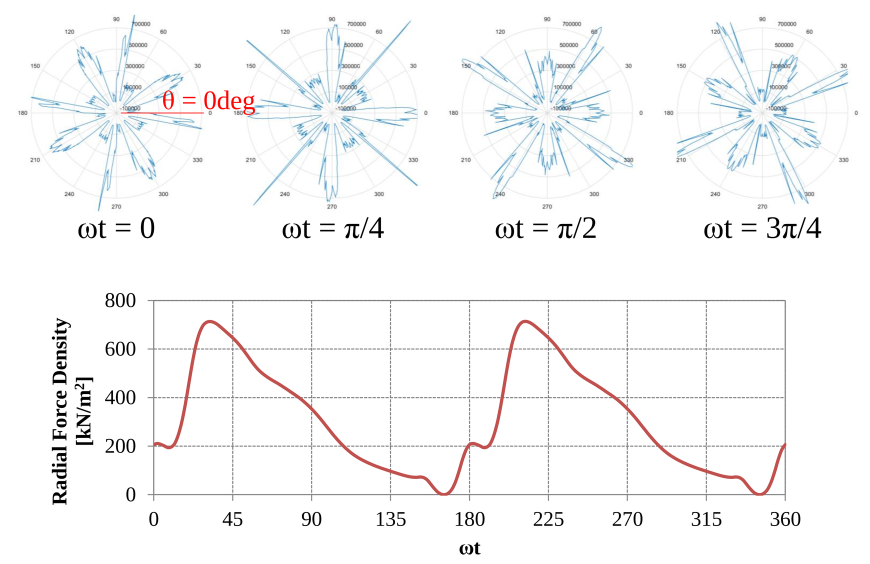
III. Analysis of Main Vibration Factors by Seperating the Vibration Source

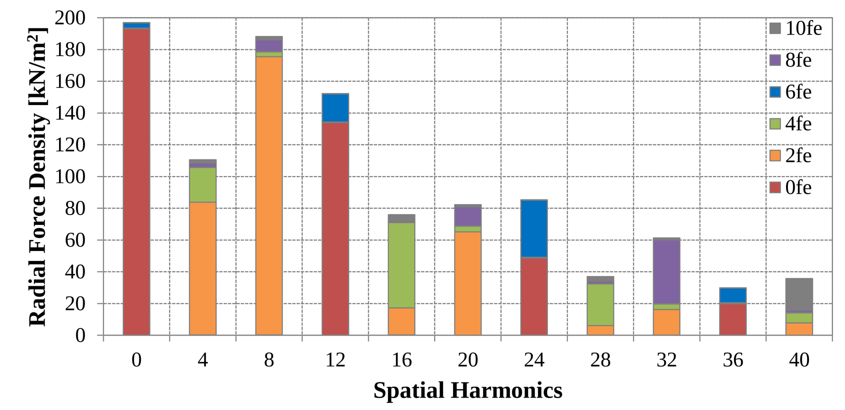
A. Time / Spatial Harmonics Separation of Radial Force Density

- Radial Force Density

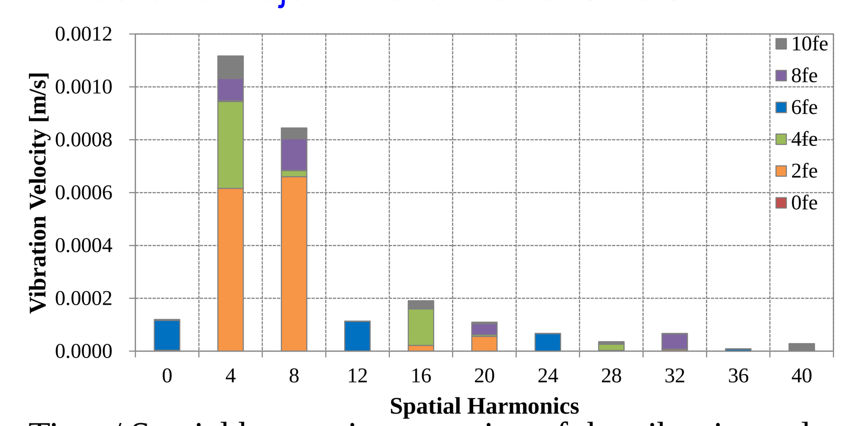
$$p(\theta,t) = \frac{1}{2\mu_0}\left[B_r^2(\theta,t) - B_t^2(\theta,t)\right] \cong \frac{1}{2\mu_0} B_r^2(\theta,t)$$

$$p(\theta,t) = \sum_{r=0}^{\infty}\sum_{n=0}^{\infty} P_{rn}\cos(n\omega^e t \pm r\theta)$$

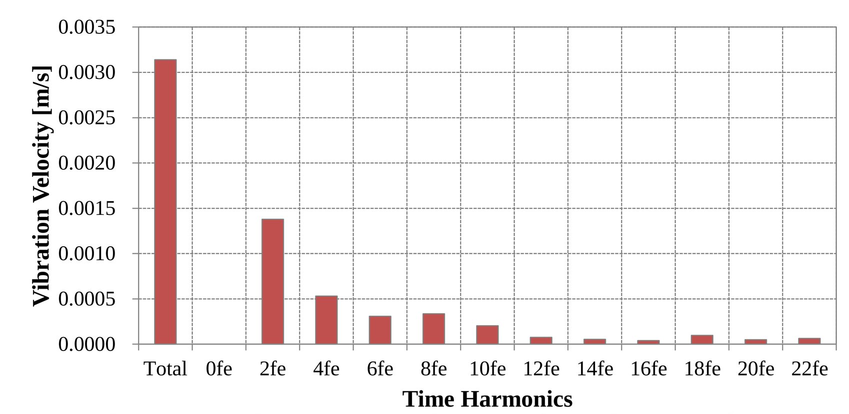




B. Extraction of Major Vibration Factor Orders



- Time / Spatial harmonic separation of the vibration velocity



- Vibration velocity according to the vibration frequency

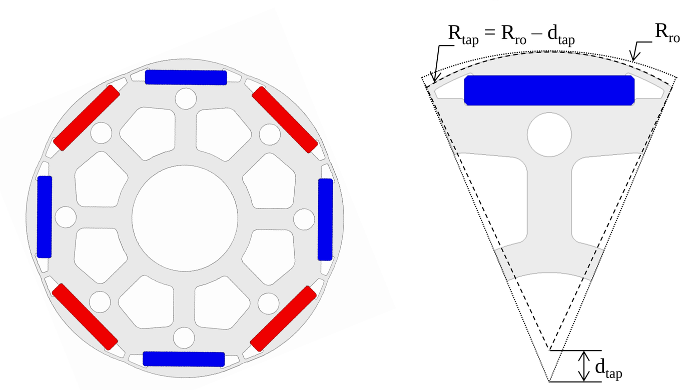
- Selected Time / Spatial Harmonics

	Time Harmonics				
	2fe	4fe	6fe	8fe	10fe
Spatial Harmonics	4, 8, 16, 20	4, 16, 28	0, 12, 24	4, 8, 20, 32	4, 8, 16

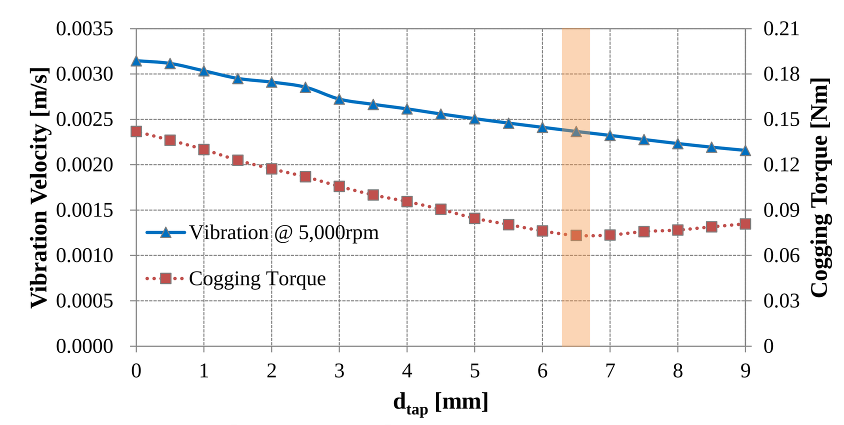
C. Improved Design for Vibration Reduction

- Objective Function

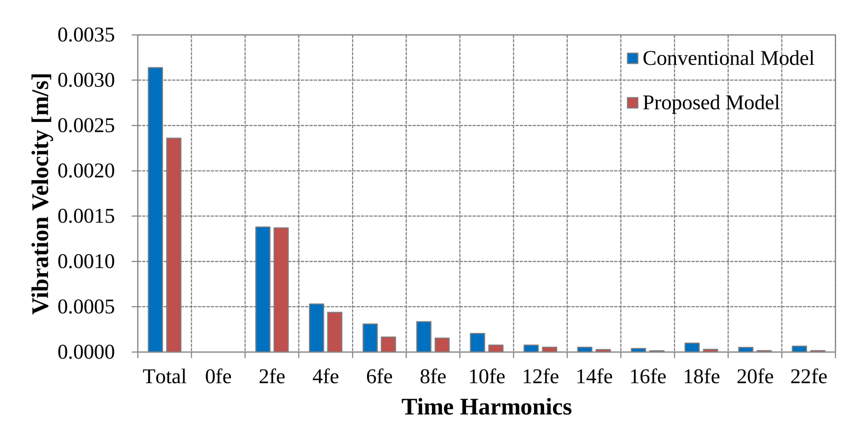
1. Minimizing the cogging torque
2. 20% reduction in the electromagnetic vibration



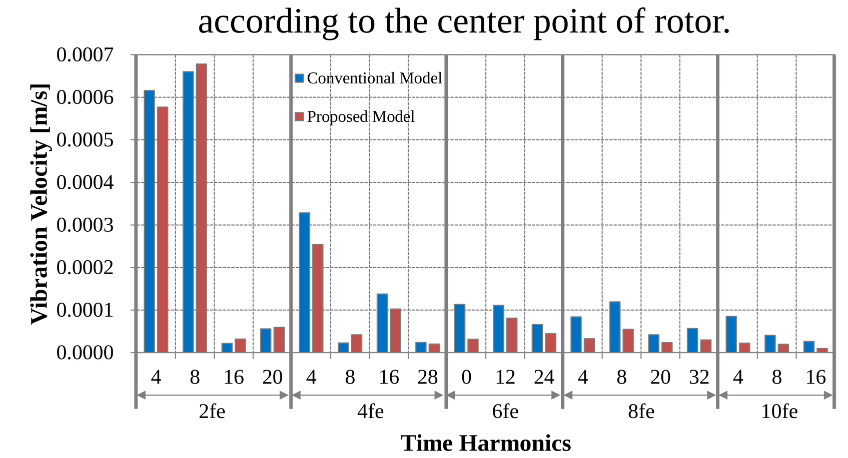
- Cross-section of conventional model



- Vibration and cogging torque according to the center point of rotor.



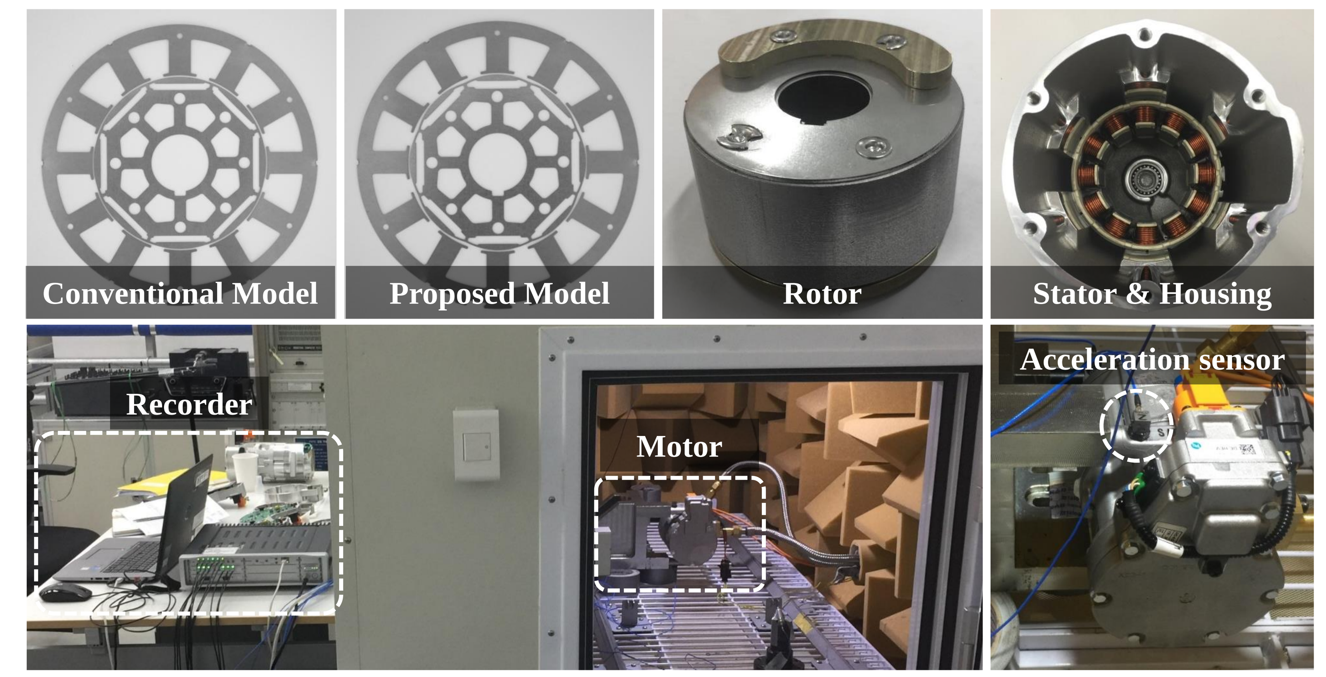
- Vibration of the proposed model and conventional model



- Selected Time / Spatial harmonics of the vibration velocity

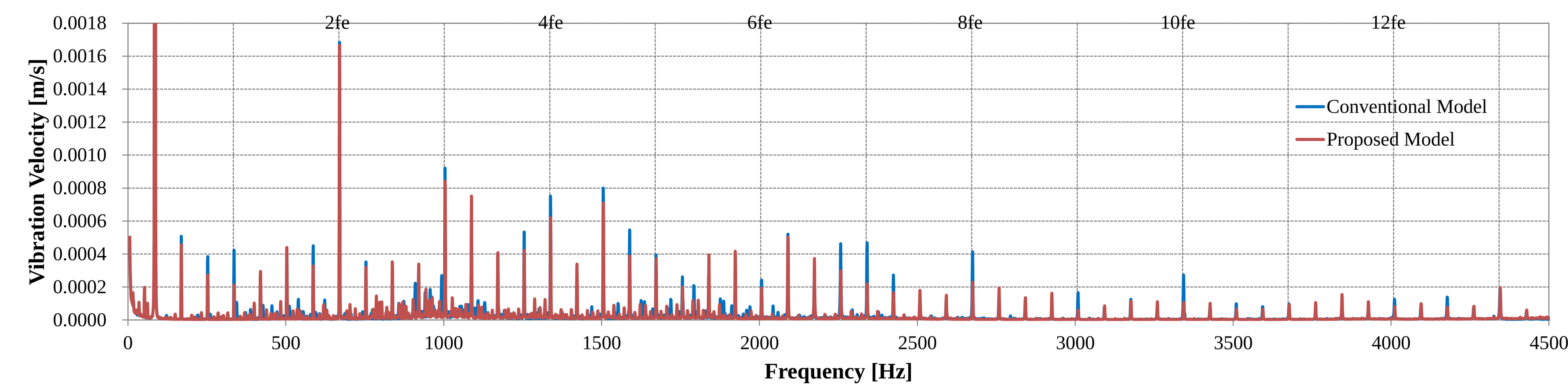
IV. Test and Verification

- Test Condition : 4Nm @ 5,000rpm

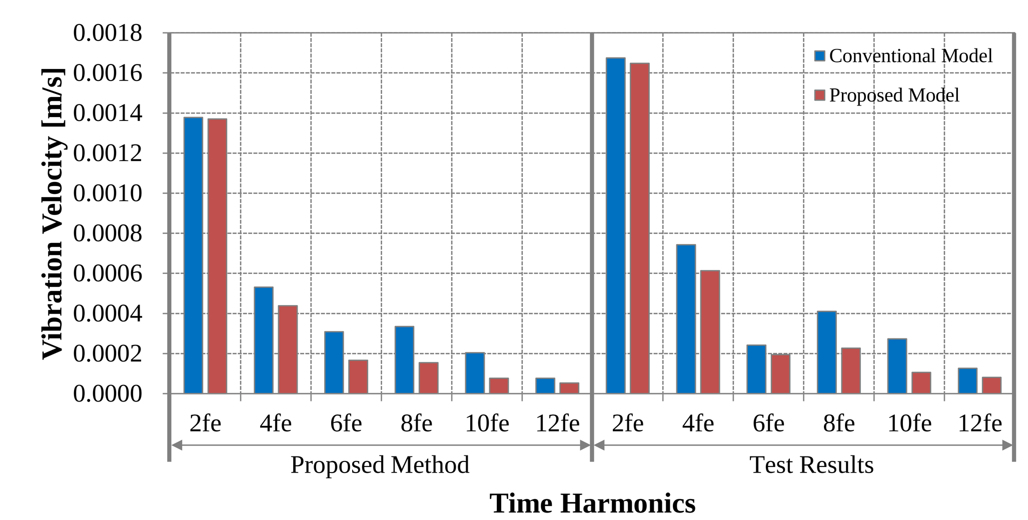


- Manufactured prototypes and test equipment settings

- Test Results



- Test results of the proposed model and conventional model



- Comparison of the test results with the proposed method

V. Conclusion

In this study, the electromagnetic vibration review process was proposed. Components with a large influence on vibration were derived through influence factors for limited spatial harmonic dimensions and time-space harmonics separation and vibration. To verify the proposed process, the design was evaluated to reduce the electromagnetic vibration by reducing the vibration other than the 2fe component, which constitutes the main frequency. It was verified through experiments.

The proposed process is not an electromagnetic-structure interlocking analysis but a method to examine the results of electromagnetic analysis. There is an advantage that vibration can be examined simultaneously in the electromagnetic optimum design process.