[Bui * *et al.*, 6(10): October, 2017]
IC™ Value: 3.00

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

ACOUSTIC NOISE ANALYSIS OF HIGH SPEED SRMS BY ELECTROMAGNETIC FORCES

Minh Dinh Bui*
*IEEE Student Member, Hanoi University of Science and Technology, HUST

DOI: 10.5281/zenodo.1002608

ABSTRACT

This paper presents a simple procedure for acoustic noise reduction in switched reluctance motor (SRMs). Radial forces between rotor and stator teeth cause a vibration of stator laminations and windings. The vibrations lead to acoustic noise. The radial forces can be determined by the two-dimensional finite element method (FEM). The magnitude of the acoustic noise at any operating speed is calculated by an analytical mode which depends on the radial forces and circumferential deflection. The calculation, simulation and measurement results are useful to improve stator and rotor poles with acoustic noise reduction. Moreover, it is important for the SRM to avoid the mechanical resonant frequency. If the electric frequency equals mechanical resonant frequency, the vibration and acoustic noise is extremely high and destroys the mechanical structure of the high speed motor.

I. INTRODUCTION

from automotive vehicles [1] to the aircraftengine areas. The SRM has been used as a starter/alternator for moreelectric aircraft [2-8]. However, a torque is maximized to speed up in starting mode and efficiency is maximized in higher speed by torque per RMS current.

The torque-speed characteristics are functionsof the reference currents, turn-on and turn-off angles. Theywere determined by a dynamic SRM simulation in differentspeeds and control modes. In over a wide range of speeds, the maximized torque control can be achieved by current

controller and optimization of choosing turn on-off angles. Atlow and medium speeds, the phase currents are controlled bydiscontinuous conduction mode DCM and at higher speedsby continuous conduction mode (CCM) to maintain torquevalues.

II. IMPACT TEST

Every electric motor has its own natural mode frequencies. They depend on the statorshapes, mass and material. The SRM stator is composed silicon steel lamination, aluminum rings and copper windings. In order to investigate the frequency, animpulse excitation by a hammer impact was used to measure the natural frequencies of themotor in fig 1.

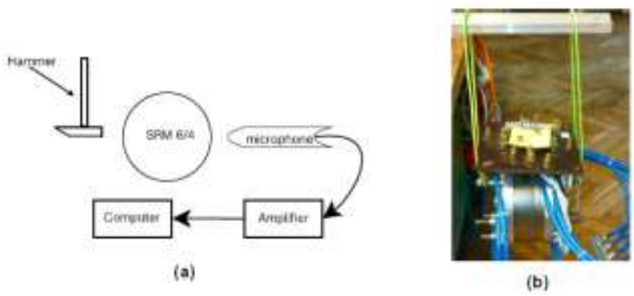

Fig 1. Hammer impact setup (a) and SRM for test (b) [2]

The impact test results are shown in fig 2.The plastic hummer was used to impact on the stator and the microphone was placed 1m from the impact point.

The frequency spectrum of the stator lamination and aluminum rings.It was noticed that the resonant frequencies of the aluminum water jacket areabout 1.1 kHz and 2.6 kHz (Al mode2).

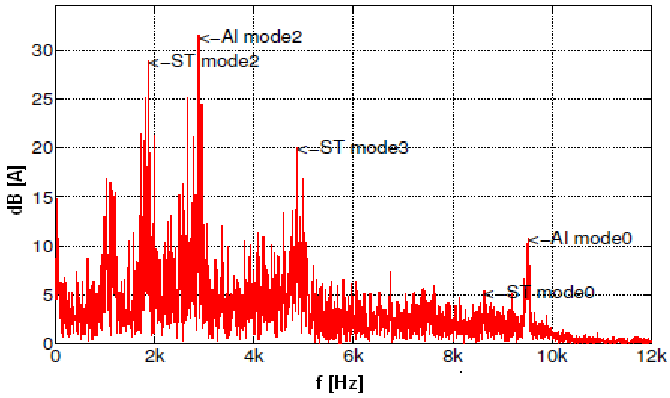

Fig. 2*Vibration modes calculated by a 2D FEM simulation*

The resonant frequencies of the steel lamination are 1.9 kHz (ST mode2), 4.9kHz (ST mode3) and 8.7 kHz (ST mode0).

The resonant frequencies were distinguished by a FFT analysis of the acoustic noise in Master thesis [2]. Those frequencies are very important to validate the mode frequencies of the SRM stator vibration forms as fig 3.This method was introduced for the acoustic noise model of electric motor in [10].

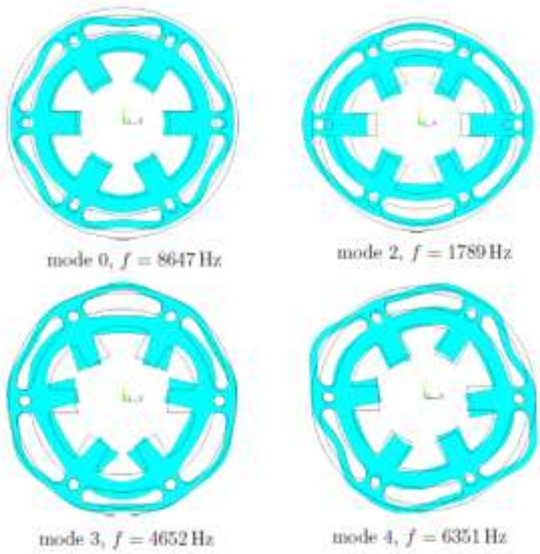

Fig 3.*Vibration modes calculated by a 2D FEM simulation*

III. CALCULATION OF THE ELECTROMAGNETIC RADIAL FORCES

In the SRM, radial force is dependent on the flux density in the air gap. A 2D FEM model has been built to investigate the radial force vs current and rotor position is fig 4a ,b.

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

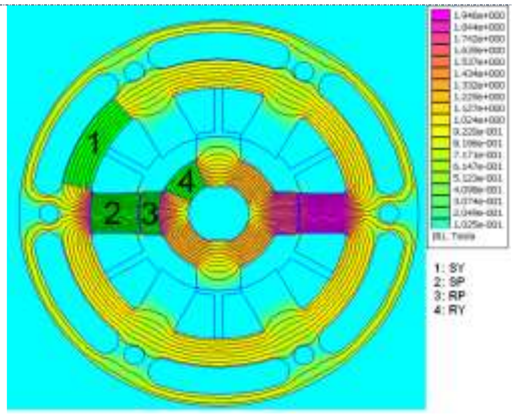

Fig 4a.*A 2D FEM model*

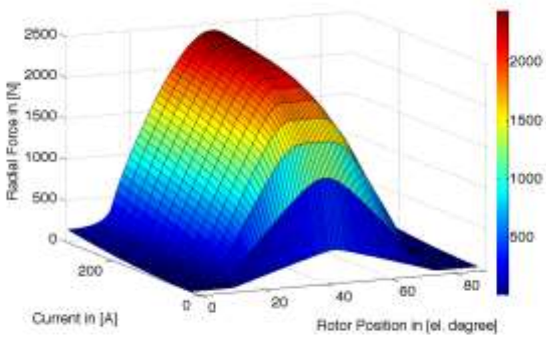

Fig 4b.Radial force vs current and rotor position results.

From a dynamic SRM model in [4,5,6], the radial force waveform can be obtained at different speeds in fig 5. This force is used to calculate the deformation and acoustic noise late.

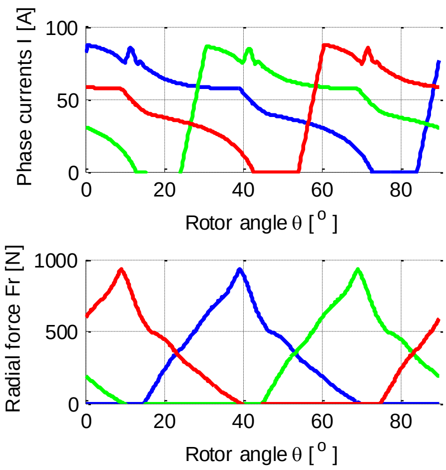

Fig. 5Radial force waveforms vs rotor position at 30000 rpm

IV. ACOUSTIC NOISE CALCULATION

The magnitude of the acoustic noise at any operating conditiondepends on the circumferential deflection due to the radial force density, which is the radial force perunit operating square. The analytical expression for the dynamiccircumferential deflection for modes m>=2 can be expressed as(1) from an analytical model [9]:

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

$$D_{f_{exc}} = \frac{\dfrac{12.F_{r(f_{exc})} \cdot R_m}{m^4 \cdot E}\left(\dfrac{R_m}{h_s}\right)^3}{\sqrt{\left[1+\left(\dfrac{f_{exc}}{f_m}\right)^2\right]^2 + \left[\dfrac{\delta}{\pi}\cdot\dfrac{f_{exc}}{f_m}\right]^2}} \quad (1)$$

where,
D f exc amplitude of dynamic deflection (m);
*F*ramplitude of radial force density (N/m2);
δlogarithmic decrement =2π . (damping factor);
*f p*fundamental frequency of phase current (Hz);
*f exc*excitation frequency (Hz);
*R m*mean radius of stator yoke;
*hs*stator pole height;
m, *fm*circumferential mode number and modefrequency;
*E*module of stator material elasticity;

The harmonic radial forces and their frequencies have been determined by a FFT analysis of the radial force waveforms as depicted in fig 6. The harmonic order 1 was defined 100% and the other less than 70% are displayed in fig 6.

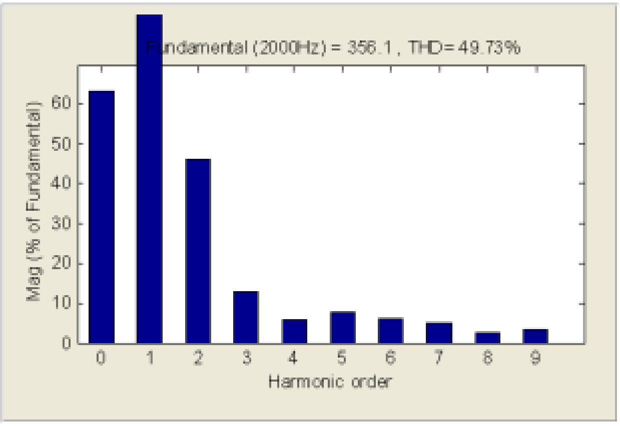

Fig. 6Radial force harmonics and their frequencies, fundamental frequency of 2000 Hz

The deformation was calculated by radial force waveforms at different speeds and modes [9].

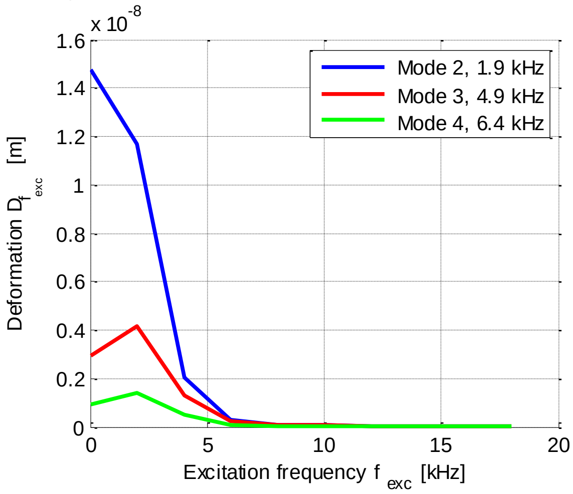

Fig. 7*Deformation vs harmonic frequencies*.

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

Sound power radiated by an electric machine can be expressed as (2) in [9]:

$$P = 4 \cdot \sigma_{ref} \cdot \rho \cdot c \cdot \pi^3 \cdot f_{exc}^2 \cdot D_{f_{exc}}^2 \cdot R_{out} \cdot L_{stk} \qquad (2)$$

where,
P radiated sound power (W);
σ *rel* relative sound intensity $\sigma_{ref} = k^2/(1+k^2)$
k wave number k=(2. π.Rout . fexc)/c
c traveling speed of sound (m/s) in the medium;
$\rho \cdot c = 415 N \cdot s \cdot m^{-3}$ for air density;
Rout, Lstk outer radius and stack length of the stator (m).
The sound power results have been calculated in fig 8. The mode 2 has a highest sound power at 1,9 kHz frequency corresponding to the motor speed of 27.000 rpm.

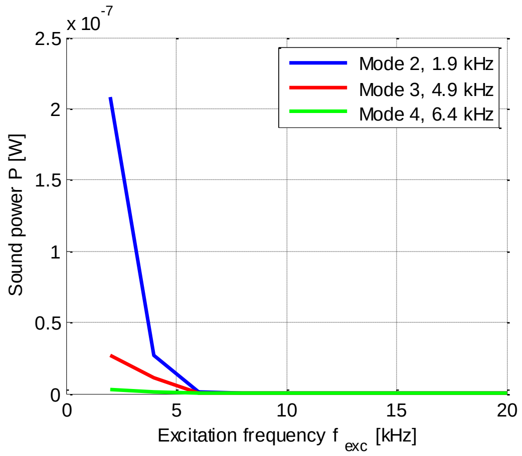

Fig. 8Sound power vs excitation frequency

Depending on the threshold of human ear sensation, thereference of sound power level is well known. Consequently, the acoustic noise power level in decibels becomes.

$$L_{\varpi} = 10 \cdot \log\left(\frac{2 \cdot P}{P_{ref}}\right) \qquad (3)$$

With, the reference sound power level $P_{ref} = 10^{-12}$ W

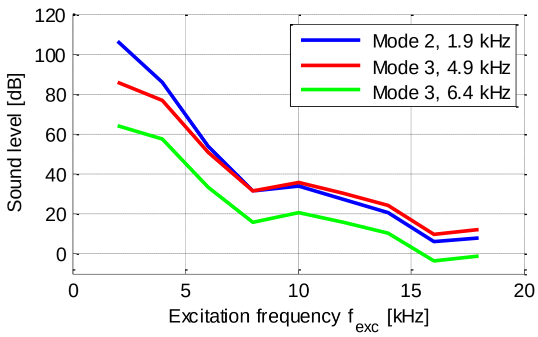

Fig. 9*Sound power vs excitation frequency*

The sound level are extremely high at different mode in a wide frequency. With Mode 2, the sound level is about 110 dB at the frequency of 1.9 kHz. From this analysis, the electric frequency of SRM is not equal 1.9 kHz (27.000 rpm). Because the resonance problem happens and they can destroyed the mechanical structure.

V. SRM SOUND LEVEL MEASUREMENTS

The magnitude of acoustic noise depends on many factors such as magnetic radial force,mode shapes and stator damping. The peak acoustic noise corresponds to the maximumdeflection of the stator for the dominant circumferential mode frequencies and modes.

In order to determine the noise level at very high speed of the SRM, the digital noise meterwas used to measure at different constant speeds. The test bench of the noise level and spectrum has been built in fig 10. The noise was measured at no-load test to remove the influence of the radial force noise.

Fig 10The test bench for sound level measurement

The test bench was isolated from surrounding environment to remove undesired noise. Moreover, at very high speeds, the mechanical components can fly away due to radial forces or unbalance mistakes.The measurement condition includes a sandbag box and microphone installed inside box with 1m from motor in underground, there was no motor or other machine run at that time.

Table 1Noise level measurement

Speed(rpm)	electrical frequency (Hz)	Noise level (dB)
5,000	333	70
10,000	667	88
15,000	1,000	99
20,000	1,333	112
25,000	1,667	113
35,000	2,333	115
40,000	2,667	114
43,000	2,866	120
47,000	3,133	112

The acoustic noise resonant frequencies have been determined in fig 10 at different speeds from 10.000rpm to 40.000 rpm.

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

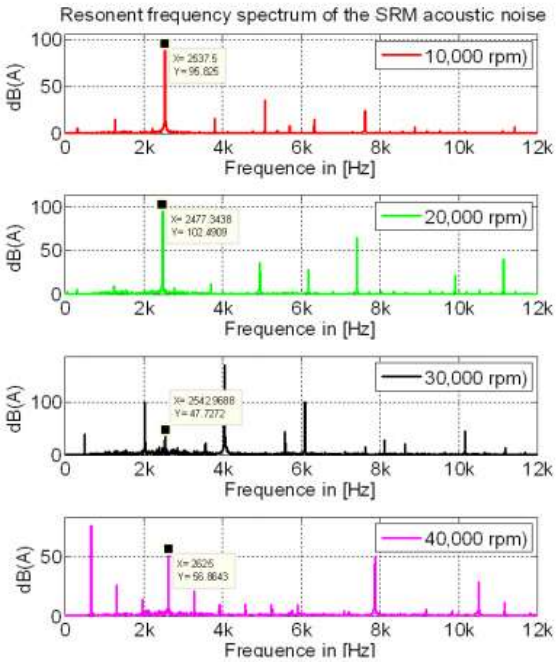

Fig 11Acoustic noise spectrum vs resonant frequency

The table 1 shows the noise level vs speed. The noise values are very high up to 120 dB at43,000 rpm. However, it is reduced at 47,000rpm due to avoid the mechanical frequency resonance. The switched reluctance motor was operated at no-load, so the radial magneticforces which depend on the phase current and flux density has no significant influence on themeasured results. The noise source is only from the mechanical vibration.

The precision of the sound level measurement was effected by microphone and analyzer. The sound level has been measured with the frequency from 0 to 20kHz.

VI. CONCLUSION

The acoustic noise level has been measured with speed up to 47,000 rpm and the noise spectrumfrequency was analyzed for different speeds. To improve the acoustic noise performanceof the SRM, there were some proposals of changing the shape of the stator or rotor teeth.To reduce the radial force, the corners of the stator teeth have changed to round shape todecrease the radial force. The stiffness of the stator yokes was increased to reduce the deformationof the stator. A detailed analysis of the modified shapes was done in [3]. Due tothe rotor has salient poles, the air-gaps between rotor teeth and slots are not equal and thehigh velocity of the air blocks in rotor slots can create a the acoustic noise significantly. Toreduce this part of the acoustic noise, the rotor slots can be fulfilled by plastic material.

VII. ACKNOWLEDGMENT

This research was supported the National Research Foundation of Vietnam funded by the Ministry of Science and Technology under Program KC.05/16-20..

VIII. REFERENCES

[1] Xue, X.D.; Cheng, K.W.E.; Lin, J.K.; Zhang, Z.; Luk, K.F.; Ng, T.W.; Cheung, N.C., "Optimal Control Method of Motoring Operation for SRM Drives in Electric Vehicles," Vehicular Technology, IEEE Transactions on , vol.59, no.3, pp.1191,1204, March 2010.
[2] Simon Michael Schneider, Master thesis, "Analysis and Reduction of Acoustic Noise in High Speed Switched Reluctance Motor", July 2013, TU-Berlin, Germany.
[3] Minh Dinh Bui, Stefan Hoffmann and Uwe Schäfer, "An Accurete Magnetic Characteristics Measurement Method for Switched Reluctance Machines", ICEMs2011, August 20-23, Beijing, China.

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

[4] Minh Dinh Bui; Uwe Schäfer, "Core losses measurement technique for high frequency and flux density of switched reluctance machines", XXth International Conference on Electrical Machines (ICEM), 2012, Page(s): 1619 – 1624.
[5] Bui, Minh Dinh; Schneider, Simon; Arnaout, Samy; Schaefer, Uwe "Torque maximization of a high-speed switched reluctance starter in acceleration test", 15th European Conference on Power Electronics and Applications (EPE), 2013.
[6] Stefan Hoffmann, Master thesis, "Aufbau und Inbetriebnahme eines SR- Flugzeug-Starter-Generatorsystems", TU-Berlin 2010, Germany.
[7] Song Shoujun, PhD thesis, "Detailed design of a 30 kW Switched Reluctance Starter/Generator system used in more/ all electric aircraft ", TU-Berlin 2009.
[8] Minh Dinh Bui, PhD thesis, "Maximum torque control of a high speed Switched Reluctance Stater/Generator used in more/ all electric aircraft ", TU-Berlin 20014.
[9] M. N. Anwar, I. Husain "Radial force Calculation and Acoustic Noise Prediction in Switched Reluctance Machines," IEEE Transactions on Industry Applications, Vol. 36, No.6, PP. 1589-1597, November/December 2000.
[10] Colby, R.S.; Mottier, Francois M.; Miller, T.J.E., "Vibration modes and acoustic noise in a four-phase switched reluctance motor," Industry Applications, IEEE Transactions on , vol.32, no.6, pp.1357,1364, Nov/Dec 1996.

BIOGRAPHIES

Minh Dinh Bui received the B.S. degree in electrical engineering from Hanoi University of Technology, Vietnam, in 2003 and the M.Sc. degree in the Department of Electrical Engineering from Hanoi University of Mining and Geology, Vietnam, in 2007.

He has graduated doctor degree at the Department of Electrical Drive, Institute for Power Engineering and Automation, Berlin Institute of Technology in April 2014. Now he is a lecturer and scientific researcher at Hanoi University of Science and Technology (HUST). His researchinterests are simulation and control of switched-reluctance machines and high speed drives.

CITE AN ARTICLE

Bui, M. D. (2017). ACOUSTIC NOISE ANALYSIS OF HIGH SPEED SRMS BY ELECTROMAGNETIC FORCES. ***INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY, 6*****(10), 1-8.**