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ACOUSTIC BEHAVIOUR OF A SWITCHED RELUCTANCE MOTOR

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Abstract
Switched reluctance Motors (SRMs) are considered as viable substitutes for AC motors in a variety of applications, because they offer many advantages such as simple mechanical construction, high-speed operation and greater reliance on sophistication in the controller. However, despite these excellent attributes, high levels of torque ripple and audible noise caused by SRMs remain as an open problem that appears to be particularly important, when introducing SRM technology for domestic products. As sound and vibrations are function of geometry, material properties and rotational speed of the motor, the knowledge of the mode shapes, the mode frequencies, and the noise spectrum can be effectively used to develop SRMs with minimal noise through design modifications.
The existing research on acoustic noise of a SRM mostly deals with the radial vibration of the stator due to the radial magnetic force, but to characterize the acoustic noise emitted by a SRM it is necessary to know the dynamic behaviour of the rotor. This paper presents the acoustic characterization of a flat shaped SRM designed as a direct drive in a domestic washing machine. This SRM follows an 8/6 basic structure repeated three times, it has four phases with 24 poles in an external stator and 18 rotor poles placed inside. This means that the sound pressure is measured in a test bench, and this spectrum is correlated to the mode shapes and mode frequencies of the rotor and stator, previously obtained by numerical computation. This correlation will let know which element or property, is responsible for sound emission.

INTRODUCTION

Many investigations [1-3] about possible noise sources in a SRM have revealed that there are three areas of interest:

Mechanical Noise sources

- Bearing faults, due to its manufacturing process or to normal wear, can lead to vibrations of the rotor shaft, which are transmitted to the motor's case or load.
- Manufacturing asymmetries of the rotor and stator can produce unbalanced radial or axial forces which can cause unwanted vibrations such as the bending of the rotor shaft.

These sources are interrelated since any misbalance of the rotor will result in an additional load being placed on the bearings. These noise sources could also result in additional structural vibration which could lead to sound generated by the outer surface structure.

Electromagnetic sources

- The magnetic circuit tends to adopt a configuration of minimum reluctance, which develops an attractive radial force between rotor and stator. This force leads to stator vibrations.
- The current through the stator windings could interact with local magnetic fields to produce a force on the windings. This force could excite winding vibrations.
- Magnetostrictive forces are present in all compressible magnetic materials under the influence of a magnetic field. These forces can cause lamination vibration of the stator and rotor.
- The torque ripple, that is the tangential magnetic force exerted on the poles, mainly excites stator vibrations.

Aerodynamic sources

- The rotor poles behave like blades, which cause acoustic noise due to windage.

For SRM's with a length/diameter ratio of the stator bigger than 1, many authors [4-6] have revealed that radial vibrations of the stator are responsible for most of the acoustic noise. These vibrations are caused by radial magnetic force which acts to decrease the gap separation between the rotor and stator as their poles approach alignment. The rest of possible noise sources are neglected.

This paper analyses the noise emission of a SRM with a length/diameter ratio lower than 0,1. The motor has a flat shape, as shown in Fig. 1, and has been adapted to be housed as a direct drive in the back side of the drum of a domestic washing machine. It has a rotor size of diameter 164 mm and 12 mm of thickness. The stator and the rotor have 24 teeth and 18 teeth, respectively. The number of phases is 4 yielding an angular step of 5 degrees. The experiments performed are aimed at identifying which of the above sources is dominant for this flat shaped motor.

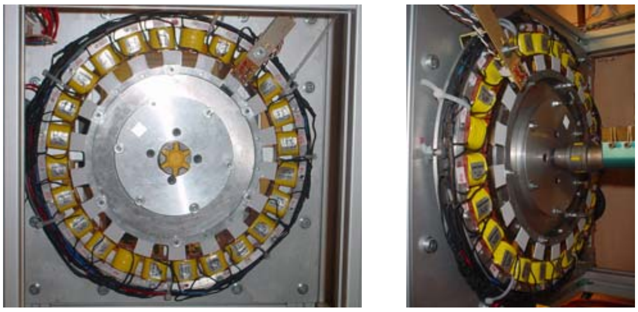

Figure 1 – Flat shaped SRM

MODE SHAPES AND RESONANT FREQUENCIES

Vibrations and acoustic noise are present in all electric rotating motors, they can be particularly problematic in the SRM. The main noise source is the stator back-iron ovalization induced by radial magnetic forces. This is why the determination of stator radial natural resonance frequencies is so important [7].

There are major papers available in the literature to investigate vibrations in SRM based on 2D modal analysis considering the stator frame alone, but there are contributions form other parts such as rotor. The 3D modal analysis reveals certain modes which are producing vibration and the associated acoustic noise in SRM due to the rotor and the stator [8]. The natural frequencies and corresponding vibration modes can be obtained, using structural finite element methods. In this work, the FEM software used has been ABAQUS. Any ovalization modes of rotor and stator are depicted in Figures 2 and 3.

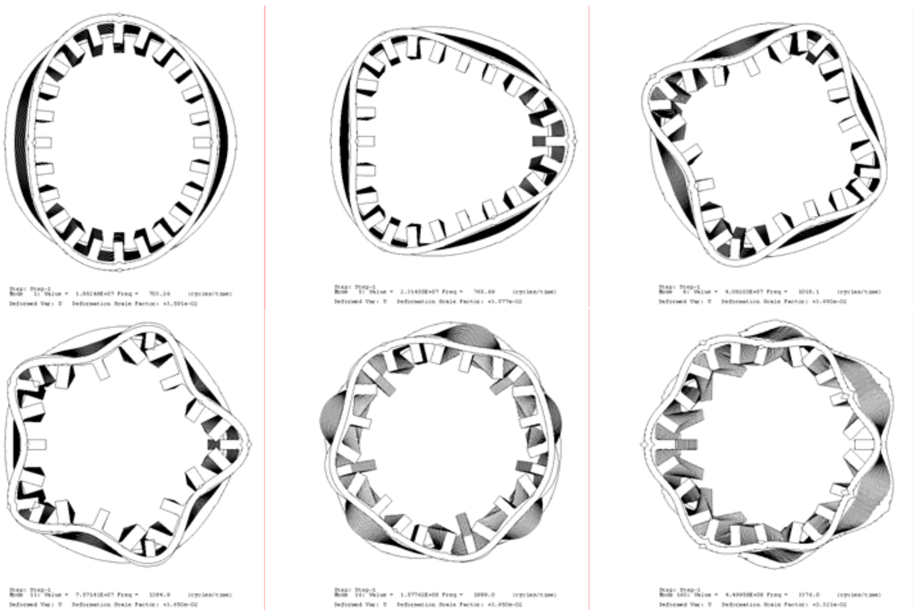

Figure 2 – Mode shapes of a 24-pole stator

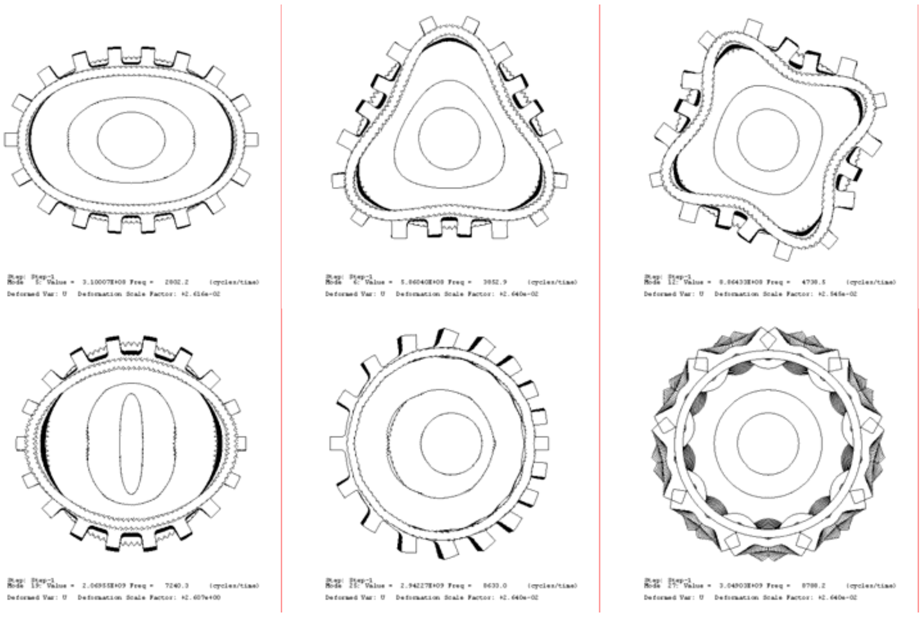

Figure 3 – Mode shapes of a 18-pole rotor

3D resonant frequencies calculated up to 6,4 KHz are listed in Table 1.

Table 1 – Resonant frequencies (Hz)

Rotor	560, 635, 1140, 1220, 1315, 1436, 1575, 1723, 1867, 1955, 2313, 2430, 2550, 2800, 3300, 3425, 3523, 3626, 3750, 3900, 3960, 4480, 4550, 4710, 4738, 5030, 5200, 5356, 5620, 5647, 5770, 5866, 5965
Stator	170, 280, 320, 340, 360, 380, 705, 740, 760, 830, 840, 930, 1020, 1380, 1500, 1550, 1706, 1750, 1970, 2020, 2150, 2250, 2270, 2535, 2700, 2900, 3143, 3350, 3376, 4300, 5400, 5900

SOUND PRESSURE LEVEL MEASUREMENT

The measurement of sound pressure in dBA, has taken place at a semianechoic room with the microphone placed at position 1, according to the engineering method (grade 2 accuracy), of ISO 3744, [9]. The FFT spectrum in a frequency range from 0 Hz to 6,4 KHz, bandwidth 1 Hz, has been obtained for 500 rpm, 800 rpm and 1000 rpm, as Figure 4 shows. For each velocity, the corresponding sound pressure levels are 59, 63, and 67 dBA.

The noise of the SRM was found to generate broad band noise as well as harmonic components. The main source of broad band noise is turbulence in the air flow. Harmonic noise is related to the frequency of the rotation of the rotor poles. The spectra shows that at 500 rpm or 8,33 Hz, the harmonic components are multiples of 150 Hz, (= 8,33 Hz x 18 rotor poles). At 800 rpm and 1000 rpm, the harmonic components are multiples of 240 Hz and 300 Hz, respectively.

If these results are compared with the theoretical analysis, it is observed that the resonant frequencies corresponding to the vibrations modes of the rotor and stator do not appear in the spectra noise, as Figure 5 shows. It corroborates that the noise harmonic components of the sound pressure spectra are not related to the structural vibration of the stator or rotor, and the noise emission for a flat shaped SRM is mainly due to the aerodynamic noise generated when a rotor pole passes through a stator air gap.

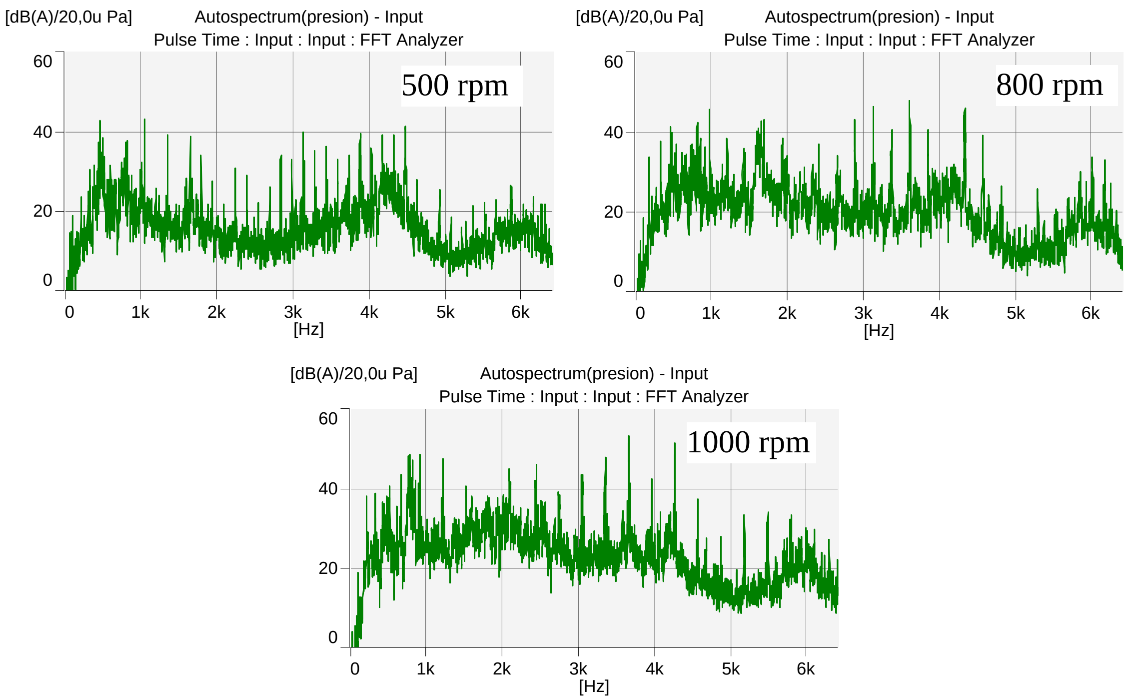

Figure 4 – FFT spectrum

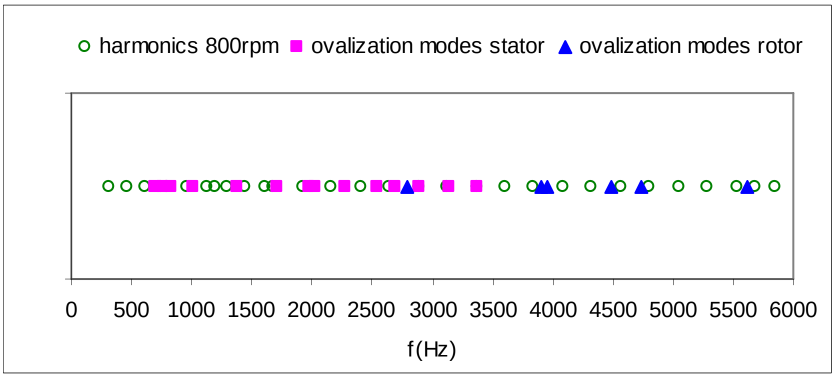

Figure 5 – Frequencies comparison

CONCLUSIONS

Most of the SRMs are made from iron and have a length/diameter ratio bigger than 1, being the structure-borne noise due to the vibration of the stator the main source. If the length/diameter ratio is decreased and the material used is less rigid, the contribution of the vibration of the stator to the noise emission is less relevant.

For the case of the flat-shaped motor designed to drive a washing machine, the length/diameter ratio is less than 0,1 and the support plates of the stator and rotor poles are of aluminium. Under these conditions the noise caused by the vibration of the stator can be neglected, and now the major noise source is the pressure fluctuation produced when a rotor pole passes a stator air gap.

Further work will involve the use of computational fluid dynamics that makes possible to evaluate new designs of number and geometry of poles, and air gap between rotor and stator, that take into account the compromise with the motor efficiency, specific torque and power, motion accuracy, reliability and cost.

REFERENCES

[1| P. Pillay, W. Cai, " An investigation into vibration in switched reluctance motors", Proc. IEEE IAS, Vol **35**, No.3, pp.589-596, (1999)

[2| C.Y. Wu, C. Pollock "Time domain analysis of vibration and acoustic noise in SR drive", IEE International Electrical Machines and Drives Conference, pp.558-563 (1993)

[3| M.N. Anwar, "Radial force calculation and acoustic noise prediction in Switched Reluctance Machines", IEEE Trans. On Industry Applications, Vol **36**, No.6, pp.1589-1597, (2000)

[4| D.E, Cameron, J.H. Lang, S.D. Umans., " The origin and reduction of acoustic noise in variable-reluctance motors", Proc. IEEE IAS Ann.Mtg (San Diego, CA), pp.108-115.(1989)

[5| C.Y. Wu, C. Pollock "Analysis and reduction of acoustic noise and vibration in the switched reluctance drive", Proc. IEEE IAS, Vol **31**, No.3, pp.91-98, (1995)

[6| W. Cai, P. Pillay, " Resonance frequencies and mode shapes of switched reluctance motors", Proc. IEEE Transaction on Energy Conversion, Vol **16**, No.1, pp.43-48, (2001)

[7] J.P. Lecointe et alt, "Analysis and active reduction of vibration and acoustic noise in the switched reluctance motor" IEE Proc-Electr. Power Appl., Vol **151**, No.6, pp.725-733, (2004)

[8] K.N. Srinivas, "Analysis and characterization of switched reluctance motor: Part II" IEEE Trans. On Magnetics., Vol 41, No.4, pp.1321-1332, (2005)

[9] ISO 3744:1994, *Acoustics- Determination of sound power levels of noise sources using sound pressure- Engineering method in an essentially free field over a reflecting plane*