ACOUSTIC NOISE AND VIBRATIONS DUE TO MAGNETIC FORCES IN ROTATING ELECTRICAL MACHINES
- Evaluation -

Trainee's Name/Surname :
Date :

Introduction

The following exercises reflect the content of EOMYS ENGINEERING technical training on analysis and reduction of NVH (Noise Vibration and Harshness) issues due to magnetic forces in electric powertrains and more generally in rotating electrical machines.

A. Sound and vibrations – generalities and application to electric machines

A1. Sound Power Level of an electric machine is measured at 80dB (by intensimetry).
Assuming the machine is on the ground and in free field conditions, what is the Sound Pressure Level at 2m from the machine's center?

A2. The 80dB Sound Power Level from the A1 electric machine was measured without the auxiliary systems (pumps and ventilation system) in operation. Another measurement shows that Sound Power Level of auxiliary systems is 70dB.
What is the total Sound Pressure Level at 2m (from motor + auxiliaries)?

A3. The acoustic spectrum displays one specific harmonic at 1000Hz of 80dB and another one at 500Hz of 20dB.
What is the Sound Power Level in dBA?

A4. A deeper analysis reveals vibration at 500Hz from motor's electric box. The box surface is 0.5 m^2 and the RMS vibration velocity level is 1 mm/s.
Is the box vibration a significant contributor to the 80dB acoustic Sound Power Level of the electric motor?

A5. An induction motor is located on the ground in the center of a 8mx5mx3m room.
From which frequency can the acoustic field inside this room be considered as diffuse?
Reverberation time and Sound Power Level are given in octave band in the following table.

Frequency bands	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Time reverberation (s)	5,0	4,0	3,5	3,2	2,8	2,2
L_w (dB(A) ref. 10^{-12} W)	90	95	100	110	105	100

Compute the sound pressure level in the room at 4 m of the machine.

Porous material with absorption coefficient given in octave band (see table below) is applied on the ceiling of the room.

Frequency bands	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Absorption coefficient α_{por} (-)	0,3	0,5	0,8	0,9	1,0	0,9

Compute the sound power level in the room after applying the absorbent material on the ceiling.

A6. Two independent electric motors are running in the same room. The first one as a Sound Power Level of 70dB, the second one of 75dB. What is the total Sound Power Level?
Do the same considering 70dB and 81dB.

B. Generation process of magnetic noise and vibrations

B1. Can tangential forces be the source of radial vibration on stator yoke? Can they generate noise through the rotor?

B2. On an induction machine at no-load, what is the noise increase if the current is doubled?

B3. An induction machine with stator teeth Zs=36, rotor teeth Zr=28, pole pairs p=3 has an ovalization mode (2,0) at 1200Hz. Does a resonance occur? If yes, at which speed?

B4. Qualitatively sketch the shape of fundamental flux (p=2 pole pairs) and induced radial forces on stator teeth with Zs=6 teeth. What is the yoke deflection order?

C. Analytical characterization of noise and vibration of electric origin

C1. Consider a permanent magnet synchronous machine with p = 5 pole pairs and Zs = 12 stator slots. What is the smallest wavenumber of the existing magnetic forces? Calculate the associated harmonic effort frequency. Is it possible to reduce it without changing the machine's torque?

C2. A permanent magnet synchronous machine has p = 32 pole pairs and Zs = 72 slots. What is the frequency of the detent torque at 2000 rpm? What are the rotor mmf harmonics responsible for the detent torque? Is this torque harmonic dangerous from a vibroacoustic point of view?

C3. Show that, in no-load case, rows 11 and 13 of the rotor field of a Permanent Magnet Synchronous Machine (PMSM) with Zs = 48 p = 4 (qs = 3 phases) can create a pulsing effort of wavenumber r = 0 at 12 fs.
Load case: demonstrate that magnetomotive force harmonics may also create this type of effort. Can it act on this effort with a change of the shorted pitch?

C4. What are the three types of harmonic efforts in a permanent magnet electric motor?
Case of an PMSM: what happens to each of the types of efforts if the current amplitude is doubled?

C5. Consider a PMSM in Zs = 120 p = 10 (nb of pole pairs) (qs = 3 phases). Does the machine have a distributed winding?
Plot its expected acoustic spectrogram from 0 to 3000 rpm (ordinate axis) and 0 to 6400 Hz (abscissa axis) by placing the pulse excitations on open circuit. It is recalled that N = 60 f/p (N speed in RPM, f electrical frequency in Hz). Place the breathing mode at 3 kHz. What are the expected resonances?
It is assumed that the machine is in charge and is powered by an asynchronous 4 kHz PWM. Add the PWM lines on the spectrogram. Will new resonances occur? If so at what speeds in rpm? Show that the stator current field in load case adds a new pulsating radial effort harmonic at 6 f (it is recalled that the magnetomotive force of stator creates harmonics -5p and 7p). Will new resonances occur? If so at what speeds in rpm?

D. Vibroacoustic computation techniques under electromagnetic excitations

D1. Cite two numerical problems related to the use of finite elements.

D2. What is the main disadvantage of the permeance / mmf method?

D3. Can we assume weak magnetic / structure coupling in the calculation of electrical noise?

D4. It is desired to simulate a rise in speed of a synchronous electrical powertrain (Zs = 48, p = 4) from 20 to 10000 rpm and simulate the vibro-acoustic behavior up to 10 kHz. What is the smallest time step to simulate? How many revolutions do you have to simulate to capture the sidebands related to eccentricity?
The machine has a mode 0 at 4 kHz with a 2% damping, how to choose a speed step that allows to capture the resonance? Assuming a numerical electromagnetic / acoustic direct coupling take 4 hours of finite element simulation for one velocity point, deduce the simulation time for a rise in speed assuming that the calculations can be parallelized on 10 machines. What method can be used to reduce the calculation time?

E. Noise and vibration reduction techniques from magnetic stresses

E1. An important noise is created by a 2Zs (rank 2) stator permeance harmonic: what is the theoretical ratio between slot opening and teeth opening to cancel it?

E2. We want to reduce the detent torque of a PMSM of Zs = 12 slots and p = 2 pole pairs. What is the optimal magnets offset angle (by simply segmenting them into two parts) minimizing the detent couple?
Same question for the pulsating radial force.

E3. It is desired to reduce a noise appearing at 12fs on a PMSM. What are the current frequencies to inject into the DQH system of axis that can act on the electrical noise? Assuming that the noise is due to order 4 rotating effort in the same direction as the fundamental flux density, and that the machine has p = 2 pole pairs, deduce the only harmonic current frequency capable of reducing noise.
Is it recommended to inject it following Id or Iq?

E4. An auxiliary slot per tooth is introduced to reduce the noise of a PMSM of Zs = 12 p = 5. What is the new spatial order of the expected efforts? Is this technique effective?

E5. We want to reduce the noise and the vibrations by increasing the thickness of the stack (increase of the radius external of the stator). What are the 3 side effects that can instead increase the noise?

F. Experimental characterization

F1. How can the natural frequency of resonance be calculated from the mechanical order k involved in the resonance and the speed N at the resonance (considering a Synchronous machine)?

F2. What is the cause of vibration V-shape patterns on a spectrogram (when they are not crossing the origin)?

F3. High vibration levels are seen at 2fs on a PMSM with p=5 and Zs=12.
What is the minimum number of accelerometers to capture mode shape at 2fs?

F4. What can be done to ensure that the source of noise on an induction machine is magnetic?

F5. A magnetic noise issue is occuring at 6kHz on a machine of 10cm diameter and 4cm length. It is likely to be due to the ovalization mode. What should we pay attention to during the measurements? At which distance the assumption of a punctual noise source is valid?

G. Application with MANATEE software

G1. Define the IPMSM from the following tutorial
https://eomys.com/produits/manatee/tutoriaux/electromagnetic-and-vibro-acoustic-simulation-of-buried-permanent-magnet/

Run an open circuit electromagnetic and vibroacoustic simulation using subdomain electromagnetic models and semi analytic vibroacoustic models. The variable speed NVH behavior is calculated with spectrogram synthesis technique.
Plot the sound pressure level at 2m from machine outer surface as a function of speed.
Find the origin of the resonance in terms flux density wave combinations and harmonic source.

G2. We would like to reduce the noise using rotor step skew:
https://eomys.com/produits/manatee/tutoriaux/electromagnetic-and-vibro-acoustic-simulation-of-buried-permanent-magnet/article/multi-simulation-rotor-stepped-skew-effect-at-no-load-variable-speed

Plot the effect of the skewing angle on the maximum noise level during run-up.

G3. We would like to reduce the noise level at nominal speed by shifting the natural frequencies of the stator stack. Plot the effect of the outer diameter on the sound power level in dB (not dBA).