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ANALYSIS OF THE NOISE, VIBRATION AND TRANSMISSION CHARACTERISTICS OF INDUCTION MOTORS

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ABSTRACT
The noise and vibration generated by the high frequency components of the modulation signal of pulse width modulation induction motors constitute one of the principal problems facing their use in industrial applications. The problems can be reduced by changing the modulation frequency which can even include the possibility of increasing it to above the audible range, but this approach leads to reduced efficiency due to higher losses in the electronic components. In order to deal with these problems the vibration generation mechanisms are analysed and compared with measurements of the noise, vibrations, the input signal and the transfer characteristics to the structure under different running conditions. Inverse force identification techniques were used to characterise the forces generated by the motor at the motor-flange interface using a relatively simple force distribution model.

1 - INTRODUCTION
The noise and vibrations generated by the high frequency components of the converter signal of induction motors are often unacceptable either due to the noise radiated by the motor or transmitted to the structure of the machine and limit their use in many industrial applications. This preliminary investigation deals with the noise and vibration characteristics of a prototype motor developed by the electromechanical group in the Mechanical Engineering Department at the University of Technology of Compiègne.

In order to understand the source mechanisms and to try and reduce the noise and vibrations generated by the motor and its interaction with the structure this investigation included an analysis of the characteristics of the electromagnetic excitation and the effects of the coupling of the motor with the structure. These results were validated with the aid of an experimental modal analysis of the motor and noise and vibration measurements of the motor body and support structure under running conditions. An inverse approach for the identification of the characteristics of the force excitation at the motor flange interface was used to determine the vibration forces transmitted to the flange and the rest of structure.

2 - ELECTROMAGNETIC CHARACTERISTICS
The motor tested has two pairs of poles, 27 slots in the stator and 21 in the rotor. The converter frequency could be varied and the nominal power was in the range of 1.25 kW. Figure 1 shows the spectrum of the converter voltage when modulated at 1500 Hz for a nominal motor speed of 25 Hz or 1500 rpm. The electromagnetic forces generating the vibrations in the system are due to the influence of the electrical inputs which are themselves coupled and modulated as a function of the motor speed, the number of slots in the stator and rotor and the slip ratio. These efforts and the vibration response of the motor structure are principally associated with the modes of the stator pack which behaves essentially like a cylindrical shell with variable characteristics in the axial direction.

Initial tests carried out on the system using a normal 50 Hz signal from a transformer directly connected to the mains showed that the noise and vibration were at very low levels. The influence of the converter is therefore the most significant factor influencing the increased noise and vibration levels.

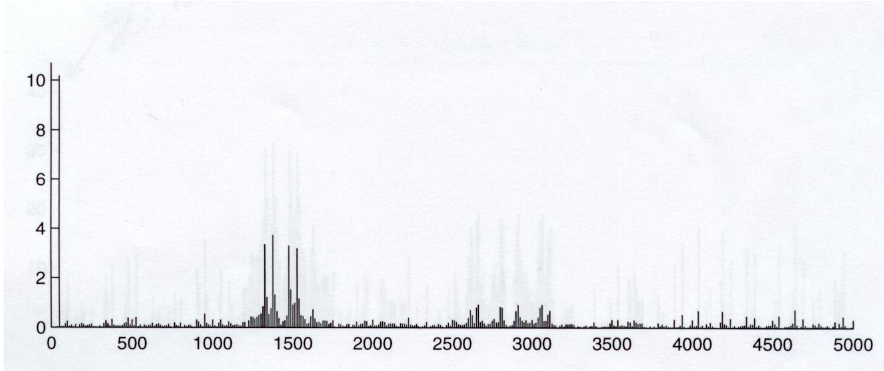

Figure 1: Spectrum of the converter voltage.

In order to investigate the coupling of the system with the forces transmitted to the mounting flange, the motor was mounted on a stand with a generator and variable resistance to act as a brake. Measurements were made under free running and loaded conditions with 7 accelerometers, a microphone, a small electrodynamic shaker and a force transducer.

3 - EXPERIMENTAL SETUP

The experimental set up is illustrated in figure 2 where it can be seen that the main accelerometer measurements were made on the motor mounting flange. The 6 measurement points on the flange were used to provide the response data for the inverse force identification procedure where the force inputs of the motor at the flange interface were assimilated to four point excitations as indicated.

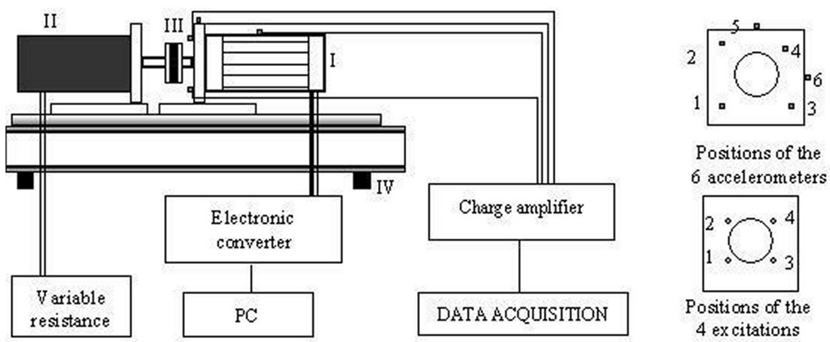

Figure 2: Experimental set up; I induction motor, II brake/generator, III coupling, IV support structure and isolators.

A seventh accelerometer was fixed to the centre of the motor body to verify the amplitudes and frequencies associated with the vibration response in this zone. Previous modal analysis measurements showed that the measured value for the first flexural mode of the cylinder at 2423 Hz corresponded closely to the value calculated by finite elements for the stator pack. The data acquisition and modal analysis was performed with an LMS Roadrunner system which was equipped with eight channels capable of acquiring data up to 50 KHz.

The vibration response data was acquired in free running and loaded conditions in an acquisition and processing configuration permitting the direct calculation of the full cross spectral response matrix for all six accelerometers on the flange. The converter frequency was changed from 2000 Hz to 2400 Hz and then 1670 Hz for three loading conditions with a nominal frequency of 50 Hz in each case. The 2000 Hz converter frequency produced the highest noise and vibration levels due principally to the side bands generated between 2200 Hz and 2500 Hz which are strongly coupled in terms of spatial distribution as well as close to the frequency of the first flexural mode of the motor. In this particular case the motor itself was the highest source of radiated noise.

Figure 3 shows the auto spectra of the first four accelerometers on the flange at full load with a converter frequency of 2000 Hz. The high level of vibrations generated by the converter side bands between 2200 Hz and 2500 Hz are clearly visible. Other noticeable peaks occur just below 500 Hz and just above 1400

Hz, the first due to the effects of the number of poles and the loaded rotation speed of 17 Hz and the second due to the first bending mode of the motor flange and support structure.

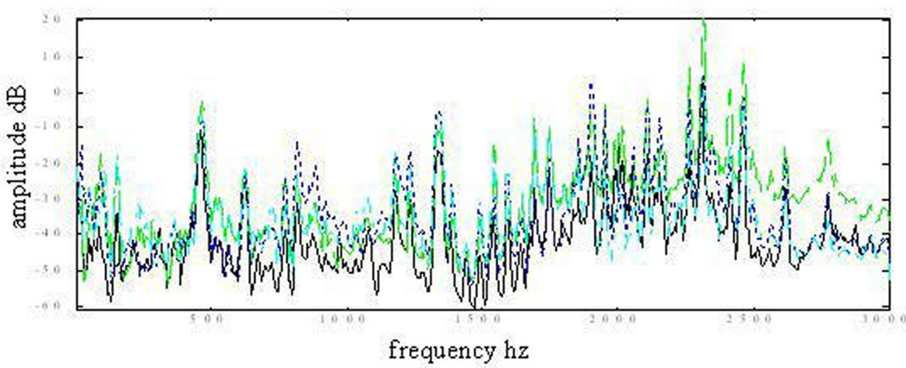

Figure 3: Auto spectra of accelerometers at four positions: ___ 1, _ _ 2, – 5 et -.- 6; converter frequency 2000 Hz with the motor under maximum load.

4 - FORCE IDENTIFICATION

From this data and previous acquisitions of the frequency response functions between the 4 input positions and the six output responses it was possible to calculate the force model using software developed by the company ACOVIB for this type of application.

The principle of the inverse method will be recalled briefly. The relation ship between the dynamic response of M points and the input points on the structure may be expressed in terms of frequency matrix equation as follows:

$$[G_{xx}] = [H]^H_{M\times N}\,[G_{ff}]_{N\times N}\,[H]_{N\times M} \tag{1}$$

where $[G_{xx}]$ is the dynamic response matrix whose elements represent the auto and cross spectral responses at all M output response positions (6 in this case), measured under running conditions. This response is due to the N unknown input forces (4 in this case). $[H]$ is the previously measured frequency response function matrix between each pair of input and output points and $[\,]^H$ indicates the hermitian transpose operation. The measurement positions and conditions for measuring the frequency response functions must be selected carefully to obtain accurate results. The inverse of this expression is used to calculate the unknown force matrix using the SVD and the pseudo inverse of the frequency response function matrix.

The mode of identification of the forces is based on the assumption that the distribution of the excitation to the structure may be reduced to four equivalent forces at the bolts connecting he motor to the flange. The autospectrum of the force at the first excitation point as calculated by the pseudo inverse method is presented in figure 4 (in dB's referenced to 1N) for three different loading conditions at the 2000 Hz. converter frequency which produces most noise. These and other results confirm that the coupling of the electromagnetic excitation with the first and second flexural modes of the motor is strongly linked to the side bands of the excitation produced by the converter frequency and the harmoniques due to the two pairs of poles of the motor. These deformations produce the forces that excite the support structure.

It can be seen that peaks are higher under maximum load conditions and that some, but not all of them appear to be shifted towards the lower frequencies. This is due to the fact that the motor speed is not controlled and is reduced by the effects of the load by around 25 % in this case. These frequency shifts enable us to distinguish between the effects of excitation frequencies linked to the rotational speed and those linked to the fixed parameters which in this case are the converter frequency, the nominal frequency and the physical characteristics of the motor and support structure. The effects of a change in the converter frequency on the force inputs to the structure are illustrated in figure 5 where the spectrum of the identified force at point 1 is compared for the three converter frequencies under maximum load conditions.

5 - CONCLUSIONS

Space limitations prevent a more extensive presentation and discussion of the results, but the conclusion of this preliminary study shows that the identified excitation forces at the flange correspond closely to the

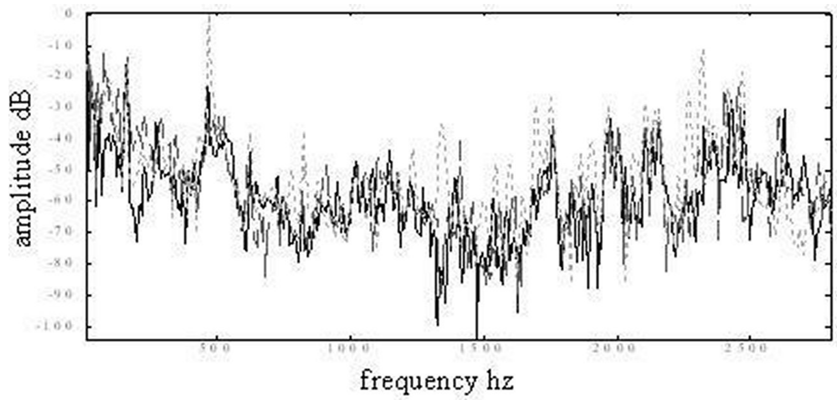

Figure 4: Identified spectrum of force at motor flange interface point 1: converter frequency 2000 Hz, (___ free running, _ _ light load and — maximum load).

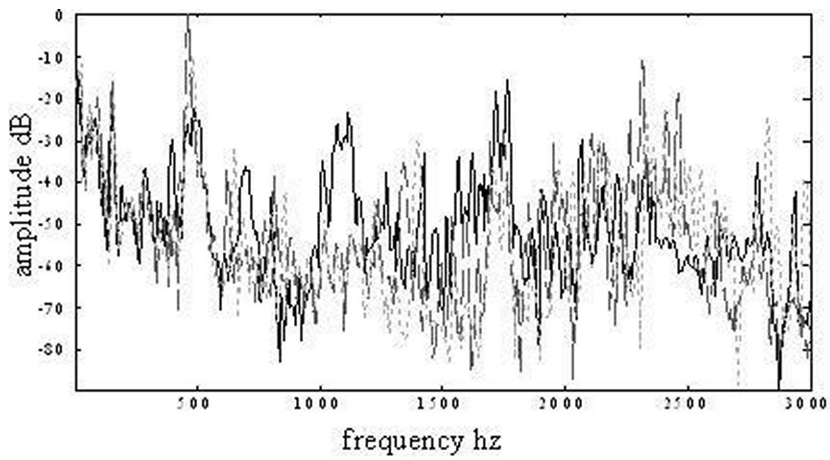

Figure 5: Identified force spectrum at motor-flange interface point 1, maximum load: (___ converter frequency 1670 Hz, _ _ converter frequency 2000 Hz and — converter frequency 2400 Hz).

predicted frequencies of the maximum electromagnetic excitation of the motor structure up to 3000 Hz. One problem is that the generator used to load the system also produces vibrations that are captured by the response accelerometers and influence the results of the force identification. Work is currently in progress to resolve this problem.