inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 3.8

SOLUTION OF A NOISE PROBLEM FOR AN ASYNCHRONOUS ELECTRICAL MOTOR

J. Dickens

Aeronautical and Maritime Research Laboratory, Defence Science and Technology Organization, Department of Defence, PO Box 4331, Melbourne, Victoria, 3001, Melbourne, Australia

Tel.: +613 9626 8224 / Fax: +613 9626 8373 / Email: john.dickens@dsto.defence.gov.au

Keywords:
MOTOR, ELECTRIC, STRUCTURE-BORNE, AIR-BORNE

ABSTRACT
This paper describes the effective elimination of a tonal noise generated by a machine consisting of an asynchronous electrical motor driving a fan. Conventional methods aimed at reducing the air-borne and structure-borne noise by employing noise enclosures and vibration isolation elements were unsuccessful. The motor was a squirrel cage, three phase, two speed induction motor, and the noise source was identified as electromagnetic in nature. The solution was to electrically reduce the noise at its source, without compromising the operation of the machine. This represented an electrical solution to an acoustic problem. Experimental data are presented, and show a noise reduction of 20 dB.

1 - INTRODUCTION
Ventilation systems for a number of rooms were found to transmit high levels of unwanted tonal noises to the surrounding areas. Each ventilation system consisted of ducting and a fan driven by an electric motor. The ventilation systems were similar to each other, and the unwanted tonal noises were all at the same frequency. The problem was to significantly reduce the sound pressure level (SPL) of the structure-borne and air-borne noise in the surrounding areas. Various methods had previously been tried without success, including sound enclosures and two-stage vibration isolation systems for the motors and fans.

A typical ventilation system was investigated, and comprised an electric motor coupled to a fan and associated duct-work. The motor and fan were housed within a metal enclosure, and the fan consisted of a centrifugal fan-wheel contained within a housing. The motor was a three phase, two speed, totally enclosed, squirrel cage induction motor. The two speeds provided a high and low flow rate, and only the low speed operation generated the unwanted noise. Consequently the low speed operation of the motor was investigated. Preliminary investigations showed that the tonal noise was caused by the electric motor and had an electromagnetic origin. This was confirmed by the fact that the noise immediately disappeared when the power was disconnected from the running motor.

There are two main methods to reduce the radiated noise from the enclosure at the problem frequency. One is to reduce the source excitation, and the other is to reduce the noise during its transmission path from the source to the walls of the enclosure. However, it was unknown if the transmission path was structure-borne and/or air-borne. Also it is a fundamentally better solution to reduce the excitation at its source wherever possible. Consequently an electrical solution was proposed to reduce the electromagnetic forces generated by the motor, without significantly degrading the performance of the fan. In the ensuing investigations, measured signals were acquired, averaged and analyzed to yield frequency response functions (FRFs), using a multi-channel FFT spectrum/network analyzer. The near-field SPLs inside and outside the enclosure are termed the "internal SPL" and "external SPL", respectively.

2 - MOTOR
The important motor parameters that affect the emanated noise frequencies are the supply frequency, number of pole pairs, shaft speed, number of stator slots, number of rotor conductors, eccentricity of the rotor and stator, and magnetic saturation. These factors cause the magnetomotive force and permeance of the air gap to vary with time and around the periphery of the rotor, thus generating infinite series of

Fourier components for the magnetomotive force waves and permeance waves. The flux density waves are equal to the product of the magnetomotive force waves and magnetic permeance waves of the air gap. The radial pressure exerted on the inner bore of the stator is proportional to the square of the flux density existing in the air gap. Thus the radial pressure exerted on the inner bore of the stator and the rotor comprises a set of infinite series of pressure waves. These produce radial force waves that cause vibrations in the stator and rotor, and so generate structure-borne and air-borne noise.
The motor was operated and the radial accelerations around the perimeter of its stator were measured to give FRFs relative to the acceleration at the top of the stator. Analysis of this data yielded the mode shape of 1 at the noisy frequency, which is characterized by a rotating radial force applied to the rotor and stator that introduces a bending deformation to the rotor. The bending deformation of the rotor causes the attached backing plate of the fan wheel to vibrate and act as an acoustic noise radiator. Thus both structure-borne and air-borne noise may be generated by the motor and fan at the noisy frequency.
The problem noise is produced by a pulsating one-sided force with amplitude approximately proportional to the square of the motor voltage. Therefore, a possible solution is to reduce the motor voltage. The motor has two separate stator windings giving a synchronous speed ratio of four, and is rated at 4.8 kW and 600 W respectively for the high and low speeds. It was designed primarily to satisfy the requirements of the high speed operation with a frame size of 132, and was lightly loaded for the low speed operation. At low speed, the required power to drive the fan is 100 W, and the motor is rated at 600 W. Thus the available motor power and torque are six times that required to drive the fan. Thus it is feasible to decrease the motor voltage whilst still providing the necessary torque to drive the fan. It follows that the voltage may be reduced by a factor of $1/\sqrt{6}$, i.e. 0.41.

3 - EXPERIMENTS

The motor was driven by a variable speed drive (VSD) and its terminal voltage was varied. The line voltage, line current, rotational speed, radial acceleration, axial acceleration and vertical acceleration of the motor were measured. Additionally, the output air flow of the fan and the internal and external SPLs were measured. The measured accelerations and internal SPL signals yielded FRFs with the external SPL used as the reference. The peaks in the narrowband spectra corresponding to the tonal noise were identified, and their amplitudes are plotted as a function of the normalized motor voltage in Figure 1. The normalized voltage is the terminal voltage divided by the rated voltage. These curves have similar shapes and decrease monotonically as the voltage is reduced. At the normalized motor voltage of 0.45, the speed of the motor was greater than the rated speed, and the output air flow of the fan met the specified value. At this voltage, the attenuation in the external SPL was 19 dB compared to the operation at the rated voltage. Furthermore, other tonal frequencies emanating from the electromagnetic origins were significantly reduced. Term this voltage the reduced motor voltage.

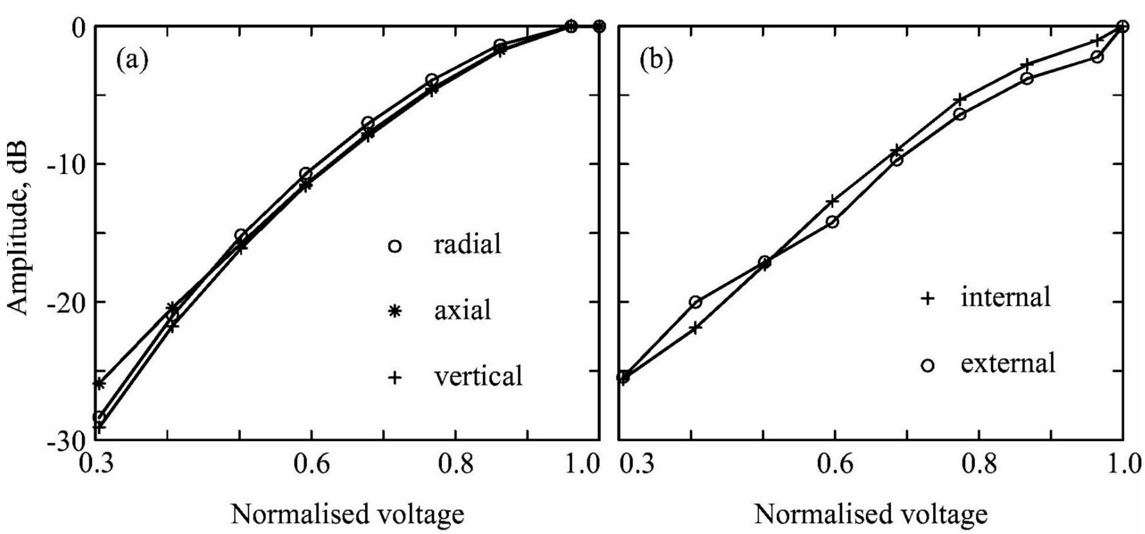

Figure 1: Acceleration and SPL amplitudes: (a) motor accelerations and (b) SPLs.

The speed of the motor was varied by changing its frequency with the VSD, whilst keeping the motor voltage at the rated value. The tonal problem frequency changed in sympathy to the changing driving

frequency, and no significant resonances were evident at, or near to the problem frequency. This indicates that the problem noise is predominantly a forced response function of the electromagnetic excitation.
The noisy frequency is demonstrated in low speed, but not high speed, operation. The two speeds of the motor are obtained by switching between two stator windings with different numbers of poles. This results in the noisy frequency for the high speed being increased to a frequency beyond the frequency range of interest. Thus the noise problem was only evident for the low speed operation.
The performance of the motor was next investigated at the rated and reduced voltages, using a dynamometer. A spare motor of the same type as those in the ventilation system was employed. The motor ran satisfactorily with the reduced voltage and a load of 100 W. The efficiency of the motor operating with normal and reduced voltages and a load of 100 W was 19 and 42 %, respectively. The motor with the reduced voltage had a maximum load of 280 W, and so the motor driving the fan will not stall in normal operation. Thus the motor can satisfactorily drive the ventilation fan when operated with the reduced voltage.
The VSD generates its output waveform using pulse width modulation (PWM), and consequently may introduce additional exciting frequencies. A better method of reducing the motor voltage is to introduce series inductance elements. This has the additional advantages of reducing the motor power requirement and improving the low speed stability of the motor.

4 - IMPLEMENTATION OF SOLUTION

The technique of reducing the motor voltage with tapped inductance elements was implemented. Only the low speed circuit of the motor was modified, and the high speed operation remained unaffected. The tap of the inductance element was selected that gave a motor voltage closest to, but not less than, the reduced voltage. The motor was started directly on line, and a timer was incorporated to switch in the inductor elements once normal operating speed was reached. This yielded the same run-up time as a motor operating at the rated voltage. Switching the inductance elements into the circuit reduced the radial, axial and vertical accelerations, and the internal and external SPLs by 18, 18, 19, 20 and 19 dB, respectively.

5 - CONCLUSION

A simple electrical solution to a motor noise problem has been implemented. The radial, axial and vertical motor accelerations, and the internal and external SPLs have been reduced by approximately 20 dB. The solution also improves the operation and efficiency of the motor.
This technique has the potential of being applied to other AC motors with noise problems having an electromagnetic origin. This is particularly true for two speed motors, where a compromise may be needed between the load requirements at the two speeds and the ratings of commercially available motors.
For a single speed motor, the required rating is often determined by short periods of high power requirements. For the periods of low loading, a control system could introduce the requisite inductor elements into the supply lines. Another concept would be to control the inductance elements electronically, in order to match the mechanical load driven to the supplied power output of the motor.
Instead of inductance elements, power semiconductor devices may be employed to reduce the motor voltage, and are used in AC motor drives. However, their application involves switching that introduces additional harmonic components. These harmonic components may cause increased motor losses, torque pulsations and noise emissions.

REFERENCES

1. **YANG, S.J.**, *Low-noise electrical motors*, Oxford University Press, 1981