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NOISE FROM PRIME MOVERS.

NOISE FROM ROTATING ELECTRICAL MACHINERY

S.J. YANG

HERIOT-WATT UNIVERSITY, EDINBURGH

The noise field of rotating electrical machinery contains noise of mechanical, aerodynamic and magnetic origins. Appropriate attention should be given to each of these origins at the design stage.

Mechanically induced noise consists mainly of noise produced by bearings and brushes. Brush noise is normally not a major noise contributor except for high speed d.c. machines. However, bearing noise may become troublesome for small and medium-sized machines having ball bearings due to wear and resonances of structure parts excited by bearing vibrations.

Aerodynamic noise is by far the predominant noise for high speed electric machines. Methods for the calculation of the sound emission from this origin were given by Talaat(1) and Rentzsch(2). Various measures to reduce the aerodynamic noise from electrical machines are also available(2),(3).

The design routine to determine the magnetic noise level consists of the following steps: (1) to calculate the important magnetic force waves; (2) to calculate the surface vibrations of the machine and (3) to calculate the sound power radiation from the known surface vibrations.

In the calculation of magnetic force waves, special attention should be given to those force waves with low pole pairs. For small electric machines, the most important force waves usually have 2, 3 or 4 pole pairs. Stator-rotor eccentricity and magnetic saturation may play an important role in producing these low pole-pair force waves. Fig. 1 shows the effects of rotor eccentricity on the surface vibration of a 4-pole induction motor. It can be shown(4) that for this machine various combinations of the fundamental mmf wave, 5th harmonic mmf wave, stator-rotor slot permeance wave, rotor eccentricity permeance wave and the equivalent magnetic saturation permeance wave produce 2 pole-pair force waves at 900, 1000, 1100 and 1200 Hz.

The magnetic force waves acting on the cores of the stator and rotor can produce troublesome noise and vibration, especially when the natural frequencies of the exciting forces are equal or near to the natural frequencies of the machine structure. To displace the natural frequencies of the stator and rotor from near coincidence with important exciting frequencies is of great importance in the solution of noise problems.

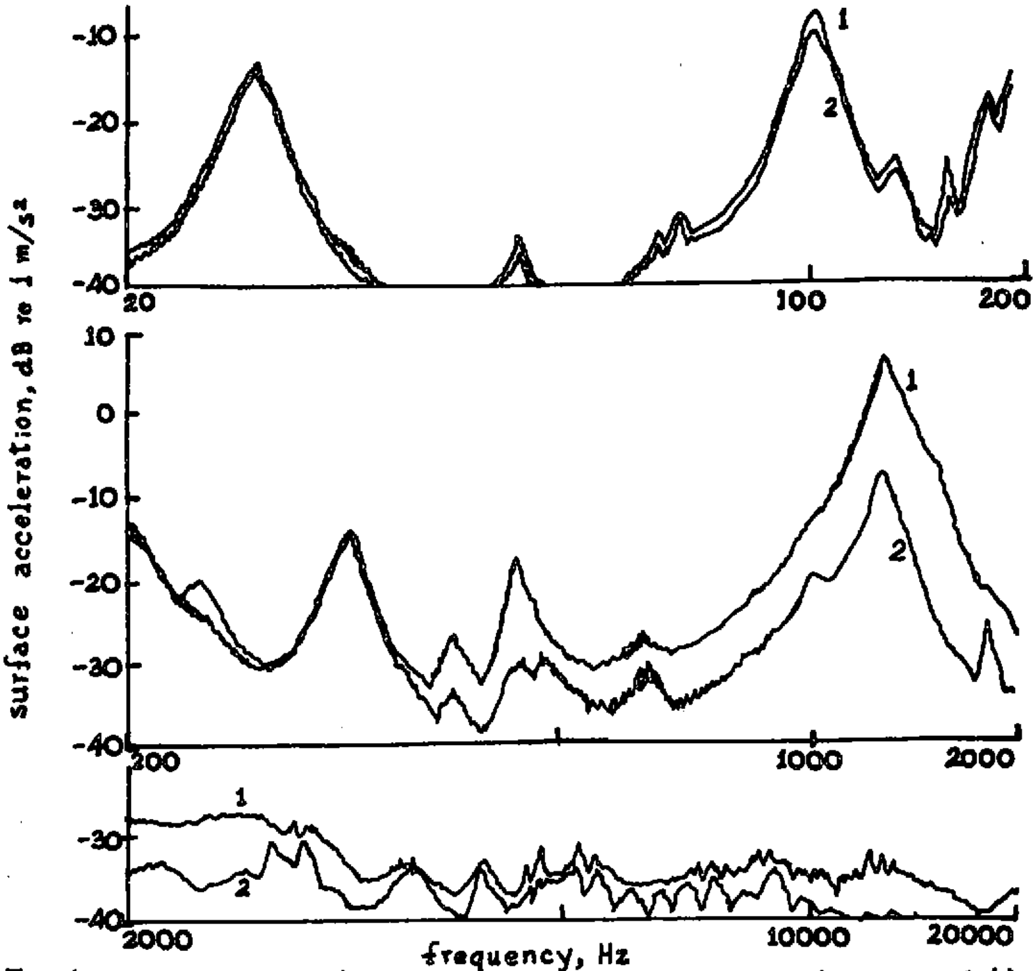

Fig. 1 Surface acceleration of a 4-pole machine (passband 6%)
Curve 1: relative eccentricity = 75%
Curve 2: relative eccentricity = 25%, at same point

Jordan et al[5] presented methods to calculate the natural frequencies of the stator of a single thin ring structure. Erdelyi[6] calculated the natural frequencies of the stators of medium-sized induction motors having two thin cylinders solidly joined by the key-bars. However, for special low noise machines, many small machines and 2-pole medium-sized machines the ratio of the radial thickness of the core laminations to the mean radius of the core may well exceed 0.2 and the assumption of a thin cylinder may lead to inaccurate results. For these machines the stator should be treated as a thick ring loaded with teeth and windings and it is necessary to take into account shear, extension and rotary energies in calculating the natural frequencies with the use of Lagrange's equation[7].

In calculating the surface vibrations, the effects of both resonance and damping should be taken into account. The damping characteristics of the machine structure can only be determined by tests. Fig. 2 shows the logarithmic decrement values of an induction machine. Although the results for the machine were taken at several discrete frequencies, Fig. 2 shows that there is a tendency for the logarithmic decrements to increase with frequency. This tendency is consistent with Hubner's result[8]. The logarithmic decrements of a stator core without a winding were found to be much lower than those carrying windings. This difference is caused by the additional energy dissipation in winding-to-core friction and in the windings.

The surface of most electric machines is basically of cylindrical form and the surface vibrations due to magnetic force waves may be

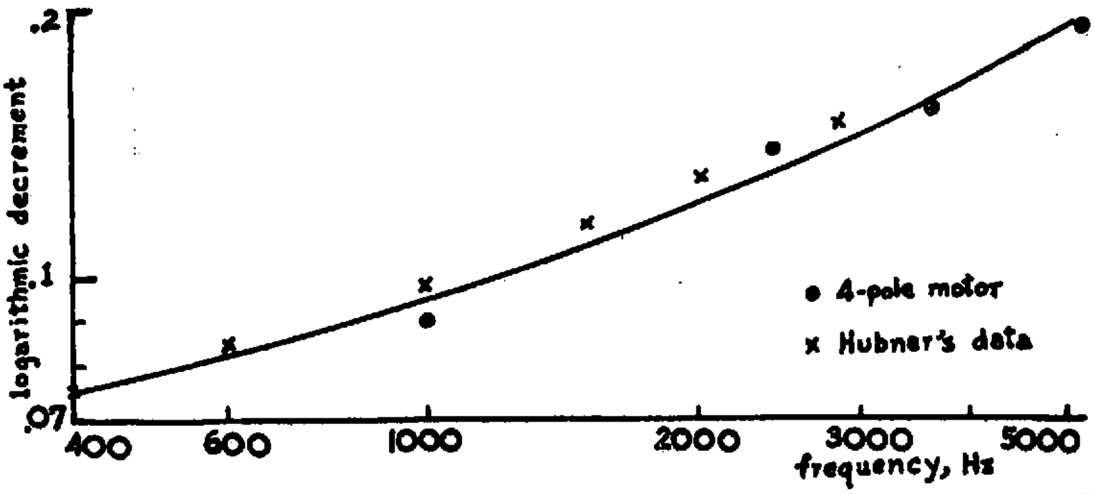

Fig.2 Variation of logarithmic decrement with frequency

regarded as a series of travelling sinusoidal waves of displacement. The sound power can be expressed as[9]

$$P = \int_0^b \frac{2A^2\omega^3b^2\rho a}{\pi}(Q_{pR}^2+Q_{pM}^2)^{\frac{1}{2}}(Q_{vR}^2+Q_{vM}^2)^{\frac{1}{2}}\cos\left[\frac{\pi}{2} + \tan^{-1}\frac{Q_{pM}}{Q_{pR}} - \tan^{-1}\frac{Q_{vM}}{Q_{vR}}\right]dz$$

where A is the amplitude of vibration, ω the angular frequency of the vibration, b half of the length of the machine, ρ the air density, a the radius of the machine and z the axial distance from the centre of the machine. Q_{pR}, Q_{pM}, Q_{vR} and Q_{vM} are functions of the vibration frequency, the mode of vibration, the length and radius of the machine and the axial distance. The effect of mode of vibration on sound radiation is shown in Table 1. It is seen that, other things being equal,

Table 1

Mode of vibration	Calculated sound power level at 1000 Hz for machine 1* (dB re 10^{-12} W)	Calculated sound power level at 1000 Hz for machine 2** (dB re 10^{-12} W)
2	38.7	75.7
3	26.3	75.0
4	11.1	67.8
5	-5.8	56.3
6	-24.2	43.4
7	-43.9	29.3

*Machine 1: a = 8.1 cm, b = 5.0 cm, A = 1 x 10^{-6} cm
**Machine 2: a = 15.0 cm, b = 22.5 cm, A = 1 x 10^{-5} cm

the sound power radiated from a small or medium-sized machine vibrating with a mode number of 2 is greater than that vibrating with a higher mode number. This explains why it is essential to minimise those force waves having low pole pairs, hence causing vibrations at low mode numbers. The stator-rotor slot combination should be so chosen that the lowest number of pole pairs of the important force waves is as high as possible since not only the stator of the machine is stiffer in higher modes but also the machine vibrating with higher modes is usually a poorer sound radiator.

Table 2 shows the effect of vibration frequency on sound power radiation. The air-borne sound power radiation at 100 Hz is much smaller than is that at a higher frequency. Generally the fundamental flux density waves in an electric machine produce a significant vibration level at twice the supply frequency. Except for large machines, this low frequency vibration may only become important from the structure-borne noise point of view. However, high level vibrations can cause damage to stator core laminations and to stator winding insulation. Acceptable vibration levels have therefore steadily been lowered in order to prolong motor bearing and winding life[10] (see Fig. 3).

Table 2

Vibration frequency (Hz)	Calculated sound power level with mode number of 2 for machine 1* (dB re 10^{-12} W)	Calculated sound power level with mode number of 2 for machine 2** (dB re 10^{-12} W)
31.5	-79.3	-30.0
100	-41.1	8.0
500	15.6	63.5
1000	38.7	75.7
2000	51.9	86.2
8000	72.2	104.3

*Machine 1: a = 8.1 cm, b = 5.0 cm, A = 1 x 10^{-6} cm
**Machine 2: a = 15.0 cm, b = 22.5 cm, A = 1 x 10^{-5} cm

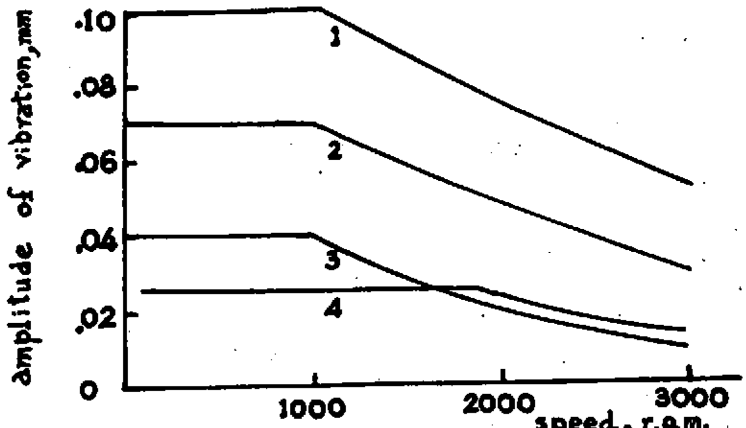

Fig. 3 Vibration limits for rotating electrical machines
Curve 1: maximum vibration limits (1940, Ref. 11)
Curve 2: vibration values, 'good' grade (1940, Ref. 11)
Curve 3: vibration values, 'excellent' grade (1940, Ref. 11)
Curve 4: typical vibration limits for large induction motors (1971, Ref. 10)

References

(1) Talaat, M.E., Trans. Amer. Inst. Elect. Engrs., 1957, 76, Pt. III, pp 46-55.
(2) Rentzsch, H., ETZ(A), 1961, 82, pp792-798.
(3) Burke, R.F., Glew, C.N. and Wakeley, H., Elect. Rev., 21 Feb. 1969, pp 269-273.
(4) Ellison, A.J. and Yang, S.J., Proc. I.E.E., 118, 1971, pp 174-185.
(5) Jordan, H. and Frohne, H., Larmbekampfung, 1957, 1, pp 137-140.
(6) Erdelyi, E., Trans. Amer. Inst. Elect. Engrs, 1955, 74, Pt. III, pp 1269-1280.
(7) Ellison, A.J. and Yang, S.J., Proc. IEE, 118, 1971, pp 185-190.
(8) Hubner, G., ETZ(A), 1959, 80, pp 33-39.
(9) Ellison, A.J. and Yang, S.J., Acustica, 1971, 25, pp 28-34.
(10) Brozek, B., IEEE 18th Annual Petroleum and Chem. Ind. Conference, 1971, paper PCI-71-6.
(11) L.Z. Rubinshtein and L.Ya. Stanislavskii, Elektricheskie Stantsii, 1940, 7, pp 5-12.