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Noise from Electric Machines

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The subject matter of this paper keeps closely to the electric machine because other speakers are covering comprehensively the noise from coupled items of equipment such as fans, pumps and pipes, and the transmission of airborne noise and vibration. The sources of noise in an electric machine are first briefly described. Then the pattern of noise to be found round an electric machine is described. After this description of the acoustic field the measurement of that noise and its specification are next considered. The latter is the subject of a forthcoming British Standard, which is very relevant, and the probable general form will be described.

Electric machines consist of a stator and a rotor and, usually, have a bearing at each end, mechanically joined to the stator. The stator and rotor each carry a winding, and these set up two component electromagnetic field patterns in the air-gap. These flux patterns have an angle between them and the tendency to aligment of the two patterns leads to the torque. The flux patterns may both be stationary, as in a d.c. machine, or they may both be rotating, as in most synchronous and induction machines. The flux patterns are set up by currents flowing in the windings: the flux passes in closed loops round a magnetic circuit mainly of iron, part on the stator, part on the rotor and with the air-gap between them. The windings are embedded in slots arranged round the periphery of one or both members. The variations in flux in the iron parts of the magnetic circuit lead to heat losses - the so-called core losses. The currents flowing in the windings lead to ohmic losses, that is, additional heat losses. These and other smaller losses are removed by cooling air which is drawn through the machine by a fan.

From this brief description of the principles of operation of electric machines the sources of noise will be clear. Briefly, they are in three groups: mechanical, magnetic and aerodynamic. Forces of mechanical and magnetic origin produce vibration directly in the machine structure; aerodynamic sources cause direct pressure fluctuations in the surrounding air. Mechanical vibratory forces may be produced by a dynamic out-of-balance condition of the rotor, and by rubbing and rolling motions of the bearings. Out-of-balance conditions produce a noise at low frequency - at the frequency of rotation of the machine. They therefore produce mainly structure-born vibration, most machines being poor radiators at these low frequencies and the ear being relatively insensitive. All conventional bearings involve rolling or sliding between two surfaces and produce noise owing to irregularities of those surfaces. Sleeve bearings are usually quieter than ball or roller bearings because a wedge of oil is more easily maintained in sleeve bearings.

Magnetic noise is produced in the following way. The flux distribution may be imagined as composed of a series of space harmonics, and each may be considered separately. The force between stator and rotor at each point of the air-gap is proportional to the square of the flux density. In this way it may be seen that a series of positively and negatively travelling waves of force is produced. These result in corresponding waves of displacement round the stator surface and corresponding waves in the air and therefore noise. Clearly, eccentricity of the rotor will affect the flux distribution in the air-gap and will lead to additional noise. The most important factor in all this is resonance, as the largest displacements and loudest noises will be produced when forcing frequencies are equal to or close to the natural frequencies of the structure.

Aerodynamic noise occurs whenever there is any rapid local change in the pressure of the ventilating air flowing through a machine. The pressure variations are usually radiated directly from the air stream; in some cases they may excite resonances of the ventilating ducts. Aerodynamic noises are produced partically as a result of periodic fluctuations in the flow resistance of the air paths. These are due to pressure fluctuations at the outlets and inlets of fans, by vortexes formed in the wake of an object in the air flow breaking against other objects, and by the irregular flow of air through ducts of rapidly changing cross section, or in which the air flow is suddenly changed in direction.

The pattern of noise to be found around an electric machine will now be described. This noise field is produced by those varying internal forces and pressure fluctuations in the cooling air already described, and which are by-products of the operation of the machine. The field depends on the shape and dimensions of the outer surface, which determine the sound radiation properties. The variation of the sound pressure in the space around a machine is therefore complicated, and varies considerably with position.

The frequency spectrum of the noise is usually of the broadband type, with superimposed pure tones, some of which may be harmonics. Fig. 1.

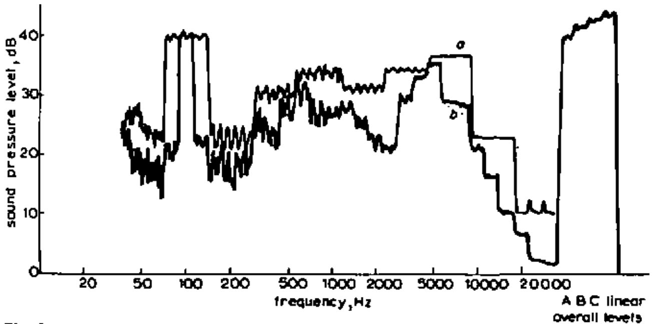

Fig. 1

S.P.L. in octave and ⅓-octave bands at a single point in acoustic field

a Octave bands
b 1/3-octave bands

shows 1/3-octave and octave analyses of the sound pressure level (s.p.l.) at one position in the acoustic field of an electric machine. Such analyses are useful if an estimate of the frequency distribution of the sound is required for the design of an enclosure or resilient mounting, or if the total subjective effect of the sound is to be calculated.

If more detail of the spectrum is required, a narrow-band analyser with a continuously variable centre frequency is used.

Fig. 2 shows a narrow-band analysis of the same noise as Fig. 1., the filter having a pass band of 6% of the centr[e] frequency. A narrow-band analysis is usually used to identify the frequencies of pure-tone components of the noise when its causes are being analysed.

Analysis of the spatial distribution of sound pressure is more complex. The sound pressure in any frequency band varies considerably with direction and with distance from the machine. Fig. 3 shows the variation of the s.p.l. of a pure-tone component of noise in the horizontal plane through the shaft of a small electric machine which is radiating freely. The variations are shown for four radii measured from the centre of the machine. Similar patterns are produced in other planes through the machine, and at other frequencies. The number of lobes on the radiation pattern varies with frequency and the shape and dimensions of the radiating surfaces. The magnitude of the variation depends on the bandwidth of the filter and whether pure-tone or wide-band noise is present.

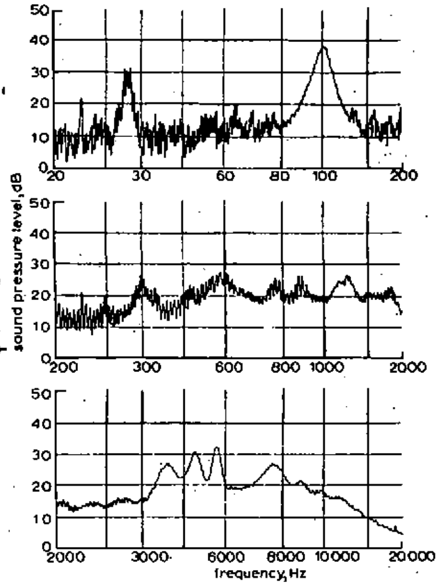

Fig. 2

Narrow-band analysis at a single point in acoustic field

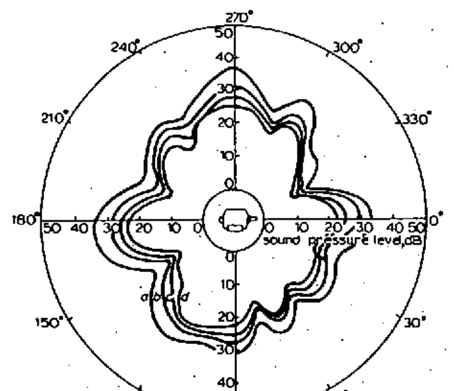

Fig. 3

Variations of s.p.l. along radial lines for a pure-tone component

Distance from motor
(a) 12 in
(b) 18 in
(c) 24 in
(d) 30 in

After that brief description of the noise field around an electric machine it is now appropriate to describe how that noise is measured and specified. Clearly, since the s.p.l. varies considerably with distance and angular position, a single-point frequency analysis is insuffient to represent completely the noise produced by a machine. It is therefore necessary to make measurements which represent the entire noise output of the machine. The parameter which is measured most often is the level of the total acoustic power output in specified frequency bands. It may be measured in several different ways. In the first way, the total sound power radiating from the source is measured under free field conditions, i.e. in an anechoic chamber. When this is inconvenient the machine may be mounted on a sound-reflecting floor and similar measurements made. With appropriate corrections to the readings, results of good accuracy may be obtained.

As mentioned earlier, there will be before long a British Standard specifying how the noise of electric machines is to be measured. That specification will be based on a forthcoming internation specification. Both will include tables stating, for electric machines within a stepped series of power rating limits and speed limits, the maximum noise permitted. The figures will have been measured in accordance with the methods specified, which will now be briefly described and will be typical of good modern engineering practice, both in the U.K. and on the Continent.

Machines will be divided into three classes according to the permitted noise. Machines of Normal Noise Rating will be of manufacturers' standard design where the output has not been limited nor has special acoustic treatment been provided to reduce the noise emitted. Machines of Reduced Noise Rating will have the noise power reduced by a stated amount. Machines of this class will be basically standard but will have some simple modifications , for example special fans, to obtain a moderate reduction in the noise emitted. Such modifications may not be practicable for standard machines below a rating of about 132kW. The third class of machine will be of Special Noise Rating. Machines in this class will have special electrical and mechanical design to obtain noise levels below those of the first two classes, for special applications. Noise powers for such machines will be a matter of special agreement between manufacturer and purchaser.

Tests determining machine noise usually consist of measurements of sound pressure level in a free field over a reflecting plane, taken at certain points on a specified semi-cylindrical surface enclosing a horizontal-shaft machine or a cylindrical one for a vertical-shaft machine. Hence, for each octave band, the level of mean square sound pressure is calculated and using the radius of an equivalent hemisphere, derived from dimensions of the measuring surface, the sound power is calculated as a level above 1 picowatt.

As the relevant International and British Standard Specifications have not yet been finalized, there are several possible forms of specifying machine noise: (a) as total noise power in each octave band stated as a level; (b) as a Noise Rating Number, obtained by plotting the level of the mean square sound pressure in octave bands at specified distances on a chart of Noise Rating Curves (see Ref.2); (c) as a Noise Power Rating Number, similarly obtained, which avoids the need of specifying distance. For comparing two similar machines single sound pressure levels in 'A' weighting (dBA), measured at the same position, can be used.

Tests described above, are usually taken at no load. To assess the effect of load, near field measurements (eliminating noise due to coupled apparatus and surroundings) both on load and at no load, can be made.

The author is grateful to The Institution of Electrical Engineers for permission to use Fig. 1, 2 and 3 and other material from Ref.1.

<u>References</u>

1. Ellison, A.J., Moore, C.J. and Yang, S.J., Methods of Measurement of Acoustic Noise Radiated by an Electric Machine, Proc.I.E.E., 1969, 116, pp. 1419-1431

2. BEAMA recommendations for the measurement and classification of acoustic noise from rotating electrical machines, BEAMA publication 225, 1967