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'APPLIANCE NOISE'

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THE NOISE OF SMALL ELECTRIC MOTORS

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Introduction In considering the noise produced by an electric machine it is helpful to understand the sources of the noise components from the machine, and this necessitates understanding its principles of operation. The reason for the presence of the components in the noise spectrum is then clear and a more enlightened approach can be made to the consideration of the measurement, specification and limitation of the noise produced.

The paper starts by briefly summarising the principles of operation of electric machines (of all types). It continues by describing the noise pattern surrounding a particularly common type of a.c. machine,explaining how the noise pattern is measured in an adequate and meaningful way. It then goes on to describe briefly and in general terms parts of the contents relating to small machines of the forthcoming British Standard concerning the measurement and limitation of the noise produced by electric machines.

Principles of electric machines 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 alignment 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.

Sources of Noise 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 travelling at different speeds, some in each direction, 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 partially as a result of periodic fluctuations in the flow resistance of the air paths. These are due to pressure fluctuations at the outlets 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.

Surrounding noise pattern 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 broad-band type, with superimposed pure tones, some of which may be harmonics.

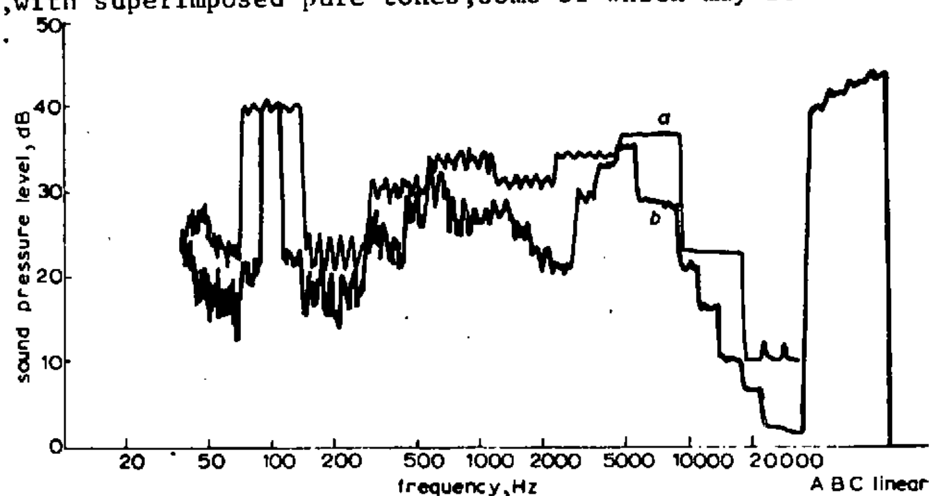

Fig. 1

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

a Octave bands
b 1/3-octave bands

Fig.1 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 centre 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.

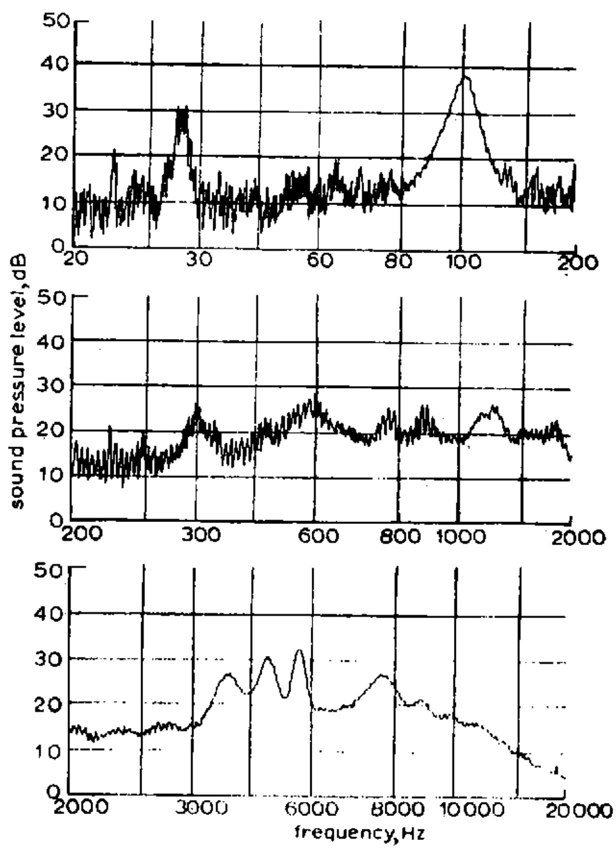

Fig. 2

Narrow-band analysis at a single point in acoustic field

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.

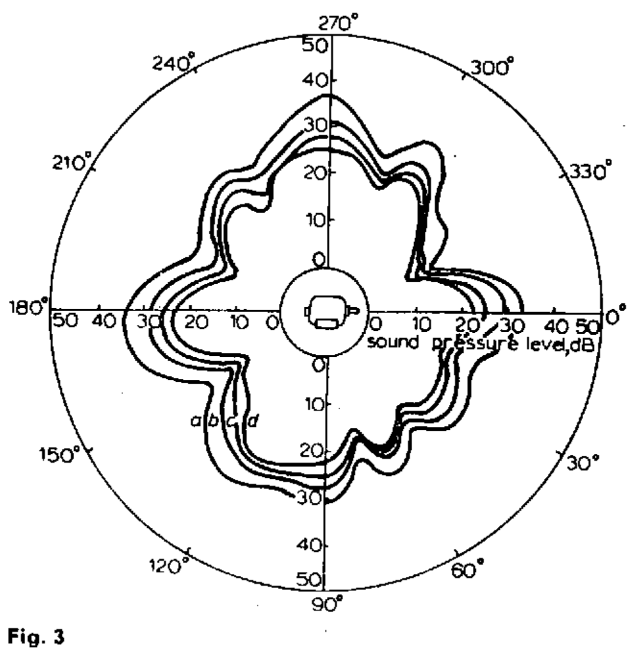

Fig. 3

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

Noise measurement and specification After that brief description of the noise field around an electric machine it is 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 measurement is insufficient 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 would appear to be most useful is the level of the total acoustic power output, either over the whole audible spectrum or in specified frequency bands. The former is almost always completely adequate for the assessment of small electric motors, although the latter is sometimes useful. The single-figure (A) weighted sound power level is independent of distance from the machine, and is measured as follows. (The details of both the methods are set out in Ref.2, which should appear early in 1973.)

It is assumed that the machine is a noise source radiating in free field conditions over a reflecting plane considered as its base. The room suitability is checked first (for reasonably free-field conditions) and, if necessary, measurement of the background noise is made. The measuring points are on prescribed paths symmetrically arranged around the machine and five readings of (A) weighted sound level are taken (more for a large machine) - at the ends of the machine, at the sides and over the top, each point being 1 metre distant from the carcase. The readings are averaged on an energy basis and the radius of an equivalent hemisphere to be associated with this value is calculated from the dimensions of the machine. From this the sound power level is derived. (If any pure notes are present or the machine is exceptionally noisy - both unlikely with small machines - octave band sound power levels are measured and corrections then made for pure notes. Corrections may also be made, if necessary, for background noise.)

The final figure of total sound power (in dB(A)) must not exceed the value given in a table in Ref.2 for a machine of that size, speed and enclosure. The values given are typical of those for standard machines made in accordance with good practice, and termed "Normal Sound Power". Machines with very simple modifications can sometimes be made 5 dB(A) quieter ("Reduced Sound Power") but this is not normally practicable for small machines. (A third class of machine of "Specially Low Sound Power" can be specially designed and agreed.)

The method above is used with the machine running under normal conditions at no load. If the sound power on load is required then the difference from the no-load sound power can be found by near-field sound pressure level measurements on no load and on load (Ref.2).

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References

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2. BS 4999: General requirements for rotating electrical machines Part 51: Noise levels (to be published in 1973).