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TEST CODE FOR THE MEASUREMENT OF THE AIRBORNE NOISE EMITTED BY ROTATING ELECTRICAL MACHINERY

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TEST CODE FOR THE MEASUREMENT OF THE AIRBORNE NOISE EMITTED BY ROTATING ELECTRICAL MACHINERY

INTRODUCTION

This ISO Recommendation has been drafted in accordance with ISO Recommendation R 495,* and gives the detailed instructions for conducting and reporting tests on rotating electrical machines, to determine the airborne noise characteristics under steady state conditions.

The main purpose of the test code is to give specific instructions so that the results obtained can always be compared.

The test code is divided into two parts :

Part I : Methods for usual tests based on sound level (A) measurements.

Part II : Methods for special tests based on frequency band analysis measurements.

1. SCOPE

This test code for the measurement of noise applies to rotating electrical machines such as motors and generators of all sizes without limitation of output or voltage, when fitted with their normal auxiliaries.

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* ISO Recommendation R 495, *General requirements for the preparation of test codes for measuring the noise emitted by machines.*

2. TERMS AND DEFINITIONS

For the purpose of this ISO Recommendation the following terms and definitions are used.

2.1 *Sound pressure level*, L_p, is expressed as

$$20 \log_{10} \frac{p}{p_0} \quad \text{in decibels (see ISO Recommendation R 131*)}$$

where

p is the measured sound pressure;

p_0 is the reference sound pressure expressed in the same units as p :

$$p_0 = 2 \cdot 10^{-5}\ \text{N/m}^2 \quad \text{or} \quad 20\ \mu\text{N/m}^2.$$

2.2 *Sound level* is defined as the reading given by a sound level meter complying with IEC Publication 179, *Recommendations for precision sound level meters.*

2.3 *Noise spectrum*. A spectrum showing the sound pressure level distribution throughout the frequency range. The appearance of the spectrum depends on the bandwidth characteristics of the analyser used.

2.4 *Band pressure level*. For a specified frequency band, the effective sound pressure level corresponding to the sound energy contained within the band.

2.5 *Sound power level*, L_P, is expressed as

$$L_P = 10 \log_{10} \frac{P}{P_0} \quad \text{in decibels}$$

where

P is the measured sound power;

P_0 is the reference sound power expressed in the same units as P :

$$P_0 = 10^{-12} \text{ watt (or 1 pW).}$$

NOTE. – L_{PA} is a weighted sound power level determined in such a manner that the acoustic power level in each of the frequency bands is weighted according to the A scale.

2.6 *Prescribed path*. An imaginary line around the machine as given in this test code and along which the measurement points are located.

NOTE. – As this code covers electrical machines of all sizes and shapes it was found impractical to define a prescribed surface as given by ISO Recommendation R 495; hence prescribed paths are defined which can be used in all cases.

2.7 *Equivalent hemisphere*. A hypothetical hemisphere surrounding the machine on which the measurements are assumed to be made, its radius being denoted by r_s.

2.8 *Reference radius*. A radius (measured from the centre of the equivalent hemisphere), to which all the results of measurements made on machines of the same category (tested according to the same code) are reduced.

The reference radius for all machines is 3 m.

2.9 *Background noise*. Any noise at the points of measurement other than that of the machine being tested. It also includes the noise of any test equipment.

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* ISO Recommendation R 131, *Expression of the physical and subjective magnitudes of sound or noise.*

PART I

METHODS FOR USUAL TESTS

3. APPLICATION

The measurement of the noise of electrical machines by the methods given in Part I yields a value for the average sound level of the airborne noise. Such simplified measurements are often sufficient when the purpose of the measurement is to make a comparison between the noise emitted by electrical machines built to the same specifications and having approximately the same noise spectra, and to calculate the approximate (A) weighted sound power level.

For these measurements the weighted sound level (A) should be adopted and slow response is recommended.

4. TEST CONDITIONS

4.1 General assumption

It is assumed that the machine is a noise source radiating in free field conditions over a reflecting plane which is considered as its base.

4.2 Test environment

Sound reflections from walls or from objects in the test room should have no significant influence on the measurements.

The room suitability can be established by placing a small broad-band noise source (some types of aerodynamic source may not be suitable) at the positions to be occupied by the geometric centre of the machine to be tested, and determining the mean sound levels at the measurement positions and at the corresponding positions at half their distance from the source.

The difference between these two averages should be at least 5 dB. Calculation of the mean value should be made according to clause 8.2.

For large machines such a test cannot always be performed. In such cases this fact should be stated in the test report.

NOTE. – If the machine on test is sufficiently small in respect to the size of the room and of broad noise character, it may be taken as the reference source.

4.3 Background noise

The background noise reading when the machine is not on test should be determined at the same points as for the test. The reading at each point with the machine on test ought to exceed those due to the background noise alone by at least 10 dB.

When the differences are less than 10 dB, corrections as given below should be applied.

dB increase in level produced by the machine	dB to be subtracted from the measured value
3	3
4 to 5	2
6 to 9	1

When corrections of 3 dB are applied, the corrected levels should be reported in brackets.

When the increase is less than 3 dB, measurements in general cease to have any significance.

4.4 Mounting of machine

Structure-borne vibrations from a machine to its mounting, or to other parts of the test room, can influence the sound pressure level in the test room. Such effects should be minimized, for example by mounting the machine on suitably designed resilient mountings.

4.5 Operating conditions

The machine noise of interest is usually that measured with the machine operating under its rated load, speed and excitation conditions. The noise should therefore, ideally, be measured under these conditions.

When the machine noise is independent of loading or when the effects of load are known, the noise measurements under no-load conditions will usually suffice.

5. MEASURING INSTRUMENTS

5.1 Grade

The sound level meter should comply with IEC Publication 179, *Recommendations for precision sound level meters*.

The instructions in the use of the equipment are to be complied with to ensure that the intended degree of precision is maintained.

5.2 Calibration of measuring equipment

The overall acoustical performance of the complete measuring equipment should be checked, and any specified adjustments made, immediately before each series of machine noise measurements, and re-checking should be carried out immediately after.

These site checks should be augmented by more detailed laboratory calibrations of the measuring equipment carried out at least once every 2 years.

5.3 Location of instruments and observer

The observer should be at least 1 m from the microphone to reduce errors due to reflections.

6. METHODS OF MEASUREMENT

For all machines, measurements should be made on the prescribed paths shown in Figure 1 or Figure 2.

For machines having a maximum linear dimension l (excluding shaft) equal to or exceeding 0.25 m, these rectilinear paths are, at their nearest points, 1 m from the surface of the machine.

For cases where l is less than 0.25 m these rectilinear paths are, at their nearest points, at a distance d from the surface of the machine between 4 l and 1 m but not less than 0.25 m.

For all horizontal machines the prescribed path parallel to the reflecting ground plane should be at shaft height or 0.25 m above the ground, whichever is the greater (see Fig. 1).

For all vertical machines, the prescribed path parallel to the reflecting ground plane should be at half the height of the machine but not less than a height of 0.25 m (see Fig. 2).

In all cases the prescribed path in the vertical plane should be in the plane of the shaft.

7. LOCATION OF THE MEASURING POINTS

The position of the measuring points (the number of which depends upon the size of the machine and the symmetry of the acoustic radiation, but should be at least 5) should be as indicated in Figure 1 or 2. The measuring points on each path should be placed at successive intervals of no more than 1 m commencing at the 5 key measuring points.

8. CALCULATIONS AND INTERPRETATION OF RESULTS

8.1 Measurement corrections

The results of the measurements at each measuring point should be corrected for the effects of any background noise (see clause 4.3).

No corrections should be applied for the effects of the test environment.

Any correction indicated by the calibration checks, however, should be taken into account.

8.2 Calculation of the mean sound level (A)

The mean sound level (A) should be calculated from the results of the measurements at all the test positions (after correction according to clause 8.1), by averaging according to

$$L_{A\,(M)} = 10 \log_{10} \left[\frac{1}{n} \left(\text{antilog}_{10} \frac{L_{A\,(1)}}{10} + \text{antilog}_{10} \frac{L_{A\,(2)}}{10} + \ldots + \text{antilog}_{10} \frac{L_{A\,(n)}}{10} \right) \right] \quad \ldots (1)$$

where

- $L_{A\,(M)}$ is the mean sound level (A) in decibels;
- $L_{A\,(1)}$ is the sound level (A) in decibels at the 1st position;
- $L_{A\,(n)}$ is the sound level (A) in decibels at the nth position;
- n is the number of measuring positions.

When the decibel readings at the various test positions do not differ by more than 5 dB, a simple arithmetic average of these dB readings will give a result differing not more than 0.7 dB from that given by equation (1).

8.3 Calculation of the radius and area of the equivalent hemisphere

For the purpose of calculation of mean sound level (A) at the reference radius of 3 m (see clause 8.4), the measurements made along the prescribed paths of Figures 1 or 2 should be assumed to have been made over a hemisphere of radius

$$r_s = \left[\frac{a\,(b + c)}{2} \right]^{\frac{1}{2}}$$

where a, b and c are shown in Figures 1 and 2.

The area of this equivalent hemisphere is given by

$$S = \pi\, a\,(b + c)$$

NOTE. – The area of the equivalent hemisphere with radius r_s as specified is somewhat smaller than the surface area denoted by the paths of measurement.

8.4 Calculation of the mean sound level (A) at the reference radius

The mean sound level (A) at the reference radius of 3 m is given by

$$L_{A\,(r_o)} = L_{A\,(M)} + 20 \log_{10} \frac{r_s}{r_o}$$

where

- $L_{A\,(r_o)}$ is the mean sound level (A) at a radius of 3 m;
- r_o = 3 m;
- $L_{A\,(M)}$ is the mean sound level (A) as calculated from measurements at the test positions (see clause 8.2).

8.5 Calculation of (A) weighted sound power level from mean sound level (A)

The formula used is as follows :

$$L_{PA} = L_{p\ (M)} + 10 \log_{10} \frac{2\,\pi\,r_s^{\,2}}{S_o} + K_1$$

where

L_{PA} is the (A) weighted sound power level;

$L_{p\ (M)}$ is the mean sound level (A) (see clause 8.2);

r_s is the radius of the equivalent hemisphere (see clause 8.3);

S_o = 1 m^2

$K_1 = -10 \log \dfrac{\rho c}{400}$

where ρc is the characteristic impedance of the medium in $kg/m^2\,s$. For air at temperature t °C and barometric pressure p_a in millibars :

$$K_1 = -10 \log_{10} \left[\frac{423}{400} \left(\frac{273}{273 + t} \right)^{\frac{1}{2}} \frac{p_a}{1000} \right]$$

At $t = 20$ °C and $p_a = 980$ mbar, $K_1 = 0$

NOTE. – (A) weighted sound power level may also be satisfactorily determined from measurement points distributed other than as indicated in section 7.

For example, with measurement points distributed on a hemispherical surface, the value of (A) weighted sound power level will be substantially equal to that given by the method of measurement recommended in section 6.

9. TEST REPORT

A test report should be supplied and should give the following information :

(*a*) reference to this test code;

(*b*) description of the machine, its conditions of installation and operation;

(*c*) dimensional sketch of the test room showing the location of the machine and significant room objects in the immediate vicinity;

(*d*) make, model and serial number of sound level meter used;

(*e*) position of measuring points;

(*f*) results of sound pressure level measurements at each measuring point;

(*g*) background sound level (A) at each measuring point;

(*h*) results of corrected sound level measurements at each measuring point;

(*i*) mean sound level (A);

(*j*) radius r_s and area S of the equivalent hemisphere;

(*k*) the mean sound level (A) at the reference radius of 3 m;

(*l*) (A) weighted sound power level.

PART II

METHODS FOR SPECIAL TESTS

10. APPLICATION

If the tests prescribed in Part I are not sufficient, more detailed measurements based on frequency band analysis and specified acoustical environments can be carried out according to Part II.

The results of the measurements should always be expressed in dB (A), in octave bands, and in the actual frequency bands employed.

11. TEST CONDITIONS

11.1 Test environment

The tests according to Part II are assumed to have been made under free-field, reverberant field or semi-reverberant conditions.

The suitability of any given test environment for carrying out tests according to any of these conditions should first be ascertained by carrying out the "test of room suitability" checks indicated in the appropriate clauses 13.1.1, 13.2.2 and 13.3.1.

11.2 Background noise

The background noise reading when the machine is not on test should be determined at the same points as for the test. The readings at each point with the machine on test ought to exceed those due to the background noise alone by at least 10 dB. When the differences are less than 10 dB, corrections as given below should be applied.

dB increase in level produced by the machine	dB to be subtracted from the measured value
3	3
4 to 5	2
6 to 9	1

When corrections of 3 dB are applied, the corrected levels should be reported in brackets.

When the increase is less than 3 dB, measurements in general cease to have any significance.

11.3 Mounting of machine

Structure-borne vibrations from a machine to its mounting, or other parts of the test room, can influence the sound pressure level in the test room. Such effects should be minimized, for example, by mounting the machine on suitably designed resilient mountings.

11.4 Operating conditions

The machine noise of interest is usually that measured with the machine operating under its rated load, speed, and excitation conditions. The noise should therefore, ideally, be measured under these conditions.

When the machine noise is independent of loading or the effects of load are known, then noise measurements under no-load conditions will usually suffice.

12. MEASURING INSTRUMENTS

12.1 Grade

The sound level meter should comply with IEC Publication 179, *Recommendations for precision sound level meters.*

The instructions in the use of the equipment are to be complied with to ensure that the intended degree of precision is realized.

Any filters used for noise analyses should comply with IEC Publication 225, *Recommendations for octave, 1/2 octave, and 1/3 octave band filters intended for the analysis of sound and vibrations.* If filters with other bandwidths are employed, their characteristics should be stated.

12.2 Calibration of measuring equipment

The overall acoustical performance of the complete measuring equipment should be checked, and any specified adjustments made, immediately before each series of machine noise measurements, and re-checking should be carried out immediately after.

These site checks should be augmented by more detailed laboratory calibrations of the whole measuring equipment carried out at least once every 2 years.

12.3 Location of instruments and observer

Any measuring amplifiers or filters should be at least 0.3 m and the observer should be at least 1 m from the microphone to reduce errors due to reflections.

13. METHODS OF MEASUREMENT

13.1 Radiation in a free-field over a reflecting plane

13.1.1 *Test of room suitability.* Sound reflection from walls or from objects in the test room should have no significant influence on the measurements.

The room suitability should be established by placing a small broad-band noise source (some types of aerodynamic source may not be suitable) at the position to be occupied by the geometric centre of the machine to be tested, and determining the mean sound level at the measurement positions and at corresponding positions at half their distance from the source.

The difference between these two means should be at least 5 dB for each frequency band employed. Calculation of the mean levels should be made according to clause 13.1.6.

NOTE. – If the machine on test is sufficiently small and of broad band noise character, it may be taken as a reference source.

13.1.2 *Method of measurement.* For all machines, measurements should be made on the prescribed paths shown in Figure 1 or 2.

For machines having a maximum linear dimension l (excluding shaft) equal to or exceeding 0.25 m these rectilinear paths are, at their nearest point, 1 m from the surface of the machine.

For cases where l is less than 0.25 m these rectilinear paths are, at their nearest points, at a distance from the surface of the machine between $4\,l$ and 1 m but not less than 0.25 m.

For all horizontal machines the prescribed path parallel to the reflecting ground plane should be at shaft height or 0.25 m above the ground, whichever is the greater. (See Fig. 1.)

For vertical machines the prescribed path parallel to the reflecting ground plane should be at half the height of the machine but not less than a height of 0.25 m. (See Fig. 2.)

In all cases the prescribed path in the vertical plane should be in the plane of the shaft.

13.1.3 *Location of the measuring points*. The position of the measuring points (the number of which depends upon the size of the machine and the symmetry of the acoustic radiation, but should be at least 5) should be as indicated in Figure 1 or 2.

The measuring points on each path should be placed at intervals of no more than 1 m from the 5 key measuring points.

If measurements at these points indicate levels which exceed the mean level (calculated according to clause 13.1.6) by more than 5 dB, additional points should be added midway between the measuring points already in use.

In some cases the acoustic radiation pattern of the machine requires the use of one or more extra pairs of paths. These extra pairs of paths should not destroy the basic symmetry of the measurement points.

13.1.4 *Quantities to be determined*. From the measurements required by clause 13.1.2 the following quantities should be determined at each measurement point :

(*a*) sound level in dB (A);

(*b*) band pressure levels in the octave bands centered on 63 Hz to 8 000 Hz.

13.1.5 *Measurement correction*. The results of the measurements at each measuring point should be corrected for the effects of any background noise (see clause 11.2).

13.1.6 *Calculation of the mean levels*. The mean sound level and band mean sound pressure levels should be calculated from the results of the measurement at all the test positions (after correction according to clause 13.1.5), by averaging according to equation (2) :

$$L_{p\ (M)} = 10 \log_{10} \left[\frac{1}{n} \left(\text{antilog}_{10} \frac{L_{p\ (1)}}{10} + \text{antilog}_{10} \frac{L_{p\ (2)}}{10} + \ldots + \text{antilog}_{10} \frac{L_{p\ (n)}}{10} \right) \right] \quad \ldots (2)$$

where

$L_{p\ (M)}$ is the mean sound level (A) (or band mean pressure level) in decibels;

$L_{p\ (1)}$ is the sound level (A) (or band pressure level) in decibels at the 1st position;

$L_{p\ (n)}$ is the sound level (A) (or band pressure level) in decibels at the *n*th position;

n is the number of measuring positions.

When the decibel readings at the various test positions do not differ by more than 5 dB, a simple arithmetic average of the dB readings will give a result differing not more than 0.7 dB from that given by equation (2).

13.1.7 *Calculation of the radius and area of the equivalent hemisphere*. For the purpose of calculation of the mean sound level or octave band mean pressure levels at the reference radius, the measurements made along the prescribed paths of Figures 1 and 2 should be assumed to have been made over a hemisphere of radius

$$r_s = \left[\frac{a\,(b+c)}{2} \right]^{\frac{1}{2}}$$

where a, b and c are as shown in Figures 1 and 2.

The area of this equivalent hemisphere is given by

$$S = \pi\, a\,(b+c)$$

NOTE. – The area of the equivalent hemisphere with radius r_s as specified is somewhat smaller than the surface area denoted by the paths of measurement.