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SOUND POWER MEASUREMENT OF A DIESEL ENGINE BY ISO/DIS 9614-2 AND ISO 3746 IN DIFFERENT ACOUSTICAL CONDITIONS

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1 INTRODUCTION

The sound pressure level and sound power level of a medium speed diesel engine was studied under different acoustical conditions. The sound pressure level varied even 5 dB in the field depending on the acoustical conditions. Because of the environmental requirements and economic considerations prevailing in building practices today, the sound pressure level caused by the engine should be predictable.

The diesel engine discussed here is shown in Fig. 1. The engines of this type produce 500-16000 kW output power depending on the cylinder number and cylinder diameter. The engine weight varies between 7 and 255 tons. These engines are designed for power plants and ships. The laboratory measurement of sound power level is practically impossible. Moreover, the environment in the factory as well as the operating site is not appropriate for precision measurements.

The problem can be divided into three parts which are studied in this paper:

- How accurate methods are available to determine sound power level reliably and what is the performance of the method in different environments ?
- Could the sound power level be determined in an easy and fast way reliably and what is the performance of the method in different environments ?
- Is the sound pressure level predictable at the operating site ?

METHODS

Intensity Method. One precision grade method exists for the determination of sound power level L_w in situ: ISO 9614-1:1993 intensity method by point measurements.[1] The method is very useful when operating with small test objects. When the measurement area is large and time available is limited the situation is different. On the other hand, ISO/DIS 9614-2:1989 intensity method by scanning is much faster. According to the comparison made [3], the measurement accuracy can be very good, even better than with ISO 9614-1, when the test is carried out carefully.

In the sound intensity method, L_w is calculated using equation

$$L_w = \overline{L_I} + 10\log S \qquad (1)$$

where $\overline{L_I}$ is the average sound intensity level (dB) on the measurement surface and S is the area of the that surface (m^2). The pI-index F_{pI}=L_p-L_I and the negative partial power indicator $F_{+/-}$ must be calculated. The criteria F_{pI}<L_d and $F_{+/-}$<3 dB must be fulfilled to ensure Grade 2 accuracy.

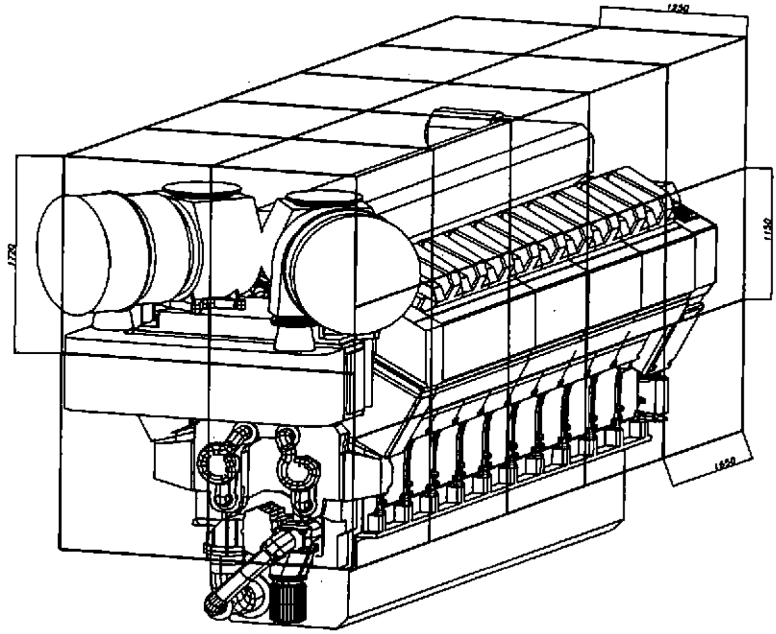

Fig. 1. The diesel engine and the partial measurement surfaces used in the ISO 9614-2 measurements.

The measurements were carried out with two microphone spacings: 6 mm (25-1250 Hz) and 50 mm (125-10000 Hz). [2] The results obtained with different spacings were combined afterwards. The intensity differences in the overlapping frequencies were below 1 dB. The dynamics of the intensity equipment, L_d=$F_{pI,max}$-10 dB, was determined in a small calibration chamber. $F_{pI,max}$ is the maximal pI-index measured in the calibration chamber. The measurement distance from the reference surface (minimum surface enclosing the engine) was 400 mm, so the total surface was 8250 x 2500 x 3450 mm, or 94.8 m^2. The measurement surface was divided into 48 partial surfaces, so as to obtain partial areas as similar as possible (2.16 m^2 at ends, 1.90 m^2 at long sides, and 2.06 m^2 on the top side). The small differences in the partial areas were not compensated, e.g., by varying the measurement time, because the source was close to omnidirectional. The error due to incorrect spatial weighting was therefore small. On the partial surfaces, the total scanning time was 32 s. The A-weighted sound power level $L_{W,A}$ was calculated from the measured frequencies.

Pressure Method. In the sound pressure method, L_w is calculated by

$$L_w = \overline{L_p} + 10\log S - K = \overline{L_p} + 10\log S - 10\log\left(1+\frac{4S}{A}\right) \qquad (2)$$

where $\overline{L_p}$ is the average sound pressure level (dB) on the measurement surface, K is the environmental correction (dB) and A is the total absorption area of the room (m^2). The background noise level must be more than 7 dB below the noise measured, and the measurement is valid after background noise level corrections. The absorption area A is determined from the reverberation time measurements using equation

$$A = \frac{0.161\cdot V}{T} = \sum_i \alpha_i S_i \qquad (3)$$

where V is the volume (m^3), T is the reverberation time (s) of the room using 10 dB decay range, and α_i is the absorption coefficient in the partial surface S_i. The latter term can be used when the reverberation time can not be determined or when sufficient absorption data is available.

In our arrangement, a modified ISO 3746 was used and only $L_{w,A}$ was determined. The $\overline{L_A}$ was measured as an equivalent level at a distance of one meter from the engine, walking slowly (0.5 m/s) around the engine and pointing the sound level meter towards the engine. The height was fixed to 1.5 m. No data were collected overhead and at the top corners because the levels scarcely deviated from the levels measured on the floor, and it was often impossible to collect data overhead. The modified ISO 3746 and official ISO 3746 gave similar results in an accuracy of 0.5 dB.

The Prediction of The Sound Pressure Level. From Eq. (2), the sound pressure level depends on the distance from the original measurement surface according to equation

$$L_p(d) = L_w + 10\log\left(\frac{1}{S(d)}+\frac{4}{A}\right) \qquad (4)$$

where $S(d)=2(x+2d)(y+2d)+2(y+2d)(z+d)+(x+2d)(z+d)$. The original measurement surface $S=2xy+2yz+xz$ is thus streched by d to all directions excluding the floor direction. The dimensions were x=7450 mm, y=1700 mm, and z=3050 mm. A diffuse sound field and an omnidirectional point source is assumed. If the room dimensions are asymmetric or absorption is not smoothly distributed in the room, the attenuation is stronger with increasing distance. [4]

The Test Cases. The sound power level of the same engine was measured in three Cases:

Case A: in the large test run room, the engine running alone,
Case B: in the large test run room, a similar engine was running 5 m away,
Case C: in a small room, the engine running alone.

Case C corresponds a typical power plant room. The room dimensions in cases A and B were 22.0 x 29.5 x 14.0 m and in Case C they were 22.0 x 8.0 x 7.5 m. The reverberation times of both rooms are shown in Table 1. The A-weighted absorption area A was 775 m^2 in cases A and B, and 150 m^2 in Case C.

RESULTS AND DISCUSSION

Table 1 shows the values of L_w obtained by ISO 9614-2 and the intensity indicators in cases A-C. The sound intensity method ISO 9614-2 gave almost equal results for L_w (±2.5 dB in 1/3 octaves) in the cases A (large room) and C (small room).

Table 1. ISO 9614-2 results in conditions A, B and C and reverberation times for both rooms.

Frequency	L_w (A)	F_{pI} (A)	F_{pI} (B)	F_{pI} (C)	$F_{+/-}$ (A)	$F_{+/-}$ (B)	$F_{+/-}$ (C)	T (A,B)	T (C)
Hz	dB	dB	dB	dB	dB	dB	dB	s	s
63	112.4	5.8	6.8	5.1	0.1	4.3	1.5	-	-
125	109.9	4.8	6.6	5.1	0.0	3.9	0.2	1.11	1.15
250	118.2	4.8	5.5	7.4	0.0	3.5	0.1	1.64	1.44
500	116.7	4.9	5.7	7.2	0.0	2.4	0.0	2.10	1.47
1000	118.0	5.3	6.4	7.4	0.0	2.4	0.0	2.24	1.57
2000	116.2	5.2	6.6	8.4	0.0	2.1	0.8	1.85	1.39
4000	114.5	4.1	6.1	7.1	0.0	1.7	0.2	1.35	1.01
8000	111.7	3.8	5.3	6.1	0.0	1.1	0.0	1.01	0.88

In Case B, where a similar engine was running next to the measured engine, the results were considered unreliable with both methods. ISO 9614-2 gave better results than ISO 3746, as supposed, but the reliability of the former was not as good as expected. The background noise affected the sound intensity measurements by causing negative sound intensity values on the disturbed side of the measurement surface. The total effect of the sound passing through the closed measurement surface was theoretically zero but, practically, the indicator $F_{+/-}$ increased too much.

$L_{w,A}$ values obtained with both methods are tabulated in Table 2. The reverberation times of both rooms are shown in Table 1. The A-weighted absorption area was 775 m^2 in cases A and C, and 150 m^2 in Case B. In cases A and C the measured value $L_{A,meas}$ was higher than predicted value $L_{A,pred1}$. The ISO 9614-2 result was used in predictions. In Case A the average A-weighted F_{pI} value at a distance of 1 m from the reference surface was 5.1 dB but the environmental correction K was only 2.4 dB. The rest of the F_{pI}, marked by K'=2.7 dB, was supposed to be due to the nearfield effects. Theoretically, far from the sound source, the L_{pI} is due to the reverberant sound only, and the environmental correction K explains entirely the deviation between L_I and L_p. Close to the engine, the sound flow observed by the intensity probe also contained sound entering from the sides. This increased L_p but decreased L_I. When K' is added to the predicted value L_{Apred1}, the new prediction, $L_{A,pred2}$, is consistent with $L_{A,meas}$. In Case C, F_{pI} and K were closer to each other. The reverberant sound field (K=6.8 dB) was stronger than the near field effect, which is constant and independent of acoustic environment. The course of the calculations in Cases A and C is shown in Table 2.

Table 2. Correction of the $L_{w,A}$ due to the nearfield effects, by determining the difference of K and F_{pI}. The ISO 9614-2 result was used in prediction 1.

Parameter	Case A	Case C
$L_{A,meas}$	**106.4 dB**	**109.0 dB**
K	2.4 dB	6.8 dB
F_{pI}	5.1 dB	7.7 dB
$K'=F_{pI} - K$	2.7 dB	0.9 dB
$L_{A,pred1}$	103.8 dB	108.2 dB
$L_{A,pred2}=L_{A,pred1}+K'$	**106.5 dB**	**109.1 dB**

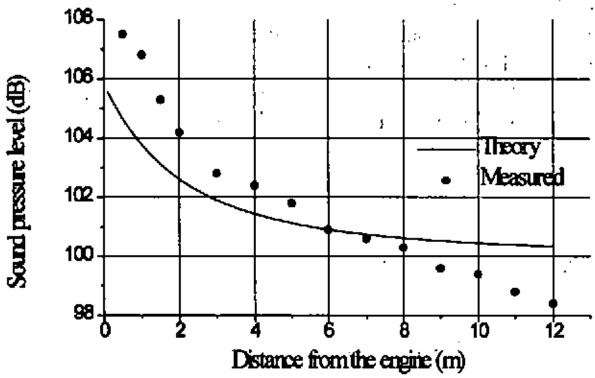

Fig. 2. The measured and predicted (Eq. 4) attenuation of A-weighted SPL as a function of distance from the engine in the test run room (Case A). The difference near the engine is due to the strong near field, and far from the engine Eq. (4) fails.

The proportion of K' in F_{pI} should decrease with increasing distance from the engine because the far field is approximated better. This is evident according to Fig. 2, where the attenuation of sound in the test run room (Case A) is measured and calculated according to Eq. (4).

The obtained $L_{W,A}$ in different Cases and with different methods are shown in Table 3. The uniformity between ISO 9614 and ISO 3746 was not satisfactory without the correction shown in Table 2.

Table 3. Comparison of A-weighted sound power levels $L_{W,A}$ obtained by ISO 9614-2, ISO 3746, and corrected ISO 3746 in Cases A and C.

Method	Case A	Case C
ISO 9614-2	122.9	122.6
ISO 3746	125.5	123.7
(corrected) ISO 3746	122.8	122.8

CONCLUSIONS

Different results of sound power level were obtained with ISO 9614 and modified ISO 3746. The reason for the difference was supposed to be in the nearfield effects. The relation between pI-index F_{pI} and environmental correction term K was discussed. When a nearfield correction was applied to the results measured by the modified ISO 3746, both standards gave similar results under both tested acoustical conditions. The results concern so far only the tested engine type, but similar results are expected in future for different engine types.

In this examination, the effect of background noise was detrimental for both methods. Even the intensity method gave unacceptable results. The background noise level should be hence distinctly lower (7-10 dB) than the level caused by the test object. The reverberation did not affect the measurement accuracy of either method noteworthly. ISO 9614-2 was found to be the best method for the sound power level measurements which will be used as a reference in SPL predictions.

The sound level at the final operation site, at a distance of 1 m, seems to be predictable when the acoustical conditions and the pI-index of the engine (in free field) are known.

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