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SIMPLIFIED METHOD FOR PREDICTING SOUND LEVEL A IN ACCOMMODATION SPACES ABOARD
SEA-GOING MOTORSHIPS

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SUMMARY

The paper is a concise description and evaluation of a method for predicting accommodation noise aboard sea-going ships; noise sources included are main and auxiliary diesel engines, reduction gears and propellers. The method is a rigorous simplification in terms of sound level A of empirical prediction procedures published before; it is intended for use by shipbuilders during the preliminary design stage when assessing various noise countermeasures. Its usefulness is illustrated by comparing calculated and measured noise levels A in 67 cabins aboard 15 ships of different types.

1. INTRODUCTION

Acoustic experts have developed methods for predicting the noise levels in accommodation spaces aboard sea-going ships. These models combine data on the main sound sources, the transmission losses in the ship's structure and the effectiveness of noise reduction measures. Because of the frequency dependence of these data and the large variety of structures etc., such calculations are usually carried out with the aid of computers by the acoustic consultants. In addition, however, there is a need for a quick and much simpler method which can be used by the yard in a very early design stage. It should provide an estimate of the total amount of noise reduction and give sufficiently accurate information on alternative measures, e.g., floating floors, resiliently mounting systems for diesel engines or complete deck houses. Then the financial consequences can be assessed.

In this paper such a simple method is given; it has been derived from a well established practical experience based scheme, from which some data have been published in [1] and [2]. This simplified method has been published in a Dutch report [3] in the form of nomograms. The simplification consists of a condensation of all frequency dependent information to one A-level connected figure and of a presentation of typical attenuations and insertion losses for certain types of ships and structures respectively. The prediction result is the sound pressure level A in a standardized cabin.

2. OUTLINE OF THE METHOD

The empirical prediction method, on which the present simplification has been based, calculates the sound pressure levels in cabins from essentially three types of data, i.e., source strengths, attenuation losses between source and cabin and a relation between the sound pressure in the cabin and the velocity level of the deck. A similar procedure is followed here and for each of the main structure-borne and airborne sound sources the A-weighted sound level is calculated for a standardized cabin. The following contributions are taken into account:

1. $L_A(pde)$: due to propulsion diesel engines
2. $L_A(red)$: due to reduction gears as a part of the propulsion system

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3. $L_A(\text{prp})$: due to propellers
4. $L_A(\text{aux})$: due to auxiliary diesel engines
5. $L_A(\text{air})$: due to airborne sound transmission from engine room to adjacent cabins.

The total sound level A is obtained from eq. (1)

$$L_A = 10 \log \left[\sum_{i=1}^5 10^{0.1 L_A(i)} \right], \text{ with } i = \text{pde, red, } \dots \quad (1)$$

When more than one propulsion diesel engine exists the contribution of all of them has to be considered unless engines are situated at equal fore and aft positions. In the latter case the contribution of the engine with the highest source strength has to be considered only. The same remark applies to the contributions of sources no. 2 and 4.

We shall now consider the data which are to be used for prediction of $L_A(\text{cabin})$ for the various sources. The standard cabin is supposed to have a volume of 30 m^3 and a reasonable amount of absorption ($T_{60} = 0.25 \text{ s}$ for the higher frequencies).

3. DIESEL ENGINES AND REDUCTION GEARS

For the structure-borne sound sources like diesels and reduction gear boxes we start with the fictitious case that the velocity levels on the engine feet are equal to those on the deck on which the cabin is located. There are no noise reduction measures. In this situation when there is no propagation loss in the ship and no attenuation by acoustic measures, there is a simple one figure relation between the sound level A at 1 m distance from the source measured under free field condition and the sound level A inside the cabin. This quantity, see eq. (2), depends on the type of source and is given in table 3.

$$c_e = L_A(\text{cabin}) - L_A(1 \text{ m f f}) \quad (2)$$

For the derivation of c_e we have used two empirical sets of data. These are the frequency dependent relations $[L_p(\text{cabin, re } 2 \cdot 10^{-5} \text{ Pa}) - L_v(\text{deck, re } 5 \cdot 10^{-8} \text{ m/s})]$ and $[L_v(\text{engine foot, vertical direction, re } 5 \cdot 10^{-8} \text{ m/s}) - L_A(1 \text{ m f f})]$.

The former can be found from [4], figures 3 and 9, and the latter from [1], lines 1-5 of the table. By adding these two relations for the fictitious case that $L_v(\text{deck}) = L_v(\text{engine foot})$ one gets the required c_e , after conversion of $[L_p(\text{cabin}) - L_A(1 \text{ m f f})]$.

For real situations one has to add one figure terms for the propagation attenuation and for the insertion loss of acoustic measures. The $L_A(\text{cabin})$ is then obtained from eq. (3)

$$L_A(\text{cabin}) = L_A(1 \text{ m, f f engine}) + c_e - \text{TD}(\text{hor}) - \text{TD}(\text{vert}) - \text{E}(\text{IL}) \text{ dB(A)} \quad (3)$$

where $\text{TD}(\text{hor})$ is the transfer level difference in fore-and-aft-direction distance between source and cabin, $\text{TD}(\text{vert})$ the same for the vertical distance and $\text{E}(\text{IL})$ the total effect of acoustic measures. All quantities are expressed in dB(A).

3.1 Diesel engines

$L_A(1 \text{ m, f f})$ for diesel engines can be derived from the mechanical data of the engine or from measurements.

For the derivation from mechanical data we use, as we did in [1], the empirical relation in eq. (4) which is taken from [5].

$$L_A(1 \text{ m, f f}) = 5.5 \log \frac{n_e}{1 \text{ MW}} + 10 \log \frac{n_e}{1 \text{ Hz}} - 30 \log \frac{n_e}{n} + 90 \text{ dB(A)} \quad (4)$$

where

n_e = full power (MW) for one engine at n_e revolutions per second

n = actual number of revolutions (Hz)

$L_A(1 \text{ m, f f})$ can also be derived from actual measured octave band levels $L_v(\text{engine foot, re } 5 \cdot 10^{-8} \text{ m/s})$. By adding to each octave band level the appropriate data of table 1 and taking the arithmetic average of these data according to eq. (5).

$$L_A(1 \text{ m, f f}) = \frac{1}{6} \sum_{f_c=63 \text{ Hz}}^{2000 \text{ Hz}} \left[L_v(f_c, \text{measured}) + L_c(f_c) \right] \text{ dB(A)} \quad (5)$$

The sound levels in the cabin, i.e., $L_A(\text{pde})$ or $L_A(\text{aux})$ are then found from eq. (6)

$$L_A = L_A(1 \text{ m, f f}) + c_e - 0.5 k - \text{TD}(\text{vert}) - \text{IL}(\text{engine}) - \text{IL}(\text{acc}) \text{ dB(A)} \quad (6)$$

where k is the number of frames between the diesel engine and the cabin and c_e , TD and IL are taken from the tables 2 and 3.

3.2 Reduction gears

For the gearboxes a similar procedure is followed as for the diesel engines. For the derivation of $L_A(1 \text{ m, f f})$ from mechanical data we use, as in [1], the eq. (7) which has been taken with some simplifications from [6].

$$L_A(1 \text{ m, f f}) = 10 \log \frac{P}{1 \text{ MW}} - 20 \log \frac{(1+b+3m)}{1 \text{ m}} + \Delta L_g + 107 \text{ dB(A)} \quad (7)$$

where P is the total power (MW) transferred by the gearbox and l and b the principal dimensions in the horizontal plane (in m). The term L is a measure for the quality of the gearbox. The connection between this term and quality classes as described in [6] is given below:

class	B_3	C_1	C_2	C_3	D_1	D_2	D_3
ΔL_g	0	2.5	5	7.5	10	12.5	15.

It has been proved that for shipboard reduction gears the quality of class B_3 is attainable.

If measurements of L on the feet of the gearbox are available, one may derive $L_A(1 \text{ m, f f})$ from eq. (5), in the same way as for diesels.

The sound level in the cabin, $L_A(\text{red})$, is then calculated from eq. (6). If the gearbox is not resiliently mounted the term $\text{IL}(\text{engine})$ vanishes.

4. PROPELLERS

For the prediction of the sound level due to the propellers, $L_A(\text{prp})$, eq. (8) is used.

$$L_A(\text{prp}) = 20 \log N_p + 23 N/N_p - \text{ak} - \text{TD}(\text{vert}) - \text{IL}(\text{acc}) + 43 \text{ dB(A)} \quad (8)$$

where N_p = total full power (MW) of all propellers

N = actual power, but $\geq 0.7 N_p$ (MW)

a = 0.2 for frames 1-10 and 0.4 for greater distances between cabin and propeller(s)

k = number of frames between cabin and propeller(s)

TD and IL are given in tables no. 2 and 3.

5. TRANSFER OF AIRBORNE SOUND

The sound level $L_A(\text{air})$ due to airborne sound transmission from one sound source in an engine room underneath the deck on which the cabin is situated, is found from eq. (9).

$$L_A(\text{air}) = L_A(1 \text{ m, f f}) - 0.002V + 0.7(1+b) - \text{IL}(\text{air}) - 36 \text{ dB(A)} \quad (9)$$

where V = volume of engine room in m^3

l , b = length and width of the source in m

The source strength $L_A(1 \text{ m, f f})$ is obtained from eq. (4), (5) or (6). The term $\text{IL}(\text{air})$ is zero when no acoustical measures are taken, 11 dB(A) when a floating floor is applied and $> 25 \text{ dB(A)}$ when the deckhouse is resiliently mounted.

If there is more than one strong airborne sound source in the engine room, their contributions to $L_A(\text{cabin})$ are to be added.

6. NOISE REDUCTION MEASURES

The insertion losses of acoustical measures in the accommodation have been derived from data in [2] and [4] and from literature which is referred to in [3]. For the data which have been presented in table 3 the following constructions are supposed:

- floating floor: composed of 25 mm glass fibre or mineral wool (55 kg/m^3) and a highly damped top layer (ca. 70 kg/m^3) on top of which the cabin bulkheads are fitted; other mechanical connections of bulkheads to steelwork only by means of soft rubber mountings.

- floating floors and additional measures: floating floors as mentioned above but in addition 1) the insertion of 50 mm thick glass fibre blankets in the cavities above ceiling and behind lining, of steel bulkheads, 2) port-hole boxes to be air-tight closed with a 6 mm thick extra window pane.

- resiliently mounted engines: stiff and heavy constructed structures below and above the mounts, natural frequency for the vertical vibration lower than 10Hz, stiffnesses in horizontal directions equal or lower than the stiffness in vertical direction.
- resiliently mounted deckhouses: natural frequency for the vertical vibration lower than 15 Hz; stiff and heavy constructions at both sides of the mounts.

7. TEST RESULTS

To test the accuracy of the method and the data presented above, we have calculated L_A (cabin) for 67 cabins on board 15 ships of different types. From none of these ships, transmission data were used to derive the data of table 2 or 3. From the calculated L_A 's 46% differed less than 3 dB(A) from the measures values. The standard deviation of the differences between measured and calculated values was 4 dB(A). The largest differences (up to 8 dB(A)) occur for cabins in which the propellers are the pre-dominant sound source.

For cabins in which the machinery noise predominates, the accuracy can be improved by using:

1. measurement values for L_V (engine), e.g. from test bed
2. replacement in eq.(3) of the terms $c' - IL(acc)$ by c' which is derived from published data on L_p (cabin - L_V (deck)) for situations with specified accommodation systems and acoustic measures.
3. replacement of the data for TD(vert) in table 2 by class averages. The data in table 2 originate from one ship of the type for each type of ship, see table 2 in [2].

8. TABLES

Table 1: Conversion terms L_A to obtain L_A (1 m f f) from L_V measured at the feet of diesel engines and gearboxes

source	speed rev./s	octave band centre frequencies f_c (Hz)					
		63	125	250	500	1000	2000
diesel engines	1,5- 4	22	23	25	27	29	35
	6 -10	19	20	21	24	28	34
	12 -20	8	10	14	16	21	26
reduction gears	any	22	30	27	25	27	28

Table 2: Vertical transfer level difference TD(vert) in dB(A).

Number of deck above tank top :		1	2	3	4	5
For diesel engines and reduction gears on board						
- passenger ships	:	5	9	16	20	23
- freighters, hoppersuction dredgers:	:	4	7	11	15	18
- bulkcarriers	:	-	-	-	12	13
For propellers (all ships)						
horizontal distance	1 < k < 11 :	4	7	10	12	14
from propeller to cabin (number of frames)	k > 10 :	2	4	7	9	11

Table 3: Insertion losses of acoustical measures and values of c_e in dB(A)

Acoustical measure	diesel engines			reduction gears	propellers
	1,5-4 rev./s	6-10 rev./s	12-20 rev./s		
-at the engine: IL(engine) resiliently mounted	-	13	8-15*	15	-
-in the accommodation: IL(acc)floating floors:	5	5	6	6	4
fl.floors and additional measures:	10	10	10	10	7
resiliently mounted deckhouse	10	10	10	10	10
-values of c_e	-24	-22	-14	-23	-

*low value when the engine is fitted close to the hull or tank top, see also [7].

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