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SOUND INTENSITY MEASUREMENTS OF FANS IN SUBMARINES

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ABSTRACT

Airborne noise is one of the many factors which need to be considered when setting the required environmental conditions within a submarine. In order for the crew to work and rest free from hazardous or intrusive noise, one must first be able to identify dominant onboard sources of noise and hence those acoustic treatments which are necessary to reduce noise to an acceptable level and are practical to install.

Of all machinery items fitted onboard a submarine, fans are amongst the major sources of airborne noise. This paper discusses, through various case studies, how sound intensity measurements have been used to: a) validate and improve the prediction of sound pressure levels in submarine compartments due to fan noise before the installation of the fans takes place; b) identify which fans fitted onboard are potential noise hazards; c) identify the parts of particular fans which radiate most noise with a view to fitting acoustic treatments to reduce their contribution to compartment airborne noise levels.

1. INTRODUCTION

The ventilation system onboard a submarine is a closed system. While the submarine is operating under submerged patrol conditions no air can be drawn from or discharged to the atmosphere except during snorting. Air which is circulated throughout the boat must therefore return to its point of supply. With such a closed system, carbon dioxide must be continually removed from the air and oxygen re-introduced.

There are several types of fan installed onboard a submarine and example uses include: circulating air throughout the entire submarine to maintain a breathable atmosphere, circulating and cooling the air in compartments such as machinery spaces where there is likely to be a build-up of heat, cooling specific items of electronic equipment and purging toxic or flammable fumes which may build up in parts of the submarine from time to time. Individual fans have to be able to operate at multiple duties to perform the tasks that would normally be carried out by several fans in other environments, because of space constraints on the amount of equipment that can be installed in the submarine.

SOUND INTENSITY MEASUREMENTS OF FANS IN SUBMARINES

The control of airborne noise within a submarine is an important factor which needs to be considered when setting the required environmental conditions under which the crew have to work and rest. In addition to recirculating air, fans are also major sources of noise onboard a submarine. Not only do fans contribute to noise levels in the compartments in which they are located, but also to levels in other areas of the submarine which either share common compartment boundaries with the source area or are linked to the source area by ventilation ducts. A common problem found in submarines is that fan spaces are often sited adjacent to quiet areas such as cabins or offices because of space constraints.

The determination of sound power levels (SWLs) of fans is important in establishing their contribution to compartment airborne noise levels. Once this is achieved then practical acoustic treatments can be selected to reduce their contribution to within acceptable limits where target levels are currently exceeded or are likely to do so. This paper discusses how sound intensity techniques are being used to measure the SWLs at various stages of the submarine build to achieve these aims.

2. SOUND INTENSITY

Sound intensity can be defined as the average rate of sound energy flow per unit area and is measured using the now familiar two-microphone probe. By defining a series of measurement surfaces which together enclose a noise source, one can obtain the SWLs of that source by integrating the measured sound intensity levels over the measurement surfaces. The sound intensity levels having been measured normal to these surfaces.

Most items of machinery including fans are noise and vibration tested, generally under semi-reverberant conditions, at the manufacturer's works or on site at the shipyard prior to installation onboard a submarine. Current standards require that sound pressure level (SPL) measurements are taken during these tests. SWLs can then be calculated knowing the distance between the source and the measurement points, the acoustic absorption in the test facility and the directivity of the source. The latter two factors often have to be estimated since the location of the machine under test is often in a factory or workshop where the acoustic environment cannot be accurately controlled. In such situations by measuring sound intensity levels over known surfaces around the machine under test, SWLs can be obtained directly without requiring knowledge of the acoustic absorption of the test environment or the directivity of the source.

SPL readings taken during many pre-installation tests on machines to be fitted onboard the submarine are affected by background noise. Usually the SPLs can be corrected to account for this but there are occasions where the background levels are so high that accurate SPL measurements of the machine under test cannot be obtained. One benefit that sound intensity measurements have over measurements of SPLs is that they are unaffected by background noise providing that the background noise is steady, is external to the measurement volume over the noise source and there is no absorbent material within the measurement volume. Under these conditions the sound energy flow due to background noise into the enclosed volume will equal its sound energy flow out of the volume and intensity readings obtained will thus be due solely to the machine under test.

Sound intensity measurements can also be used to determine the SWLs of individual parts of a machine. This is achieved by taking intensity readings over measurement surfaces which enclose each component of the machine under test.

3. CASE STUDY A

The aim of this case study was to compare the SWLs of a fan (see Figure 1), calculated from SPL measurements, with those obtained using sound intensity measurements. Using the SWLs obtained, the contribution of the fan to compartment airborne noise levels was then determined. Two tests were carried out on the fan. First, with an inlet silencer attached, and second with inlet and discharge silencers fitted. In both tests, the fan was tested under free inlet and outlet conditions in the shipyard test facility prior to the fan being installed in a submarine.

SPLs were first measured using a sound level meter over an array of positions at set distances from the fan. SWLs were then calculated using these measurements and known values of the acoustic absorption in the test facility determined from previous tests. The SWLs obtained are shown in Table 1. Swept sound intensity measurements using a two-microphone probe were then taken over imaginary surfaces combining to form a box around the fan. Knowing the areas of the surfaces, SWLs were then determined from the intensity measurements and are shown in Table 1. From this table one can see that there is good agreement between the SWLs determined from the SPL measurements and those obtained from sound intensity measurements, both for the one and two silencer cases.

The SWLs of the fan, determined from sound intensity measurements, were then input to a computer acoustic model of the machinery space of the submarine in which the fan was to be located. The SPL contribution of the fan to compartment levels was then calculated, using this model, for both silencer options. Results from the model showed that with only an inlet silencer fitted, the fan would contribute an overall level of 95 dBA to compartment SPLs, but only 83 dBA when the discharge silencer was also fitted. Since the target level of the compartment was 85 dBA, this would be exceeded unless both silencers were fitted. Once the fan was installed onboard with both its silencers fitted, SPL measurements were taken and were found to be within 1 dBA of those obtained from the acoustic model.

4. CASE STUDY B

The aim of this case study was to identify which fans fitted onboard a submarine in a particular compartment produced most noise. The compartment investigated in this case study contained three fans which would operate continually at the same time under patrol conditions. In order therefore to determine which fan contributes most to compartment levels it was first necessary to measure sound intensity levels with the two-microphone probe around each fan in turn. The SWLs of the fans were then determined, knowing the areas of the relevant intensity measurement surfaces, and input to a computer acoustic model of the compartment concerned so that the contribution of each fan to compartment SPLs could be obtained. The resulting levels shown in Table 2 indicate that each fan would exceed its target SPL of 75 dBA.

Once conditions allowed the fans to be run individually, the SPLs due to each fan were measured using a sound level meter and these are shown in Table 2. From this table one can see that the measured SPLs agree favourably with those determined from SWLs obtained using sound intensity measurements and that Fan 1 contributed most noise to compartment levels. As a result of this assessment it was recommended that each fan should have improved silencers fitted and their casing lagged with acoustic insulation in order that their contribution to compartment levels be reduced.

5. CASE STUDY C

The aim of this case study was to identify which parts of a particular fan, already installed on a submarine, radiate most noise in order that appropriate acoustic treatments could be fitted to reduce the fan's contribution to compartment airborne noise levels. The fan in question, a known noise hazard contributing 81 dBA to SPLs in the compartment in which it was located, had already been fitted with inlet and discharge silencers, as shown in Figure 2. Sound intensity measurement boxes were drawn around each component of the fan and swept measurements taken over each surface with a two-microphone probe. Knowing the surface areas, SWLs of each component were then determined as shown in Figure 2.

This figure shows that most noise is radiated from the fan and discharge silencer casings and a recommendation was made to lag these areas. A lagging material, consisting of a fibreglass mattress containing a sheet lead core, applied to the casings during a later SPL measurement test resulted in an 8 dBA reduction in the contribution of the fan to compartment SPLs.

6. CONCLUSIONS

This paper has shown through the case studies how sound intensity measurements have been used in the determination of submarine fan SWLs. SWLs determined from sound intensity measurements of fans prior to installation allow compartment SPLs to be predicted and appropriate noise control measures identified before the fans are fitted. For fans already onboard, sound intensity measurements can be used to identify those machines which are likely to be noise hazards and also those components of individual fans which will radiate most noise. Once this is achieved then appropriate acoustic treatments can be recommended.

FIGURE 1 FAN WITH BOTH SILENCERS

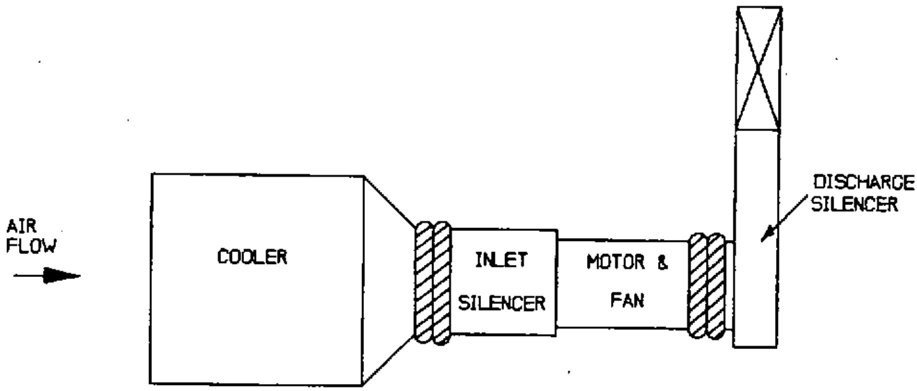

FIGURE 2 SOUND POWER LEVELS OF FAN

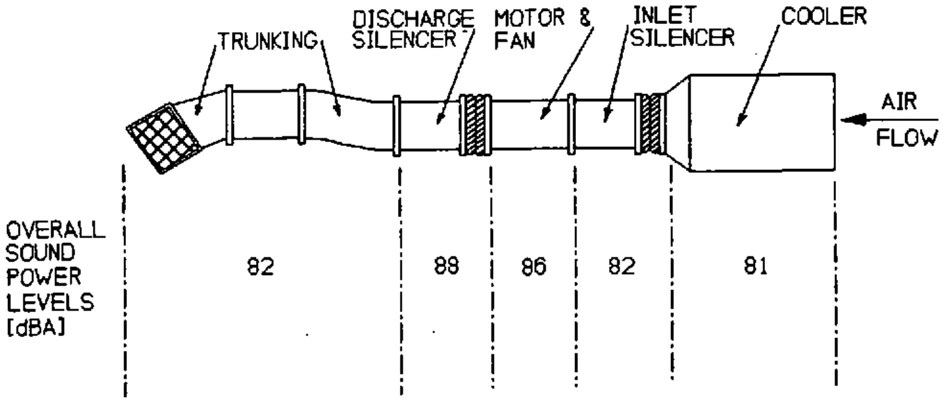

TABLE 1 SOUND POWER LEVELS OF FAN

TEST	METHOD	SOUND POWER LEVELS (dBA ref. 10^{-12} W)						
		125	250	500	1k	2k	4k	8k
FAN WITH INLET SILENCER	SOUND PRESSURE	69	79	92	101	99	95	85
	SOUND INTENSITY	74	80	94	103	99	95	86
FAN WITH INLET AND DISCHARGE SILENCERS	SOUND PRESSURE	76	83	87	89	83	79	72
	SOUND INTENSITY	77	84	87	90	84	78	73

TABLE 2 COMPARTMENT SOUND PRESSURE LEVELS

	OVERALL SOUND PRESSURE LEVELS (dBA ref. 2 x 10^{-5} Pa)	
	CALCULATED	MEASURED
FAN 1	82	81
FAN 2	78	76
FAN 3	76	77