PRINCIPLES OF AN ACTIVE NOISE AND VIBRATION CONTROL SYSTEM CONSTRUCTION FOR SHIP

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ABSTRACT

Main sources of increased vibrations and air noise on ship are main and auxiliary engines and ship ducts. The various ways of transfer of vibration energy and air noise in passenger cabin of a vessel require, in general case, of various methods of attenuation.
The transfer of vibration energy from engines through a support requires, alongside with shock-absorbers, availability active shock-absorbers. The transfer of vibration energy and hydrodynamic noise on ship ducts requires availability, alongside with flexible muffler, active mufflers. The availability of air noise from working equipment can require, along with sound absorbent covers, of space systems of active noise control.
In the given article it is spoken about the unified approach to formation of the block-diagram of active noise and vibration control. The complex approach permits to receive additional efficiency in reduction of noise in passenger cabin of vessels.

1. INTRODUCTION

This paper discusses possible application of multichannel active noise and vibration control (ANVC) systems to attenuate vibration and air noise radiation from ship machinery through pipes and foundations into adjacent compartment structures which subsequently transmit the radiation further.
Present-day adaptive ANVC arrangements consist as a rule of four major sub-system. Each sub-system is designed to suit its intended attenuation task while the relevant devices and their control algorithms are made as sophisticated as required by the involved number of direction-frequency channels to be compensated. Any active compensation system should satisfy $n \cdot N = const$, where N is the number of compensating frequency components, n is the number of excitation points in the compensation field. Thus, in designing an ANVC system there always is a question of what would be the optimum ratio between n and N. The second related problem is a rational (optimum) layout for the secondary compensating sources.

2. THEORY

Let us consider the task of choosing the appropriate number of ANVC channels and the optimum arrangement of the secondary sources among ship structures on an example of an system intended to cancel noise and vibration originating from a circulating pump which provides sea water for auxiliary machinery cooling. As regards the basic advisability and efficiency of ANVC system for auxiliary machinery cooling circuits, that has been already discussed in detail in [1].

The sound pressure built-up outside the ship comes from four components: c1 which is due to direct radiation into the water through the fluid running in the pipes; c2 which is due to ship hull radiation caused by the forces acting at sea water line attachments; c3 which is due to ship hull radiation from the pump foundation location; c4 which is due to the compartment air noise and the ship's outward noise insulation. As far as concerns the sound pressure inside the ship, it forms due to the radiation from the principal source (the pump) and to the above components c2, c3. Therefore, it would be useful to find an analytical solution for optimum ANVC network layout to ensure hull vibration attenuation and reducing the sound pressure due to c2 and c3 components.

Let us take for the theoretical model an infinite plate which on one side contacts a half-space filled with a compressible acoustic media. The plate is excited by a harmonic concentrated force $F_o e^{i\omega t}$ at an $r = 0$ point and by a force which is distributed around this point within a radius r_o and has a uniform density f_o.

The relevant plate oscillation equation written in cylindrical coordinates originating from the force input point would look like:

$$\Delta^2\xi(r) - k_w^4\xi(r) = F_o\frac{\delta(r)}{D\pi r} + f_o\frac{\delta(r-r_o)}{D} - \frac{P(r,z=0)}{D}, \tag{1}$$

where $\xi(r)$ is the plate's lateral displacement.

The sound pressure propagation may be described by:

$$\Delta P + \frac{\partial^2 P}{\partial z^2} + k_o^2 P = 0, \tag{2}$$

These equations (1) and (2) are related to each other through a contact condition

$$\xi(r) = \frac{1}{\rho_o\omega^2}\cdot\frac{\partial P}{\partial z}\,|_{z=0}, \tag{3}$$

Applying Hankel's transformation for (1) and segregating the variables in (2) we would come to:

$$P(r,z) = F_o P_o(r,z)[1 + \frac{f_o 2\pi r_o}{F_o} J_o(k_o r_o \sin\theta)], \tag{4}$$

For the total radiation energy within $\frac{\omega m}{\rho c} \ll 1$ (the low-frequency domain) and $k_o r_o < 1$ we would have:

$$W = \frac{F_o^2 k_o^2}{12\pi\rho_o c_o}\cdot\frac{(k_o r_o)^4}{840},$$

i.e. a value sizably below point force radiation where $W = \frac{F_o^2 k_o^2}{12\pi\rho_o c_o}$. Reverting now to (4) we may also see that with the f_o density independent of F_o one may choose the r_o

radius for placing the secondary sources in such a manner that the selected direction would have no radiation due to the condition of $1 + \frac{f_o 2\pi r_o}{F_o} J_o(kr_o \sin\theta) = 0$.
Thus, the tasks of reducing the plate's energy radiation into the acoustic media and the task of reducing the energy input to the plate are tackled differently. In the former case if is sufficient to put the secondary sources to provide for a force segregation density of $f_o = -\frac{F_o}{2\pi r_o}$ within any radius, while in the latter one we can't randomly choose a radius and have to found if from $J_o(k_w r_o) = \frac{F_o}{2\pi r_o f_o}$.
Designating the ratio between cylindrical wave amplitudes in the plate with the secondary sources and in the one without them through M, we can see that at $M < 1$ the wave attenuates. The wave propagation problem for the above-indicated layout of the principal and the secondary sources may be solved as:

$$L, dB = -20\lg|M| = -20\lg|1 - 2\pi r_o J(k_w r_o)\frac{f_o}{F_o}| \tag{5}$$

Therefore, by analytically finding the k_w and them selecting a suitable r_o one may establish the best ratio of f_o/F_o.

3. EXPERIMENTAL METHODOLOGY AND RESULTS

The experimental methodology used in the here reported exercise for individual contributions of c1-c4 components to the total ship sound field due to the circulating pump was as follows. The c2, c3 contributions due to hull radiation were found utilizing the effect of the large wave distance from the input and output openings of the sea water line to the pump's foundation. The c1 contribution was established with the help of flow noise mufflers fitted for the purpose into the pipes. The c4 contribution resulting from the air noise was obtained using an artificial air noise source.
The thus acquired experimental data were analyzed with the above-shown formulae to get coordinates for ANVC secondary sources (vibrators) and the number of direction and frequency channels. It has turned out that the relevant contributions were coming from c1, c2 and c4 components at the pump's rotational frequency of 43.3 Hz in respect of the outside sound pressure and at the same frequency in respect of vibrations at the discharge opening.
The c2, c4 radiation components and hull vibrations were reduced by an 8-channel ANVC system. Six of the channels sewed to attenuate the c2 component and the vibration, two were applied against the c4 component. The vibrators were set in a circle of $r_o = 1.15m$ centered at the sea water pipe opening. Computations with the above formulae have shown that with such ANVC network layout the outboard sound pressure should have been 12 to 15 dB on the average across the directivity pattern; the vibration beyond the vibrator circle should have been 18 dB. Actual measurements resulted in 12 dB at 43.3 Hz for the sound pressure (Fig.1) and 16 dB for the vibration (Fig.2). All attempts to alter the f_o/F_o ratio or r_o have only worsened the ANVC effect.

REFERENCE

[1] V.Maslov "Active/Passive noise control for ship system ducts" Proceedings of the 1993 International Congress on Noise Control Engineering, Lenven, Belgium, 1993, p.p. 837-840.

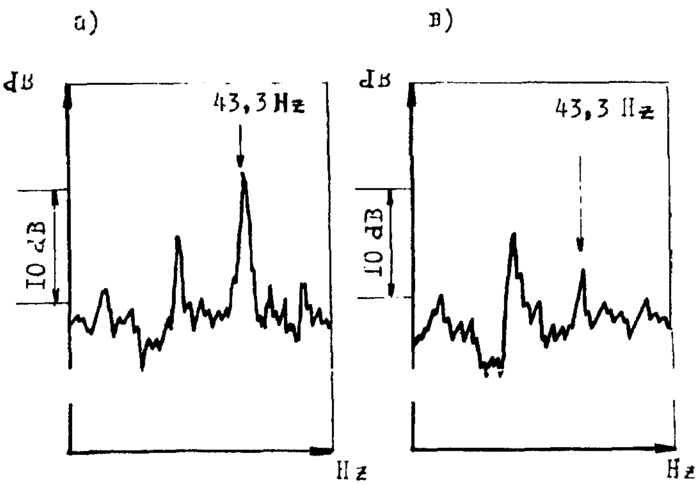

Fig.1. Sound pressure spectrum characteristic

a).without ANVC
b).with ANVC

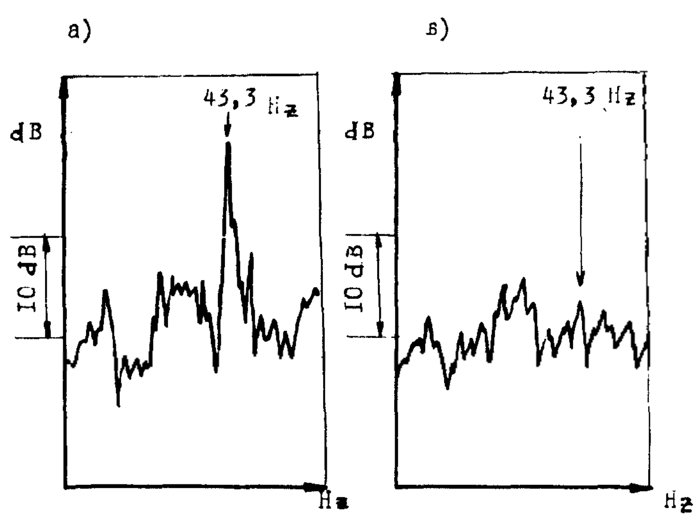

Fig.2. Vibration spectrum characteristic

a).without ANVC
b).with ANVC