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AN EXPERIMENTAL INVESTIGATION ON VIBRATIONAL SIMILITUDE OF STIFFENED CYLINDRICAL SHELLS

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ABSTRACT

This paper experimentally investigates the vibrational similitude between three models of stiffened cylindrical shells. The results show that the dimensionless frequency $\omega l/(E/\rho)^{1/2}$ and the normalized vibration acceleration $l^3\rho a/F$ of models are similar. The measurement has also told us that scaling factor λ_l octave index K of spectrum level and number of octave band N of frequency shift should satisfy $2^{N/K}=\lambda_l$.

1 - INTRODUCTION

It is a very complex problem that the numerical simulation of acoustic radiation, used for noise prediction of underwater vehicles, depends on the physical-mathematical model, which refers to many aspects of structure-fluid and acoustic. Therefore, it is necessary to make acoustic experiment with large-scale model. One of its purposes is to study and predict the vibration and underwater noise control techniques. This puts forward an important topic that is the acoustic similitude relation between model and prototype.

The reference [1] comprehensively investigates the similitude of vibration coupled vibration and acoustic radiation for the typical structure of underwater vehicle - elastic stiffened cylindrical shells of finite length, in which the effects of structural damping and fluid load are emphasized. The paper showed that if model and prototype are geometric similarity with the same boundary condition material and the same position of stiffeners, the frequency scaling factor is inversely proportional to geometric scaling factor, meanwhile, their ratio of vibration acceleration is proportional to the ratio of exciting force and inversely proportional to cube of geometric scaling factor. The purpose of this paper is to test these similarity relations experimentally.

2 - EXPERIMENTAL OUTLINE

2.1 - Experimental model

According to the requirement of vibrational similitude, three models of stiffened cylindrical shell are designed with the same numbers and position of stiffener (Marked by M1, M2 and M3). The dimensions of these models are as follow, diameter: 660 mm, 440 mm, 220 mm; length: 900 mm, 600 mm, 300 mm; wall thickness: 6 mm, 4 mm, 2 mm; and width and height of stiffener are 9 mm, 6 mm, 3 mm and 30 mm, 20 mm, 10 mm respectively.

The experimental arrangement for the test is shown in Fig. 1. The model was suspended from a crossbeam with rubber rope, and was excited by an electromagnetic exciter, which was also hung from the beam. The force was monitored by a force transducer. The vibration response of 25 points on the model was measured by lightweight accelerometers attached to small studs cemented to the surface of the model.

2.2 - Measurement

The instruments used for the measurement are also shown in Fig. 1.

In order to be able to compare effectively the vibration acceleration of models, the relative position of modal frequencies of the same order mode for three models in the corresponding frequency band should

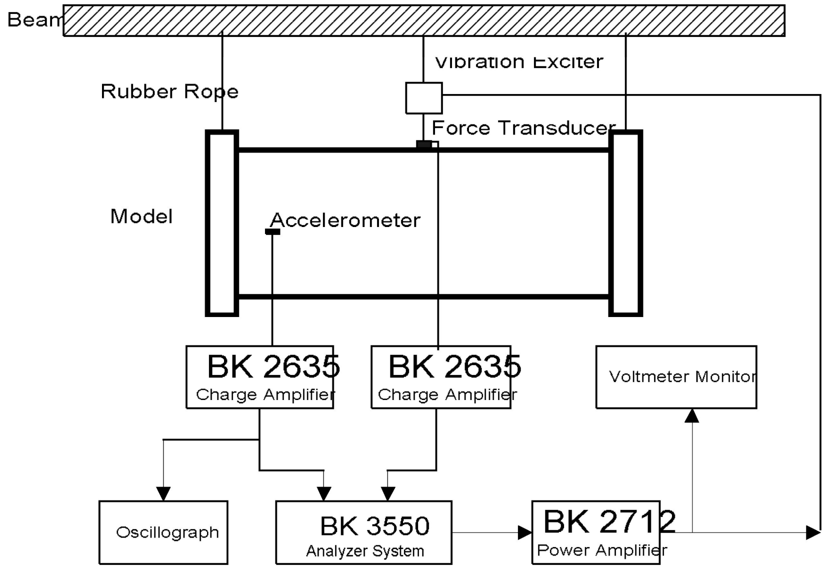

Figure 1: The experimental set-up.

be kept the same. Therefore, it is required that the octave index K used in the spectrum of vibrational acceleration satisfies:

$$2^{N/K} = \lambda_l \tag{1}$$

Where, λ_l is the scaling factor of models, N is the number of octave band, always taking integer.
Because the scaling factors between the three models are 1.5, 2 and 3, 1/12 Oct. and 1/1 Oct. spectrum are used in the spectral analysis of vibration acceleration.
The relation also should be considered in the designing of model.
According to the similarity relation of structural vibration given by the reference [1], define the dimensionless frequency Ω and the normalized acceleration A as follow:

$$\Omega = \frac{\omega l}{\sqrt{E/\rho}} \tag{2}$$

$$A = \frac{a l^3 \rho}{F} \tag{3}$$

Where, l is length of model, ρ is density, E is Young's modulus, F is the amplitude of exciting force, ω is circular frequency, a is acceleration.
So, the relation of spectrum level of acceleration and exciting force between the models is given by:

$$L_{a1} - L_{f1} = L_{a2} - L_{f2} + \Delta \tag{4}$$

Where, $\Delta = 10\lg\left(1/\lambda_l^6\right)$ is a modified term.

$$\Delta = \begin{cases} 10.6 \text{ dB} & , \ \lambda_l = 1.5 \\ 12.1 \text{ dB} & , \ \lambda_l = 2 \\ 28.67 \text{ dB} & , \ \lambda_l = 3 \end{cases}$$

The modal frequencies of the first ten modes are obtained from the narrow band linear spectrum of vibrational response. The relevant dimensionless modal frequencies of three models shown in Fig. 2 coincide with the theoretical result of the similitude, that is, the frequency-scaling factor is inversely proportional to geometric scaling factor, under the condition of geometric similarity and the same material. The maximum relative error of the same order modal frequency of different models is about 5%.
The measured spectral level (1/12 Oct. or 1/1 Oct.) of vibrational acceleration is normalized by eq. (3). Fig. 3 is the comparison of the normalized acceleration spectral level of one measuring point for M1 and M2, in which the normalized acceleration level of these models shows little difference on the whole at lower frequency range, but there is certain difference for them at higher frequency range. The spatial

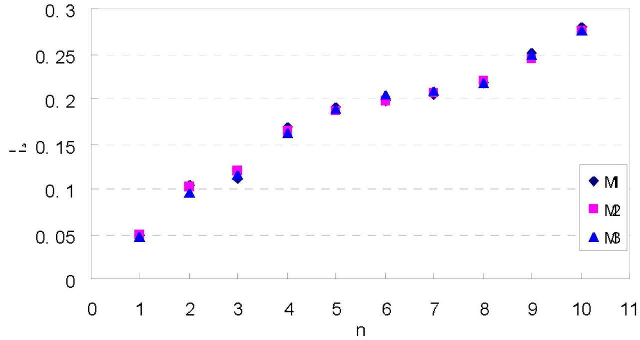

Figure 2: The comparison of dimensionless frequency.

mean value of normalized acceleration of many measuring points for M1 and M2 is compared in Fig. 4, in which the similitude relation of M1 and M2 becomes more coincident. The difference is less than 3 dB. The comparison of normalized acceleration for M2 and M3 uses 1/1 Oct. spectral level, given by Fig. 5. The degree of coincidence of normalized acceleration is obviously better than the result expressed by 1/12 Oct., and the difference is about 1 dB.

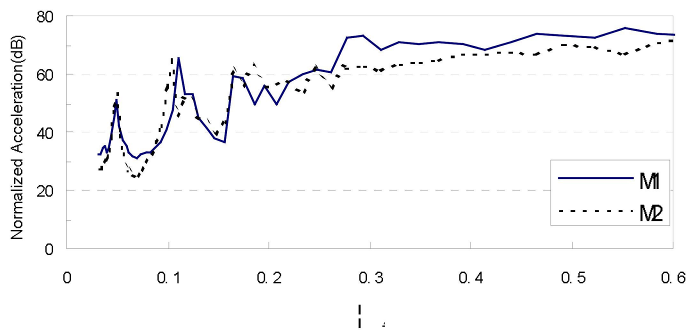

Figure 3: Comparison of the normalized acceleration for M1 and M2.

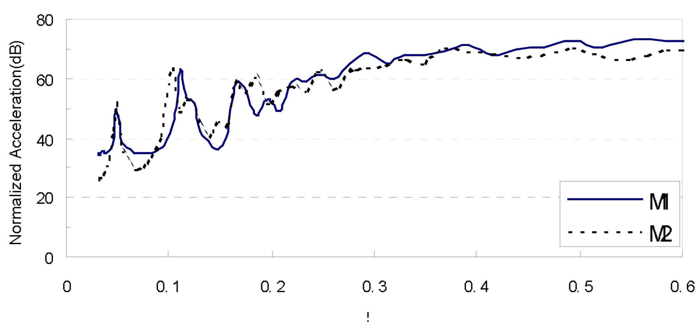

Figure 4: Comparison of the average normalized acceleration for M1 and M2.

For the total spectral level of normalized acceleration in the whole measuring frequency range, the difference between the three models is about 2 dB.
The theoretical analysis of vibration similitude for elastic structure shows that the vibration response is similar completely only when the models have the same damping factor. In fact, there may be some difference of damping factor for different models, which is caused probably by different welding technology and the length of welding seam as well as other reasons. If the normalized acceleration is modified by measured damping factor, the experimental results of vibrational similitude should be improved.
As we know, from the point of acoustic radiation, the parameter used to appraise structural vibration is not the vibration velocity of a single point, but the spatially averaged mean-square velocity. So from this we can say that there is satisfying precision of vibration similitude in the experiment.

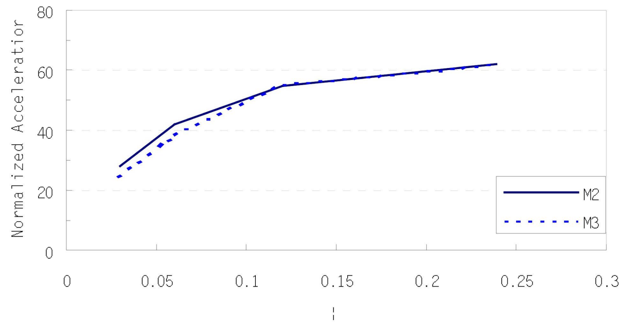

Figure 5: Comparison of the normalized acceleration for M2 and M3.

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