STUDY ON THE RADIATED NOISE OF UNDERWATER TARGET BASED ON THE TEST MODEL OF IMPACT SYSTEM

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The underwater target radiated noise of the impact system mainly includes the impact noise of the system structure and the target flow noise. In order to quantitatively analyze the energy components of underwater target radiated noise, a scale test model of underwater impact system was established.A series of experiments were carried out to obtain the time-frequency response spectrum of the impact noise of the system structure and underwater target radiation noise. In addition, by means of changing the impact time of the experimental model system and the jet flow velocity of the target, the database for the impact noise of experimental model system structure and underwater target radiation noise signal was obtained. In terms of the response signal of system impact, the effective duration, the absolute peak of the process, the effective level of duration integral, the general of duration integral, Fourier power spectrum, the transient shock response spectrum and the one-third octave energy spectrum have been established to study the variation law of mathematical models. The experimental results show that there is a linear sensitive relationship between the impact action time of the experimental model system and the energy amplitude of underwater target radiated noise, and the influence of the jet flow velocity is not obvious.The structural shock vibration noise has greater contribution to the radiated noise at high frequency, and flow noise and cavitation noise has a greater contribution on the radiation noise in low frequency.

Keywords: underwater target radiated noise,test model of impact system,impact time

1. Introduction

Mechanical noise includes mechanical shock noise, vibration noise and friction noise. Impact noise is the noise caused by the impact of acceleration or deceleration between the moving parts and the noise generated by the reaction force of acting operation material against the fixed parts; mechanical vibration noise refers to the noise generated by the vibration transmitted by other noise sources to the launch tube body and ship hull, etc.; friction noise is created by the high-speed movement and friction between the mechanical parts during the transmission process.

Fluid noise includes aerodynamic noise and seawater flow noise. The injection of high-pressure air into the cylinder or launch tube will produce a strong injection noise, and after the launching process when the gas within the cylinder is discharged into the cabin, the interaction between the gas and solid boundary in the fluid will make a strong radiation noise; seawater flow noise is the water hammer noise between flows and between flows and the surrounding solid boundary caused by the sudden acceleration or deceleration of flows in the launching process; in the launching process, both high-pressure air and seawater movement will produce turbulence noise, and it is the noise made by the fluid in the turbulent flow due to the medium vibration.

Cavitation noise is the bubble noise generated by the bubble phenomenon in which the negative pressure is lower than the local bubble pressure.The influence of the underwater target radiated noise of the impact system is becoming more and more serious, and it has become a major problem which reduces the vitality and combat effectiveness of the ship. The launch noise has very short duration but relatively large source level, which means it can make it easier for the enemy to capture the launch boat and have time to avoid and confront our attacking weapons. Therefore, the reduction of launch noise is one the major issues has to be considered and solved in the design research of launchers. Understanding the mechanism of noise generation and controlling the radiated noise are core issues for the design of launching design. The source characteristics of the launching noise of the impact system and the relevant knowledge of noise spectrum are the basis of noise control. In order to perform a mathematical explanation for the vibration and noise control, it is necessary to understand the principle of radiation noise in the process of transmission. Through the analysis of the various factors affecting the radiated noise in the transmission process, the formation mechanism of the launching noise of the impact system can be revealed.

2. The production mechanism of the radiated noise in impact system

The 3D wave equation can be deduced from continuity equation, the kinetic equation and the state equation,

$$\nabla^2 p - \frac{1}{c_0^2} \bullet \frac{\partial^2 p}{\partial t^2} = 0 \tag{1}$$

wherein ∇^2 is the Laplace operator.

The universal equation, i.e., the generalized Hill equation, with body source, force source and shear stress source can be obtained through the simultaneous continuity equation and the motion equation.

$$\frac{\partial^2 \rho}{\partial t^2} - c^2 \nabla^2 \rho = \frac{\partial q_m}{\partial t} - g_i \frac{\partial \rho}{\partial x_i} - \frac{\partial f_i}{\partial x_i} + \frac{\partial T_{ij}}{\partial x_i \partial x_j} \tag{2}$$

The first two items of Eq. (2) are non-stationary mass flows, and the function is equivalent to a monopole. The third item is the non-stationary force applied to certain interfaces and has the properties of a dipole. The fourth item represents the turbulent stress of the fluid and has the properties of a quadrupole. The Hill equation depicts the generation of sound and gives the mathematical explanation of the sound generation process from the perspective of the vocal mechanism. The underwater noise source can be further studied from the perspective of generation mechanism based on the wave equation and the Hill equation. The propagation of sound waves is one or more variations of the pressure, stress and particle movements, etc. propagated in elastic media (gas, liquid and solid). In a fluid medium, any process that causes a non-stationary pressure field may produce sound waves. The physical processes that may cause non-stationary pressure fields include the vibration or pulsation of the interface, the non-stationary forces acting on the fluid, the turbulence motion of the fluid and the temperature of the oscillation. Each noise source can be summed up as a certain order 1 multipolar sound source in microcosm, or at least can be mathematically simplified in this way. Many important sources of noise from ships, ships, torpedoes and underwater weapons are hydrodynamic and are related to the fluid movement which goes through the craft or pipelines. The hydrodynamic sources can be classified according to their main vocalization mechanism: the volume change of the monopoles, the oscillatory force of the dipole and the vibrational motion of the small objects and the free turbulence of the quadrupole.

3. Design of the test model for radiated noise of impact system

The test model for underwater target radiated noise of impact system is a reciprocating pump-type launcher, which is com-posed by a cylinder, a muffler, a water tank, a water chamber for the water tank, a water pipe, a circulating waterway of the reciprocating pump, a launch tube, a false sea cylinder and other components. The experimental process of the test model is divided into two parts. The first part is the launching phase completed by the cylinder under the high pressure of the high-pressure cylinder in a short time. And the second part was the returning stage of the water tank piston under negative pressure after the launching.

The reciprocating pump-type launching device, also known as piston-type launch device, uses gas cylinders and piston assemblies to convert the energy of the launcher into the pressure of seawater, and such energy pushes the weapon out of the pipe. The process in which high-pressure gas enters into the cylinder and push the piston to add pressure to the seawater can be considered as the energy conversion module, and the emission energy of high-pressure gas is converted in the pressure of pressurized sea water. Through the mathematical modeling of the weapon launching process, simulation calculation is carried out based on the model. By means of conducting dynamic analysis for each moving component, the physical state parameters of the cylinder, water tank and launch tube are obtained, which mainly includes the displacement of the moving components, the law of velocity change and the stress analysis of relevant parts. By doing so, the projectile pressure of the weapon in the tube and the outburst of the weapon are obtained, providing data for the analysis of the launch tube's jet flow. Feasible improvements should be made based on the characteristics of the components of the launcher to reduce the launching noise under the premise of meeting the launching requirements. When high pressure gas enters into the cylinder to drive the piston and to add pressure to the sea water in the water tank, analysis for the stress and movement of different components is carried out to study the production mechanism of the noise. The injection noise created when the high-pressure gas enters into the cylinder is one of the most important noise sources in the process of weapon launching. The pressure increases dramatically after the high-pressure gas enters the cylinder, and the pressure affects the top of the cylinder and the head of the piston. The noise created by the rapid change of such pressure is the injection noise. It is known from the air jet theory that when the fluid is ejected at high speed from the nozzle, the noise caused by the severe fluid disturbance generated by the impact of high-speed fluid and the surrounding medium is the quadrupole sound source, which can be divided into core zone, transition zone and fully extended zone. Jet air flow will lead to the structural vibration of the cylinder wall and piston structure, while pressurized sea water will also stimulate the structural vibration of the cylinder wall. If such structural vibration is passed out, relatively large noise will be produced. More importantly, when the piston components are under stress in the launching process, it will generate impact force on the hull through the fixed support from the cylinder and hydraulic cylinder to the hull, and the structural vibration of clapboard is caused. If the vibration is transmitted to the shell, relatively large radiated noise will be generated. The generation mechanism of such impulsive noise is the structural vibration caused by the impact, and the radiated noise is generated when the structural vibration is transmitted to the hull. Such problem can be solved by the response theory of mechanical vibration under the impact excitation. Traditional weapon launchers are rigidly attached to the hull without considering the impact of vibration shocks. Such impact problem can be solved by disconnecting the energy transfer path, and the main transferable impact energy can be consumed by using a damped impact isolator. The piston components move forward with inertia at certain speed in the water tank piston at the end of the launch. Relying on the design of the special hole in the water tank, the fluid can be used to realize certain buffer effect, and the buffer can be finished by using the red copper gasket together. The further optimization of buffer design can be considered to increase the buffer effect and reduce the rigid contact. Since the power mode adopted is the stress created by high-pressure gas, the generation of exhaust noise is inevitable. But further optimization of the silencer design used when high-pressure gas is discharged in the cabin can reduce the generated exhaust noise.

4. Characterization model of the radiated noise of impact system

The radiated noise of the underwater target of impact system is unstable impact noise, and the characterization models of the impact noise in unsteady state and in stable state are quite different. Using only one average mathematical model is far from enough for the characterization of impact noise. For this reason, seven characterization mathematical models have established, including the effective duration, the absolute peak of the process, the effective level of duration integral, the general of duration integral, Fourier power spectrum, the transient shock response spectrum, the one-third octave energy spectrum of the impact response signal of the radiated noise of the underwater target of impact system. The equations are as follows:

$$sp_{\max} = 20\log_{10}\left(\frac{p_{\max}}{p_0}\right) \quad (3)$$

In Eq. (3), $sp_{\max}$ is the maximum level of impact response signal; $p_{\max}$ is the absolute peak of the process; p_0 is the reference level of impact response signal.

$$t_p = (t_1 - t_2) \quad (4)$$

In Eq. (4), t_p is the effective duration of impact response signal; t_1 and t_2 are the corresponding time values when the maximum level of impact response signal is reduced by 20dB.

$$\mathrm{sp}_{\mathrm{rms}} = 10\log_{10}\frac{\frac{1}{t_p}\int_0^{t_p} P^2(t)\,dt}{p_0^2} \quad (5)$$

In Eq. (5), $\mathrm{sp}_{\mathrm{rms}}$ is the effective level of impact response signal in the duration; $p(t)$ is the time function of impact response signal.

$$\mathrm{sp}_{\mathrm{i}} = 10\log_{10}\frac{\int_0^{t_p} P^2(t)\,dt}{p_0^2} \quad (6)$$

In Eq. (6), sp_{i} is the sum of the impact response signal in the duration; $p(t)$ is the time function of impact response signal.

In above Eq. (3) ~ Eq. (6) are the characterization models of impact response signal in the time domain.

$$X(f) = \int_0^{t_p} P(t) e^{-j2\pi f t}\,dt \quad (7)$$

In Eq. (7), $X(f)$ is the Fourier spectrum of impact response signal in the duration, f is the frequency corresponding to the impact response signal.

$$A(f) = 3\left[\frac{\pi}{2}G(f) fQ\right]^{\frac{1}{2}} \quad (8)$$

In Eq. (8), $A(f)$ is the amplitude of impact response spectrum at frequency f; $G(f)$ is the acceleration spectral density at frequency f. The value of Q is generally 10.

Above Eq. (7) ~ Eq. (8) are the characterization models of impact response signal in the frequency domain. The one-third octave energy spectrum characterizes the energy spectrum of the impact response signal when it passes the equal bandwidth filter during the time period of t_p.

5. Experimental analysis of impact system

The main design parameters of underwater impact system test include the launch pressure of launch system, *X*; the discharge speed of the target, *V*; the depth of water of the simulated launch, *H*; the implementation agency type of the launch, *C*; whether there is vibration reduction measures, *I*. The typical design conditions are shown in Table 1:

Conditions	X / (MPa)	V/ (m/s)	H/(m)	I	C
1-1	m-6	n -2.4	h	no	C1
1-2	m+3	n +2.1	h	no	C1
2-1	m-2	n -0.9	h	yes	C1
2-2	m+3	n +1.2	h	yes	C1
3-1	m+3	n	1/4h	no	C2
3-2	m+3	n+0.4	h	no	C2

Table 1: System experimental conditions

In the launch process of each above-mentioned test case, the signal amplitudes in time domain of impact system radiated noise were recorded. As shown in Fig. 1, the abscissa was the time course of system launch, and the ordinate was the signal sound pressure amplitude of acquisition sensor corresponding to the time history. The sampling frequency was 32.786 kHz, and the entire launch time was about 3 seconds.

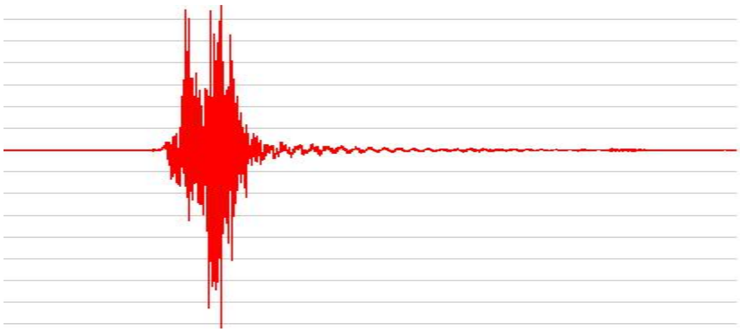

Fig. 1: Amplitude of impact response signal in time domain.

The time-domain signal of each experimental condition was obtained by the experiment, and based on the time-domain characterization mathematical model of system experimental conditions, the mathematical analysis software, MATLAB, was used to conduct programming calculation for the characterization model. By doing so, the characterization model results for system experimental conditions were obtained as shown in Table 2.

It can be seen from the test results, that the higher the launching pressure *X* of launch system, the higher the discharging speed *V* of the target, and this is the inherent parameter characteristic of the system. By comparing the time-domain characterization models of condition 1-1 with condition 1-2, it can be found that when the discharging speed *V* of the target was higher, the corresponding amplitude of time-domain characterization model was higher, but the change of amplitude was not obvious, which was only 2 ~ 3dB. Besides, the effective duration of impact response signal was smaller. By comparing the time-domain characterization results of condition 1-2 and condition 2-2, it can be seen that when vibration reduction measures were added to the implementing agency of the launch, the amplitude change of corresponding time-domain characterization model was quite obvious, which was almost 20dB. And the effective duration of impact response signal increased by 0.05s. By comparing the time-domain characterization model results of condition 3-1 and condition 3-2, it can be found that the higher the water depth *H* of simulated launch was, the smaller the amplitude of time-domain characterization model became, and the longer the effective duration of impact response signal became. Through comparing the time-domain characterization model results of condition 2-2 and condition 3-2, it can be discovered that when *C*, the implementation agency type of the launch, was different, the results of radiated noise of the underwater target of impact system were quite different.

Through the comparison of three pairs of working conditions, it could be concluded that the amplitude of time-domain model was inversely proportional to the effective duration of the impact response signal. In terms of the same type of implementation agency of the launch, in order to reduce the radiated noise amplitude of the underwater target of the impact system, it is necessary to increase the action time of impact system. Adding appropriate buffer device to the impact system is one of the effective methods.

Conditions	sp_{max}	t_p	sp_{rms}	sp_i
1-1	91.9	0.67	79.2	77.5
1-2	96.7	0.45	81.9	78.4
2-1	75.8	0.39	60.2	56.1
2-2	75.5	0.50	61.5	58.5
3-1	92.3	1.44	79.1	80.7
3-2	87.0	2.36	70.9	74.7

Table 2: Results of the time-domain characterization model in system experimental conditions

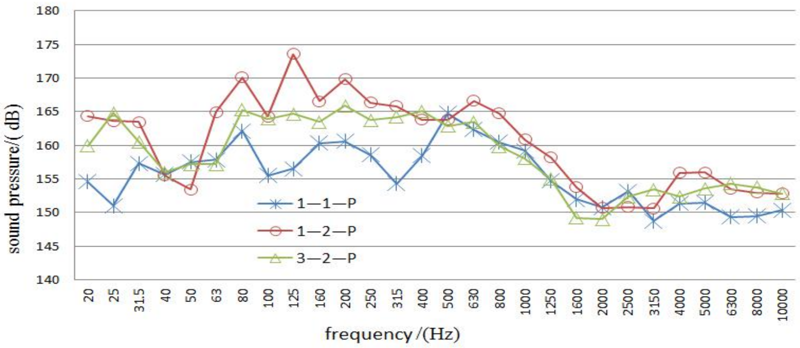

Fig. 2:Energy spectrum of radiation sound in the frequency domain

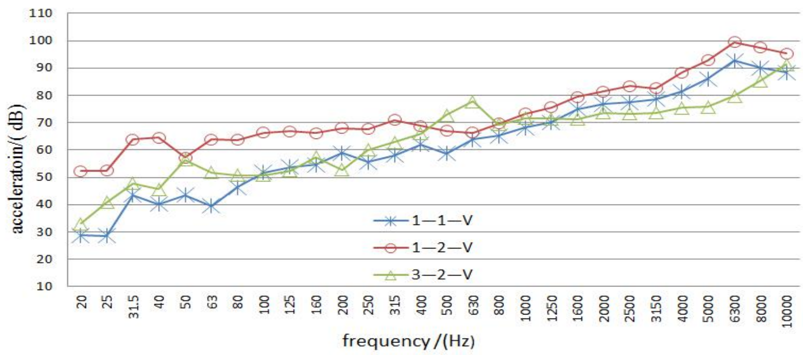

Fig. 3:Energy spectrum of structural vibration in the frequency domain

The energy spectrums of impact response signal in the frequency domain are shown in Fig. 1 and Fig.2. SPL represents to the sound pressure level of the radiation sound; VAL is the acceleration level of the structural vibration; f represents the central band value of 1/3Oct. From Figure 1 and Figure 2, it can be seen that within the whole frequency range, the variation trend of energy spectrum corresponds with the change of working conditions. High frequency dominates the acceleration level energy spectrum of structural vibration, whole low frequency dominates the sound pressure level energy spectrum of radiation water sound. The higher the launch pressure of the test working condition is, the higher the energy spectrum becomes. In Figure 1, the change of the energy spectrum of the three working conditions in the central band range higher than 500 Hz is relatively small, while the change of the energy spectrum of the three working conditions in the central band range higher than 500 Hz is relatively large. This means the shock vibration of structural impact contributes more for the radiated noise at high frequency, while flow noise and cavitation noise make greater contribution for the radiated noise at low and medium frequency.

6. Conclusions

The radiated noise of the underwater target of impact system mainly includes the impact noise of the system structure and the flow noise of target. In order to quantitatively analyze the energy components of the radiated noise of underwater target, a scale test model of underwater impact system was established, and a series of experiments were carried out to obtain the time-frequency response spectrum of the impact noise of the system structure and the radiated noise of underwater target. Besides, by changing the action time of the structural impact of the test model and the jet flow velocity of the target, the data base of structural impact noise and the radiated noise signal of underwater target of the test model were obtained. The mathematical models of the effective duration, the absolute peak of the process, the effective level of duration integral, the general of duration integral, Fourier power spectrum, the transient shock response spectrum and the one-third octave energy spectrum of the system impact response signal were established to study the variation law of mathematical models. Experimental studies have shown that:

The greater the launch pressure of the launch system, X, was, the greater discharging velocity of the target, V, became, and the larger the corresponding time-domain characterization model amplitude, but the amplitude change was not very obvious.

When vibration reduction measures were added to the implementation agency of the launch, the change of corresponding time-domain characterization model amplitude was obvious, which was almost 20dB, and the duration time of impact response signal increased 0.05s. This indicates that the buffer device has obvious effect for the absorption of energy rather than the ab-sorption of buffer time.

The larger the water depth of the simulated launch, H, was, the smaller the corresponding time-domain characterization model amplitude became, and the longer the effective duration of impact response signal. When the implementation agency type of the launch was different, the radiated noise results of the underground target of impact system were quite different.

In the frequency-domain characterization model, high frequency dominated the acceleration-level energy spectrum of the structural vibration, while low frequency dominated the sound pressure level energy spectrum of the radiated water sound. The higher the launch pressure of the test condition was, the higher the energy spectrum became. The structural impact vibration contributed more for the radiated noise at high frequency, while flow noise and cavitation noise made greater contribution for the radiated noise at low and medium frequency.

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