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Experimental study on resistance and noise reduction of low functional surfaces hydrophobic coatings

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Abstract: The objects of move in viscous fluid will accepting two kinds resistance, one kind is the friction drag that the fluid imposed on the surface of object directly , another is the pressure drag that because of separating the fluid come into being, and this drag force can create the flow noise. This article analyses the relation between physical properties of the material and flow resistance and flow noise on theoretical aspect. The conclusion is that the surface material has the effect of reducing the flow resistance and noise because of its experimental on reducing the mutual action between fluid and solid surface under certain conditions. In the test, use the gravitational low noise water tunnel test condition and adopt torpedo model, many times have the test on the drag and noise reduction of the torpedo model under diversity flow rate, have coating and not coating circumstances test. Through analysis shows that the low functional surface hydrophobic coatings used in experiment have a certain drag and noise reduction effect under high velocity, and with the increase of velocity, drag and noise reduction effect getting better and better.

Key words: flow noise; flow resistance; dewatering material; resistance and noise reduction

1 Introduction

When sailing in the water of high-speed movement ,the flow noise which speed and pressure pulsation have not big contribution to the navigation radiated noise ,but it is the main factor to decided sonar signal-to-noise ratio(SNR).The flow noise can increase the background noise of sonar, and cover up the echo signal receive where come from remote. So it is not ignoring that the flow noise and fluid resistance have effect to moving target in the water [1].

For navigation in the water, the drag reduction and noise reduction are closely linked. As reduce resistance often corresponding to the reduction of flow noise, drag reduction have a special significance [2]. Acoustics works also want to have a kind of surface function material, used to reduce the flow noise which sonar dome and towing array creating, and if for torpedo, while reducing resistance and increase the lead role in the double role of distance. At present, foreign countries scholars have come up with addition Micro-bubbles on wall surface, riblets surface, compliant coating, bionic coating, surface function coating and others to reduce the fluid resistance [3-7]. With the rapid development of material science, many new material especially a surface specificity function coating provides more choice for study of drag and noise reduction, such as super-hydrophilic /super-dewatering material, low surface function material. Experiments show that the surface function coating can reduces the friction drag, make turbulent flow transition point after turning, reduce turbulent flow, delay capitation occurred, and decrease resistance[8].

This article staring from the theory of surface coating reducing resistance and noise, use one kind of low surface hydrophilic material which preparation by Lanzhou Physics-Chemistry Institute and coated in a streamlined Rotary model, performing many times noise measurement with model have coating or not under variable velocity in gravity low noise water tunnel, and analysis the effects of the coating reducing drag and noise.

2 Theory of drag and noise reduction

There have two kinds of resistance which viscous resistance and non-viscous resistance to the objects moving in the water. The former includes the shape of drag (pressure drag) and surface friction resistance. The latter includes cavitations resistance (objects at high speed) and the wave

resistance (objects in the fluid surface). Viscous resistance play a major role to smooth movement of objects which completely submerged in water, can be described as [9]:

$$F_r = F_s + F_w = \rho_0 u_0^2 [A_s C_d(u_0) + A_w C_f(u_0)] / 2 \quad (1)$$

Where ρ_0 denotes the density of the fluid, u_0 being the flow velocity, A_s the face flow areas of object, A_w the wet areas of object, C_d the shape drag coefficient, it can be considered as constant when form-finding and in certain flow velocity(Reynolds number) range, C_f the skin friction drag coefficient, defined as:

$$C_f = 2\tau_w / \rho_0 u_0^2 \quad (2)$$

Where τ_w being the shearing stress between the fluid and objects surface.

The surface functional materials generally brushing object-surface by a thin method, when its hydrophilic or hydrophobic coating, can directly change surface friction resistance, at the same time change position of turbulence transition point, it also change the pressure drag, and change cavitations resistance with high speed moving.

The fluid resistance reduction and flow noise reduction are complementary to each other, but the reason of noises generated is more complicated. The flow noise including far-end turbulent (cavitations) noise, near-end turbulent boundary layer noise, vibration and sound production by turbulent pressure pulsation works on pressure pulsation and so on. About the noise mean square spectrum density which turbulent pressure pulsation generated can expressed by the following empirical formula:

$$\text{when } f < f_0, P_f^2 \approx 0.75 \times 10^{-5} \rho_0^2 u_0^3 h^* \quad (3)$$

$$\text{when } f > f_0, P_f^2 \approx 1.5 \times 10^{-5} \rho_0^2 u_0^6 \omega^{-3} h^{*-2} \quad (4)$$

Where f_0 being the transition frequency, h^* being the exclusion thickness. The noise energy of turbulent boundary layer is proportional to the thickness of exclusion, and not directly related to the frequency in the low-frequency region, but it inversely proportional to square of the exclusion thickness and the noise energy attenuation with the frequency's three parties in the high-frequency

region. Because of the surface coating can reduce the exclusion thickness h^* of the boundary layer, it can reduce the noise energy of turbulent boundary layer in the low-frequency region, but seemingly increase the noise energy of turbulent boundary layer in the high-frequency region, but to a certain frequency f , it also necessary joint transition frequency f_0 can be accurately judged.

3 Test measurement system

3.1 model design and sensors deployment

Model using aluminum alloys material, designed as streamlined bodies of revolution in order to reduce the shape resistance, polishing the surface anodic and oxidation treatment. Model consists of three segments, the front is the hemispherical shell of length is 56.2mm and external diameter is 82.7mm and shell thickness is 23.4mm; the middle is the circular cylinder of length is 481.0mm and external diameter is 82.7mm and wall thickness is 11.3mm; the tail is the ellipsoid of length is 158mm and hollow; connecting the three segments with threads. Figure 1 show the arrangement of three kinds of sensors which pressure hydrophones Hi, plane pressure sensors Pi and vibration accelerometer V in each part of model .The plane pressure sensor P1 was made at the center of ball head, the air cavities of thickness is 10.5mm exposed in circular cylinder where distanced ball head joint are 80mm and 200mm, the pressure hydrophone H1 located in two air cavities, the plane pressure sensor P2 located at 300mm where distance between ball head and circular cylinder , the pressure hydrophone H2 located in circular cylinder where distance between circular cylinder and taper is 100mm, the plane pressure sensor P3 located at 30mm where distance the connection with circular cylinder and taper, the vibration accelerometer pasted at 20mm in surface where distance the connection with circular cylinder and taper.

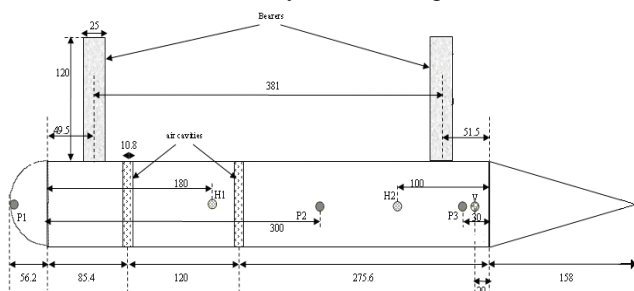


Fig1. Schematic diagrams of sensors deployed in the model

3.2 Design of air cavity in the model

We can find that there are two plastic substate air cavities of the thickness are 10.5mm placed in the model, and the hydrophone H1 put among the air cavities in the figure1. As follows are reflection coefficient β and transmission coefficient α when acoustic wave propagation in different medium:

$$\beta = I_r / I_i = (z_2 - z_1)^2 / (z_2 + z_1)^2 \quad (5)$$

$$\alpha = I_t / I_i = 4z_2z_1 / (z_2 + z_1)^2 \quad (6)$$

Because of the acoustic characteristics impedance between water and air have a great difference, $z_{water} \gg z_{air}$, $I_r \approx I_i$, $I_t \approx 0$, the reflection coefficient approximate to 1 and the transmission coefficient approximate to 0, that is air cavities played acoustic shielding role, can shields the noise which come from the head and tail of model, only the noise where come from solid angle corresponding the compartment can be receive by hydrophone [11].

The noise power spectrum received by hydrophone when no air cavities as follows:

$$P = B_{background\ noise} (no\ directivity) + P_{flow\ noise} (no\ directivity) \quad (7)$$

But the background noise need to formulae with a directional factor when have air cavities, the noise power spectrum shows as:

$$P = B_{background\ noise} \iint D(\theta, \psi) d\Omega + P_{flow\ noise} \quad (8)$$

We can find that there reduces the background noise when have air cavities.

3.3 Introduction of the testing system

The gravity low noise tunnel is take the water to head tank which height is 193.m by use pump at first, then let the water in head tank flow into working section by use the gravitation to make the noise test, the velocity of the work is depends on 5 valves' full open or full close, so the background noise of the gravity low noise tunnel is relatively small. We dipping the model to the working section which length is 1.5m and area is 400mm*400mm when star the test, the fig 2 shows that the schematic of the measurement system connection which each received signals from the model after amplification, filtering and sent to the collector. Because of the test environmental conditions and measurement methods are main factors to impact noise testing error ,the liquid level of head tank must maintained at 1.63m each measuring ,make two or three times measures separately with have or no coating on coating under different velocity when test methods consistent with test environment conditions , take the average value of repeated measuring to analyze and to reduces system random error, take contrast-analysis method to analyze the hydrophone placed at same position received the noise signals which have or not have coating on model , summarized the drag and noise reduction effect of the surface coating.

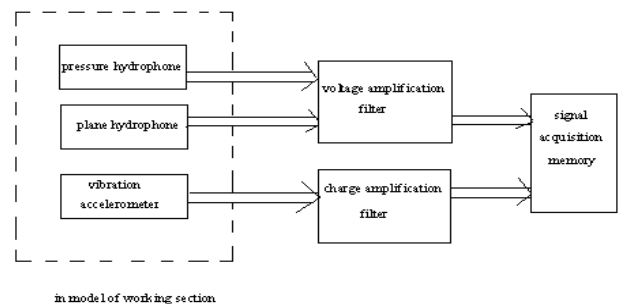


Fig.2 schematic of the measurement system connections

Table 1 Paragraph formats

4 Analysis of test result

The fig3(a),(b) and fig4(a), (b) are the power spectrum of flow noise by hydrophones H1,H2 received with have or no coating at four velocities which 10m/s,7m/s,8m/s and 6m/s. We can find that the surface coating drag and noise reduction effect gradually emerged (7m/s and above) along with the increase of velocity, and the noise frequency band also extending and widening to low frequency. Through compared the power spectral of fig3 and fig4, can find that the power spectral which H1 received is lower than H2 received, it reflects that the air cavities have the noise reduction effect.

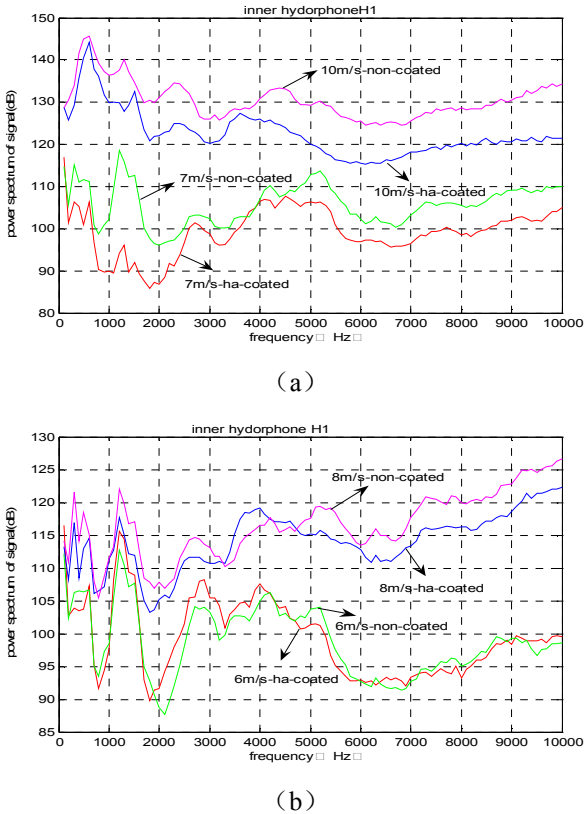
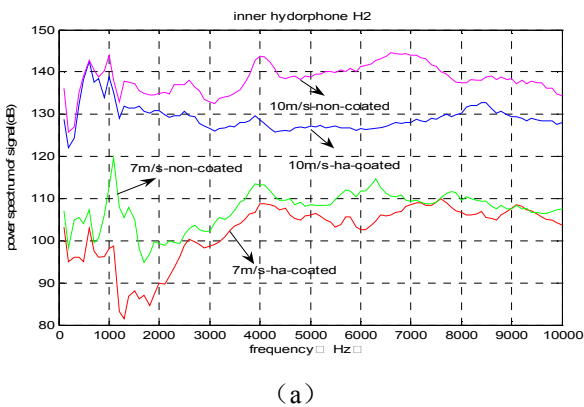


Fig.3 power spectrum of flow noise by H1 received in four different flow rates



The fig5 (a), (b) and (c) are the power spectrum of fluctuating pressure by three pressure hydrophones received with have or no coating at two velocities which 10m/s and 7m/s. We can find that low surface coating have good inhibitory effect to fluctuating pressure above the 7m/s, the inhibitory effect is better and better with increase of velocity, and the inhibitory effect is better than hydrophones H1, H2. It also shows that fluctuating pressure

where the head of model is less, the next is the middle of model, and the biggest is the tail of model where the pressure hydrophones received.

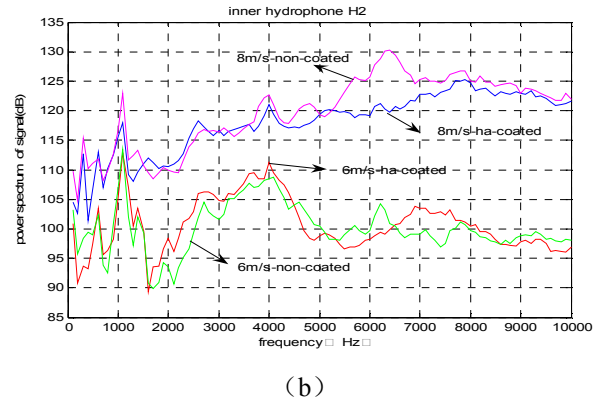


Fig.4 power spectrum of flow noise by H2 received in four different flow rates

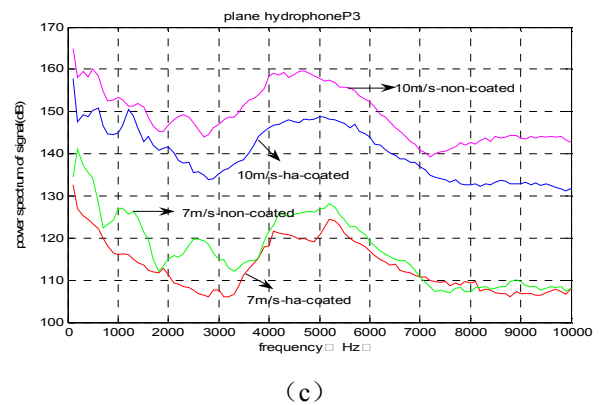
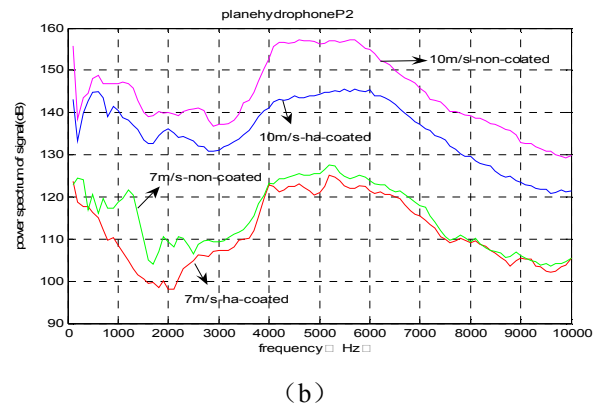
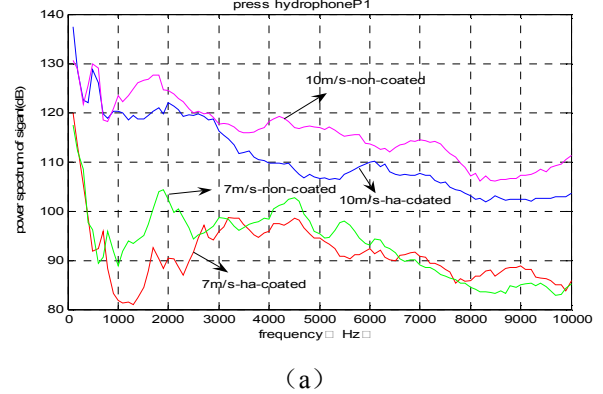


Fig.5 power spectrum by flat surface hydrophone received under high flow rate

The fig6 is the power spectrum of shell vibration by vibration accelerometer received with have or no coating at two velocities which 10m/s and 7m/s. We can find that the

low surface coating also have better inhibitory effect to shell vibration when velocity higher than 7m/s, and the inhibitory effect is better and better with velocity increases.

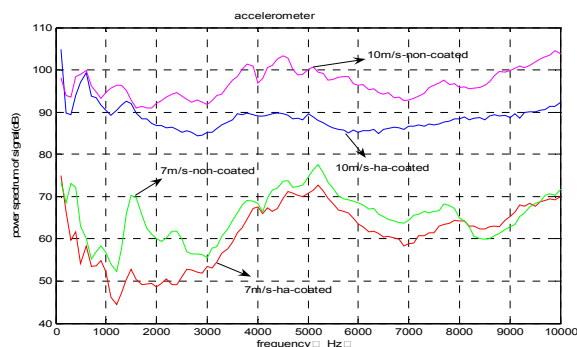


Fig.6 power spectrum by accelerometer received under high flow rate

5 Conclusion

This article concludes that the low surface hydrophobicity coating has drag and noise reduction effects at high flow rates (flow velocity higher than 7m/s), and drag and noise reduction frequency bands extending and widening to low frequencies. The drag and noise reduction effect is better and better no matter the internal hydrophone signals, turbulent pressure pulsation signals or vibration signals after contrastive analyzing some kinds of signals at different velocities under have coating or not.

On the other hand, the air cavities can decrease the background noises.

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