MEASUREMENT OF SHIP-PROPELLER-NOISE BY DESIGNING TIME DOMAIN BROADBAND SPATIAL MATRIX FILTER

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In order to solve ship propeller noise measuring and separating problem. Measuring technique for ship-propeller-noise by designing of time domain broadband spatial matrix filter (TDBSF) is provided. Main technical points of the technique include supposing ship noise as several point noise sources, using space filtering function of sonar array to design broadband frequency hydrophone array, designing time domain broadband spatial matrix filter according propeller noise measuring requirement. According to the staying time length of the propeller noise in the matrix filter pass-band, to achieve the time domain data of the propeller. To verify effectiveness of the measure technique, broadband frequency hydrophone array and matrix filter are designed. Simulation results show that the proposed measuring technique can get out propeller noise signal from ship radiating noise in condition of signal to noise(SNR) $\geq -5$dB. Totalized error of propeller noise signal separated by this method is no more than 2dB.

Keywords: matrix filter; propeller noise; Hydrophone array

1. Introduction

The propeller noise is an important component of the ship’s radiating underwater sound. How to collect the propeller noise from the regular navigation noise source of ship data, is a present ship noise measuring technological difficulty.

There are three ship propeller noise measuring means can be used. The first one is departing mechanical noise and water driving force from the ship radiated noise to obtain the propeller noise\cite{1} by the noise departing method. This mean not only need special test for the ship noise, but also need special test to gain the mechanical noise data and the water driving force noise data. It is difficult realized as the propeller noise measuring. The second mean is using the inflexible equipment to drive propeller, cutting down the ship mechanical noise effects and capturing propeller noise. Difficulty of this means is that inflexible equipment criterion is very hard fixed. The third means is using beamforming technique. It can access the spatial distribution of noise source energy, utilize the array signal processing technique, by means of designing the measuring system, realize propeller noise source locating and surveying\cite{2}. By transferring noise source data capturing difficulty of measure system to data handling technique, it can simplify the ship noise measure complexity.

Ship radiated noise can be supposed as bulk target property. As the literature\cite{3} - \cite{5}, the ship is supposed as a three shine spots noise radiation pattern. The propeller and mechanical noise sources have the obvious spatial separation degree. The ship propeller noise measuring technique by designing broadband spatial filtering technique\cite{5}, is using the spatial filtering property of the string hydrophone array and the array signal processing method to resolve the ship radiated noise source spatial departing problems. Such as the beam takes shape like focusing and the constant broadband beamforming are living in the external ship noise characteristic analysis\cite{7} \cite{6}. 
The TDBSF\cite{8} has the specified spatial noise source time domain measure data capturing capability. It may achieve surely by means of the rightful designing measure system. It can be use to get the no-distortion data for the noise source analyzing.

The original supposes the ship noise as some shines feature along ship, uses the time domain broadband matrix filter's time-spatial filtering property, designs underwater noise measure system and designs time domain broadband matrix filter for main frequency band of propeller noise, provides the measuring method for ship-propeller-noise. It can solve warship propeller noise measuring and separating problem.

2. The measuring of ship propeller noise analysis

2.1 The mainly noise source spatial separation

Under the cruising velocity condition, the ship radiated noise is main consist of mechanical noise and propeller noise\cite{9}. For the length overtake 80m ships, the spatial separation degree between propeller with the mechanical noise source may be greater than 50m when mechanicals are selected running. As figure 1, in case measure hydrophone array be living away from the ship navigation course 150m place, two kinds of main noise sources is living to hydrophone array takes shape included angle $\alpha + \beta \approx 20^\circ$, according to the theory of string array beamforming, the width of the beam is calculated by formula (1):

$$
\theta_{3dB} = 2\sin^{-1}\left(0.44 \frac{\lambda}{2d}\right)
$$

For the 20 elements string array of clearance 4m, beam-width of 150Hz frequency signal correspondence - 3dB's is 3.2°, beam-width of 2000Hz frequency signal correspondence - 3dB's is 0.23°. It is incomparably smaller than two main noise source spatial angles. So by the designing spatial matrix filter can realize different noise sources departing.

2.2 Feasible quality of propeller steady-state noise data acquisition

When the ship is cruising, in order to obtain the specified period sampling steady sampling data of propeller noise, the measure system must have properties of steady tracking propeller noise
source and not effecting by the propeller noise spatial directivity. Just as Fig.2, the ship goes forward with 10m/s velocity, steadies sampling period is 3s. It is necessary to design the measure system with spatial filter capability of $\theta \geq 12^\circ$. According to the TDBSF designing theory for string array, the 20 elements unit clearance string array can be designed as one octave broadband filtering, and the spatial-filter-width is $\theta \geq 12^\circ$. So, it is possible to obtain the steady propeller noise data of specified sampling period by designing a clearance varies string array.

![Designing example](image)

### 3. Designing example

#### 3.1 Measuring system design

As section 2.2, suppose that the several ship noise sources are separated away from each other at 50m length, the fathom of the design string array system and the ship survey navigation is 150m. Measuring system designed for each octave bandwidth is one 20 elements uniform string array. It's designing pass-band is $12^\circ$ spatial room in array normal direction. It's stopband is outside of the $18^\circ$ spatial room in array normal direction. The total frequency-band designed of measuring system is 150Hz~4kHz.

On the basis of the TDBSF designed capacity, when the array elements selected clearance equal to 1/2 wavelength, the child measuring system array can achieve TDBSF for the homologous frequency and upwards octave. According to the octave relationship decomposition in the interest of 150Hz~4kHz, it can be decomposed 144Hz~286Hz, 286Hz~608Hz, 608Hz~1256Hz, 1256Hz~2080Hz, 2144Hz~4096Hz as five child frequency bands. The correspondence design to meet distinct child frequency band measuring array. As fig3, the designing measuring system total length is 76m and the number of elements is 60. These 60 elements can be formed five child system array by unit clearance as 4m, 2m, 1m, 0.5m and 0.25m.

![Designing of Hydrophone array for five frequency band signal processing](image)

#### 3.2 TDBSF designing

For example, according to the method of TDBSF designing in reference[8], TDBSF for the child measuring system array of clearance 0.5m is designed. The design filter working frequency band is
1256Hz~2080Hz. As fig 4~fig 5 showing, the TDBSF is designed can realize the passband 12° and stopband outside 18° designing requirement. It's passband ripple degree is no more than 0.3dB and stopband attenuation is no less than 10dB.

3.3 Example of propeller noise measurement

In order to really simulate validity of the measuring system which proposed in this paper for the surveing ship. As section 2.1 descripting spatial relationship of measure system and ship, the included angle between ship mechanical noise source and propeller noise source is more than 20°. The steady sampling period of propeller noise is that the ship propeller surving in the -6°~6° of the measuring system array normal direction. The propeller noise source is simulated as a frequency band from 1200Hz to 2000Hz attune signal, which time series show in fig6. The mechanical noise source is simulated as a frequency band from 1200Hz to 2000Hz random noise, which time series show in fig7. The signal to noise ratio is installated as 0dB. The include angle between mechanical noise source and propeller noise source is 20°. As fig.8 showing, at the original time series recieved by the 2# hydrophone, it is impossible to distinguish out mechanical noise source and propeller noise source. As fig.9 showing, the time series exported TDBSF's 2# hydrophone have the better compatibility of the propeller noise original signal.

In order to validate spatial passband availability of the measuring system, we definite the distortion degree of the passband by formula (2).

\[
\text{Dis} = 20 \log_{10}\left(\frac{\text{signal1} - \text{signal2}}{\text{signal1}}\right)
\]  

(2)

As shown in fig.10, orignal signal at diferent azimuth, filtered time series for 2# hydrophone distortion is less than 1.1dB. Moreover, fig.11 is showing the passband distortion for different SNR from -5dB to 5dB. The conclusion is that measure system proposed in this paper is applicable to be used for the propeller noise measuring in case of SNR> -5dB, and the passband distortion is no more than 2dB.
4. Conclusion

1) when the measuring system array total length is 76m and the number of elements is 60. It can be used to measure frequency band from 150Hz ~ 4000Hz ship-propeller-noise.

2) The designed measuring system's passband ripple degree is no more than 0.3dB and stopband attenuation is no less than 10dB.

3) the Measuring system proposed in this paper is applicable to be used for the propeller noise measuring in case of SNR> -5dB, and the passband distortion is no more than 2dB.

REFERENCES


