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Development of Seakeeping Test and Data Processing System

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ABSTRACT:
A seakeeping test and data processing system is developed for towing tanks. This system includes two main procedures: wave-generating and data processing. In the wave-generating procedure, the linear filtering method is used to generate irregular waveswith the full consideration of the actual efficiency of the machine and the compensation for the actual stroke of piston. Furthermore, groups of piston motion data meeting the requirements of target spectrum are afforded. To ensure the normal operation of a wave machine, the above data within the range of the rated strokes of piston should be chosen. In the data processing procedure, the correlation function method is used to handle the time domain signals which contain irregular waves, ship swaying motion, hull stress and so on. Then the spectrum curve of these test data can be drawn and some statistical values can be obtained based on the narrow-band spectrum theory. According to these statistical values, the frequency response function can be derived, and the predicted value of ship motion in irregular waves can be calculated. By comparing the predicted and experimental results, the reliability of this system can be evaluated. On the basis of the movement of a boat in irregular waves and a series of dynamic responding experiments, this paper proves that thedeveloped system has many advantages, such as succinctness, completeness, accurate data process, reliability, accurate simulation from actual spectrum to target spectrum and so on.

KEY WORD *: Wave generator; irregular wave; seakeeping test; software*

I. INTRODUCTION

Wave loadsare the main external loads of ship and ocean structure, which directly affects their sailing, performance and operation in the sea. At present, we mainly predict ship and ocean structure's seakeeping performance in real ocean waves through experiment[1, 2]. In the laboratory, waves can be divided into regular, irregular and short-crested wave [3]. Irregular wave test of ship and marine structures mainly includes the following contents: the simulation of irregular waves; the movement of marine structures on wave; collection and analysis of test data. At present, the regular wave linear superposition and energy halving of ocean wave spectrum method are mainly adopted to simulate two-dimensional irregular waves. Luo Chao-lin and He Qi-lian have designed a set of multi-directional irregular wave generator system using the regular wave linear superposition[4]. Using the method of equal energy, Jiang Man-song has developed an AC servo 16 cells rocker-flap wave making system [5]. The analytical methods of test data include spectrum analysis [6, 7] and statistical analysis [8].In this paper, we develop a seakeeping test and data processing system combining the modern sensor technology, data acquisition technology, and computer technology, which adopts the linear filtering method and spectrum analysis to produce two-dimensional irregular waves and deal with the experimental data.

Simulation of two-dimensional irregular waves

The basic principles of using linear filtering method to generate two dimensional irregular waves are expressed in this section. In order to generate wave signals meeting the requirements, we make a white noise with

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normal distribution to get through a designed filter according to the given target spectrum in advance. Then we could simulate any number of irregular wave signals meeting the requirements of target spectrum on the computer, which can control the movement of the wave machine and without periodically repeating two-dimensional irregular waves [9]. For a fixed point, the wave high ηchanging with time can be expressed as:

$$\eta(t_i) = \sum_{i=1}^{\infty} a_i \cos(\omega_i t_i + \varepsilon_i) \tag{1-1}$$

where $a_i$representsthe wave amplitude of the ith component wave; $\omega_i$represents the circular frequency of the ith component wave; t_i represents the time; $\varepsilon_i$represents initial phase of ith component wave, which is uniformly distributed random numbers within$(0\sim2\pi)$. Changing the equation (1-1) in discrete form with equal time interval, we obtain

$$\eta(n\Delta t) = \sum_{i=1}^{L} a_i \cos(\widehat{\omega_i} n\Delta t + \varepsilon_i) \tag{1-2}$$

whereΔtrepresents the time interval; $n = 1,2,3,4,5,6,\cdots,N$, $N$is the wave signal points determined by the duration of wave, Lrepresentsthe number of component waves within spectrum scope; $\widehat{\omega_i}$ represents the frequency in the frequency increment. To prevent cyclical repeat of two-dimensional irregular wave signal, its value can be calculated by the following equation.

$$\widehat{\omega_i} = \omega_{i-1} + q\Delta\omega \tag{1-3}$$

where$q$is arandom number within $0\sim1$; $\Delta\omega$ stands for the frequency increment,which is constant when using the frequency to divide the whole spectrum range.According to the theory of waves, the amplitude of irregular wave and wave spectrum has the following relationship:

$$a_i = \sqrt[2]{2S(\widehat{\omega_i})\Delta\omega} \tag{1-4}$$

where$\widehat{\omega_i}$=$(\omega_{i-1} + \omega_i)/2$.

According to the Eq. (1-2) and the transfer function of wave machine $M(\omega)$, the irregular wave signals $e(n\Delta t)$ can be expressed as:

$$e(n\Delta t) = \sum_{i=1}^{L} \frac{\sqrt[2]{2S(\widehat{\omega_i})\Delta\omega}}{M(\omega_i)} \cos(\widehat{\omega_i} n\Delta t + \varepsilon_i) \tag{1-5}$$

where

$$M = -0.00002\lambda^3 + 0.0022\lambda^2 - 0.0841\lambda + 1.0427 \tag{1-6}$$

whereλrepresents the wave length. This transfer function is obtained by the way of experiment. For different wave tanks, their transfer functionsare not the same.

The main advantages of this method is that we can fully consider the actual efficiency of wave machine, and can make some compensation for the actual stroke of electric cylinder, which will generate the actual irregular waves signal meeting the requirements of the target spectrum.

II. PROCESSING METHOD OF TEST DATA

2.1.The time domain processing method

The time domain analysis is the most basic method to process the test date of the seakeeping experiment. It not only reflects the essence of the problem, but also verifies the frequency domain analysis of seakeeping test. Through the experimental data collected from various channels, this system visually displaysthe spectrums of irregular waves, ship swaying motion and hull stress in the time domain. In addition, sincethe test data collected by one experiment is insufficient, this system provides a function to link test data from experiments with same condition. To exclude the interference of high frequency concussion signal, the system also provides high frequency filtering and smoothing function. Moreover, this system provides some auxiliary function to eliminate the unrepresentative data.

According to the time domain curves and the test data, we can examine the test results and obtain the various statistics results of irregular waves, the ship swaying motions and the hull stresses.

2.2.The Frequency processing method

Using the correlation function, we can convert the time domain data collected by sensors into oscillation spectrum curve in frequency domain and displays this curve on the screen.According to the theory of narrow band spectrum, the statistics value and the amplitude response function of amplitude can be calculated. The basic theory of correlation function can be expressed as follows:

Considering the test data collected by sensors with equal time intervals as a sample, the correlation function$R(\tau)$can be solved through the following formula [10]:

$$R(\tau) = \frac{1}{N_0 - \nu} \sum_{n=0}^{N_0-\nu} \xi(t_n) \cdot \xi(t_n + \tau) \tag{2-1}$$

where$\tau = \nu\Delta t, \nu = 0, 1, 2, \cdots, m; N_0, m, \Delta t$ represents respectively the simple size, maximum slip multiplied and sampling interval. $\xi(t_n)$is the experimental data at time sequence of n . Since the covariance function is an even function, one-sided spectrum of the volatility process can be obtained by the numerical integration of the following formula.

$$S'(\omega) = \frac{2}{\pi} \int_0^{\infty} R(\tau) \cos(\omega\tau) d\tau \tag{2-2}$$

There is obvious vibrating of the spectrum curve obtained directly from the above method. The spectral values are not very accurate. Therefore, to improve the accuracy, in this system, we uses the Hamming method to fair this spectrum curve, which means we multiplies the correlationfunction by a weighting function$D(\tau)$.

$$D(\tau) = \begin{cases} 0.54 + 0.46\cos\frac{\pi\tau}{T_m}, & |\tau| \le T_m \\ 0, & |\tau| > T_m \end{cases} \tag{2-3}$$

where$T_m = m\Delta t$.

III. SEAKEEPING EXPERIMENT

3.1.Main parameters

The main parameters of the real ship and model are shown in table 3-1.

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Main dimension	Symbol	Unit	Model	Real ship
Overall Length	L_{oa}	m	3.000	60
Waterline length	L_{wl}	m	2.844	56.888
Breadth	B	m	0.420	8.4
Draft	T	m	0.102	2.046
Drainage volume	Δ	t	0.0489	400
Wet area	S	m^2	1.085	434
Scale	λ	20		

3.2. Spectrum of experiment

In this experiment, we select the limited wind area spectrum which was recommended by the 15Th international towing tank conference (ITTC) as the given target spectrum. Its expression can be written as.

$$S(\omega) = 0.658 S_\xi(\omega) 3.3^{\exp\left[-\left(\frac{206\omega T_1 - 1}{\sqrt[2]{\sigma}}\right)^2\right]} \tag{3-1}$$

where$S_\xi(\omega)$represent the wave spectrum of 12thITTC, $\sigma = 0.07$, when $\omega \le 4.85/T_1$,
$\sigma = 0.09$, when $\omega > 4.85/T_1$.

Before the experiment we need to verify the accuracy of the waves generated by our wave machine. As shown in 3.1, the blue and red curves represent the target spectrum and generated spectrum obtained from our wave machine respectively.Fig 3.1shows that the generated wave fully satisfy the experimental requirements.

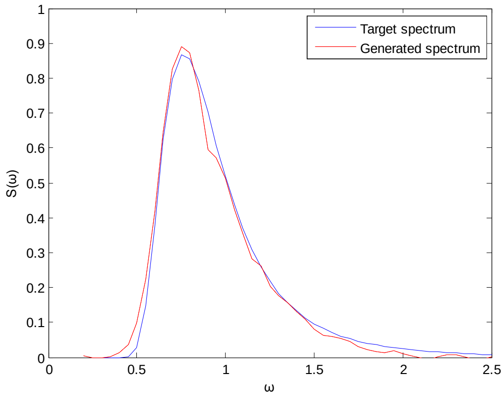


Figure3.1. Target spectrum v. s. Generated spectrum

3.3. Data processing

In this experiment, the speed of model is $2.0\ m/s$, which is corresponding to $18Kn$ of the real ship.The classification of wave is IV, the significant wave heigh$H_1 = 1.85m$, characteristic period $T_1 = 6.34$s. Besides in this experiment, we mainly collect the data ofheaving and acceleration and adopt two ways the time domain processing and frequency processing method to deal with the data. Fig 3.2 shows the heaving curve of model in time domain, and its spectrum curve frequency is shown in Fig 3.3.

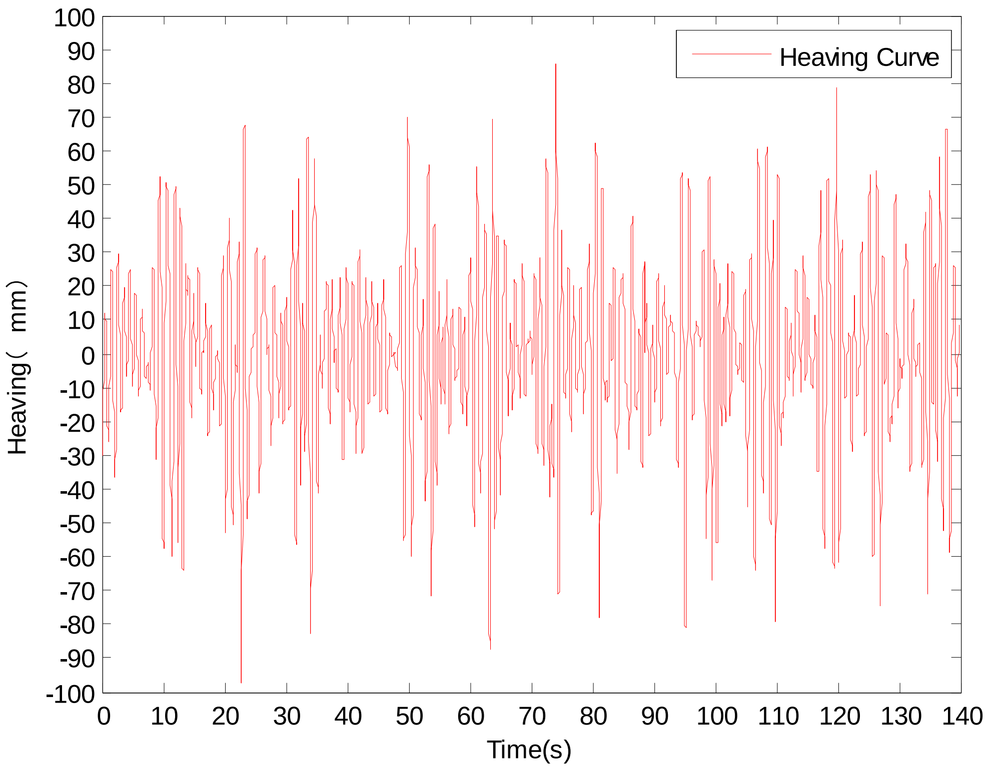
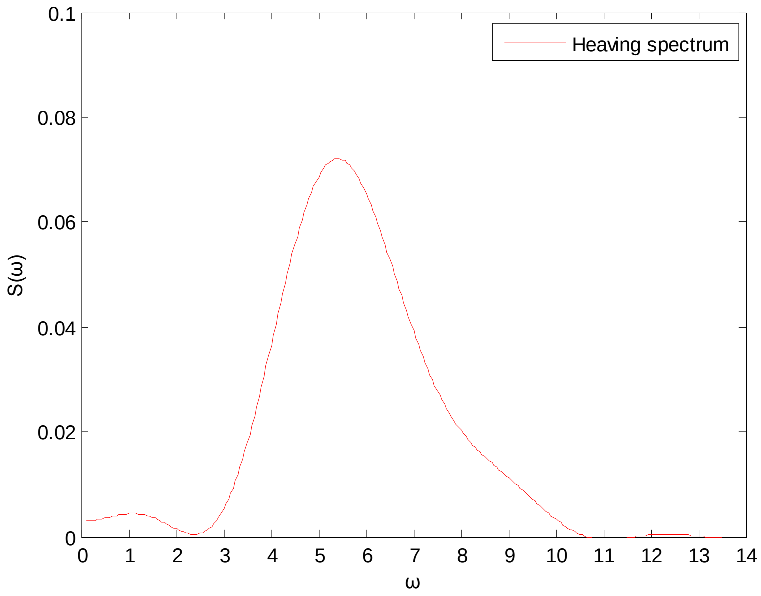


Figure3.3. The heaving curve of model in time domain



Fgiure3.3 The spectrum curve of model

The acceleration curves of model in time domain and its spectrum curve are shown in Fig 3.4 and Fig3.5 respectively.

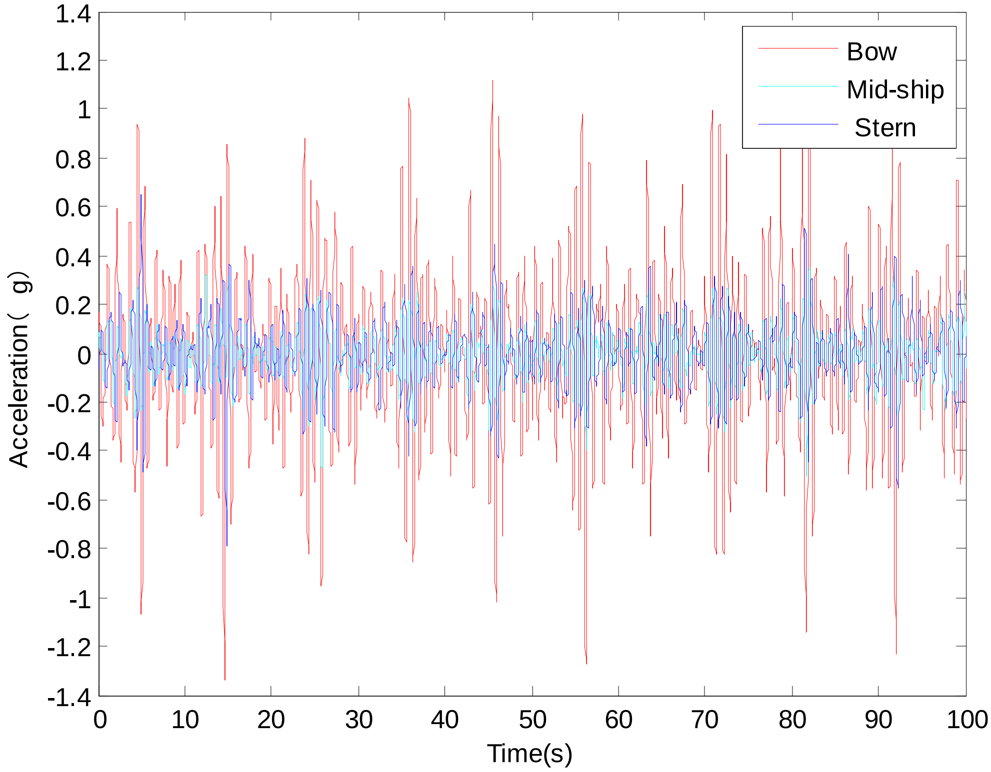


Figure3.4. The acceleration curve of model

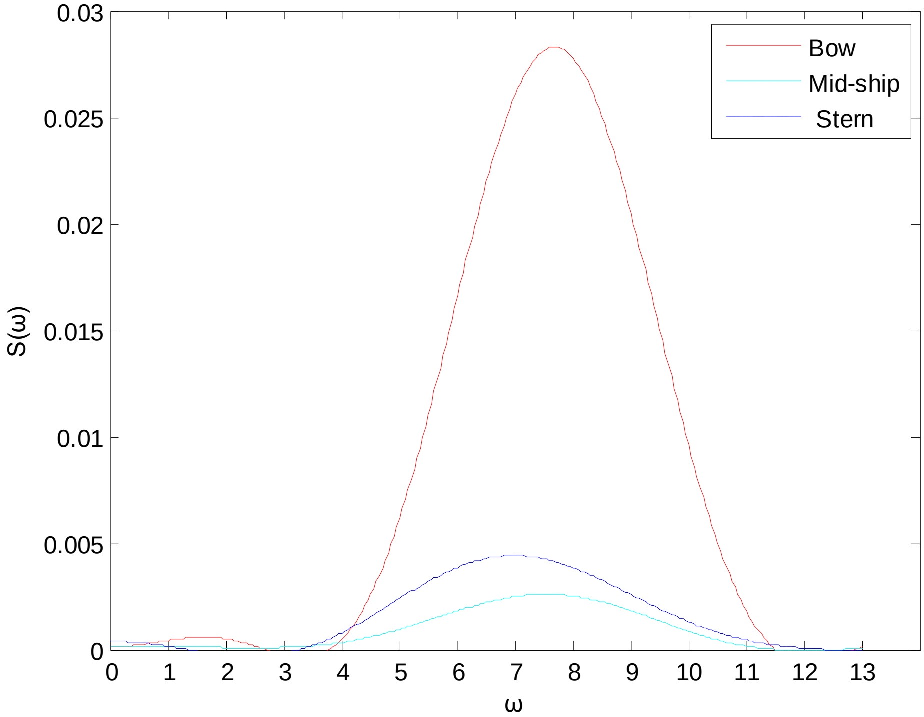


Figure3.5 The spectrum curve of modle

In figure 3.4 and 3.5, the red, yellow and blue curves respectively represents the acceleration of model on the bow, mid-ship and stern.

3.4. Experimental result

Before the irregular wave experiment, we have carried out the regular wave experiment of model. Basis on the data of the regular wave test, we forecasted the irregular wave result. In table 3-2, the forecast value and experimental value are shown.

Table 3-2 .Forecast value and Irregular experimental value

Forecast project		Significant shaking value			
		Heaving(*m*)	Acceleration		
			Bow (g)	Mid-ship(g)	Stern(g)
18*kn*	Irregular experimental value	0.796	0.552	0.170	0.233
	forecast values of regular wave	0.764	0.507	0.155	0.250

IV. CONCLUSION

Fromtable 3-2, theforecast value is very close to the irregular experimental value, whichindicates that it is reasonable to adopt these basic method and principle, and this system can be used for our wave machine.In addition, this system can also produce some commonly used spectrum in the seakeeping test, such as12th ITTC standard spectrum, north Atlantic spectrum, JONSWAP spectrum, China ocean wave spectrum. Because the system provides 16 data channels, we can visually select the data processing channels to set the minimum and maximum coordinate value for each channel.

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