Study on numerical calculation method for hydrodynamic parameters of WEC

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Abstract: For the effect of hydrodynamic parameters on the dynamic performance of wave energy devices is very significant, these parameters must be considered carefully when adjusting dynamic characteristics of devices. On the other hand calculating hydrodynamic parameter of devices accurately can guarantee rational dynamic property parameter adjustment. By using CFD technique and considering the definition of hydrodynamic parameters, the phase relationship between added mass and damp as well as the equation of forces, one new calculation method of hydrodynamic parameter was presented. Finally one example demonstrated the effectiveness of the new analysis method presented in this paper.

Keyword: wave energy extraction, hydrodynamic parameters, CFD, resonance dynamic characteristics

1 Introduction

Wave engine covert (WEC) is one of the main methods to harvest wave engine, which belongs to hot issue of using wave engine at present. Existing experiment result and theory indicates that the efficiency of WEC is the highest when WEC is in resonance with the wave. Therefore using the resonance method is one high-efficiency way to convert the wave engine. The effect of hydrodynamic parameters on the dynamic performance of wave energy devices is very significant, and it is important to calculate the hydrodynamic parameters of WEC accurately. Hence, to work out a new method to calculate hydrodynamic is necessary, not only for WEC, but also for the ocean construction and ship.

If the shape of the construction is simple and regular, such as sphere, cylinder etc, the hydrodynamic parameters is easy to be solved by the analysis equation. However if the shape of the construction is complete, it is hard to get the hydrodynamic parameters. Therefore, many calculating methods for the hydrodynamic parameters are put forward at home and aboard. Slice theory as well as the slender body theory has been developed based on the potential flow theory, which is appropriate for the hydrodynamic parameters of the ship whose shape is simple. However, the results of these methods need to be modified by the empirical equation gotten from experiment, and the veracity is weak. Another kind of method is Green function method, which belongs to Hess-Smith method. This method supposes the source density of every element is constant, so that velocity potential can be calculated using source sink and doublet distribution on wet surface. This method is more accurate than the slender body theory, but it is hard to calculate the growth characteristics, high frequency oscillation and singularity accurately. According to the correlational research of ISSC and ITTC, it is found that results of different program based on the same theory are inconsistent.

With the development of the computer technology, computational fluid mechanics is more and more mature. Because of the advantages such as the low computational expense and comprehensive analysis factor, the method based on CFD theory has become one of the most important methods to study the hydrodynamic parameters. More and more methods to calculate hydrodynamic parameters are put forward.

The shape of the WEC proposed by ref.[5] is complete. Hydrodynamic parameters have an effect on adjusting the dynamic characteristics of the device. In order to ensure that the device keeps the resonant mode, it is important to calculate the hydrodynamic parameters of the device accurately. Therefore, according to the definition of the hydrodynamic parameters, this paper put forward a computing method based on CFD. The ideal of this method is: Firstly, a numerical wave tank and couple modal of device and water is built. Secondly, the resultant force on the device is calculated at every time step while the device is on forced harmonic vibration. Finally, the hydrodynamic parameters are gotten by decomposing the resultant force. The resultant force includes added mass and add damping dynamic pressure, inertia force, hydrostatic restoring force and so on. Add damping could be decomposed from dynamic pressure by using triangular decomposition. Then, based on the equilibrium equation, the dynamic pressure caused by added mass could be separated from remain pressure. Hydrodynamic parameters are calculated by separated pressure.

2 Method

Floating body radiates wave in the process of movement, the wave induces a pressure field in fluid domain. According to the potential flow theory, a part of the dynamic pressure field has the same phase as the acceleration of floating body. Meanwhile another part has the same phase as the velocity acceleration of floating body. The dynamic resultant force can be gotten by dynamic pressure integration on the wet surface of floating body. the resultant force is:

$$M_{ij}\frac{\mathrm{d}^2\eta}{\mathrm{d}t^2}+C_{ij}\frac{\mathrm{d}\eta}{\mathrm{d}t}=\iint_S \boldsymbol{p}_d\boldsymbol{n}\mathrm{d}s \tag{1}$$

$$M_{ij}\frac{\mathrm{d}^2\eta}{\mathrm{d}t^2}+C_{ij}\frac{\mathrm{d}\eta}{\mathrm{d}t}=\iint_S \boldsymbol{p}_d(\boldsymbol{r}\times\boldsymbol{n})\mathrm{d}s \tag{2}$$

The pressure filed caused by the floating body can be divided into two part, one has the same phase with the acceleration of floating body, another has the same phase with the velocity acceleration of floating body like this:

$$M_{ij}\frac{\mathrm{d}^2\eta}{\mathrm{d}t^2}=\iint_S \boldsymbol{p}_{\mathrm{dm}}\boldsymbol{n}\mathrm{d}s \tag{3}$$

$$C_{ij}\frac{\mathrm{d}\eta}{\mathrm{d}t}=\iint_S \boldsymbol{p}_{\mathrm{dc}}\boldsymbol{n}\mathrm{d}s \tag{4}$$

Added mass and added dumping are defined by equation (3) and equation (4). Where, M_{ij} is added mass. C_{ij} is added dumping, η is displacement of floating body, t is time, $\boldsymbol{p}_d$ is dynamic pressure caused by floating body, S is the wet surface of the floating body.

Added mass and added dumping are related to the floating body shape, when the floating body shape is complete, it is hard to get the hydrodynamic parameters by analysis equation. Otherwise, the hydrodynamic parameters are functions of frequency. Equation (3) and function(4) is interesting, they are the product of the frequency domain function and time domain function. if $m_{ij}(t)$ is the time domain function of added mass, then the dynamic pressure induced by added dumping can be calculated in the same way:

$$M_{ij}(\omega)\frac{\mathrm{d}^2\eta}{\mathrm{d}t^2}=m_{ij}(t)*\frac{\mathrm{d}^2\eta}{\mathrm{d}t^2} \tag{5}$$

From the above function, it can be found that the radiation pressure caused by floating body movement appears as the convolution type. Hence, it is hard to calculate the hydrodynamic parameters by equation (3) and equation (4).

When the floating body moves in a harmonic motion, its displacement is a harmonic function, which shows as a δ function in frequency domain. As a result, the convolution is a harmonic function in time domain, and the corresponding added mass and added dumping is the value under the harmonic movement frequency. if the accelerate of the floating body is as follows:

$$\frac{\mathrm{d}^2\eta}{\mathrm{d}t^2}=A_m\sin(\omega t) \tag{6}$$

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$$\mathrm{F}^{-1}(M_{ij}(\omega)\cdot A_m\pi/2(\delta(\lambda+\omega)-\delta(\lambda-\omega)\boldsymbol{i})=M_{ij,\omega}A_m\sin(\omega t) \quad (7)$$

where $m_{i,j}$ is added mass with the frequency being ω,the added dumping can be calculated in the same way.

According to the equation(7),when the floating body moves as a constant frequency, the added mass and added dumping could be calculated by the steady hydrodynamic pressure or moment on the wet surface of the floating body. Because hydrodynamic pressure induced by the added mass and the added dumping has the same phases with the accelerate and the velocity of the floating body, the phases difference between the hydrodynamic pressure induced by the added mass and the added dumping is π/2.

Without incident wave, floating body is forced to move in a harmonic motion η_j, the equilibrium equation on the floating body is as follows:

$$F_i=-M_{ij,\omega}\frac{\mathrm{d}^2\eta}{\mathrm{d}t^2}-C_{ij,\omega}\frac{\mathrm{d}\eta}{\mathrm{d}t}+f_i \quad (8)$$

Where, F_i is the resultant force on the floating body, f_i is the statics force on the floating body at this direction, including restoring force or moment on the floating body and the force(moment) of gravity at this direction.

$$f_i=K_\mathrm{w}\eta_j+G_\mathrm{i} \quad (9)$$

Known from equation (8), the resultant force on the floating body is the sum of the radiation pressure caused by the added mass and the added dumping as well as the statics force. In practice, it is easy to calculate the resultant on the floating body, but it is hard to calculate the pressure separately, thus the added mass and the added dumping can not be calculated by the resultant force directly.

The displacement of the floating body can be taken as a harmonic function as follows:

$$\eta_i=A_i\sin(\omega t+\varphi) \quad (10)$$

Substitute equation (10) into equation (8), then

$$F_i=\left(-M_{ij,\omega}\omega^2+K_i\right)A_i\sin(\omega t+\varphi)-\omega C_{ij,\omega}A_i\cos(\omega t+\varphi) \quad (11)$$

Known from the above equation, the resultant force can be divided into two parts, of which the phase difference is π/2. So by taking the time of equation(10) as a standard, based on equation(11), the resultant force can be divided into two part by using triangular decomposition. And noticed that the second part is the force induced by added dumping, then, the added dumping of float body can be calculated by the equation (4).

The first part of equation (11) also can be divided into two parts: restoring force and the force caused by the added mass. For restoring force can be calculated directly by the shape of floating body, the force induced by the added mass can be calculated after substituting the restoring stiffness into equation (11), then added mass with the frequency being ω can be calculated.

Based on CFD, the couple model of floating body and fluid field should be built, the floating body is forced to move as a harmonic motion, and the resultant force on the floating body is calculated at every time step. Then the hydrodynamic parameters of the floating body can be calculated by the method proposed in this paper. Because the water viscidity can be considered in CFD, the degree of accuracy is higher.

3 Example

Based on the software FLUENT, a circular wave tank is established for the incident wave is not needed. The boundary of the tank should meet the Sommerfeld radiation condition, thus the source term wave absorbing method is employed. Wave absorbing field is near the boundary and the wave energy covert is at the center of the tank. The field around the device is dynamic grid field. The radius of the tank is 2.5 times of the wave length induced by the device. The height of the tank is equal to the wave length induced by the device. The field above the device model is full of air, and the field under the device is full of water. The free surface is traced by the method of VOF, and control functions are solved by RANS.

The wave energy convert shape of reference 5 is shown in fig 2. The upper part of the device is cylindricality, of which the diameter is 3.5m, with the height of the device being 3.3m. Because the device has two disymmetric faces, surging, heaving and pitching mode of the device is not coupled with the swaying, rolling and yawing mode . And for the

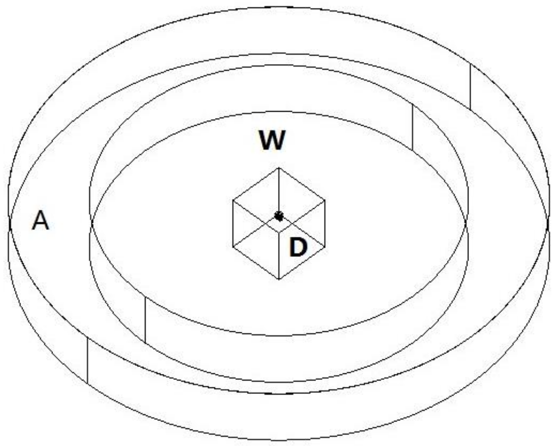


Figure 1. Numerical flume model

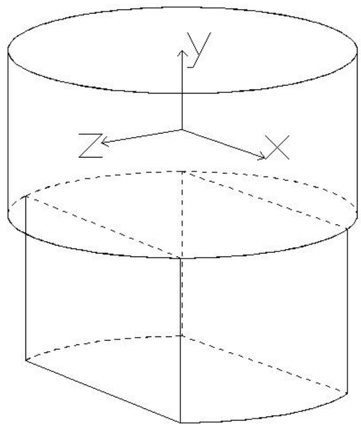


Figure 2. Device outside diagram

device harvesting the wave energy is mainly through heaving and pitching direction, the hydrodynamic parameters of the device at the direction of surging, heaving and pitching are concerned. On account of the relationship of heaving and pitch, this paper only calculates the hydrodynamic parameters of the device at the direction of surging and heaving.

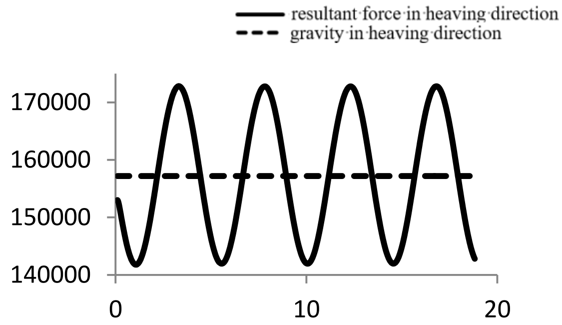


Figure 3. Force on the heaving direction

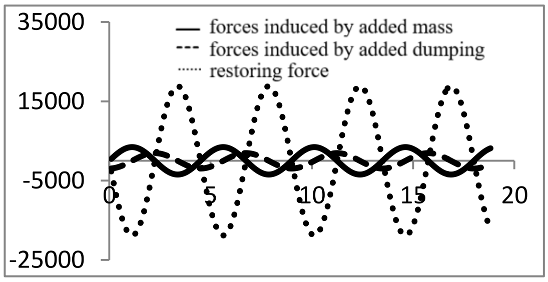


Figure 4. Force component on the heaving direction

In the process of calculation, the device is forced to be a rigid motion of which the displacement is a sine function. At every time step, the force at every direction on the wet surface of the device is calculated. The displacement amplitude is 0.2m, and the period is 4.5s. The force at the direction of heaving on the wet surface of the device changes over time is shown in fig 3. From the figure it can be found that when the device is forced to be a rigid harmonic motion, the force on the device comes into a stable state quickly, and conform to the harmonic rule. Thus it can be seen that the wave absorbing performance of the numerical tank is fine. Only two or three periods data is needed to realize the triangular decomposition, thus this method can save a lot of calculation time.

The calculated resultant force is divided by the method proposed in this paper, the curves of components are shown in figure 4. From the figure, it can be found out that the phase difference between forces induced by the added mass and added dumping is $\pi/2$, and the phase difference between the force induced by the added mass and the restoring force is π

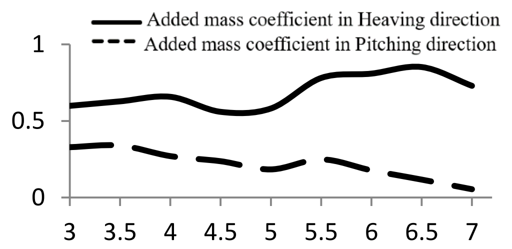
The wet surface has a great effect on the hydrodynamic parameters, in order to confirm the method proposed in this paper, different periods and amplitudes are employed to calculate the hydrodynamic parameters.

The results of calculated added mass and added dumping are modified by dimensionless treatment. The results are shown in table 1, from the table, it can be found that the effect of the amplitude on the hydrodynamic parameters are small.

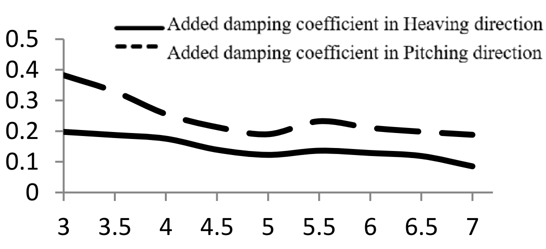
Table. 1. Relationship between the hydrodynamic coefficient and vibration state

Vibration peirod	4.5s	4.5s	5.5s	5.5s
amplitude	0.2	0.3	0.2	0.3
added mass factor μ_{ij}	0.55985	0.55940	0.77568	0.78060
added dumping factor λ_{ij}	0.1227	0.1393	0.1361	0.1361

If the amplitude is 0.2m, the periods is 3s~7s, curves of the added mass and added dumping are shown in figure 5, Obviously, the relationship between the period and the hydrodynamic parameters is complete.



(a)Added mass coefficient



(b)Added damping coefficient

Figure 5. Relationship between the hydrodynamic coefficient and vibration period

4. Conclusion

It is important to calculate the hydrodynamic parameters for the WEC which harvests the wave energy by resonance stage with the wave. The method proposed in this paper can get the hydrodynamic parameters quickly and actually. In this method, the effect of the amplitude on the hydrodynamic parameters is small, but the relationship between the period and the hydrodynamic parameters is complete.

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