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Research on optimization model of wave energy transmission device

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Abstract: *As a pollution-free renewable resource with great energy conversion potential, wave energy is attracting more and more attention from the society. There is an existing wave energy power generation energy output device. Considering the motion stability of the device in the ocean and the energy conversion problem, this paper will introduce the principle and establish a mathematical model around two main problems. Under the condition that only the heave motion is considered, this paper establishes the motion period model of the float and the vibrator based on the linear wave principle, analyzes the force on the float and the vibrator respectively, mainly based on the second-order constant coefficient differential equation of time t established by Newton's second law, and gives the displacement and velocity of the float and the vibrator in heave motion at,,, and under different damping coefficient conditions according to the condition solution. When the damping coefficient is constant, the damping coefficient at the maximum average output power is obtained. In this paper, based on the differential equation obtained from the motion state of the float and vibrator, an optimization model with the average output power as the objective function is established. The damping coefficient is taken as the decision variable, and the decision variable is optimized through genetic algorithm. When the damping coefficient is constant, the damping coefficient is, and the maximum power is. When there is a power exponential relationship between the damping coefficient and the relative velocity, it is found that when the damping coefficient is, the maximum power is.*

Keywords: *Wave power generation, constant coefficient differential equation, optimization model, pitch motion, genetic algorithm*

1. Introduction

As the ocean area occupies the global area, wave energy, as a kind of marine renewable resource, will solve some energy consumption problems and reduce environmental pollution if fully utilized. The installation of wave energy conversion device will be the first step and a very important link in the conversion project. The existing device consists of a float, a central shaft, a vibrator and four parts, and is composed of a spring and a damper. The device is also subject to wave fluctuation, thus driving the internal vibrator to vibrate up and down along the central axis. At the same time, the damper will also act on the vibrator, affecting the movement of the vibrator on the central axis. In addition, the float device is also affected by the restoring force of the excitation force inertial force wave damping force, but the friction force is ignored[1].

2. Establishment and solution of model

2.1 Model preparation

Based on linear wave theory, this paper requires to analyze the periodic motion model of floater and vibrator. Assume that the heave displacement of the float in periodic motion is, the velocity is, and the acceleration is. Assume that the heave displacement of the vibrator in periodic motion is, the velocity is, and the acceleration is. The formula is as follows

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$$\begin{cases} \dot{X}(t) = \frac{dX}{dt} \\ \ddot{X}(t) = A = \frac{d^2X}{dt^2} \\ \dot{x}(t) = \frac{dx}{dt} \\ \ddot{x}(t) = a = \frac{d^2x}{dt^2} \end{cases} \tag{1}$$

In the equilibrium state, the particle on the wave coincides with the particle on the float. If the trajectory of water quality points conforms to the linear wave theory, there are:

$$\begin{cases} Z = \frac{H}{2} cos \frac{2\pi}{\lambda} x_1 \\ \lambda = \frac{gT}{2\pi} tan\hbar \frac{2\pi d}{\lambda} \end{cases} \tag{2}$$

According to the calculation, the volume of the cone is $\frac{1}{3}\pi r^2 l$, and the maximum buoyancy brought by the cone can be calculated as $\frac{1}{3}\pi\rho g r^2 l$. The specific result is $8411.013N$. Only the gravity of the float is calculated as $47696.7N$, and the maximum wave excitation force is $6250N$. The sum of buoyancy and excitation force is also far less than gravity. Therefore, it can be explained that the cone has always been underwater. With the general wave profile as the plane, a plane rectangular coordinate system is established. Z is the position of the water quality point on the z-axis of the wave longitudinal profile, λ is the wave wavelength, and H is the wave height, that is, twice the amplitude. Is the position on the wave longitudinal section axis, as shown in Fig 1:

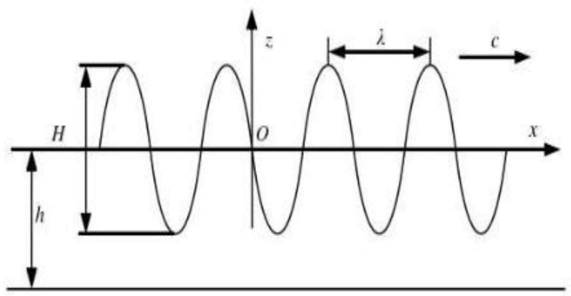

Figure 1: Water Quality Points and Device Location in Equilibrium

The trend chart is made according to the time variation trend of the fluctuation state of the profile. The vertical axis is the value on the profile, and the horizontal axis is the movement time. Suppose that when the water quality point on the wave moves to the highest point, it is the initial movement state. As shown in Fig 2, the periodic expression of the highest point, the lowest point, and the balance point is:$\frac{(4n-3)T}{4}, \frac{(4n-1)T}{4}, \frac{nT}{2} (n \in Z)$

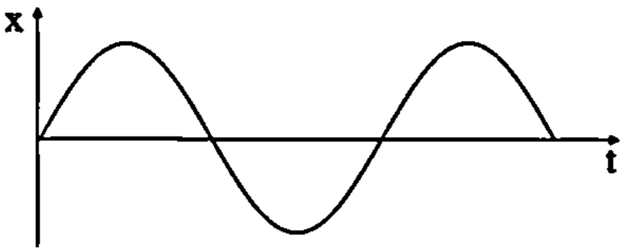

Figure 2: Time varying curve of particle motion position

2.2 Force analysis of moving objects

Since the wave motion is periodic, and the wave also has periodic wave excitation force on the overall device, the device heave motion is divided into two stages. Based on the wave motion direction, the first stage is the descending stage, that is, the wave gives the excitation force to the entire device downward, the moving stage from the highest point to the lowest point, that is, $t \in [\frac{(4n-3)T}{4}, \frac{(4n-1)T}{4}]$, and the second stage is the rising stage, that is, the wave gives the excitation force to the entire device upward, The

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movement phase from the lowest point to the highest point, namely $t \in [\frac{(4n-1)T}{4}, \frac{(4n+1)T}{4}]$, where $n \in Z$. Since the water molecules in contact with the float are relatively static, the float is in equilibrium when only gravity and buoyancy are considered, and other forces except gravity and buoyancy are considered.

If the damping coefficient is proportional to the power of the relative velocity of the float and the vibrator, and the coefficient is $10000\mathrm{N} \cdot s/m$, and the power index is 1/2, $\varphi = 10000\sqrt{v}$, then $\varphi = 10000\sqrt{\frac{dx}{dt}}$ can be known, but the mass of the vibrator cannot be ignored relative to the mass of the float, and the relative force between the two must be considered[2].

The force analysis of float motion under wave action is shown in Fig 3 (taking the wave upward motion phase as an example):

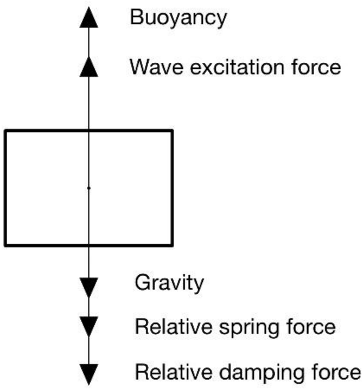

Figure 3: Schematic Diagram of Force Analysis on Float in the Stage of Wave Upward Motion

The force analysis of vibrator movement under wave action is shown in Fig 4:

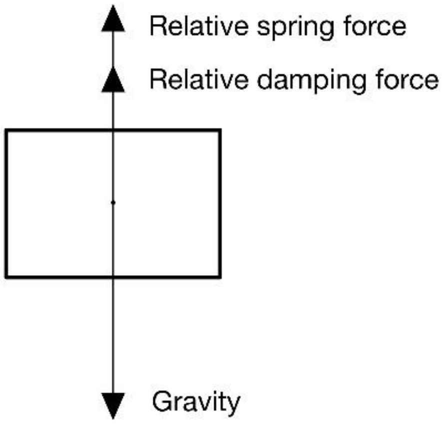

Figure 4: Force Analysis of Vibrator

2.3 Determine differential equation

According to the force analysis, there are some changes in the direction of the force in a cycle. Set the direction opposite to the gravity direction as the positive direction, and then determine the resultant force direction to determine the acceleration direction. The resultant force expression of the float in the falling and rising stages can be described by Newton's second law as follows:

$$F + f + F_k = F_1 \tag{3}$$

$$(m_1 + m_2)A + \varphi(V - v) + k(X - x) = fcoswt \tag{4}$$

$$(m_1 + m_2)\frac{d^2X}{dt^2} + \varphi\left(\frac{dX}{dt} - \frac{dx}{dt}\right) + k(X - x) = fcoswt \tag{5}$$

The resultant force expression of the vibrator in the falling and rising stages is:

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$$F + F_k + f = 0 \tag{6}$$

$$m_3 a + k(X - x) + \varphi(v - V) = 0 \tag{7}$$

$$m_3 \frac{d^2x}{dt^2} + k(X - x) + \varphi\left(\frac{dx}{dt} - \frac{dX}{dt}\right) = 0 \tag{8}$$

The second order constant coefficient differential equation can be obtained through simultaneous calculation:

$$\begin{cases} dV = -\frac{\varphi}{m_1+m_2}(V - v) - \frac{k}{m_1+m_2}(X - x) + \frac{f}{m_1+m_2}coswt \\ dv = -\frac{\varphi}{m_3}(v - V) - \frac{k}{m_3}(x - X) \end{cases} \tag{9}$$

2.4 Solution and conclusion of the model

Take the known conditions of different time periods into the differential equation (7) to get the corresponding solution. The distribution of the resulting image is shown in Figure 5. See Annex I for specific solution procedure.

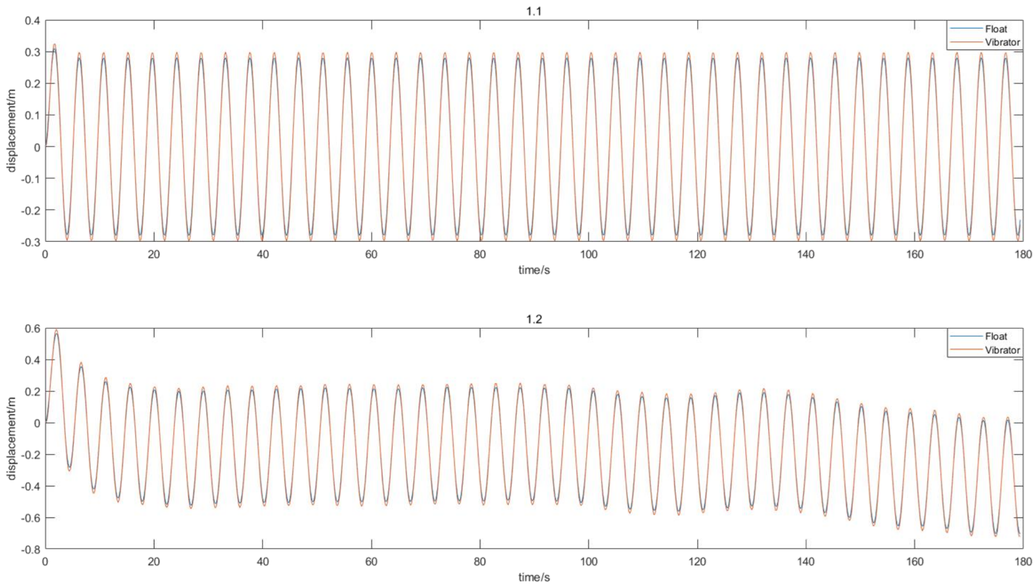

Figure 5: Distribution Image of Float and Vibrator Displacement Results

The displacement and velocity of the float and vibrator in the vertical direction can be calculated when the damping coefficient is $10000\mathrm{N}\cdot\mathrm{s/m}$ and the damping coefficient is $10s, 20s, 40s, 60s, 100s$. The conclusion is shown in Table 1 below.

When the damping coefficient is in direct proportion to the power of the relative velocity of the float and the vibrator, and the coefficient is $10000\mathrm{N}\cdot\mathrm{s/m}$, the power index is 0.5, and at $10s, 20s, 40s, 60s, 100s$ the float and the vibrator's heave displacement and velocity are shown in Table 2 below.

Table 1: Displacement and velocity of float and vibrator with known damping coefficient

Time (s)	float		Vibrator	
	Displacement (m)	Speed (m/s)	Displacement (m)	Speed (m/s)
10	0.147471	0.335129	0.153783	0.357964
20	0.256627	-0.160563	0.273672	-0.166324
40	-0.277668	0.061113	0.29518	0.06034
60	0.279425	0.042608	0.296194	0.049751
100	0.225916	0.234219	0.237869	0.252102

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Table 2: Displacement and velocity of float and vibrator with damping coefficient proportional to relative velocity

Time (s)	float		Vibrator	
	Displacement (m)	Speed (m/s)	Displacement (m)	Speed (m/s)
10	-0.080532	0.479583	-0.081606	0.5515
20	0.197391	0.065397	0.214238	0.065346
40	-0.494609	-0.19585	0.509031	-0.211681
60	0.125861	0.312291	0.13608	0.332892
100	-0.041689	0.47631	-0.040444	0.515873

3. Analysis of output power damping under wave frequency

3.1 Model preparation

In order to calculate the damping coefficient at the maximum average output power, under the condition that the wave frequency is known, according to the force analysis of the device, it is obtained that the vertical displacement X and x of the float and the vibrator have the following relationship when they are in heave motion according to formula (2) and (5).

$$\begin{cases}(m_1+m_2)A+\varphi(V-v)+k(X-x)=fcoswt\\ m_3a+k(X-x)+\varphi(v-V)=0\end{cases} \tag{10}$$

Namely:

$$\begin{cases}(m_1+m_2)\ddot{X}(t)+\varphi\big(\dot{X}(t)-\dot{x}(t)\big)+k(X(t)-x(t))=f(t)\\ m_3\ddot{x}(t)+k(X(t)-x(t))+\varphi\big(\dot{x}(t)-\dot{X}(t)\big)=0\end{cases} \tag{11}$$

In order to find the optimal solution of the device, (9) is rewritten into the formula in the frequency domain state, as shown in

$$\begin{cases}i\omega(m_1+m_2)\dot{X}(\omega)+\varphi\big(\dot{X}(\omega)-\dot{x}(\omega)\big)+\frac{k(\dot{X}(\omega)-\dot{x}(\omega))}{i\omega}=f\\ i\omega m_3\dot{x}(\omega)+\frac{k(\dot{X}(\omega)-\dot{x}(\omega))}{i\omega}+\varphi\big(\dot{x}(\omega)-\dot{X}(\omega)\big)=0\end{cases} \tag{12}$$

Further simplify (9) as follows:

$$\begin{cases}S_1\dot{X}(\omega)+S_2\dot{x}(\omega)=f\\ S_3\dot{X}(\omega)+S_4\dot{x}(\omega)=0\end{cases} \tag{13}$$

Among:$S_1=i\omega(m_1+m_2)+\varphi+\frac{k}{i\omega}, S_2=-\varphi-\frac{k}{i\omega}, S_3=i\omega m_3-\frac{k}{i\omega}+\varphi, S_4=\frac{k}{i\omega}-\varphi$。

The optimal speed can be obtained by solving (10):

$$\begin{cases}\dot{X}(\omega)=\frac{fS_4}{S_1S_4-S_2S_3}\\ \dot{x}(\omega)=-\frac{fS_2}{S_1S_4-S_2S_3}\end{cases} \tag{14}$$

3.2 Construction of objective function expression

The expression of optimal speed is solved in equation (11) above, and the displacement amplitude in this frequency domain is easily obtained:

$$x=\omega\dot{x} \tag{15}$$

The optimal damping solution can be obtained as

$$\varphi=\sqrt{\frac{{U_1}^2}{\omega^2{U_2}^2}} \tag{16}$$

Among:$U_1=(k-\omega^2m_3)(m_1+m_2)+km_3$,$U_2=m_1+m_2+m_3$.

At frequency, the maximum average power is:

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$$\bar{P}=\frac{1}{2}\varphi\left|\dot{x}(\omega)-\dot{X}(\omega)\right|^2 \tag{17}$$

Namely:

$$\bar{P}=\frac{1}{2}\varphi\left|\dot{x}(t)-\dot{X}(t)\right|^2 \tag{18}$$

It can be seen from the above formula that the average output power is related to $\dot{x}(t)-\dot{X}(t)$ and φ, that is, the average output power is related to the relative speed and damping coefficient of the vibrator and float.

3.3 Determine decision variables

It has been determined that the relative velocity and damping coefficient of float and vibrator are related to the average maximum output power. Therefore, when the damping coefficient is constant and the index is known, the maximum average output power corresponding to the optimal speed can be determined, and the value of the optimal damping coefficient can be deduced from the average maximum power. At this time, the decision variable is the damping coefficient.

When the damping coefficient is proportional to the relative speed and has a power exponential relationship, the expression of the average maximum power can be transformed into a power function with a coefficient that is only related to the relative speed, so the maximum power can be obtained. The optimal speed is used to calculate the damping coefficient and power exponent. At this time, the decision variables are relative speed and power exponent[3].

3.4 Model solution

The execution result can be obtained by (13) genetic algorithm. After the initial value is input, it is brought into equation (13) to judge and calculate the average output power and damping coefficient obtained, screen out the better results, and eliminate an iterative process of poor results. Stop the operation until the stop criteria are met. The operation result is shown in the fig 6:

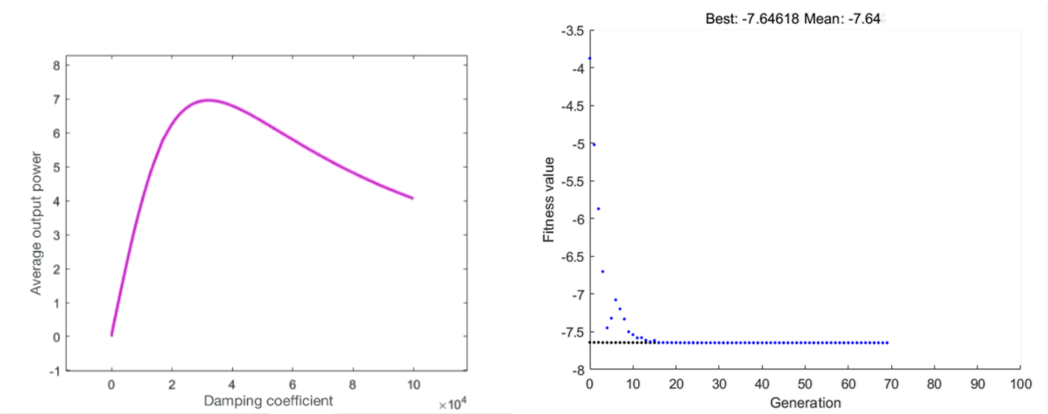

Figure 6: Curve of damping coefficient and average maximum output power

From the left figure, we can see that when the damping coefficient is close to $40000N\cdot m$, the average output power will reach the peak. When the damping coefficient is constant, the damping coefficient is $31915.958N\cdot m$ and the maximum power is $6.963w$. When the damping coefficient and relative velocity have a power exponential relationship, it is found that when the damping coefficient is $98118.07N\cdot m$, the maximum power is $7.658w$.

4. Conclusion

In this paper, a more complete analysis of the wave force device is made, including the dynamic equation and force distance balance analysis, which has a certain reference significance for the design of the wave force device. The derivation of the average output power of the wave force device involved, and the maximum damping coefficient and the maximum output power can be obtained from this formula, which can better set the damping coefficient and improve the working efficiency of the wave force device. In this paper, we can provide some ideas and help for the design of this device.

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The kinematics analysis of the model is rigorous, and the omission is immediately optimized. It is widely applicable for different assumptions and different stress conditions. When considering the more ideal motion process, more forces need to be considered. The improved model can be referred to. In particular, the deflection force is considered when the vibrator is pitching.As well as using genetic algorithm to find the average maximum output power and its corresponding damping coefficient, each iteration will get a more appropriate value. When the number of iterations is enough, the model will get a value very close to the optimal selection.

References

[1] Zhu Yanrong, Analysis of Application Scope of Several Wave Theories [J], Coastal Engineering, Volume II, Issue 2, December 1983

[2] Xie Huimei, Meng Fantai, Xu Qianlong, Performance analysis of different shape multi degree of freedom built-in wave energy conversion devices [A], Renewable Resources, Volume 40, Issue 7, July 2022

[3] Lee Y, Zhang J, Niedzwecki J M. Investigation of the Power Generated by a Disk Buoy-WEC Design [J]. International Journal of Offshore and Polar Engineers, 2018, 28(4):402-410.