Research on the Design Problem of Maximum Wave Energy Output Power

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Abstract. With the development of economy, energy and environment problems have become a big problem in today's society. To realize sustainable development and protect ecological environment has become the consensus of all countries in the world. Wave energy, as an important Marine renewable resource, is more widely distributed than conventional energy, with abundant energy storage and considerable application value. In this paper, based on the analysis of the heave and pitch motion of the wave energy device in seawater, the motion states of the float and vibrator from static to heave and pitch motion are obtained through the force analysis of the float and vibrator and the establishment of differential equations. The maximum output power of the wave energy device is analyzed and discussed by adjusting the damping coefficient of the damper and other related parameters.

Keywords: Equation of Newtonian mechanics, traversal algorithm, genetic algorithm.

1. Introduction

Environmental pollution and energy shortage are the major problems in today's society. Finding green renewable energy has become an important challenge for mankind. According to literature [1], wave energy, as an important renewable energy source, has played a huge role in alleviating today's problems. How to improve the energy conversion efficiency of wave energy is one of the key problems in wave energy popularization.

2. Float and oscillator in the heaving displacement and speed of the wave exciting force

2.1. Establishment of model

The internal diagram of the static wave device is given as shown in Figure 1, which is divided into four parts and the center of gravity of each part is calculated. When spring stationary, float and there is no relative movement between stator, the damping force of the linear damper is associated with the relative motion of the two, in a stationary, oscillator only by spring force, the force of gravity with spring oscillator phase equilibrium, column to write equations calculating the amount of compression spring when resting:

$$k_t \Delta x = m_z g \tag{1}$$

Where Δx is the shape variable of the spring and is 0.3m.

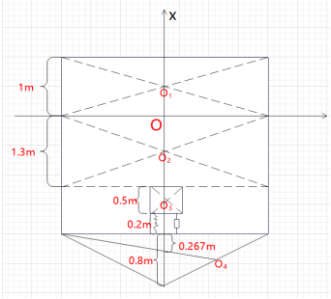


Figure 1. Schematic representation of the interior of a wave device at rest

In the figure 1, O1O2O3 respectively represents the center of gravity of the region shown in the figure, and O is the origin of coordinates. It can be seen from the figure that OO3=1.55m, which is also the relative displacement of float and oscillator at rest.

Assuming that seawater is an incompressible, inviscous and uniform fluid, ignoring the influence of float oscillation on it, we can list some corresponding mechanical equations through force analysis of float and oscillator and according to literature [2-5]:

$$\left(m_F + m_f\right)\frac{d^2x_1}{dt^2} + C_x \cdot \frac{dx_1}{dt} + F_D + K_t(x_1 - x_2) - k_z\left(\frac{dx_1}{dt} - \frac{dx_2}{dt}\right) = fcos\omega t \tag{2}$$

$$\frac{d^2x_1}{dt^2} - \frac{d^2x_2}{dt^2} + \frac{K_t(x_1 - x_2)}{m_{zh}} + \frac{k_z(\frac{dx_1}{dt} - \frac{dx_2}{dt})}{m_{zh}} = 0 \tag{3}$$

Where: m_F float is the mass of the float, m_f attached is the additional mass of the heave, ω is the wave frequency, x1 is the float displacement, x2 oscillator displacement, and k_z resistance is the damping coefficient of the linear damper. C_x is the damping coefficient of vertical wave and F_D is the hydrostatic restoring force, that is, the buoyancy force, which is determined by the displacement.

$$F_D = \pi r_F^2 \rho g x_1 \tag{4}$$

Since there is a relative displacement between the float and the oscillator at rest, that is, OO3=1.55m, the initial relative displacement should be removed.

Let μ=x1-x2-1.55, combine the above two expressions, and get

$$x_1 = 0.17\cos(1.4005t + \frac{\pi}{2}) \tag{5}$$

The general solution is obtained as $\mu(t) = C_1\cos(\omega_2 t) + C_2\sin(\omega_2 t)$.

When t=0, μ=0, that is, C1=0, then $\mu(t) = C_2\sin(\omega_2 t$

Because $\omega_2 = \sqrt{\frac{k_t}{m_{zh}}}$ if you get $\omega_2 = 5.734$, then

$$\mu(t) = C_2\sin(5.734t) \tag{6}$$

It can be seen that the motion law of wave energy generation device under the action of ocean wave is simple harmonic motion.

Substituting μ= x1-x2-1.55 into Equation (2) can be written as

$$M\frac{d^2x_1}{dt^2} = fcos\omega t - k_z\frac{d\mu}{dt} \tag{7}$$

Where M is the sum of float mass m_F float and heave additional mass m_f attach. he equation of motion of the float was obtained by solving the above equation, and the following equation was obtained by integrating the equation of motion

$$M\frac{dx_1}{dt} = \frac{f}{\omega}\sin\omega t - k_z(C_2\sin(5.734t)) + C_3 \tag{8}$$

$t_1 = 0$, then $\frac{dx_1}{dt} = 0$, the solution is $C_3 = 0$; It can be obtained by integrating equation (8):

$$M \cdot x_1(t) = \frac{-f}{\omega^2}\cos\omega t + k_z C_2\frac{\cos\omega_2 t}{\omega_2} \tag{9}$$

Where $\omega^2 = 5.734$, $\omega = 1.4005 s^{-1}$, when $t = 0$, $x_1(0) = 0$, can be obtained $C_2 = \frac{f \cdot \omega_2}{\omega^2 k_z}$ and substituting $C_2 = \frac{f \cdot \omega_2}{\omega^2 k_z}$ into equations (9) can be obtained:

$$x_1(t) = \frac{f \cdot (\cos \omega_2 t - \cos \omega t)}{\omega^2 M} \tag{10}$$

$$x_2(t) = \begin{cases} -1.55 \\ \frac{f(\cos \omega_2 t - \cos \omega t)}{\omega^2 M} - \frac{f \omega_0}{\omega^2 k_z} \sin \omega_2 t - 1.55 \end{cases} \tag{11}$$

From the continuous type, when $t = \frac{\varphi}{\omega}$ and $y_1(\frac{\varphi}{\omega}) - u(\frac{\varphi}{\omega}) - 1.55 = -1.55$, the lag time is $t = 2.3s$ and the lag Angle is 3.2211.

2.2. Solution method for model

The displacement and velocity of the float and oscillator at corresponding time are obtained as shown in Table 1.

Table 1. Time displacement and velocity of the float and oscillator

Time (s)	Float		Vibrator	
	The displacement (m)	Speed (m/s)	The displacement (m)	Speed (m/s)
10	-0.033696591	0.046811921	-0.040066301	0.084446022
20	-0.035573100	0.14438025	-0.064763376	0.077197611
40	0.018583327	0.165935107	0.006633042	0.307018245
60	0.023577308	-0.104434926	0.055443196	-0.0794778
100	-0.013963556	0.154058312	-0.045866196	0.186815395

Figure 2 shows the speed of the float.

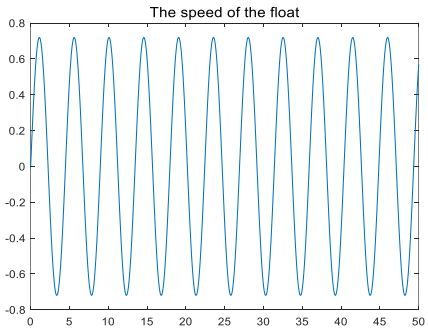


Figure 2. The velocity of the float

Figure 3 shows the displacement of the float.

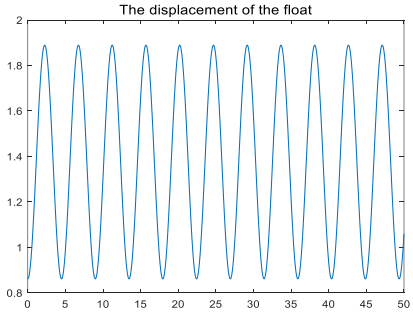


Figure 3. The displacement of the float

Figure 4 shows the velocity of the oscillator.

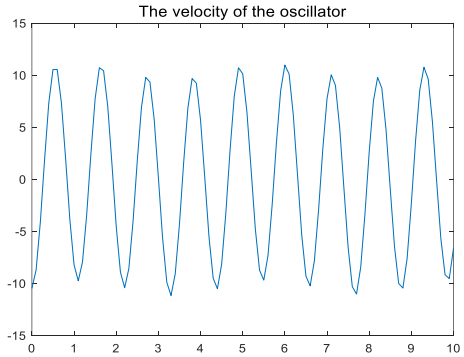


Figure 4. The velocity of the oscillator

Figure 5 shows the displacement of the oscillator.

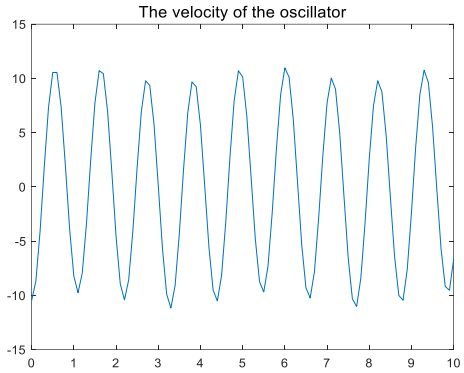


Figure 5. The velocity of the oscillator

3. Optimal damping coefficient model for heave motion

3.1. Establishment of model

In the above study, the float only moves in the vertical motion, considering that the damping coefficient of the damper has an impact on the average output power of the system. Therefore, in order to solve the maximum output power and the corresponding optimal damping coefficient, this paper should establish the equation of output power and damping coefficient, and solve the equation to get the maximum power and the corresponding optimal damping coefficient. Although the direction of motion of the device changes during movement, the direction of the external force remains consistent with the direction of motion. When the system is stable, the device vibrates with the waves.

According to literature [6-8], the output power of the damper can be expressed as follows:

$$P_{\mathrm{t}} = \frac{k_{zx} u_r^{\ 2}}{2} \tag{12}$$

Where, k_{xz} is the rotational damping coefficient, and u_r is the relative velocity of the float and the oscillator.

According to reference [9], since the relative velocity $u_r = u_r(t)$ changes with time during the vibration process, we can define the average output power within a period of time $[0,\ T]$ as:

$$P_p = \frac{\int_0^T P(t)dt}{T} \tag{13}$$

The total time obtained in this paper is the first 40 cycles established according to the above model, and the average power converted by the PTO system is:

$$P_p = \frac{1}{2} c_p |u|^2 = \frac{c_p F_0^{\ 2}}{2((c_p)^2 + (\omega \cdot M - k_t / \omega)^2} \tag{14}$$

When the natural vibration frequency of the wave energy conversion device is consistent with the propagation frequency of ocean wave energy, the device will capture the maximum wave energy and obtain the maximum power in the case of resonance. It can be seen that when the wave conditions remain unchanged, the average power obtained by the wave energy conversion device is related to the damping coefficient of the PTO system. To maximize the power obtained by the PTO system, the following requirements should be met:

$$\frac{\partial P}{\partial c_p} = 0 \tag{15}$$

$$\begin{aligned} c_p &= \sqrt{(\omega \cdot M - k_t / \omega)^2} \\ c_p &= \omega \cdot M - k_t / \omega \end{aligned} \tag{16}$$

When the damping coefficient of the PTO system meets the above equation, the optimal amplitude condition is reached and the maximum power of the PTO system is obtained:

$$P_{m\max} = \frac{f_0}{4(\omega \cdot M - k_t / \omega)} \tag{17}$$

3.2. The solution of the optimization model

When the damping constant is nonconstant, the damping coefficient is related to the relative velocity of the float and the oscillator, and the relation between the damping coefficient and the oscillator is set as the relation between the proportional coefficient and the exponent α, so that the average power is maximized. This is a multivariable problem. The relationship between average output power and fixed-length damping can be obtained as shown in figure 6.

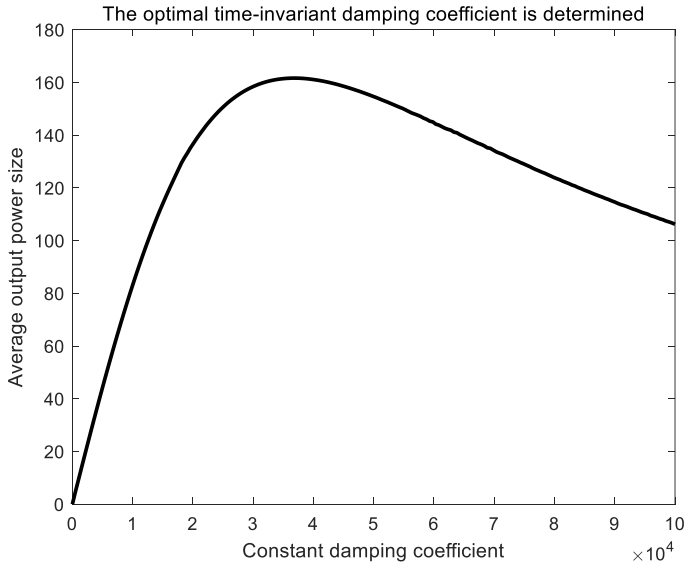


Figure 6. Relation between average output power and fixed length damping

Through the solution results, this paper can know that when the damping coefficient is 38857, the maximum output power is 1616000kW. This also satisfies the optimal damping theory, that is, in any case, there exists an optimal damping for the PTO system to maximize the generation power.

4. The heave displacement and velocity and the pitch Angle displacement and angular velocity of float and oscillator under rocking motion

The schematic diagram of float doing heave and pitch motions under the action of waves is shown in figure 7.

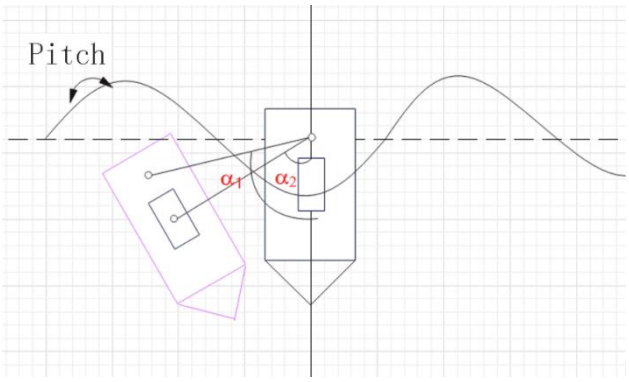


Figure 7. The schematic diagram of float doing heave and pitch motions under the action of waves

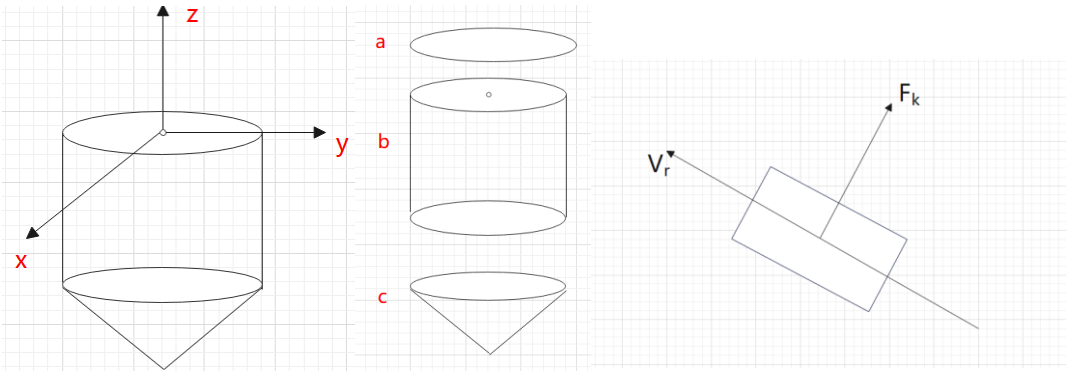


Figure 8. The splitting device establishes the coordinate system and analyzes the Coriolis force on the object

According to literature [10-11], differential equation of float rotation:

$$(I_1+I_f)\frac{d^2\alpha_1}{dt^2}+C_h\partial_1+C_y\frac{d\alpha_1}{dt}+k_n(\alpha_1-\alpha_2)+k_{xz}(\frac{d\alpha_1}{dt}-\frac{d\alpha_2}{dt})=L\cos\omega t \tag{18}$$

Since $I_1=I_a+I_b+I_c$, where I_a, I_b, I_c are respectively the moment of inertia of a, b and c in figure 8 then $I_a=\iint[y^2+(3.8-Z_a)^2]\rho ds=\rho(3.8-0.533)^2\pi+\frac{\rho\pi}{4}$, $Z_a=0.533$. $I_b$andI_c can be obtained in the same way, so $I_1=I_a+I_b+I_c=8398.8$.

Since $F_k=2m_{zh}\vec{v}_r\times\vec{\dot{\alpha}}_2$, where v_r is the velocity relative to the central axis, namely $v_r=\frac{dx_2}{dt}-\frac{dx_1}{dt}$, the moment due to the Coriolis force is: $I_k=F_k\cdot\Delta l=F_k(l_0+x_2-x_1)$, and hence the differential equation for the oscillator rotation is:

$$I_2\frac{d^2\alpha_2}{dt^2}+k_n(\alpha_2-\alpha_1)+k_{xz}(\frac{d\alpha_2}{dt}-\frac{d\alpha 1}{dt})+2m_{zh}(\frac{dx_2}{dt}-\frac{dx_1}{dt})\frac{d\alpha_2}{dt}(L_0+x_2-x_1) \tag{19}$$

Where, $I_2=m_{zh}\cdot\Delta l^2$.

So the total differential equation is:

$$(I_1 + I_F)\frac{d^2\alpha_1}{dt^2} + C_h\alpha_1 + C_y\frac{d\alpha_1}{dt} + k_n(\alpha_1 - \alpha_2) + k_{xz}(\frac{d\alpha_1}{dt} - \frac{d\alpha_2}{dt}) = L\cos\omega \tag{20}$$

$$I_2\frac{d^2\alpha_2}{dt^2} + k_n(\alpha_2 - \alpha_1) + k_z(\frac{d\alpha_2}{dt} - \frac{d\alpha_1}{dt}) + 2m_f(\frac{dx_2}{dt} - \frac{dx_1}{dt})\frac{d\alpha_2}{dt}(L_0 + x_2 - x_1) = 0 \tag{21}$$

$$\left(m_f + m_F\right)\frac{d^2x_1}{dt^2} + C_x \cdot \frac{dx_1}{dt} + F_D + K_t(x_1 - x_2) - k_{xz}\left(\frac{dx_1}{dt} - \frac{dx_2}{dt}\right) = f\cos\omega t \tag{22}$$

$$\frac{d^2x_1}{dt^2} - \frac{d^2x_2}{dt^2} + \frac{K_t(x_1 - x_2)}{m_{zh}} + \frac{k_{xz}(\frac{dx_1}{dt} - \frac{dx_2}{dt})}{m_{zh}} = 0 \tag{23}$$

The results are shown in Table 2 below:

Table 2. Float and vibrator heaving displacement and speed and pitch angular displacement and angular velocity

Time (s)	Float				Vibrator			
	Heave displacement (m)	Heave velocity (m/s)	Pitch angular displacement	Pitch angular velocity (s-1)	Heave displacement (m)	Heave velocity (m/s)	Pitch angular displacement	Pitch angular velocity (s-1)
10	-0.52827	0.96985	0.01325	-0.106428	-0.598734	1.0382155	0.013272	-0.106765
20	-0.70481	-0.26930	0.01896	0.006535	-0.772292	-0.319026	0.392651	0.006555
40	0.36936	0.75758	-0.03175	-0.022935	0.392655	0.844962	-0.031805	-0.023077
60	-0.32068	-0.72176	0.03553	0.042917	-0.341426	-0.79932	0.035577	0.04265
100	-0.05015	-0.94669	0.02030	0.073066	-0.04261	-1.036526	0.020339	0.073083

5. Conclusion

In order to design and study the maximum output power of wave energy, the structure of BP neural network is designed, and the equations of motion of float and oscillator are obtained by force analysis and simulation. When considering that the float and vibrator only move in the wave, the motion law of the float and vibrator under the action of the wave excitation force is simple harmonic motion. With the increase of damping coefficient of fixed length, the output power of system change is increased and the trend of the first, the system is obtained by MATLAB to calculate the maximum power output and its corresponding optimal damping coefficient, can improve the design efficiency, avoid the improper design caused the waste of resources. Considering the float and vibrator do swing and pitch motion, the displacement and velocity of the device are solved by MATLAB simulation, so that the device has better universality.

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