Design of maximum output power of wave energy based on multiple search algorithm

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Abstract. The wave energy device moves under the drive of waves. During the movement of the device, the damper inside the device is driven to do work and the work done by the damper is converted into energy output.In this paper, the force of the system in the initial equilibrium state of the device is first analyzed, and then according to Newton's second law, the motion state of the float and the oscillator are analyzed separately, and the differential equation motion model of the float and the oscillator is established.When the constraints are damping coefficients, multiple search algorithms are used to solve them, and the negative work done by the linear damping force is obtained, with a period of 40 times as long. After the work is analyzed and discretized, the objective function expression is obtained, and a number of average output powers are obtained and continuously compared, and finally the maximum average output power and its corresponding parameter values are obtained.The optimal damping coefficient and the maximum average power are obtained.

Keywords: Differential equation model; multiple search algorithm; wave energy.

1. Introduction

With the increasingly serious energy and environmental problems, the development of wave energy has also received more and more attention [1].There is an existing wave energy device, which consists of a float, a oscillator, a central axis and an energy output system.Among them, the float consists of a cylindrical shell and a conical shell, and the mass of the float is evenly distributed.Inside the float, there are oscillators, a central axis, and an energy output system.Under the action of waves, the float drives the movement of the oscillator, and the relative movement of the two drives the damper to do work, and the work done by the damper can be converted into energy output [2].This paper mainly studies the motion law of floats and oscillators, the relationship between the work done by the damper and the output power of the wave energy device, establishes a differential equation model, and uses Matlab programming to solve the model.

2. Establishment of system motion differential equation model

The initial state of the system is in an equilibrium position, and the overall force analysis of the system is shown in Figure 1.

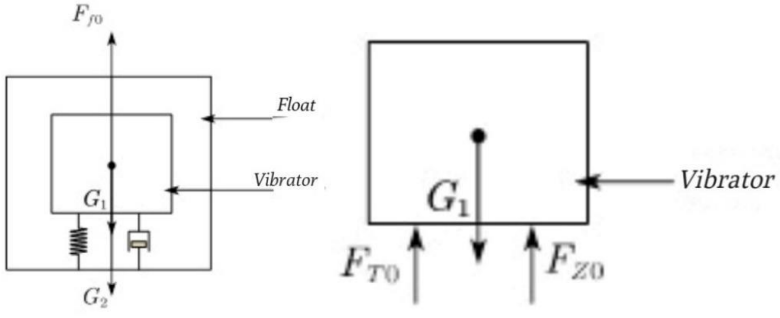


Fig.1 Analysis diagram of the initial state system and oscillator force

From Figure 1, the equilibrium equation can be listed in this article.

$$\begin{cases} F_{f0} = G_1 + G_2 \\ G_1 = m_1 g = F_{T0} + F_{Z0} = F_{T0} = k_s x_0 \\ G_1 = m_2 g \end{cases} \tag{1}$$

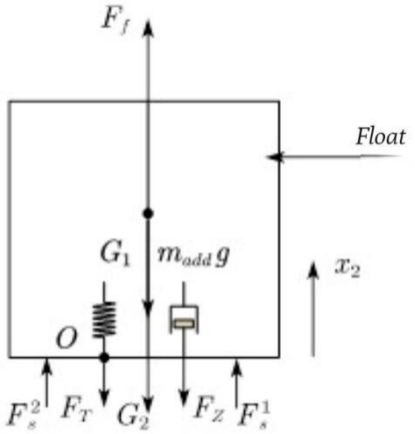
Where m_1 is the mass of the oscillator; m_2 is the mass of the float; F_{f0} is the initial state buoyancy; g is the acceleration of gravity.

The initial state is in equilibrium, and the relative velocities of the two are 0. The resistance of the damper is proportional to the relative velocities of the float and the oscillator, and $F_{Z0} = 0$ is obtained.

From this, the initial compression amount of the spring can be obtaine.

$$x_0 = \frac{G_1}{k_s} \tag{2}$$

When the float only makes vertical movement in the wave, the force analysis of the float and the oscillator is carried out separately..



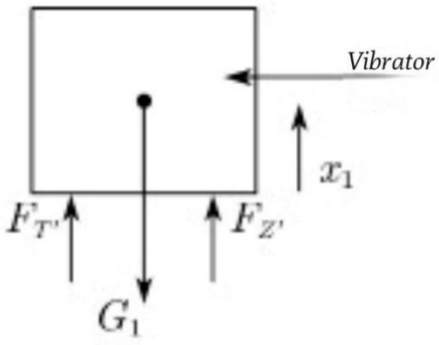


Fig.2 Float force analysis diagram **Fig.3** Oscillator force analysis diagram

Stipulation: The positive upward direction is the positive direction of the x-axis, and the origin *O* is placed at the lower end of the spring in the initial state.From Figure 2, the equation of Newton's Second law for the float column

$$\begin{cases} (m_2 + m_{add}) a_2 = F_f + F_s^1 - F_s^2 - G_2 - F_T - F_Z \\ a_2 = \dfrac{d^2 x_2}{dt^2} \\ F_f = F_{f0} - \rho_{sea} g \pi x_2 \end{cases} \tag{3}$$

In formula (3), F_f is the buoyancy force; F_s^1 is the wave excitation force; F_s^2 is the wave damping force; F_T is the spring elasticity; F_Z is the damping force; m_{add} is the additional mass; a_2 is the acceleration of the float movement; G_2 is the float gravity; x_2 is the float movement displacement.

From Figure 3, according to Newton's second law

$$\begin{cases} m_1 a_1 = F_T' + F_Z' \\ a_1 = \dfrac{d^2 x_1}{dt^2} \end{cases} \tag{4}$$

Among them

$$\begin{cases} F_s^1 = f\cos wt \\ F_s^2 = k\dfrac{dx_2}{dt} \\ F_T = k_s(x_2 - x_1) \\ F_Z = k_z\left(\dfrac{dx_2}{dt} - \dfrac{dx_1}{dt}\right) \\ F_f = F_{f0} - \rho_{sea} g x_2 \pi r^2 \end{cases} \tag{5}$$

Where f is the amplitude of the wave excitation force; w is the wave frequency; k is the damping coefficient of the vertical wave; k_s is the spring stiffness coefficient; k_z is the damping coefficient of the linear damper; r is the bottom radius of the float.

From this, the motion model of float and oscillator is established in this paper

$$\begin{cases} (m_2 + m_{add})\dfrac{d^2x_2}{dt^2} = f\cos wt - k\dfrac{dx_2}{dt} - k_s\Delta x - k_z\left(\dfrac{dx_2}{dt} - \dfrac{dx_1}{dt}\right) + F_f - G_2 \\ m_1\dfrac{d^2x_1}{dt^2} = k_s\Delta x + k_z\left(\dfrac{dx_2}{dt} - \dfrac{dx_1}{dt}\right) \\ \Delta x = x_2 - x_1 \\ x_1(0) = x_0, x_2(0) = 0 \end{cases} \tag{6}$$

3. Establishment of average power model of linear damping drive

The output energy of the energy output system (PTO) is achieved by driving the damper to do negative work through relative motion. It is assumed that the energy loss is not considered, that is, all of it is converted into energy output.

The damping force provided by the drive damper is proportional to the relative speed of the float and oscillator when they move. The proportional coefficient is the damping coefficient k_z of the drive damper, and the drive damper has to do work.

$$W = \int_0^{t_{\max}} F_Z v_{12} dt = \int_0^{t_{\max}} k_z v_{12} \cdot v_{12} dt = k_z \int_0^{t_{\max}} v_{12}^2 dt \tag{7}$$

Where dx is the relative displacement micro-element and v_{12} is the relative velocity of the float and the oscillator.

$$v_{12} = \frac{dx_2}{dt} - \frac{dx_1}{dt} \tag{8}$$

The average power of the linear damping drive in the $0 \sim t_{\max}$ time period $\bar{P}$

$$\bar{P} = \frac{k_z \int_0^{t_{\max}} \left(\frac{dx_2}{dt} - \frac{dx_1}{dt}\right)^2 dt}{t_{\max}} \tag{9}$$

Discretize formula (9)

Divide $[0,t_{\max}]$ into intervals on average: $(0,\Delta t]$、$(\Delta t,2\Delta t]\ldots\ldots((n-1)\Delta t,t_{\max}]$, the length of each interval is Δt, and the molecule of the above formula can be discretized as

$$\begin{aligned}&k_z\int_0^{t_{\max}}\left(\frac{dx_2}{dt}-\frac{dx_1}{dt}\right)^2dt\\&=k_z\sum_{i=1}^{n}\left(\frac{x_2(i\Delta t)-x_2((i-1)\Delta t)}{\Delta t}-\frac{x_1(i\Delta t)-x_1((i-1)\Delta t)}{\Delta t}\right)^2\Delta t\\&=\frac{k_z}{\Delta t}\sum_{i=1}^{n}[x_2(i\Delta t)-x_1(i\Delta t)+x_1((i-1)\Delta t)-x_2((i-1)\Delta t)]^2\end{aligned}\tag{10}$$

$x_2(i\Delta t)$ is simply denoted as x_2^i, $x_1(i\Delta t)$ is simply denoted as x_1^i, then

$$k_z\int_0^{t_{\max}}\left(\frac{dx_2}{dt}-\frac{dx_1}{dt}\right)^2dt=\frac{k_z}{\Delta t}\sum_{i=1}^{n}(x_2^i-x_1^i+x_1^{i-1}-x_2^{i-1})^2\tag{11}$$

Get average power $\overline{P}$

$$\overline{P}=\frac{k_z\sum_{i=1}^{n}(x_2^i-x_1^i+x_1^{i-1}-x_2^{i-1})^2}{t_{\max}\Delta t}\tag{12}$$

It can be seen from equation (6) that for any k, the displacement and velocity of the float and oscillator at each time can be obtained. This problem only requires displacement, and the average power can be calculated by substituting equation (12).In this paper, it is also necessary to determine the damping coefficient of the straight rod driver with the largest average output power. For the solution of this problem, this paper uses a multiple search algorithm.

4. Solving the average power model of linear damping drive

The algorithm steps of this process are as follows：

Step1: Initialize $\overline{P}_{\max}=-10^5$, first enumerate each k_z value with a stride length of 100, substitute it into the model of problem 1 to solve the float and oscillator displacement, substitute it into the model of problem 2 after discretization, and obtain the corresponding $\overline{P}$, compare with $\overline{P}_{\max}$, if $\overline{P}_{\max}=\overline{P}$, make $k_z^0=k_z$.

Step2: After obtaining the local optimal value in Step1, add and subtract the step size value of Step1 from the upper and lower boundaries, and then perform a similar Step1 calculation with a small step size of 10 to obtain the local optimal value again.

Step3: Repeat the search for elements until the optimal solution is at a more reasonable amplitude change position (confirmed according to the size of the value obtained in the topic), as the final solution, and calculate the maximum average power.

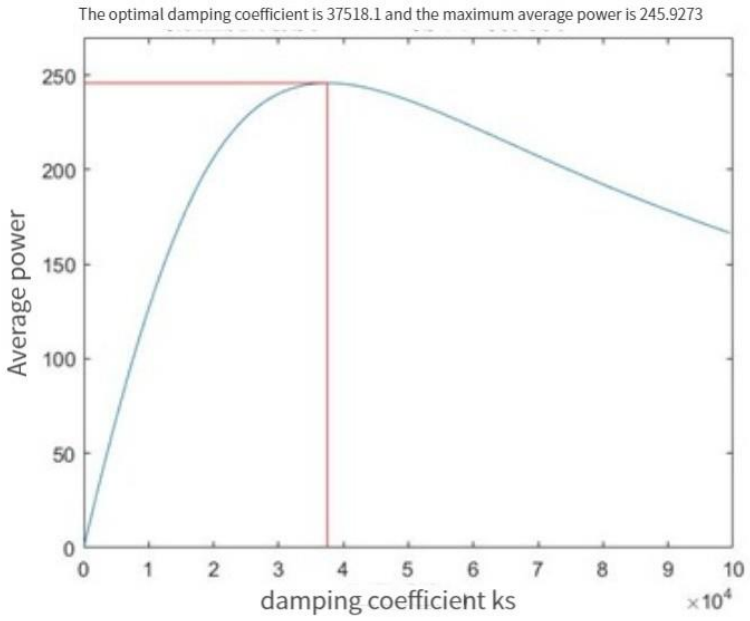


Fig.4 Optimal damping coefficient

Using MATLAB programming to solve, this paper obtains the average output power of the damping driver under different damping coefficients, and uses a multiple search algorithm to control the optimal damping coefficient within 1. Since the value here is large, the accuracy can already meet the meaning of the question well. This article can be regarded as the optimal damping coefficient k_z^0 =37518.1$N{\cdot}s/m$, which corresponds to the maximum average power of $\overline{P}_{\max}$=245.93W .

5. Conclusion

This paper studies the energy conversion efficiency of wave energy devices, the principle of which is to use damping force to do work to output energy [3]. This paper combines physical knowledge to establish a differential equation model, and adopts a multiple search algorithm, first searching in large steps and then searching in small steps. While speeding up the calculation speed, the accuracy of the results is improved. The optimal damping coefficient is 37518.1$N \cdot s/m$, and the maximum average power is 245.9273W .In addition, the model can also be extended to other devices that use damping force to do work to output energy [4], which is of very important practical significance.

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