Research on Wave energy Maximum power based on particle swarm optimization algorithm

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Abstract. With the increasing demand for energy, non-renewable resources such as coal and oil, which are the main sources of energy, are gradually depleted and have caused serious pollution to the environment. Therefore, the development and utilization of new energy has become a major research topic in today's society; wave energy, as a new energy source, is one of the most abundant energy sources in the ocean and has considerable application prospects. In this paper, the float and oscillator motion models are established by fitting the drape displacement and drape velocity, the longitudinal rocking angular displacement and longitudinal rocking angular velocity of the float and oscillator to the Runge-Kutta method and matlab toolbox. The particle swarm optimization algorithm is then used to determine the maximum output power of the system, and the optimal damping coefficient.

Keywords: Runge-Kutta, Wave energy conversion, Particle swarm optimization algorithm.

1. Introduction

As a clean and renewable energy source, wave energy not only has huge reserves, but also is widely distributed; in order to alleviate the energy crisis, increase the development of sustainable clean energy, and promote the sustainable development of human society, the research and development of wave energy devices is of great significance and objective prospect for human beings. The energy conversion efficiency of wave energy devices is one of the key issues for the large-scale utilization of wave energy.

The important principle of energy conversion of wave energy device is through the periodic fluctuation of seawater, driving the float to dangle or oscillate, so that the oscillator with the reciprocating motion of the central axis to produce vibration or oscillation, driving the damping to do work to convert and store energy into mechanical energy.

In this paper, we establish the wave pendulum and oscillation model by Runge-Kutta method [1], simulate the displacement and velocity versus time of float and oscillator. Under the action of waves, the float moves and drives the central shaft to rotate by means of a rotating shaft, a torsion spring and a rotating damper. The oscillator rotates along the central axis and slides along the central axis. The two motions are of two dimensions and four degrees of freedom, and have a degree of coupling, but the degree of mutual influence is not big. Finally, particle swarm optimization algorithm is used to solve the maximum output power and optimal damping coefficient of the wave.

2. Model preparation

2.1. Runge-Kutta method

The Runge-Kutta method is a high-precision single-step algorithm widely used in engineering for solving the numerical solutions of differential equations. In this paper, we use the Runge-Kutta method to solve the displacement and velocity numerical solutions, and combine the matlab toolbox to fit the displacement-time, velocity-time images and longitudinal rocking angle velocity versus time images of the float and oscillator.

2.2. Particle swarm optimization algorithm

Particle swarm algorithm, a new evolutionary algorithm, is one of the evolutionary algorithms. It starts from a random solution, finds the optimal solution by iteration, and evaluates the quality of the solution by fitness. It is simpler than the genetic algorithm rules and finds the global optimum by following the best quality of the current search. This algorithm has attracted attention for its easy implementation, high accuracy, and fast convergence, and has demonstrated its superiority in solving practical problems. The particle swarm algorithm is a parallel algorithm. In this paper, the algorithm is used to solve the maximum wave output power with optimal damping coefficient [2].

3. Integrated model of wave droop and oscillation

Through the analysis, we know that with the vertical upward direction as the axis, the angle of float and oscillator in the swing is very small, and it is assumed that the horizontal swing in the swing process has negligible effect on the vertical swing, so the model is divided into two motions in the horizontal and vertical directions in the swing state and analyzed independently (to reduce the coupling relationship between the two dimensions of motion) to take the angle Q between the direction of the float plane and the direction of motion is infinitely close to 0.

In the vertical direction, the angle θ between the direction taken to the plane of the float and the direction of motion is infinitely close to 0°, The expressions are as follows:

$$\lim_{\theta\to\infty}\cos\theta = 1 \quad \lim_{\theta\to\infty}\sin\theta = 0 \tag{1}$$

For floats:

$$m_B a_B = -\rho g S v_B - (R_B v_B + m_H a_B) + f\cos\omega t \tag{2}$$

For oscillators:

$$m_o a_o = f\cos\omega t - R_a x_{\text{Relative}} - k x_{\text{Relative}} \tag{3}$$

In the horizontal direction:

$$J_V \partial_V = k\sigma - C\omega_V + L_M \cos\omega_V t \tag{4}$$

$$J_B \partial_B = L_M \cos\omega_B t - L_R \cos\omega_B t - L_I \cos\omega_B t \tag{5}$$

$$\begin{cases} J_V \partial_V = m\left[\left(L + x_V\right)\sin\theta\right]^2 \\ J_B \partial_B = 0.3MR^2 + \dfrac{m_B}{2}R^2 \end{cases} \tag{6}$$

The Runge-Kutta method is used to solve for the pendular displacement, pendular velocity and swing angular displacement and swing angular velocity of the float and oscillator.

Firstly, the vertical displacement and velocity with a time interval of 0.2s in the first 40 cycles are plotted according to the analytical solutions of the motion displacement and velocity of the float and oscillator. At this time, the cycle time is solved according to the equation, the equation is $T = \frac{2\pi}{\omega}$ .After the period is calculated as 3.663 according to the equation, the step size of Runge Kutta method time is set as 0.2s and the length is 40 cycles.

Finally, Runge Kutta method was used to solve the numerical solution according to the above mechanical model based on the force analysis of the oscillator and the float in the vertical direction, and the function images of the float's vertical displacement, swing velocity, angular swing velocity and vertical swing velocity with respect to time were obtained, as shown in the figure:

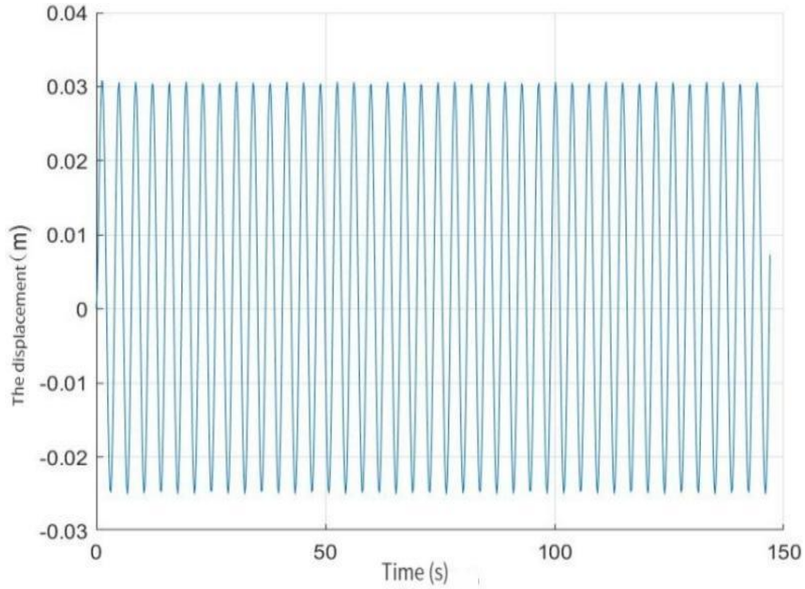

Figure 1. Graph of float heave displacement - time

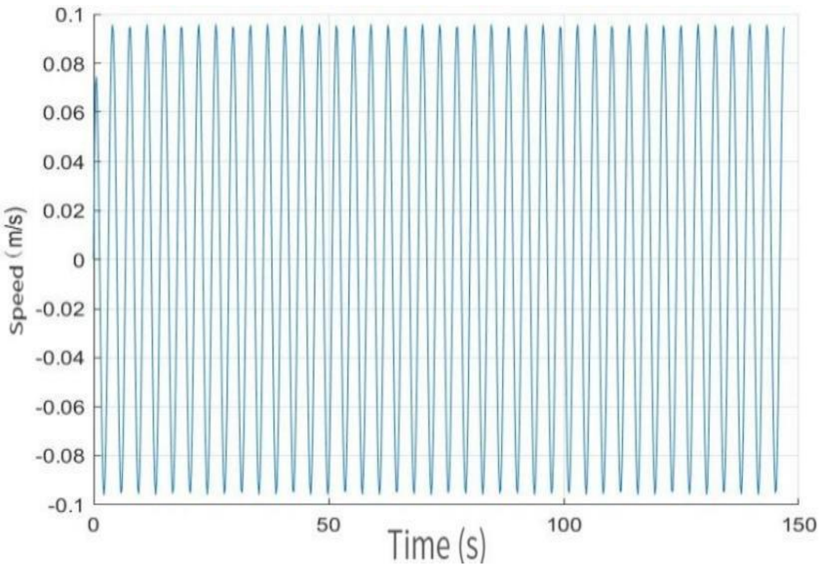

Figure 2. Graph of float heave speed and time

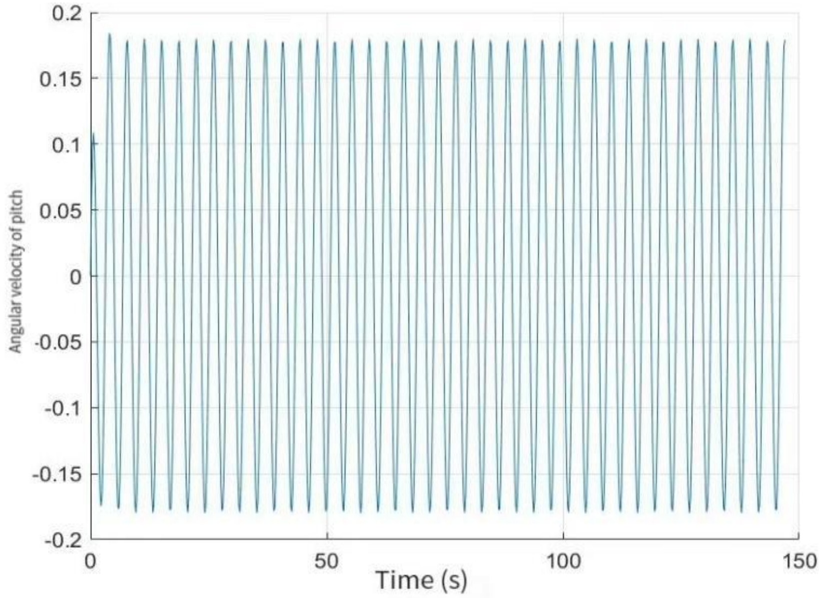

Figure 3. Image of float pitch angular velocity

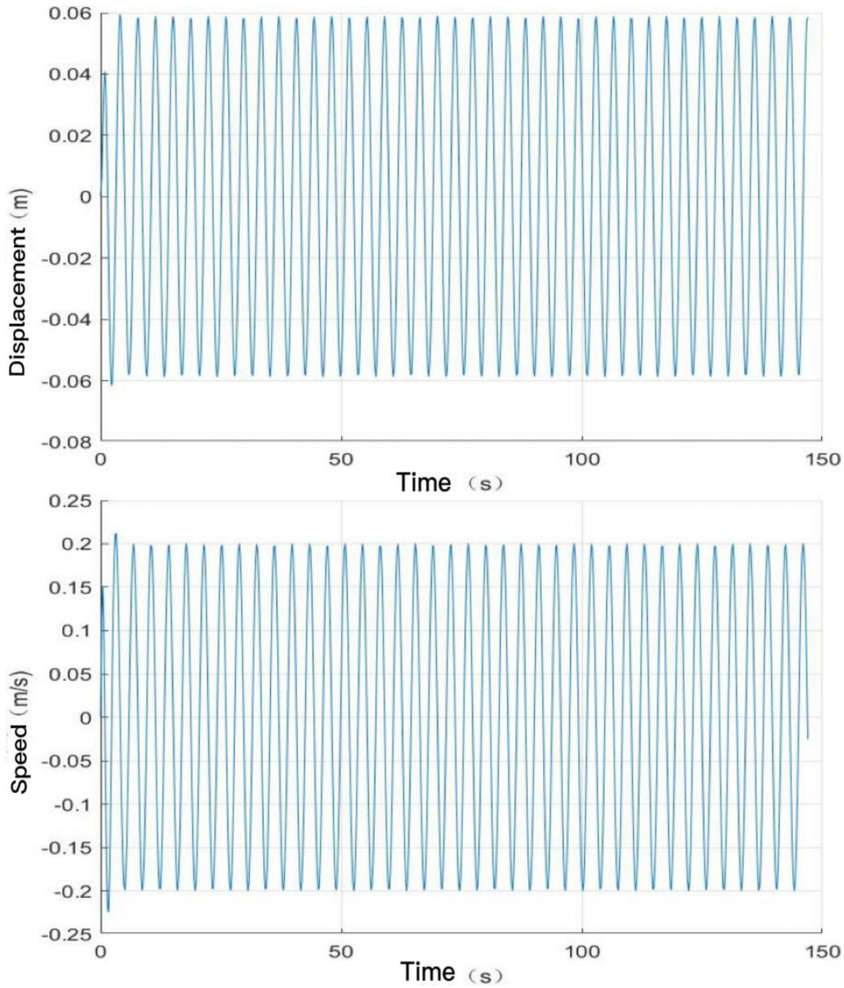

Figure 4. Oscillator pendulum displacement, pendulum velocity - time relationship

Meanwhile, the obtained displacement and velocity data of float and oscillator at 10s, 20s, 40s, 60s and 100s are as follows:

Table 2. Float and oscillator partial displacement and velocity data

Time (s)	Float displacement (m)	Float speed (m/s)	Oscillator displacement (m)	Oscillator speed (m/s)
10	-0.0171	-0.0675	-0.0423	0.1386
20	0.0246	-0.0591	-0.0353	-0.1611
40	-0.0226	0.0382	0.0223	0.1858
60	0.0303	-0.0149	-0.008	-0.1987
100	0.0291	0.033	0.0214	-0.1863

4. Maximum power and optimal damping factor model

The analysis shows that the energy in the PTO also includes the work done by the rotational damping moment in the rotation of the rigid body. Here, the work done by the damping force and the power of the rotational damping moment during the rigid body rotation are calculated separately, and finally summed to find the total power.

Its total wave energy is:

$$E = \frac{1}{8}\rho g H^2 D \tag{7}$$

Float kinetic energy:

$$E_k = \frac{1}{2} m_B {v_B}^2 \tag{8}$$

Float potential energy:

$$E_p = \frac{1}{2}\rho g S x_B \tag{9}$$

Float rotational kinetic energy:

$$E_{k2} = \frac{1}{2} J_B {\omega_B}^2 \tag{10}$$

In the direction of pendulum swing:

$$M_{\mathrm{pto}} = L\cos\omega t - C\alpha + k\alpha \tag{11}$$

Instantaneous power:

$$P_M = M_{pto}\alpha \tag{12}$$

Average power:

$$\overline{P} = \frac{\int_{t_1}^{t_2} M_{pto}\alpha dt}{t_2 - t_1} \tag{13}$$

5. Maximum power and optimal damping coefficient solving

In this paper, the mechanical equation relationship between power and damping coefficient under the state of vertical swinging motion is established, and the particle swarm algorithm is used to iteratively solve the optimization model [3-4], and the optimal solution is obtained as the damping coefficient for linear damping in about 30,000, rotating dampers in about 120,000, and the maximum output power is 83.41KW.

6. Conclusion

Nowadays, non-renewable resources are depleting and causing serious pollution to the environment. The use of wave energy can greatly alleviate the energy crisis, so the development of wave energy devices is of great importance.

In this thesis, the displacement-time and velocity-time images of the float and oscillator are solved using the Runge-Kutta method and matlab toolbox, and the maximum output power design and the optimal damping coefficient are solved using particle swarm optimization algorithm.

The final solution gets the maximum total power at 83.41KW, the optimal linear damping at about 30,000, and the optimal rotational dampers at about 120,000.

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