Design of Reciprocating Wave Power Generation System

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Abstract. The world’s energy structure, the main energy used by mankind is still oil, natural gas and coal and other non renewable resources. Therefore, renewable energy has a huge development prospect. Wave energy is a renewable energy with a high density. The system mainly depends on the wave energy in the ocean and provides a reciprocating wave power generation system. The influence of sea state on the dynamic characteristics of power tools is analyzed by using the knowledge of dynamics. The mechanical analysis of crank and connecting rod is carried out to understand its vibration characteristics, which provides necessary theoretical basis for power tools such as wave power generation system.

Key words: Waves; Electricity-generation; Dynamics; Buoyancy.

1. Introduction
China is rich in marine energy resources, and its development and utilization prospects are very broad. The coastline of China's mainland is more than 18000 kilometers, and there are more than 5000 islands. Its coastline is more than 1400 kilometers long, and the entire sea area is 4.9 million square kilometers[1]. If China's marine energy resources are converted into useful power value, it can reach at least 150 million kilowatts, which is more than twice the total installed capacity of China's electric power. In terms of the development and utilization of marine energy, China is still in its infancy. Some coastal areas have developed various experimental power generation devices and built experimental tidal power stations, which have laid a preliminary foundation for the further development and utilization of marine energy in the future[2].

In this paper, we explore the reciprocating wave power generation system, which imitates the piston motion of the automobile engine, uses the motion module of the system float to form kinetic energy through the vibration energy of water quality points in the water flow[3], and the wave fluctuation energy generates potential energy[4]. By combining the vibration characteristics of the transmission system, the technical principle of the generator, lever, elastic mechanics, three-phase voltage stabilizing technology and other physical knowledge, the sea is combined[5] Wave energy is converted into electrical energy[6]. The reciprocating wave power generation system is composed of float, driving wheel assembly, crank connecting rod, variable speed gear, three-phase alternator, rectifier and other component.
2. Principle of reciprocating wave power generation system

2.1. Analysis of reciprocating wave power generation system
Ocean current and wave coexist in the sea water, where the current is a large-scale non periodic movement from one area to another in the horizontal or vertical direction. Its generation is the movement under the action of external forces, such as the sea current caused by the wind force on the sea level, which is called wind-driven current, also known as drifting. Waves are mainly generated by the wind in the ocean. Under different wind speed, wind direction and terrain conditions, the size of waves varies greatly, and the wavelength ranges from tens of centimeters to hundreds of meters. Compared with the sea wave, the direction of current movement is relatively stable and slow, and the volume of the research object is small[7], so the influence of current on the system is ignored in this paper.

The reciprocating wave power generation system is composed of float, transmission wheel components, crank connecting rod, variable speed gear, three-phase alternator, rectifier and other components. The floating part of the moving module forms kinetic energy through the simple harmonic vibration of particles in the water flow, and the wave fluctuation energy generates potential energy. The wave energy is converted into electric energy by combining the vibration characteristics of the transmission system, the principle of electromagnetic induction phenomenon of the generator, lever, elastic mechanics, three-phase voltage stabilizing technology and other physical modules[8].

2.2. Buoyancy generated by float
For the convenience of calculation, suppose that the total effect of waves on the float is the same in all directions of the current, and the square with B side length of the bottom cross section of the float has the following [9]:

\[ \pi r^2 = b^2 \] (1)

Set the trajectory of the float \( S(t) \), The buoyancy of the float is \( F_{fb} \), so:

\[ F_{fb} = pgb \int_{-b}^{b} \frac{A}{2} \sin \left( \frac{2\pi}{\lambda} x + wt \right) + H - S(t) \] dx (2)

Simplified and available:

\[ F_{fb} = \frac{pgbA\lambda}{2\pi} \sin \left( \frac{\pi b}{\lambda} \sin(wt) - pgb^2S(t) + C \right) \] (3)

2.3. Wave dynamics analysis
The common waves on the sea surface can be described by irregular waves. The motion of waves produces dynamic pressure in the water, and its strength is related to the amplitude of waves. The main moving part of the system is at the float. The dynamic energy in the horizontal direction is offset, and the kinetic energy mainly acts on the upper and lower surfaces of the float. In this paper, the dynamic characteristics of the bottom surface of the float under sea state are mainly studied. It can be seen [10]:

\[ \xi_a^T = \xi_a e^{-k|\tau|} \] (4)

Where \( \xi_a \) is the amplitude of the free water surface, which indicates that each particle of the liquid moves uniformly along the circular orbit, \( \xi_a \) is the wave amplitude at the water depth T, and the wave number \( k = 2 \pi / \lambda \) (\( \lambda \) is the wavelength). It is known from hydrodynamics that the amplitude decreases exponentially with water depth[11].

The floating object has six degrees of freedom motion relative to o-xyz coordinate system. Because of the rolling motion, pitch motion and heave motion of the floating object on the wave are more obvious than the oscillation motion of other components. In this system, the transverse wave of the floater is the opposite dynamic pressure, so only the pitch and heave motions of the float in regular waves are
considered. Considering the difference of dynamic and static pressure gradients in sea waves, the slice method is used to modify the wave type coordinates after Smith correction coefficient, and the vertical relative displacement between transverse section and wave surface is

\[ Z_H = Z - X\theta - \xi \]  

(5)

The equivalent wave surface equation generated by wave can be expressed as

\[ \xi_a T^* = \xi_a e^{-kT^*} \cos(kx\cos\beta + k\sin\beta + \omega t) \]  

(6)

Average draft \( T^* = \frac{Ax}{2y} \), Ax is the slice area below the waterline, 2y is the slice width

The hydrodynamic force acting on the vertical moving slice consists of hydrostatic force, wave making resistance and additional inertial force. The vertical dynamic force of the float can be obtained by integrating the hydrodynamic forces on each cross section into x[12].

2.4. Dynamic analysis of crank connecting rod

The crank connecting rod mechanism is a transmission mechanism which uses the reciprocating motion of the sea wave to realize the work cycle and complete the energy conversion. It is used to transfer the force and change the direction of the force. In the process of work, the crank connecting rod mechanism transforms the up-down reciprocating motion of the sea wave into the rotary motion of the crankshaft, and outputs the power to the outside. In the process of the fluctuation of the sea wave, the rotary motion of the crankshaft is transformed into the reciprocating fluctuation motion of the float. Therefore, the crank connecting rod mechanism is the mechanism by which the wave can generate and transmit power, through which the kinetic energy of the wave can be transformed into mechanical energy[13]

As shown in Figure 3, the heavy hammer wheel (the wheel of the heavy hammer) on the crank connecting rod increases the centrifugal mass of the crank and connecting rod, so that the crank and connecting rod can obtain a higher rotating centrifugal mass, so as to reduce the rotational kinetic energy required by the crank and connecting rod, and achieve a higher utilization rate of kinetic energy for the reciprocating fluctuation of waves. The force \( P \) produced by the float and the force \( P_c \) on the connecting rod \( L \) exist a relationship:

\[ P_c = P \cos\varphi \]  

(7)

At the point A, the relationship between the force \( P_c \) in the crank direction and the tangent force \( PT \) on the crank neck is obtained:

\[ P_T = P_c \sin(\varphi + \theta) \]  

(8)

The torque \( T \) is the product of tangent force \( PT \) and radius \( r \) of crank neck,

\[ T = P_T \cdot r \]  

(9)

The simultaneous equations 4, 5 and 6 are obtained

\[ T = r \cdot P\cos\varphi\sin(\varphi + \theta) \]  

(10)

In this system, the radius of the crank is far less than that of the crank connecting rod \( L \), and the angle of \( \varphi \) tends to 0:

\[ T = r \cdot P\sin\theta \]  

(11)

According to the analysis of plane circle and cosine theorem, the relationship between \( P \) and stroke \( s \) is obtained:

\[ T = P\sqrt{2rs - s^2} \]  

(12)
When \( s \in (0, r) \) the torque \( T \) increases rapidly with the increase of stroke \( s \); when \( s \in (r, 2r) \), the torque \( T \) increases slowly with the increase of stroke \( s \). The results show that how to improve the utilization rate of crank kinetic energy between \((0, r)\) has an important reference[14].

![Structure of crank bar mechanism](image)

**Fig. 1** Structure of crank bar mechanism

### 3. Simulation of real power generation environment test

Table 1 shows the parameters of the system: output voltage and current after artificial wave making simulation environment test in calm lake. The power is compared by observing the luminous intensity of external LED lights. The experimental results show that the system runs stably, and the output DC voltage of rectifier increases with the increase of artificial wave suppressing vibration frequency in a nonlinear convex curve, and the output DC voltage increases linearly through fitting [15]

| Wave frequency | Current and Voltage value | average value |
|----------------|---------------------------|---------------|
| 0.5Hz          |                           |               |
| 1              | 4.41V                     | 4.78V         |
|                | 4.30V                     |               |
|                | 4.80V                     |               |
|                | 4.90V                     |               |
|                | 5.47V                     |               |
|                | 4.78V                     |               |
|                | 4.65mA                    | 6.81mA        |
|                | 4.30mA                    |               |
|                | 7.30mA                    |               |
|                | 6.46mA                    |               |
|                | 5.90mA                    |               |
|                | 4.77mA                    |               |
| 1Hz            |                           |               |
| 2              | 4.80V                     | 5.56V         |
|                | 5.30V                     |               |
|                | 5.30V                     |               |
|                | 7.00V                     |               |
|                | 5.41V                     |               |
|                | 5.56V                     |               |
|                | 5.30mA                    | 8.55mA        |
|                | 7.21mA                    |               |
|                | 7.00mA                    |               |
|                | 9.01mA                    |               |
|                | 9.50mA                    |               |
|                | 8.55mA                    |               |
| 2Hz            |                           |               |
| 3              | 5.30V                     | 5.73V         |
|                | 6.00V                     |               |
|                | 6.31V                     |               |
|                | 5.30V                     |               |
|                | 5.76V                     |               |
|                | 5.73V                     |               |
|                | 9.62mA                    | 9.28mA        |
|                | 9.66mA                    |               |
|                | 9.31mA                    |               |
|                | 9.31mA                    |               |
|                | 8.50mA                    |               |

### 4. Conclusion

The whole system has certain requirements for structural materials, which needs kinematic analysis to calculate the approximate force. Since the float is driven by the water quality point in the vertical direction in the sea wave, the vertical pressure can be obtained by using the wave equation of the wave, and the appropriate structural material can be selected. Due to the randomness and variability of ocean waves, the culture is complicated and simple. The irregular wave motion is simplified to regular motion, and the parameters are set and the correction coefficient is found. The determination of each parameter needs to be changed according to the situation. The experimental results show that the system can also be modified to improve the energy transmission efficiency.

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