Experimental Research on the Characteristic of a Generator Used in Wave Energy Conversion

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Abstract. Due to the environmental issues like global warming and pollution, the exploration for ocean energy becomes important. Selecting the suitable generator for wave energy generation system is essential to improve the efficiency of power generation system. Thus, the object of the research is the generator of a self-adaptation inversion type wave energy absorption device. The major focus of this paper is the characteristics and the technique of the generator used in prototype. By setting up the generator performance test platform, the output voltage, efficiency and performance of the generator are tested to select the suitable generator for the wave energy generating system.

1. Introduction
The ocean wave energy is abundant and environmental [1, 2, 3]. Moreover, it is used to provide large-scale power for people’s daily life. Meanwhile, it can be used for single generator device to supply power for beacon, light buoy or underwater vehicle [5]. The micro wave energy generator device is one of them, which is equipped with great mobility, and the power can be supplied to any devices when it was directly assembled on them. In the light of present situation, it has great development prospect. From the point of the current worldwide research results [6, 7], the various countries' research is focus on how to more efficiently capture the wave energy, the energy conversion system design study is not very thorough [8]. The traditional methods, such as hydraulic drive motor power, or simply use the up and down or rotating mechanical driving generators [9], it is difficult to effectively improve the efficiency and stability of energy conversion process in the small wave energy device [4], so this paper intends to further study of mechanism of wave energy power conversion system with adaptive inversion type wave energy device as the research object. Analyses its energy characteristics, on this basis to choose permanent magnet dc generators, implement storage utilization of wave energy device output power.

2. Description of Prototype
The generator for experiment is a permanent magnet dc generator with a maximum power of 30W, reduction ratio is 50:1. Set up the experiment platform as shown in figure 1, JN338 is equipment for measuring torque and rotation speed. The speed, torque and power data output measured by JN338 are connected to the secondary measuring instrument. Record and process the data so that the speed - voltage relation curve, voltage - current output characteristic curve and torque - current relation curve can be obtained.
3. Experiment and Results

According to the previous experimental platform, the input torque changes with the load can be measured by JN338 at a certain speed. According the formula $P = T \cdot \omega = T \cdot \frac{2\pi \cdot n}{60}$, the input power of the generator can be calculated. Among them, $T$ is the rotation torque, the unit is $N \cdot m$, the unit of rotation speed $n$ is $r/min$, and the unit of power $P$ is $W$.

After the test, when the output torque is around 0.3 $N \cdot m$, the generator can be driven to rotate, so its starting torque is about 0.3 $N \cdot m$.

The corresponding relationship data of torque and resistance value when the speed is 40r/min is shown in table 1.

| $R$ ($\Omega$) | 4.32 | 5.98 | 11.08 | 14.80 | 20.20 | 29.52 | 35.90 | 45.92 |
|---------------|------|------|-------|-------|-------|-------|-------|-------|
| $T$ ($N \cdot m$) | 0.97 | 0.85 | 0.67 | 0.58 | 0.52 | 0.45 | 0.42 | 0.39 |

In this way, the corresponding relationship between input power and load resistance can be obtained, and the data is shown in table 2.

| $R$ ($\Omega$) | 4.32 | 5.98 | 11.08 | 14.80 | 20.20 | 29.52 | 35.90 | 45.92 |
|---------------|------|------|-------|-------|-------|-------|-------|-------|
| $P$ ($W$) | 4.06 | 3.57 | 2.82 | 2.45 | 2.20 | 1.89 | 1.75 | 1.63 |

And in this way, the relationship data of efficiency and resistance can be obtained as shown in table 3, and the relationship curve is shown in figure 2. It can be seen that, when the speed is 40r/min, the efficiency of generator is very low. The maximum of efficiency is about 37%, when the resistance is around 15$\Omega$. 

![Diagram of Generator Test Platform](image)
Table 3. Relationship data of efficiency and resistance when the speed is 40r/min

| R (Ω) | 4.32 | 5.98 | 11.08 | 14.80 | 20.20 | 29.52 | 35.90 | 45.92 |
|-------|------|------|-------|-------|-------|-------|-------|-------|
| η (%) | 28.57 | 31.65 | 36.52 | 36.73 | 35.45 | 32.80 | 30.29 | 26.99 |

The relationship data of torque and resistance when the speed is 60r/min is shown in table 4.

Table 4. The relationship data of torque and resistance when the speed is 60r/min

| R (Ω) | 5.62 | 7.24 | 8.82 | 11.03 | 15.22 | 20.74 | 25.68 | 31.09 | 36.86 | 45.48 |
|-------|------|------|------|-------|-------|-------|-------|-------|-------|-------|
| T (Nm) | 1.15 | 1.04 | 0.94 | 0.86 | 0.73 | 0.64 | 0.57 | 0.51 | 0.48 | 0.44 |

In this way, the relationship data of input power and resistance can be obtained, as shown in table 5.

Table 5. The relationship data of input power and resistance when the speed is 60r/min

| R (Ω) | 5.62 | 7.24 | 8.82 | 11.03 | 15.22 | 20.74 | 25.68 | 31.09 | 36.86 | 45.48 |
|-------|------|------|------|-------|-------|-------|-------|-------|-------|-------|
| P2 (W) | 7.22 | 6.53 | 5.91 | 5.40 | 4.58 | 4.02 | 3.58 | 3.20 | 3.01 | 2.76 |

Therefore, the change of efficiency relative to resistance can be obtained at this speed, the data is shown in table 6, and the relationship curve is shown in figure 2. It can be seen that, the efficiency of generator have increased, but not much. The maximum efficiency is only 42% when the resistance is around 15Ω.

Table 6. The relationship data of efficiency and resistance when the speed is 60r/min

| R (Ω) | 5.62 | 7.24 | 8.82 | 11.03 | 15.22 | 20.74 | 25.68 | 31.09 | 36.86 | 45.48 |
|-------|------|------|------|-------|-------|-------|-------|-------|-------|-------|
| η (%) | 33.52 | 36.91 | 38.92 | 40.74 | 42.14 | 41.54 | 39.94 | 39.69 | 37.54 | 35.14 |

The relationship data of torque and resistance when the speed is 80r/min is shown in table 7.

Table 7. The relationship data of torque and resistance when the speed is 80r/min

| R (Ω) | 5.88 | 7.05 | 9.95 | 13.62 | 16.18 | 20.30 | 24.29 | 29.71 | 35.02 | 44.01 |
|-------|------|------|------|-------|-------|-------|-------|-------|-------|-------|
| T (Nm) | 1.34 | 1.28 | 1.10 | 0.92 | 0.84 | 0.74 | 0.67 | 0.61 | 0.58 | 0.52 |

In this way, the relationship data of input power and resistance can be obtained, the data is shown in table 8.

Table 8. The relationship data of input power and resistance when the speed is 80r/min

| R (Ω) | 5.88 | 7.05 | 9.95 | 13.62 | 16.18 | 20.30 | 24.29 | 29.71 | 35.02 | 44.01 |
|-------|------|------|------|-------|-------|-------|-------|-------|-------|-------|
| P2 (W) | 11.23 | 10.72 | 9.21 | 7.71 | 7.04 | 6.20 | 5.61 | 5.11 | 4.86 | 4.36 |

Therefore, the relationship data of efficiency and load can be obtained as shown in table 9, and the relationship curve is shown in figure 2.

Table 9. The relationship data of efficiency and resistance when the speed is 80r/min

| R (Ω) | 5.88 | 7.05 | 9.95 | 13.62 | 16.18 | 20.30 | 24.29 | 29.71 | 35.02 | 44.01 |
|-------|------|------|------|-------|-------|-------|-------|-------|-------|-------|
| η (%) | 33.92 | 37.46 | 41.51 | 44.70 | 44.52 | 45.30 | 45.43 | 44.29 | 41.17 | 39.21 |

The relationship data of torque and resistance when the speed is 100r/min is shown in table 10.

Table 10. The relationship data of torque and resistance when the speed is 100r/min

| R (Ω) | 5.76 | 7.03 | 8.41 | 11.11 | 13.75 | 16.30 | 20.35 | 25.93 | 34.16 | 45.95 |
|-------|------|------|------|-------|-------|-------|-------|-------|-------|-------|
| T (Nm) | 1.49 | 1.39 | 1.31 | 1.22 | 1.10 | 1.00 | 0.89 | 0.78 | 0.66 | 0.58 |
In this way, the relationship data of input power and resistance can be obtained, the data is shown in table 11.

Table 11. The relationship data of input power and resistance when the speed is 100r/min

| R (Ω) | P_2 (W) |
|-------|---------|
| 5.76  | 15.60   |
| 7.03  | 14.55   |
| 8.41  | 13.72   |
| 11.11 | 12.77   |
| 13.75 | 11.52   |
| 16.30 | 10.47   |
| 20.35 | 9.32    |
| 25.93 | 8.16    |
| 34.16 | 6.91    |
| 45.95 | 6.07    |

Therefore, the relationship data of efficiency and load can be obtained as shown in table 12, and the relationship curve is shown in figure 2. It shows that the maximum efficiency of the generator at high speed is approximately 46% when the resistance is 20Ω.

Table 12. The relationship data of efficiency and resistance when the speed is 80r/min

| R (Ω) | η (%) |
|-------|-------|
| 5.76  | 31.00 |
| 7.03  | 34.96 |
| 8.41  | 37.98 |
| 11.11 | 42.11 |
| 13.75 | 43.70 |
| 16.30 | 44.55 |
| 20.35 | 45.40 |
| 25.93 | 44.88 |
| 34.16 | 43.89 |
| 45.95 | 40.72 |

Figure 2. The relationship of efficiency and resistance

4. Discussion
It can be seen that, with the increase of resistance, the efficiency of motor power generation is increased and then decreased. When the resistance is between 15Ω and 25Ω, power generation efficiency reaches its maximum. With the increase of rotating speed, the power generation efficiency generally increases, and when the speed reaches 80r/min, the power generation efficiency basically reaches the limit value; the maximum efficiency of the generator at high speed is approximately 46% when the resistance is around 20Ω. After experimental verification, it can be seen that, the energy conversion efficiency of the generator is very low. The possible reason is that the gears in the reducer are rubbing too much and the generator has more heat in the coil in the process of generating electricity, which low power generation efficiency.

5. Conclusion
Generator selection is a critical issue in any power generation system. In this paper, we set up the generator revolution speed and torque test platform. The power and efficiency is calculated by calculation and the power generation performance of the generator is analysed. Change trend of the power generation efficiency varies with load and speed is found. The maximum power generation efficiency of a generator can reach approximately 46%. It provides reasonable experimental basis for generator selection of whole wave power generation system. In later studies, a more efficient generator could be replaced to make the wave power plant more efficient.

6. Acknowledgments
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