Performance analysis of a new type of rainwater power generation device based on piezoelectric effect

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Abstract. In this paper, the water catchment device is combined with the piezoelectric cantilever beam to gather raindrops into a larger rainball to improve the power generation efficiency of the system. This makes rainwater power generation more feasible. The results show that when the rainfall intensity is constant, the output voltage of the power generation system increases significantly as the size of the rainwater converging device increases. With the same size of rainwater converging device, as the rainfall intensity increases, the power generation effect is also significantly improved, thus demonstrating the feasibility of the new rainwater power generation device.

1. Introduction

Nowadays, the use of energy and human power in the environment to provide real-time power supply for portable micro-power appliances and wireless sensors has become a research hotspot in the world [1-4]. Common power generation systems based on vibration power generation can be divided into three types: electromagnetic type [5-6], electrostatic type [7] and piezoelectric type [8-9]. The structure of the piezoelectric energy harvester itself can easily make raindrops impact it, so as to realize the conversion of raindrop kinetic energy to electric energy. On the other hand, compared to the other two types, the piezoelectric type has a simple structure, which makes the entire device smaller, so that it can be used in some micro-devices. The combined study of piezoelectric vibration energy harvester and raindrop kinetic energy capture is of more research significance. Aimed at the problem that the potential energy of the raindrop itself is relatively small in rainwater power generation, and the vibration frequency that can be generated is low. This paper proposes a new type of rainwater power generation device based on the piezoelectric effect, which integrates rainwater into a larger rainball, generates electricity by impact on the piezoelectric cantilever, and conducts research and analysis on its related performance.

2. Rainwater excitation increasing device

Since the diameter and quality of the rain ball are important factors that affect the power generation efficiency of the system during rainwater power generation, this paper proposes a new type of rainwater power generation device based on the piezoelectric effect, which integrates rainwater into a larger rainball. The beam performs impulse power generation, and conducts research and analysis on its related performance.
The piezoelectric cantilever used has a length of \( l = 130 \text{mm} \), a thickness of 0.2\( \text{mm} \), and a width of 20\( \text{mm} \). The piezoelectric film material is PVDF and the thickness is 52\( \mu \text{m} \). The magnet material is Nd2Fe14B, the diameter of the magnet is 10\( \text{mm} \), the thickness is 3\( \text{mm} \), and the magnetization is \( 1.19 \times 10^6 \text{A/m} \).

It can be seen from Figure 2 that the potential energy function of the bistable piezoelectric cantilever beam constructed in the article has two symmetric stable equilibrium points and an unstable equilibrium point, where the distance between the equilibrium points and the depth of the potential well decrease with the increase of the magnet spacing \( D \).

As shown in Figure 3, the rainwater collection part constructed in this article is connected by six coaxial cube collection tanks. A cube collection tank is placed every 60° on the periphery of the central axis, and the rainwater runs along the pipes of the rainwater collection ceiling of the house. Flow into the cube collection tank. The position of the cube collection tank directly below the pipe is located. There is a plate below it (not shown in the figure). When the water in the device reaches the preset water level, the support force of the plate on the device is not enough to resist when the device rotates, the device starts to rotate. When the device starts to rotate, the rainwater inside the collection tank will pour out, and the support plate is reset. When the device rotates 60°, the next collection tank starts to collect rainwater. Perform periodic rotation of the device. The collection tank directly below the pipeline is the
initial position of the device to collect water. The following is to study the performance of the established rainwater collection model.

Moment of inertia of the established device:

\[ J = 6 \cdot \left( \frac{4m_0a^2}{3} + 5m_0 \left( r_0 + \frac{2}{5}a \right)^2 \right) \]  

\[ m_0 \] is the mass of a single cube collection tank, \( a \) is the side length of the cube water collection device, and \( r_0 \) is the rod length of the rotary water collection device. In order to simplify the calculation, this article assumes that the water in the device flows out at the moment the device rotates. The force model of the device can be simplified to an instantaneous force when the device is in equilibrium. The magnitude of the instantaneous force \( F_s \) instant is equal to the mass of the largest water contained in the device:

\[ F_s = \rho_w \cdot V_w = \rho_w \cdot \frac{a^3}{\sqrt{3}} \]  

\[ F_s = J \cdot \alpha \]  

\[ \frac{1}{2} \alpha T_0^2 = \frac{\pi}{3} \]  

\[ T_0 = \frac{2\pi}{3a} \]  

From (2), (3) and (4), the angular acceleration \( \alpha \) and period \( T_0 \) of the device after being subjected to instantaneous force can be obtained. Assuming that the rain hits the beam in the form of a rain ball, the radius of the rain ball is obtained as \( R \), and \( a \) is the side length of the square water collecting device.

\[ \frac{a^3}{\sqrt{3}} = \frac{4}{3} \pi R^3 \]  

\[ R = \sqrt{\frac{3a^3}{4\pi}} \]  

The instant the rain ball touches the board is

\[ v = \sqrt{2gh} \]

Assuming that there is no splash on the cantilever beam under the action of the rain ball, the action time of the water ball is

\[ t_0 = \frac{2R}{v} \]  

From the impulse theorem

\[ F't = mv = \rho_w \cdot \frac{a^3}{\sqrt{3}} \cdot \sqrt{2gh} \]

The instantaneous average force of a single rainball on the bistable piezoelectric cantilever can be obtained:

\[ F' = \frac{\rho_w \frac{a^3}{\sqrt{3}} \sqrt{2gh}}{t_0} \]

3. Dynamic analysis of piezoelectric cantilever beam power generation system under different rainfall intensities

The three rainfall intensities studied in this experiment are 10mm/h, 20mm/h, and 30mm/h, respectively corresponding to three different rainfall situations in simulated real life. It can be calculated by the above formula that the period corresponding to the device under different rainfall intensities and the power generation effect of the system corresponding to different device sizes are different when the period is the same. As shown in the figure, when the device side length \( a=30\)mm, the function graphs of rainwater impact under the rainfall intensity of 10mm/h, 20mm/h, 30mm/h respectively.
As shown in Figure 4, when the device size $\alpha = 30\text{mm}$, the raindrop impact model corresponding to different rainfall intensities shows that when the device size is fixed, the main change is the period of the device's action.
In order to see more directly the influence of the size of the excited device on the power generation efficiency of the system under continuous rainfall, simulation was carried out by Comsol software when the rainfall intensity is I=10mm/h and the side length a of the device is 20mm, 30mm, 40mm. The output voltage of the system changes with the duration of excitation, and the result is shown in Figure 5. From the figure, we can see that under the condition of constant rainfall intensity, as the size of the device a continues to increase, the diameter of the rainball that is collected by the rainwater collection device becomes larger, and the impact force of the rainball on the cantilever beam is also increased. Correspondingly become larger. The increase in the number of cantilever beam movements greatly improves the efficiency of power generation. And as the size of the device continues to increase, the output voltage of the system has been significantly improved, so it can be verified and predicted here that the diameter distribution of raindrops in actual conditions will have a great impact on the power generation efficiency of the system, that is to say, for rainwater it is necessary to lay rainwater collection devices in the power generation system to increase rainwater excitation.
Under the condition of the device size $a=30\text{mm}$ unchanged, take the rainfall intensity $I=10\text{mm/h}$, $20\text{mm/h}$, $30\text{mm/h}$, the change of the output voltage of the system with the excitation duration, and the results are shown in the figure. From the figure, we can see that as the rainfall intensity is set to $I=10\text{mm/h}$, $20\text{mm/h}$, $30\text{mm/h}$, the period of the device's action continues to become shorter, which makes the frequency of continuous rainball excitation of the piezoelectric cantilever continue to increase. The cantilever beam has increased the number of substantial movements, which effectively improves the power generation efficiency.

4. Conclusion

(1) In this paper, the rainwater excitation booster device is added to the power generation system. The process of raindrops impacting the piezoelectric beam after being converged by the rainwater excitation amplification device is established as a rainball impact excitation model.

(2) Through Comsol simulation, under the continuous raindrop impact, the output response of the system changes with the device size and rainfall intensity, and the output voltage diagram of the system response is obtained. The results show that when the continuous rainball converged by the rainwater converging device impacts the piezoelectric cantilever beam, the system response is a periodical enhancement process.

(3) When the rainfall intensity is constant, the larger the device size is, the amplitude of the vibration at the end of the piezoelectric cantilever beam will continue to increase, and the output voltage will increase significantly. In the case of the same size of the device, the greater the rainfall intensity, the greater the frequency of the substantial movement of the end of the piezoelectric cantilever beam, and the more obvious the power generation effect.

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