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Design and Research of an Energy-Feeding Backpack

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ABSTRACT. *This paper introduces a kind of load-bearing device that can realize energy recovery, which has the function of continuous power generation and can enhance the power continuation capacity of outdoor sports personnel communication equipment. The device uses the fluctuation of the center of gravity when the human body is walking to convert the relative linear motion between the load and the human body into the single-direction rotation motion of the motor, so as to achieve the function of generating electricity and realize the power supply of the portable equipment through the power electronic circuit. First establish the mathematical model of the backpack, and then verify the power generation efficiency of the backpack through simulation and experiment.*

KEYWORDS: *Backpack, Energy recovery, Power generation*

1. Introduction

In the process of survival in the wild, military and police duty, and mountaineering training, it is very necessary to carry electrical equipment for lighting, communication and life rescue, but it is difficult to obtain a continuous supply of electrical energy for long-term outdoor activities.[1]

At present, although many universities and enterprises at home and abroad are carrying out research on energy-feeding-power backpacks, the mechanical design of most products is complicated, which reduces the user experience to a certain extent, and the “energy recovery technology” is not properly integrated into the overall framework of backpacks. In addition, some backpacks can hold little space, do not meet the needs of backpackers to go out, and have a large weight, which weakens the use effect brought by the design in practical application.Therefore, a backpack with simple structure, light weight, large space and continuous power generation is of great research value.[2]

2. Design of Energy-Feeding Backpack Device

The human center of gravity fluctuates periodically when walking or running.[3] When the human body carries the backpack and moves together, the

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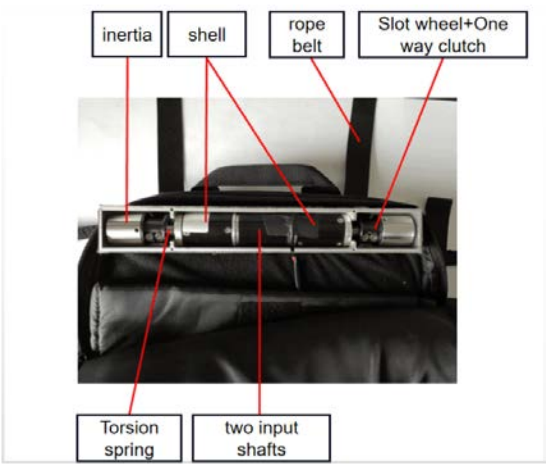
weight of the backpack and the human body will be combined. In addition, the backpack device adopts an integrated design in the overall structure, which has the characteristics of compact structure, light weight, and small size. By connecting the slide rail, it greatly alleviates the discomfort to the back of human body when the backpack is vibrating up and down.The efficiency of converting vibration energy into electric energy is improved, and the energy recycling and comfort of human body are realized.

The backpack device is mainly composed of a power feeding rectifier, an electric energy management module, a linear guide mechanism, a strap and a backpack. Among them, the energy-feeding rectifier module mainly includes a shell, a rope belt, a sheave, a torsion spring, inertia, a generator, etc., and the overall structure is compact in design and small in size.

As shown in Figure 1, the DC generator adopts the structure of double gearboxes and double input shafts, which are arranged in the shell. The shell is built in the backpack in a horizontal form. The rope belt is fixedly connected with the sheave. The torsion spring and the one-way clutch, the torsion spring in the sheave wheel and the two input shafts are connected by the one-way clutch, the input shafts at both ends of the generator are fixed with an inertia respectively, so that the whole mechanism becomes a stable vibration that can work in cycles. The system continuously recovers vibration energy.[4]



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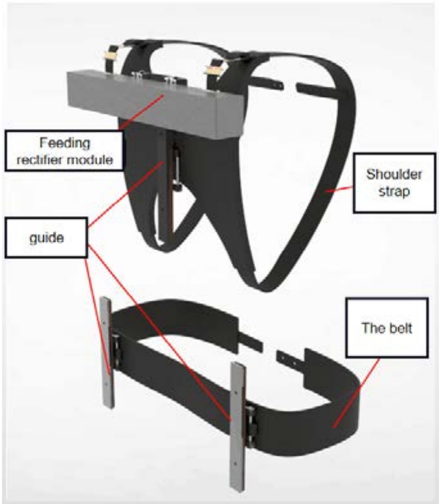

Fig.1 Schematic Diagram of Energy Recovery Device

Fig.2 Carrying Module Structure Diagram and Overall Effect Diagram

3. Build the Mathematical Model

In order to simplify the analysis, the human shoulder and the shoulder strap can be considered as a rigid connection, so that the human body is subjected to a certain impact load. In order to reduce this impact load, it is proposed to connect the human

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body with the load by using an equivalent spring link method. Due to the elastic force of the spring, the fluctuation range of the center of mass of the backpack carried will be greater than before, resulting in an unstable center of gravity of the human body and a bad experience for the user. In order to avoid this phenomenon, the human body-backpack system needs to be reasonably restricted. Therefore, we need to build a human body-backpack vibration model.

3.1 Build a Human Body-Backpack Vibration Model

The human body has periodic motion excitation during walking or running. In order to facilitate the analysis, this paper simplified the model when the human body is traveling with a load to a two-degree-of-freedom system under an excitation. The influence of the human leg can be simplified as a rigid damping element, and the connection between the load and the human body can be equivalent to a spring connection. In the process of walking, the load vibrates up and down relative to the human body, and there is a displacement difference between the center of mass of the person and the center of mass of the load. The simplified model of human walking movement is shown in Figure 3. According to the literature [7], the excitation of the system can be expressed as:

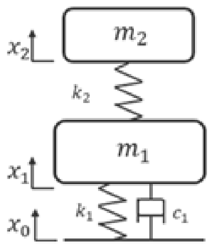

Fig.3 The System Model When the Load is in Elastic Contact with the Human Body

$$x_0 = 0.79 + 0.0162 * \sin(\omega_0 t) \quad (1)$$

Where, ω_0 is the circular frequency when the human body is traveling normally, m_1 and m_2 are the masses of the human body and the weight, k_1 and k_2 are the equivalent stiffness of the human leg and the equivalent stiffness of the weight, c_1 is the equivalent damping coefficient of the leg.

In addition, the circular frequency value ω_0 when the human body is traveling normally can be expressed as a function related to traveling speed and leg length through empirical formula (2). When analyzing the human body carrying system, formula (1) can be used as an input excitation reference.

$$\omega_0 = 9.45 \left(\frac{V}{R}\right)^{0.57} rad/s$$

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(2)

As the amplitude of gravity center fluctuation of the human body is within 10-35mm, in order to ensure the convenience of human walking, damping elements should be added to ensure the stability of vibration. At the same time, the vibration amplitude of the bearing device should be less than that of the human body. In the study of backpack vibration characteristics, the leg stiffness and damping that have little influence on the vibration characteristics of the backpack are ignored. The simplified model diagram is shown in Figure 4.

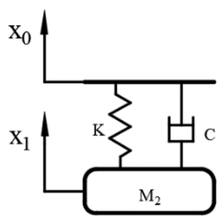

Fig.4 The Simplified System Model

According to Figure 4 of the system model, the following differential equation (3) is listed:

$$M_2\ddot{x}_1 = K(x_0 - x_1) + C(\dot{x}_0 - \dot{x}_1) \quad (3)$$

$M_2$is the weight of the backpack; $x_0$is the displacement curve of the human center of gravity; $x_1$is the displacement curve of the backpack; $K$is the spring stiffness; $C$is the damping coefficient. The weight range of this device is 5-15kg.

Carrying out the above formula to Laplace transform to obtain the transfer function of the system as follows:

$$\frac{X_1(S)}{X_0(S)} = \frac{K+CS}{MS^2+CS+K} \quad (4)$$

From equation (4) above, it can be seen that the system is a second-order oscillation link. Since the excitation is sinusoidal, the output frequency of the system is consistent with the input frequency.Frequency domain analysis of the output amplitude and transfer function shows that the amplitude-frequency characteristics of the system are as follows:

$$A(\omega) = \frac{X_1(\omega)}{X_2} \quad (5)$$

$X_1(\omega)$ is the amplitude of the output harmonic;$X_2$is the amplitude of the input harmonic.

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Knowing the range of input harmonic amplitude and the range of carrying weight, according to the condition that the output amplitude should be smaller than the input amplitude, the following equations (6) can be obtained:

$$\begin{cases} A(\omega) = \frac{X_1(\omega)}{X_2} \\ 0 < X_2 < 35mm, 5 < M_2 < 15kg \\ X_1(\omega) < X_2 \end{cases} \quad (6)$$

Solving the above equations, the ratio range of the damping coefficient to the spring stiffness is:

$$\frac{C}{K} = [0.0039, 0.0097]$$

3.2 Construct a Mathematical Model of Power Generation Function

In the backpack energy recovery device, when the human body reciprocates up and down with the backpack, both upward and downward movement will deform the spiral spring of the roller. The restoring force of the spring makes the roller rotate, driving the motor to move. For a micro generator in one cycle:

The work done by gravity on the backpack at this stage is:

$W = Mgh$ (h is the descending height of the backpack.) (7)

The power generation is:

$$P = \eta \left[W - \frac{1}{2}k\left(\Delta x_1{}^2 - \Delta x_0{}^2\right)\right]/T \quad (8)$$

$\eta \approx 80\%$ is the efficiency of the rectifier mechanism [3], Δx_0 is the stretched length of the elastic belt of the backpack reaching the top dead point, Δx_1 is the stretched length of the elastic belt of the backpack reaching the bottom dead point, and T is the body motion cycle.

4. Simulation Research of Energy-Feeding Rectifier Module

Based on the traditional rotating electromagnetic generator energy recovery device, there will be equivalent mass (m_e), mechanical damping (c_m) and motor damping (c_e) in this system. In order to study the characteristics of single-stroke energy recovery and double-stroke energy recovery performance, specially established two forms of recovery vibration models are shown in Figure 5. The two-stroke energy recovery vibration model is shown in figure a (one-way clutch engaged state). The single-stroke energy recovery vibration model can be simplified as (a) one-way clutch engaged state, and (b) the combination of the vibration energy

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recovery model diagram in the non-meshed state.

According to Figure 5, the model control equations (7) (8) when the one-way clutch and the motor gearbox shaft are engaged and disengaged can be listed respectively:

$$\begin{bmatrix} m_1+m_e & -m_e \\ -m_e & m_2+m_e \end{bmatrix}\begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{bmatrix}+\begin{bmatrix} c_1+c_m+c_e & -c_m-c_e \\ -c_m-c_e & c_m+c_e \end{bmatrix}\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix}+$$
$$\begin{bmatrix} k_1+k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}=\begin{bmatrix} k_1x_0+c_1\dot{x}_0 \\ 0 \end{bmatrix}$$

Engaged (9)

$$\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix}\begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{bmatrix}+\begin{bmatrix} c_1 & 0 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix}+\begin{bmatrix} k_1+k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}=\begin{bmatrix} k_1 & c_1 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} x_0 \\ \dot{x}_0 \end{bmatrix}$$

Disengaged (10)

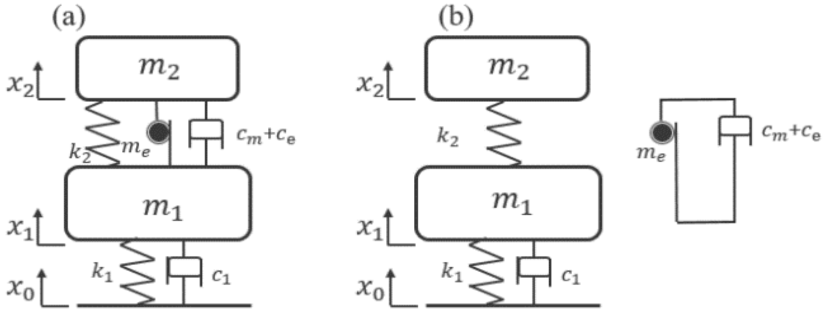

Fig.5 One-Way Energy Recovery Device Model

(a) engaged (b)Disengaged

Threshold for engaged and disengaged:

$$\begin{cases} \text{engaged}: \dot{x}_1 < 0 \ \& \dot{x}_1 - \dot{x}_2 \geq \Omega_0 r e^{-\frac{t-t_0}{\tau}} \\ \text{disengaged}: otherwise \end{cases}$$

(9)

Among them, Ω_0 is the initial speed of the gearbox shaft when it is not engaged, and its value can be obtained from the speed of the motor gearbox shaft when it is engaged $\Omega_1 = \mathrm{n}\frac{\dot{x}_2-\dot{x}_1}{\mathrm{r}}$, and the speed of the gearbox shaft when it is disengaged is $\Omega_2 = \Omega_0 \mathrm{r} e^{-\frac{t-t_0}{\tau}}$; t is the time, t_0 is the time not engaged , r is the radius of the gear.

The above two models are simulated separately by MATLAB/ Simulink , and the power diagram obtained after substituting the relevant parameters is shown in Figure 6. It can be seen from the figure that the average output power of the motor in the

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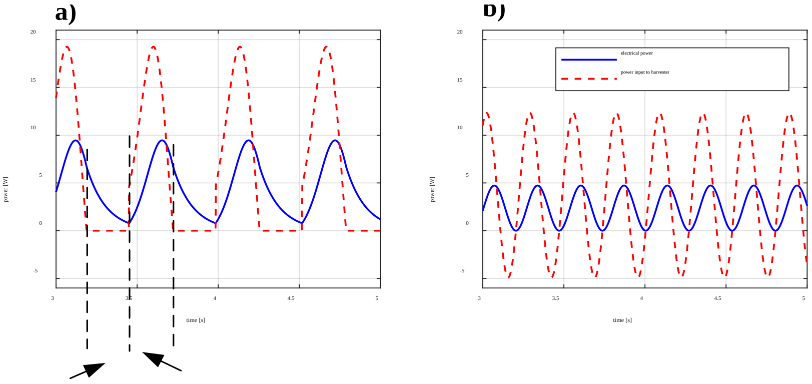
single-stroke rectification is 4.5W, which is obviously larger than the average output power of the motor in the double-stroke rectification, and can meet the standard electrical output.



a) Single stroke b) Double stroke

Fig.6 Simulation Diagram of Power Recovery Curve of Energy Recovery Device

5. Test Verification

In this experiment, the actual power generation effect of the prototype was tested. The test system is composed of power generation device, electronic load meter, computer software-electronic load meter monitoring system M9700, treadmill and connection lines. The specific test method is as follows: the test personnel carry a backpack equipped with a power generation device, connect the power management module in the power generation device to the electronic load, and the electronic load meter is connected to the computer. Set a specific walking or running speed for the treadmill. When the tester loads, the generator device collects the vibration energy of the backpack, obtains the corresponding power generation parameters of the generator through the electronic load meter, and monitors and collects the electronic load meter through the electronic load meter monitoring software M9700 Data, and finally the data file is exported, and the tester analyzes the data. Figure 7 (a) shows the actual shot of the treadmill test. Figure 7(b) is a graph of the energy collection of the device. It can be seen from the figure that when a person is traveling at a speed of 6km/h, the device can stably output 4.3W power and 5V voltage, which is basically in line with most of the market Electronic equipment charging standards.[5]

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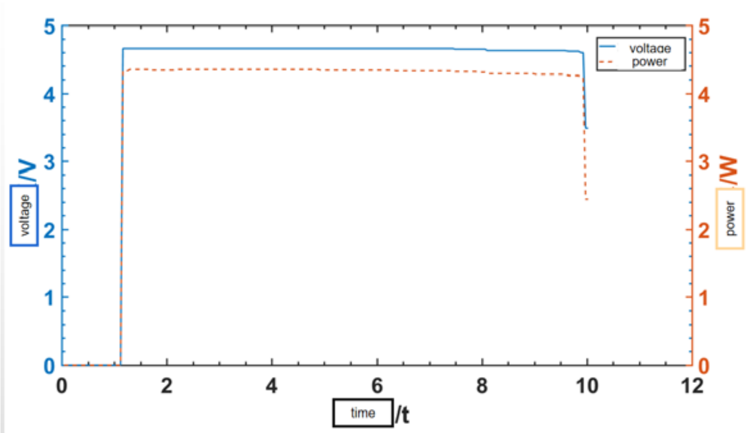
a)



b)

Fig.7 (a) Real Shot Diagram of Test (B) Energy Harvesting Curve Diagram

6. Conclusion

Backpack type energy recovery system was proved to be an effective energy recovery method based on human beings.This paper discusses an energy recovery device based on a backpack, which is used to use the kinetic energy of the backpack driven by the human body during walking.And turn it into electricity to power portable electronic devices. A mathematical model is established to study the performance of the proposed backpack energy recovery system.The structure design of the system has the characteristics of small volume and light weight. The experimental results show that the backpack-based energy recovery system has a high energy recovery efficiency and can effectively obtain a large amount of

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available electrical energy from human backpack sports.

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