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Review of Electromagnetic Vibration Energy Harvesters

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Abstract: Electromagnetic vibration energy harvester is a micro electro mechanical equipment which can provide power for low power equipments. It can transform the vibration energy which widespread in the surrounding environment into electrical harvester. This paper introduces an important vibration energy harvester-electromagnetic vibration energy harvester, and divides them into five kinds according to the method of improving the output power of vibration energy harvester, and introduces the representative electromagnetic vibration energy collector which is proposed by researchers at home and abroad. Finally, the paper analyzes the problems faced by electromagnetic vibration energy harvester and the development trend in the future.

1. Introduction

With the progress of technology, the power consumption of electronic components such as MEMS systems, wireless sensors and biological micro and nano electromechanical devices has become lower and lower, making it possible to use the vibration energy in the environment to supply it instead of traditional chemical batteries and power lines[1-2]. Vibration energy exists widely in the natural environment, and it is an inexhaustible energy source for the micro-energy system. How to effectively collect and use these weak vibration energy is the key problem of the micro-energy system, which is also the main focus of the current micro-energy research. The vibration energy is collected by piezoelectric, electromagnetic, electrostatic, magnetostriction, etc[3-4]method. Due to the simple design, easy production and easy analysis, this type of electromagnetic vibration energy collector has made a rapid development and great progress. The basic principle of the electromagnetic vibration energy collector is to use the Faraday's law of electromagnetic induction, to convert the mechanical vibration energy in the environment into electric energy[5]. It usually uses a spring-to-mass block system as a vibration pickup device to realize the vibration coupling, and realizes the magnetoelectric coupling by using the relative motion of the permanent magnet and the coil coupling. However, at present, the electromagnetic vibration energy collector still has the disadvantages of small output power, low integration degree and low assembly accuracy. In addition, because the frequency of ambient vibration is generally low, the installation space of the collector is generally small (for example, the energy collector applied in portable equipment has a large low frequency amplitude[6]Characteristics) Therefore, how to optimize the structure and performance of the energy collector at a small scale to improve the output performance is the short board that restricts the development and application of the electromagnetic vibration energy collector. This paper briefly introduces the electromagnetic vibration energy collector by improving magnetic field distribution, improving manufacturing method, optimizing relative motion, adopting new material and new structure, and coupling with other forms.

1.1 Improve the magnetic field distribution

In order to generate large induced electropotential during electromagnetic induction, it is necessary to improve the distribution of magnetic field to enhance the magnetic flux change in the coil. It is effective to enhance the magnetic induction strength of the space of the coil, and to increase the change rate of the magnetic flux in the range of motion of the coil.

Array of magnets arranged with specific rules[7]It can effectively increase the variation amount of magnetic flux in the coil[7]. In Figure 1, Ding Zhiqiang et al[8]An electromagnetic vibration energy collector is proposed. The overall structure of the energy collector is spherical, composed of spherical shell, induction coil, permanent magnet ball and other components. When external excitation acts on the energy collector, the eccentric magnetic ball generates motion to sense a current in the coil. The energy generated by the energy collector is stored in the energy storage circuit and can be used to drive the load to work when needed. The energy collector has a maximum output power of 0.8mW at an external excitation frequency of 10Hz and a load of 50 Ω. The permanent magnet sphere inside the energy collector uses a modified Halbach array structure, so that the magnetic field strength inside the permanent magnet sphere is almost zero. The magnetic field energy is concentrated and distributed between the permanent magnet sphere and the ball shell, so that the magnetic induction strength in the area of the induction coil is greatly enhanced, thus improving the output performance of the energy collector.

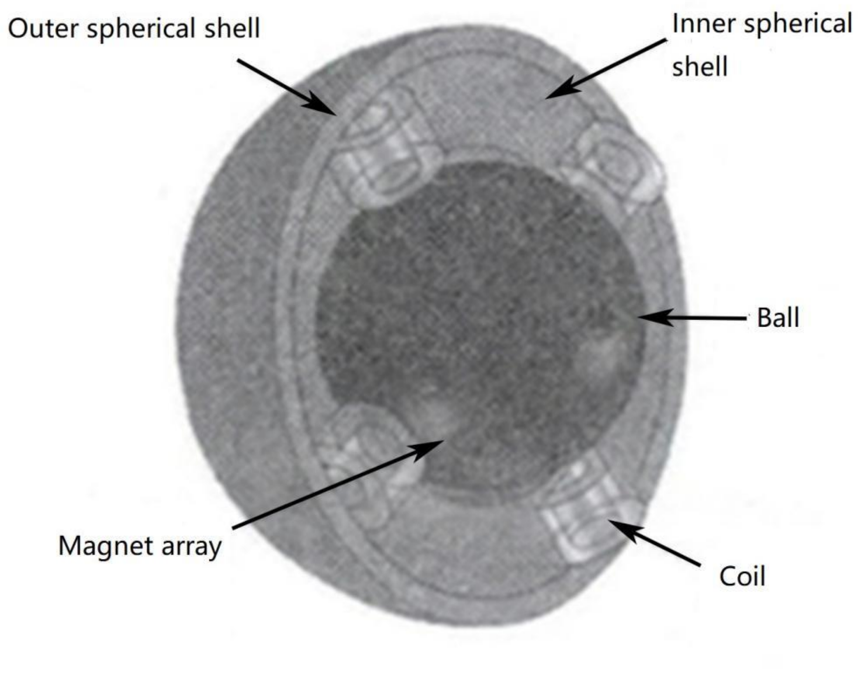

Figure 1: The spherical energy collector proposed by Ding Zhiqiang et al

In Figure 2 is Zhu Dibin et al., of the University of Southampton, UK[9-10]The proposed electromagnetic vibration energy collector based on Halbach array improvement model. The energy collector is composed of a permanent magnet array, a coil, a spring, etc. The permanent magnet array is fixed to the spring to pick up the vibration of the external environment. The vibrating magnet senses the current in the coil. The energy collector improves the Halbach array from the change rate of magnetic flux and obtains higher output power. The researchers proposed two improvement schemes, model A and model B, with model A using a triangular cross-section and model B with a dual Halbach array structure. Experimental results show 3.5 and 7 times higher energy output, respectively, compared to standard Halbach arrays.

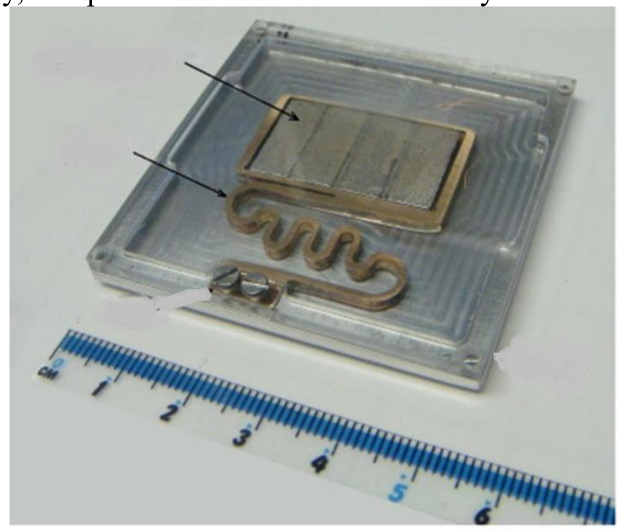

Figure 2: The energy collector proposed by Dibin Zhu et al

1.2 Improve the manufacturing method

Traditional vibrational energy collectors usually process individual components and then assemble them together. This is difficult to guarantee the accuracy required by the design, especially in some cases where a minimal clearance is difficult to guarantee or even cannot complete. Therefore, a series of new processing and manufacturing methods have emerged and achieved a good performance.

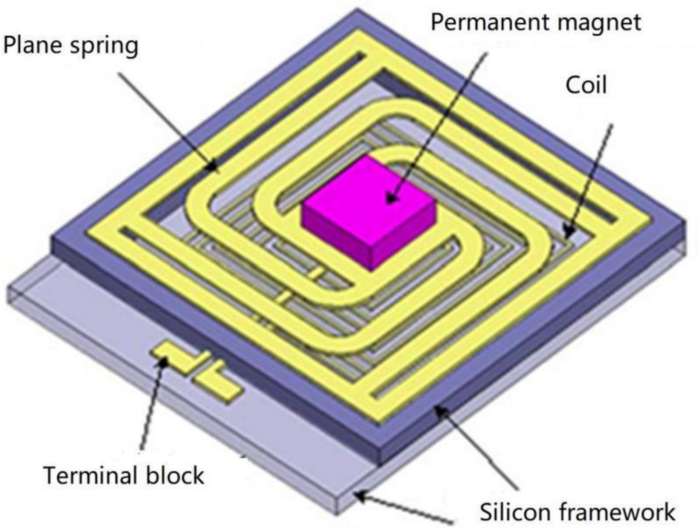

Figure 3: The energy collector proposed by Wang Peihong et al

In Figure 3, Wang Peihong et al[11-12]The proposed electromagnetic type vibration energy collector. The energy collection consists of a planar spiral spring, a permanent magnet, a double planar coil, and a silicon substrate. The permanent magnet is fixed to the center of the flat coil spring, and the double flat coil is below it. When the collector is excited by an external vibration, the permanent magnet produces a vibration, generating an induced electromotive force in the coil. Then, the excitation frequency is 94.5Hz and the acceleration is 4.94m / s^2When, the output voltage of the energy collector reaches 42.6mV. The silicon frame and nickel-made plane spring of the energy collector are made of micro-electroplating technology and silicon micromachining technology, and the plane coil is also made by micro electroplating technology. A series of MEMS processing techniques keep the size of the energy collector in a small range, with the overall size reaching 975mm^3And the machining accuracy is also easy to guarantee.

In Figure 4, Mengdi Han et al[13-14]A miniature electromagnetic vibration energy collector is proposed. The energy collector uses a planar structure, and the permanent magnet array fixed to a flat folded beam moves in the plane, causing drastic magnetic field changes in the planar coil below to produce a higher electromotive force. The energy collector has a maximum peak voltage of 48Hz of 0.98mv and an energy density of 0.16 μ W / cm^3. Copper plating technology is the technical basis of the manufacturing of the energy collector. At high temperature, the silica insulation layer is processed to the silicon substrate, and then the copper coil is plated on it and filled with photoresist, and then electroplating to obtain the folded cantilever and plate, and finally electroplating to obtain the permanent magnet array. The energy collector uses MEMS processing technology to greatly reduce the volume of the device (only 16 mm 8 mm 0.54 mm). Compared with the conventional assembled energy collector, this structure has high manufacturing accuracy, convenient processing, suitable for mass production[15].

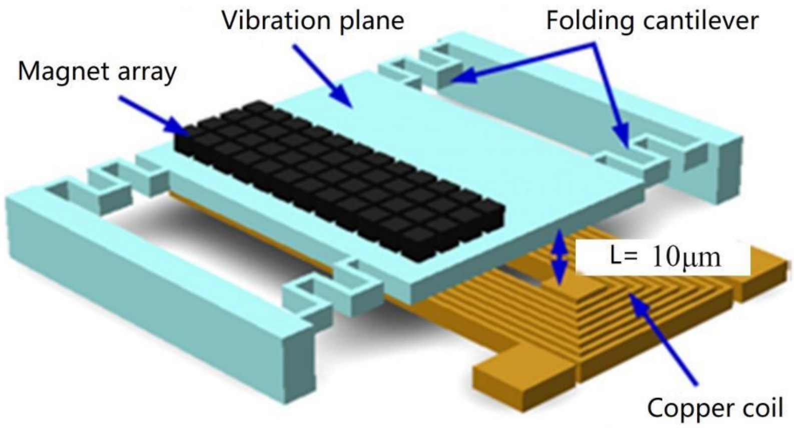

Figure 4: The energy collector proposed by Mengdi Han et al

1.3 Optimize the motion

The output performance of the vibration energy collector is not only related to the magnetic field but also to the relative motion state of the coil and the magnet. Using certain means to improve the motor relationship is a way to improve the output performance of the energy collector. For example, reducing the inherent frequency of the energy collector to better respond to the low-frequency excitation, and reducing the damping to reduce the energy loss of the moving parts are all effective means.

Spring-mass block system has its own advantages, but it is difficult to greatly improve responsiveness in low frequency environments. In Figure 5, Ahmed Haroun et al[16]A low-frequency micro-electromagnetic vibration energy collector is proposed. The energy collector consists of a circular tube, a cylindrical permanent magnet, and a coil wound around the periphery of the cylindrical tube. When the energy collector is placed in a vibrating environment, the NdFeB magnet can move in the plastic round tube, causing the magnetic flux in the copper coil to change and then sense the electric current. This structure abandons the common cantilever and spring support structure, allowing the permanent magnet to move freely in plastic circles, greatly improving the collector's responsiveness to low-frequency signals. The researchers made two different sizes to achieve high output performance. One of the models with a D9mm L12mm size was presented at 3.33Hz and 12.38m/s^2The power of 113.3 μ w is output.

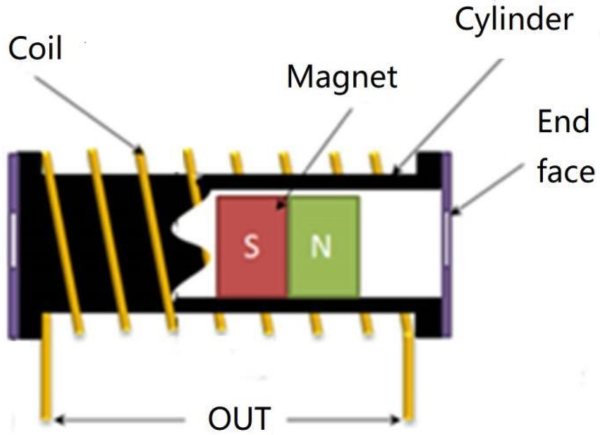

Figure 5: The energy collector proposed by Ahmed Haroun et al

Magnetic levitation is being more and more used in energy collectors, but according to Earnshaw's theorem, a stable magnetic levitation cannot be achieved by relying solely on the attraction and repulsive force between permanent magnets[17], This problem can be effectively solved by using diamagnetic materials. Figure 6 is the S. Palagummi et al[18]A monostable vertical antimaglevitation vibration energy collector. The energy collector consists of lifting permanent magnet, suspended permanent magnet, diamagnetic material plate and coil. The suspended permanent magnet is suspended under the action of the lifting magnet and the diamagnetic material plate. In this energy collector, the suspension magnet does not contact with other components, so the energy loss caused by friction damping is fundamentally eliminated, and the energy utilization rate is improved. The model was experimented with with an external excitation frequency of 2.1Hz and an acceleration of 0.081 m / s^2, When the input power is 111.41 μ W, the output can reach 1.72 μ W, and the energy conversion efficiency is 1.54%.

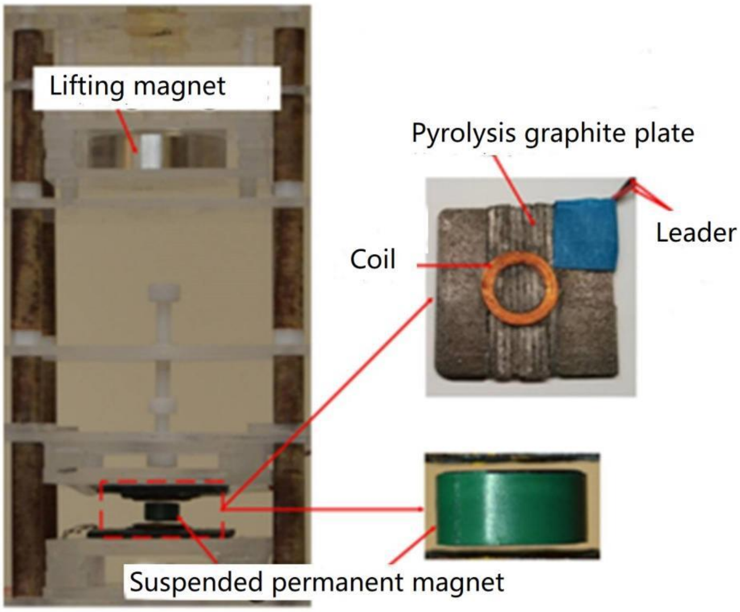

Figure 6: Monostable maglev energy collector proposed by S. Palagummi et al

1.4 New materials and structures are adopted

With the deepening of research and technology advances, new materials and new structures are applied to the design of energy collectors. The magnetic fluid that can change its shape at will is different from the two-dimensional or multidimensional response structure of the traditional one-dimensional response structure, relative to the traditional adjustable frequency energy collector with the fixed frequency, etc.

Figure 7 is the University of Clemson, A.Bibo[19]A new type of magnetic fluid-based vibration energy collector proposed by et al. The uniqueness of this energy collector is the fact that it abandons the traditional idea of relying on solid-state permanent magnet to produce magnetic field, and uses a new type of magnetic fluid material to produce magnetic field. The ferromagnetic fluid is charged into a certain container, and the magnetic dipole orientation inside the ferromagnetic fluid is randomly distributed in the free state, so the magnetism is not shown externally. When a magnetic field is added around the magnetic fluid, the ferrofluid has some characteristics of a solid-state permanent magnet, while maintaining its own flow characteristics. The experimental model uses a D32mm L55mm circular tube with two circular solid-state permanent magnets fixed at both ends to motivate the magnetic fluid in the tube. The researchers initially studied the influence of the external magnetic field strength, the magnetic fluid depth, and the external vibration excitation strength on the output potential, resulting in an energy output of about 18mv and 1 μ W (2.5m / s)$\times^2$、35Ω)

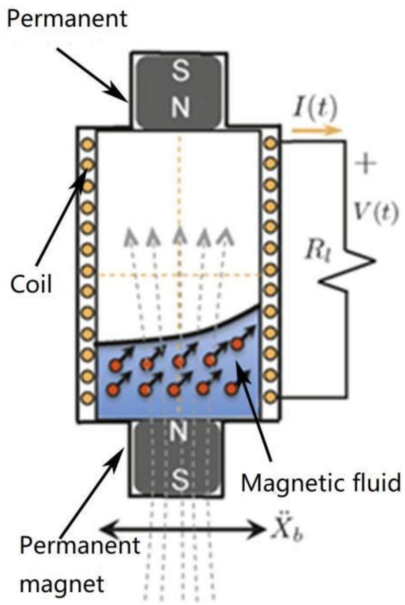

Figure 7: A. The magnetic fluid-based vibrational energy collector proposed by B i b o et al

One of the effective means to reduce the natural frequency is using low Young's modulus material. In Figure 8, as is the Pranay Podder et al[20]A proposed nonlinear bistable vibrational energy collector for the. The energy collector adopts a nonlinear bistable structure, and it has a wider frequency response range compared to the linear elements[21]. Moreover, because the vibrator cantilever is made with the FR4 material, the natural frequency of the energy collector is significantly reduced. The researchers measured that the output power could reach 22 μ W at a 0.5g excitation acceleration, a 35Hz frequency, and a load of 1K Ω, and it could be further optimized to increase the output power and expand the operating frequency range.

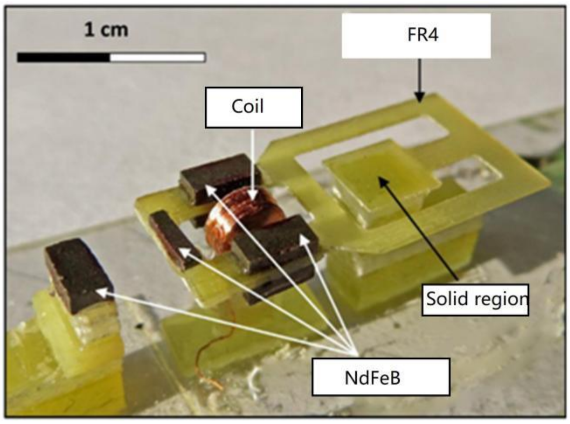

Figure 8: The vibrational energy collector proposed by Pranay Podder et al

1.5 Composite Energy Collector

A single form of vibration energy collector has its own unique advantages, but also with inherent deficiencies. Electrostatic type is easy to integrate, the output voltage is high but complex structure; piezoelectric structure is simple, high energy density but the structure is easy to fatigue damage, and over time will produce depolarization phenomenon; electromagnetic structure is simple but difficult to integrate and the output voltage is low. The composite form of the collector can effectively overcome the disadvantages of a single form collector.

Wen Yumei, of Chongqing University, et al[22-23]Different kinds of composite vibration energy collectors have been proposed. Piezoelectric-electromagnetic composite energy collector is a more common type of composite energy collector[24-25]. BrynEdwards et al of the University of Auckland, New Zealand et al[26]The proposed electromagnetic-piezoelectric composite energy collector has an output power of 44.5 μ W. Figure 9 is Yang Bing et al[27]A proposed piezoelectric-electromagnetic vibration energy collector proposed. The piezoelectric module of the vibrational energy collector is provided by PZT[28]The piezoelectric ceramic material is made. Under the action of external excitation, the PZT material deformation generates electric charge on the upper and lower surface. The permanent magnet fixed to one end of the cantilever beam follows the beam to vibration, sensing electricity in the coil below. When the external excitation is 310Hz and the acceleration is 2.5g, the maximum output voltage can reach 0.84V and the power can reach 176 μ W.

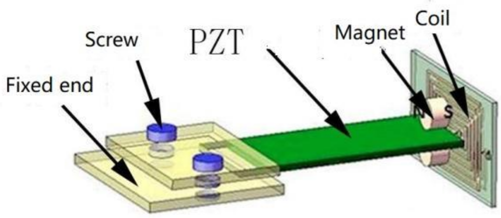

Figure 9: The Piezoelectric-electromagnetic energy collector proposed by Yang Bing et al

2. Conclusion

Using electromagnetic vibration energy collector to collect the vibration energy in the low power energy system. However, at present, the research of vibration energy collectors at home and abroad is still in a stage of development. How to improve the working performance of energy collectors to better achieve stable and high-quality power supply is still a problem that researchers need to solve.

In terms of structure, the mainstream structure is still the spring- -mass block system, and many researchers are still constantly trying to improve the performance of the system and reduce the loss of the system. The application of maglev solves the life and energy loss problems of ordinary spring system well. The application of new materials and new structures also drives the rapid development of energy collectors. In addition, how to further improve the coupling coefficient and magnetoelectric coupling coefficient of environmental vibration to vibration pickup system is still a problem that researchers have to face. In terms of the manufacturing of energy collector, MEMS technology is more and more used in the manufacturing process of vibration energy collector, which plays a great role in improving its performance. Especially in the size of the restricted place, the traditional processing method has been unable to meet the needs of today, using MEMS manufacturing technology can not only obtain a super small structure and conducive to the later large-scale production and manufacturing, promote the application of vibration energy collector. Compared with the structure research of the vibration energy collector itself, there is relatively little research on the management and storage of the output energy of the collector. High-quality and efficient energy management and storage technology may become one of the main problems restricting the development of the vibration energy collector.

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