STUDY ON SPATIAL MULTI-FREQUENCY VIBRATION PICKING AND ENERGY CAPTURE POWER SUPPLY DEVICE FOR TENSION DETECTION OF SCRAPER CONVEYOR

Qiang Zhang [1], Hezhe Zhang [2]

This paper proposes a multi-frequency vibration picking power supply device for scraper conveyor tension detection, in view of the difficulty that scraper conveyor tension detection sensors cannot be wired for power supply. The experimental analysis of the spatial type multi-frequency picking energy characteristics at different vibration frequencies of 5 Hz, 10 Hz, 15 Hz, 20 Hz, 25 Hz and 30 Hz. The results show that: The maximum power production is achieved in the vibration frequency range of 15-20 Hz, achieving a resonance with the external environmental frequency of the scraper, and the sustainable and stable power supply of the scraper conveyor tension detection sensor is verified through experimentation.

Keywords: Scraper Conveyor; Tension Detection; Piezoelectric; Multi-frequency Vibration Picking; Self-powered

1. Introduction

Scraper conveyor is the transport equipment in coal mine production, widely used in general mining workings as well as in certain surface transport environment and is one of the most important pieces of equipment for mechanised coal mining. As the running track of shearer and the push fulcrum of hydraulic support, the scraper conveyor's reliable, safe and efficient operation directly affects the production efficiency of coal mine. With China's economic development, coal production is increasing, the driving power of the scraper conveyor is increasing, coupled with the harsh underground production environment, wear and tear and other external factors on the scraper chain damage makes the scraper conveyor is easy to break the chain failure. Once the fault occurs, it will directly cause economic losses to the coal mining enterprises. If the operator cannot find out in time after the chain is broken, it will also lead to serious scraper pulling, chain, plate involved in the head, as well as lifting the head of the machine and other malignant mechanical and electrical accidents, which may even cause casualties. The processing time after the broken chain accident takes about 12 hours, which takes up a long time and seriously affects the

[1] Prof., College of Mechanical Engineering, Liaoning Technical University, Fuxin. Shandong University of science and technology, Qingdao
[2] Doctor, College of Mechanical Engineering, Liaoning Technical University, Fuxin

start-up rate of the comprehensive mining equipment, while the scraper chain breakage is mainly caused by the excessive tension force causing the chain jamming. Many experts and scholars at home and abroad have conducted a lot of research and development on the tension detection technology of scraper conveyor and achieved certain research results, Zhang Qiang and Wang Haijian [1] proposed a scraper conveyor tension detection system based on self-powered piezoelectric vibration captive energy, which achieved the effective conversion of electrical energy by collecting the vibration energy generated during the operation of the scraper to ensure the long-term effective work of the tension detection device and wireless signal transmitting device. Mao Jun, Li Weikang et al [2-4] constructed the dynamics model of scraper conveyor by considering the non-linearity of the chain, the elasticity and clearance of the central groove of the conveyor, the meshing characteristics of the sprocket and chain, etc., obtained the chain tension distribution under different working conditions, and designed an automatic control system for the chain tension of scraper conveyor.

Deng Guanqian and Chen Zhongsheng [5] studied the influence of the geometry of piezoelectric oscillators on the power generation characteristics of piezoelectric oscillators by using piezoelectric oscillators to convert environmental mechanical energy into electrical energy to power wireless sensors, and optimally designed their structures by combining theory and experiment. Lee [6] et al. conducted an in-depth study on piezoelectric material PZT through high-frequency periodic load experiments. Adrien Badel et al [7] compared the performance of piezoelectric single crystals and piezoelectric ceramics through a vibrating energy recovery system and showed that the energy recovery of piezoelectric single crystals was as much as 20 times higher than that of piezoelectric ceramics when the energy recovery of the interface circuit was the same. Sodano [8] et al. carried out a comparative analysis of three different piezoelectric materials, PZT, MFC and ACX, so that the conversion efficiency of the three materials was analysed at the resonant frequency state, and the results of the study showed that PZT had the best stability of conversion among the three specimens.

The above experts and scholars have conducted in-depth research on the tension detection system of scraper conveyor and piezoelectric power supply technology, but there is still lack of research on the power supply of tension detection sensors and lack of research on the structure of piezoelectric power generation devices, which cannot guarantee the optimal power generation of piezoelectric power generation devices. According to the principle of piezoelectric power generation, the power generation characteristics of multi-directional vibration are studied, comparing the power generation characteristics of planar vibration picking structure and spatial vibration picking structure, the power generation generated by vibration energy is utilised more efficiently, breaking through the conversion rate of planar piezoelectric vibration electromechanics, realising the maximum power generation from the self-powered device of the detection system, ensuring that the sensor of the scraper chain tension detection system of the scraper conveyor obtains the optimal power. This ensures that the sensor of the scraper chain tension detection system receives the optimum amount of electrical energy and guarantees the long-term efficient and stable operation of the detection system.

2. Material and Methods

In order to fully understand the structural characteristics and power generation characteristics of the multi-frequency picking energy generation device, the experiment was designed to scale up the practical application of the integrated power generation device, so as to derive the regular characteristics of the structure of the device to generate electricity, so as to achieve the maximum utilisation of the power generation capacity of the device in the practical application [9-13].

1) Composition of multi-frequency vibration picking and energy harvesting experimental system

The multi-frequency vibration picking and energy capture experiment platform is divided into vibration mitigation system, vibration system, vibration picking system and electrical signal acquisition and measurement system. The key components of each system are shown in Figure 1, including iron platform, vibration device, vibration picking device, protection switch, frequency controller, oscilloscope, waveform display, host, multimeter, rectifier circuit, multi-terminal parallel experiment board, line collecting board, etc.

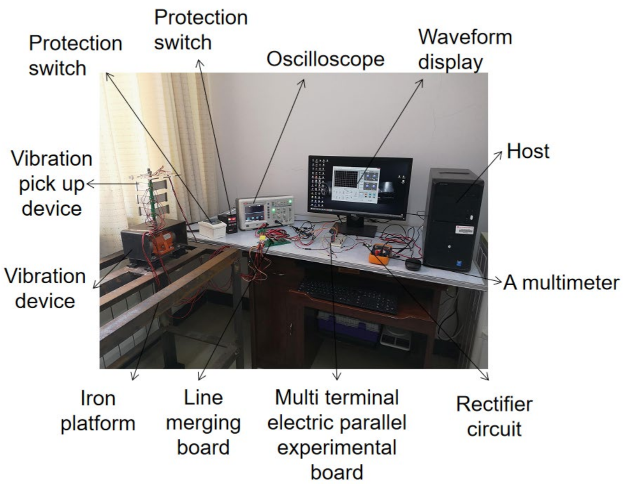


Fig. 1. Experiment System

The overall structure of vibration pickup is shown in Figure 2. The whole structure belongs to the spatial three-dimensional structure. The number of XY piezoelectric vibrators in two directions is set on the square key, and the number of Z piezoelectric vibrators is arranged on the top of the square key. In order to prevent multiple vibrator substrates from being connected in series, the square key surface is treated with insulating tape during the assembly process, while the fixed end of each piezoelectric oscillator in the XY direction is treated with insulating tape, so that the piezoelectric oscillators in the XY direction are all relatively independent, preventing the electrical signals of the piezoelectric oscillators from being confused during the pick-up and generation process and affecting the experimental analysis results.

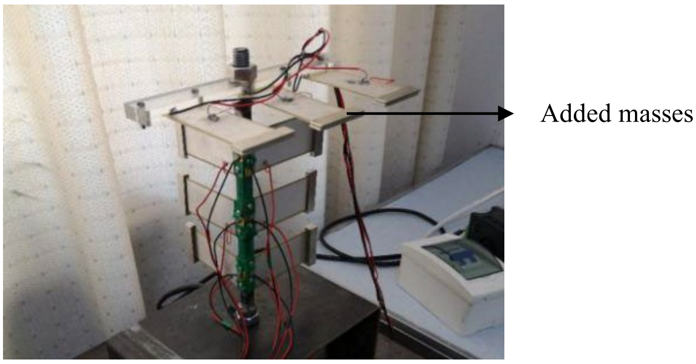


Fig. 2. Vibration pickup system

2) Principle of multi frequency vibration capture power generation device

The general principle of the multi-frequency vibration pick-up captive energy experiment system is shown in Figure 3, the vibration system vibrator is a frequency adjustable vibrator to simulate the frequency of various different working conditions in a real working environment, the vibration pick-up piezoelectric system collects the vibration of the vibration system for power generation, and then the rectifier circuit will pass all the electrical signals to the oscilloscope signal analysis, while a multimeter can be used in this process for line current measurement, and finally the voltage signal is analyzed by computer analysis software for electrical signal analysis [14-17].

In this experiment, the power generation ability of different arrangements of piezoelectric vibrator is discussed. Different arrangements include single frequency pick-up of single vibrator, single frequency pick-up of plane vibrator, multi frequency pick-up of plane vibrator and multi frequency pick-up of space vibrator.

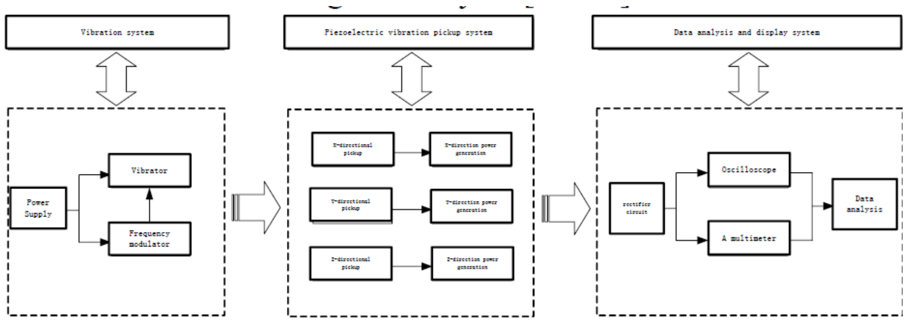
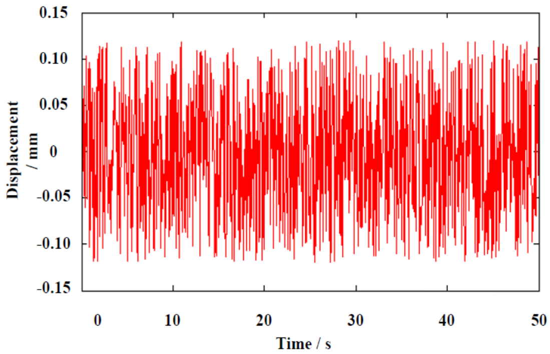


Fig. 3. General principles of experimental systems

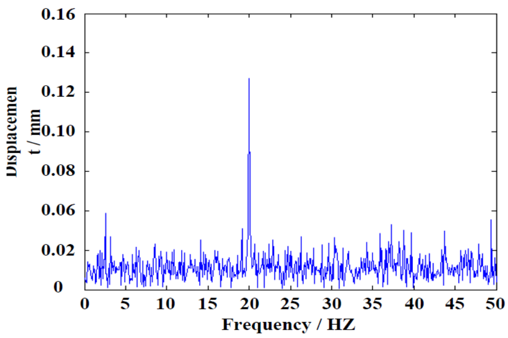
3) Determination of vibration frequency of scraper conveyor

Through the vertical vibration differential equation and initial conditions of the scraper conveyor in the vertical direction of the vibration of the approximate frequency range. Its vibration image can be obtained by MATLAB programming, and the spectrum diagram can be obtained by Fourier series, as shown in Figure 6. It can be seen from the figure that the main vibration frequency and amplitude of the scraper conveyor are 20Hz and 0.12mm respectively, so as to determine the vibration conditions of the working condition.

According to the vibration frequency of the external environment of the scraper conveyor, in order to make the natural frequency of the power generation device the same or close to the external vibration frequency of the scraper conveyor to produce resonance effect and realize the conversion of higher mechanical energy and electric energy, the vibration frequency was set as 5Hz, 10Hz, 15Hz, 20Hz, 25Hz and 30Hz in the experiment. The maximum generating capacity of the piezoelectric energy harvesting device is obtained.



Vibration diagram



spectrum

Fig. 6 Simulation curve

3. Results

In order to explore the respective generation effects of planar single-frequency piezoelectric vibrator, planar multi-frequency piezoelectric vibrator and spatial multi-frequency piezoelectric vibrator in this experiment, the generation characteristics of various forms of piezoelectric vibrator are compared, and experimental tests are carried out for different schemes. After the installation and debugging of the experimental platform and detection system, the peak-to-peak values of the generation voltage under different vibration picking structures were recorded and statistically analyzed.

1) Analysis of the characteristics of plane-type single-frequency vibration picking and energy harvesting power generation

In this experiment, we choose to configure 2 magnetic mass blocks, whose free end masses are 10g. During the experiment, we keep the direction of one-way pick-up vibration constant, keep the mass of the mass block configured at the free end of the piezoelectric oscillator constant, and change the vibration frequencies of the oscillator to 5Hz, 10Hz, 15Hz, 20Hz, 25Hz and 30Hz respectively, to investigate the power generation capacity of the planar type single frequency pick-up vibration structure under different vibration frequencies. According to the detection of the oscilloscope, the data is extracted and the power generation characteristic values of the X, Y and Z three-way planar type piezoelectric oscillator are shown in Table 1.

Table1

Planar single frequency piezoelectric peaks in all directions

Vibration frequency Pick up direction / peak to peak	5Hz	10Hz	15Hz	20Hz	25Hz	30Hz
X	1.68V	2.26V	3.84V	2.96V	2.32V	2.00V
Y	1.76V	2.28V	3.80V	3.04V	2.12V	1.96V
Z	0.68V	1.20V	2.80V	1.92V	1.34V	0.98V

The curve relationship between the generation peak-to-peak value of planar single-frequency piezoelectric vibrators and the vibration frequency can be obtained, as shown in Fig. 4.

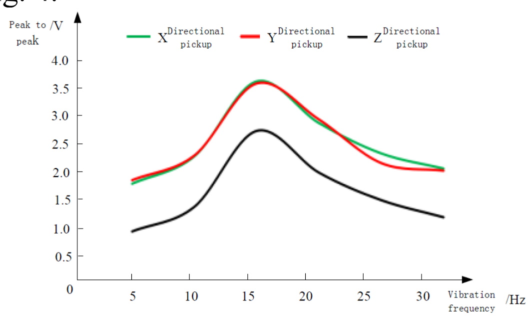


Fig. 4. Planar single frequency pickup piezoelectric relationship diagram

According to Fig. 4 and Table 1, vibration is picked up in three directions. When the external frequency is around 16Hz, the maximum piezoelectric peak value reaches 3.84V in the X direction. The maximum piezoelectric peak value in Y direction is 3.80V; the maximum piezoelectric peak-to-peak value in the Z direction is 2.80V, and the piezoelectric performance in different directions is not completely the same. The peak-to-peak value of the piezoelectric in the XY direction is close, while the peak-to-peak value of the piezoelectric in the Z direction is slightly less than the XY direction. After analysis, it can be obtained that the shaker in this experiment is close to the real working vibration through the form of eccentric wheel rotation, rather than along the Z direction positive active excitation, in addition, in this experimental structure, the Z direction pick-up structure is far away from the shaker, so in the vibration transfer process, there is a certain vibration energy loss, so the Z direction plane pick-up structure piezoelectric performance is relatively poor compared to the XY direction.

2) Analysis of the characteristics of planar multi-frequency vibration picking and energy harvesting power generation

In this experiment, the bottom-up configuration of 2, 3 and 4 magnetic mass blocks in the XY pick-up direction, whose free end masses are 10g, 15g and 20g respectively, during the experiment, keeping the one-way pick-up direction unchanged, keeping the mass of the mass block at the free end of the piezoelectric oscillator configuration unchanged, changing the vibration frequencies of the oscillator to 5Hz, 10Hz, 15Hz, 20Hz, 25Hz and 30Hz respectively, exploring the power generation capability of the planar multi-frequency pick-up structure at different vibration frequencies, according to the detection of the oscilloscope, the power generation characteristic values of the X, Y and Z three-way planar piezoelectric oscillator are shown in Table 2.

Table 2

Planar multifrequency piezoelectric peaks in all directions

Vibration frequency, vibration direction / Peak to peak	5Hz	10Hz	15Hz	20Hz	25Hz	30Hz
X	1.80V	4.08V	4.40V	4.24V	2.56V	1.60V
Y	1.84V	4.08V	4.32V	4.20V	2.64V	1.68V
Z	0.72V	2.72V	3.00V	3.04V	1.36V	0.46V

The curve relationship between the peak-to-peak value of the generation of planar multi-frequency piezoelectric vibrators and the vi-bration frequency can be obtained, as shown in Fig. 5.

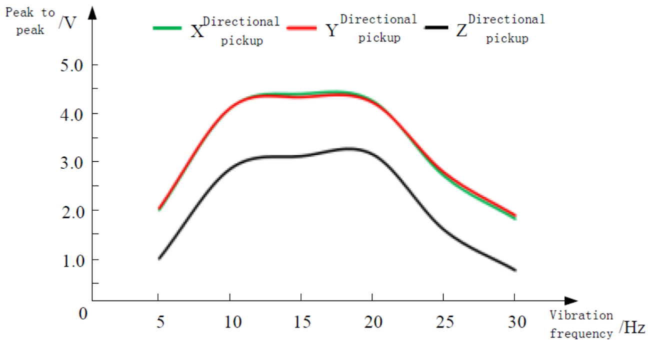


Fig. 5. Planar multifrequency pickup piezoelectric relationship diagram

According to Fig. 5 and Table 2, vibration is picked up in three directions. When the external frequency is 10~20Hz, the peak-to-peak value of the X-direction piezoelectric is within the range of 4.08V~4.4V. The peak-to-peak value of Y-direction piezoelectric is in the range of 4.08V~4.32V. The peak-to-peak value of the Z-direction piezoelectric is in the range of 2.72V~3.04V, which is similar to that of the single-frequency piezoelectric.The peak-to-peak performance of the planar piezoelectric in different directions is not exactly the same. The peak-to-peak value of the XY direction piezoelectric is close, while the peak-to-peak value of the Z-direction piezoelectric is less than that of the XY direction. According to the analysis, when the frequency changes within a certain range, the piezoelectric vibrators with different natural frequencies respond differently to the outside world, and reach the maximum power generation when they approach their own natural frequencies respectively.

3) Analysis of spatial multi-frequency vibration and energy harvesting power generation characteristics

To study the power generation performance of space-based multi-frequency pick-up structures, the three piezoelectric oscillators are configured with different masses at the free ends of the three piezoelectric oscillators in order to achieve different intrinsic frequencies of the three piezoelectric oscillators, thus realising multi-frequency pick-up. In this experiment, the free end of the piezoelectric vibrator in the XYZ direction is configured with 4, 3 and 2 magnetic mass blocks, whose free end masses are 20g, 15g and 10g, respectively. The second is multi-frequency multivibrator, that is, all the piezoelectric vibrators are selected in space. The piezoelectric vibrator in XY direction is configured with 4, 3 and 2 magnetic mass blocks from bottom to top, and the piezoelectric vibrator in Z direction is configured with 4, 3 and 2 magnetic mass blocks from left to right. During the experiment, maintain quality of piezoelectric vibrator free end configuration block quality unchanged, and change the vibration of the vibrator frequency of 5 Hz, respectively 10 Hz, 15 Hz and 20 Hz, 25 Hz, 30 Hz, explore under the different vibration frequency, the spatial type multifrequency vibration picking generating capacity of the structure, according to the testing of oscilloscope, space type multiple frequency power generation characteristics of the piezoelectric vibrator values as shown in table 3.

Table 3

Spatial multifrequency piezoelectric peaks in all directions

Vibration frequency Oscillator form / peak to peak	5Hz	10Hz	15Hz	20Hz	25Hz	30Hz
Monopole	1.32V	3.76V	4.08V	3.88V	2.34V	1.38V
Multivibrator	2.12V	4.68V	5.04V	4.92V	2.88V	1.80V

The curve relationship between the peak-peak value of the generation of spatial multi-frequency piezoelectric vibrator and the vibration frequency can be obtained, as shown in Fig. 6.

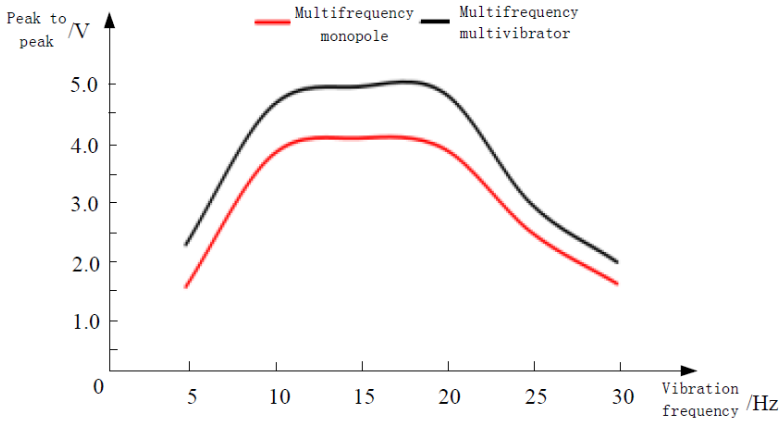


Fig. 6. Piezoelectric relationship diagram of spatial multifrequency pickup

When the external vibration frequency reaches 10Hz and continues until the vibration frequency increases to 20Hz, the peak-to-peak values of the spatial piezoelectric are all large. It can be considered that when the external vibration frequency is between 10Hz and 20Hz, the peak-to-peak values of the spatial piezoelectric are all at the maximum value.

According to Fig. 6 and Table 3, when the external frequency of spatial multi-frequency vibration pickup is 10-20Hz, the peak-to-peak value of X-direction piezoelectric is in the range of 4.68V~5.04V.

Due to the increase of the number of multi-vibrators, the natural frequency of the whole vibration picking structure decreases, and the maximum peak-to-peak value of multi-vibrators is generally higher than that of single vibrators. Space-type multi-frequency pick-up piezoelectric capacity compared to flat multi-frequency vibrator pick-up, due to the common pick-up vibration of piezoelectric vibrators on space, the maximum piezoelectric peak value increased by 14.55% ~ 65.79%, according to the external vibration frequency of the scraper conveyor 20Hz, in the space multi-frequency pick-up vibration captive power supply device to generate maximum electrical energy vibration frequency range, can achieve resonance to generate maximum power, the maximum piezoelectric peak value of about 5.04V.

4) Field experiment

To verify the reliability of the piezoelectric energy capturing device, the system performance was tested using field measurement and analysis methods, relying on the platform of Zhangjiakou "Nation-al Energy Extraction Equipment R&D Centre", in which the scraper conveyor used SGZ1000/1710 medium double chain scraper conveyor with an installed power of 2×855kW. The experimental laying conveying distance is 80m, the no-load scraper chain speed is 1.58m/s, the no-load running time for one week is 103s, and the whole machine is laid horizontally with no installation inclination. In the case of ensuring the load strength of the scraper and the chain ring, the tension detection system is modified and installed at the combination of the two, its structure and installation method is shown in Figure 7 and 8, the upper and lower ends of the scraper are respectively modified by wiring openings, where the upper end wire slot is used to install power supply and communication cables, the lower end is slotted and built with a rigid sealed chamber with the same load strength as the scraper, and the piezoelectric energy capturing device and wireless signal transmitting device are built respectively. The two piezoelectric vibration acquisition modules work simultaneously to achieve energy acquisition, the acquisition module uses a DC arch bridge, the arch bridge voltage is 2Vor 5V. Through the above experimental testing and analysis, the piezoelectric power generation device can continuously and steadily output 5V during the normal operation of the scraper conveyor, which can meet the power supply requirements of the acquisition module, while the wireless signal transmission device is a main and a backup The piezoelectric energy capturing device can supply power to the strain gauges and the wireless signal transmitter through the scraper's internal wire channel. At the same time, the outer sides of the two chain rings engaged with the scraper are milled flat and then strain gauges are attached and protected to ensure accurate engagement of the scraper with the chain rings and to guarantee the accuracy of tension detection of the scraper conveyor. The system transmits the test data via the wireless signal transmitting and receiving modules as well as the Ethernet network to the data monitoring and processing system of the upper computer.

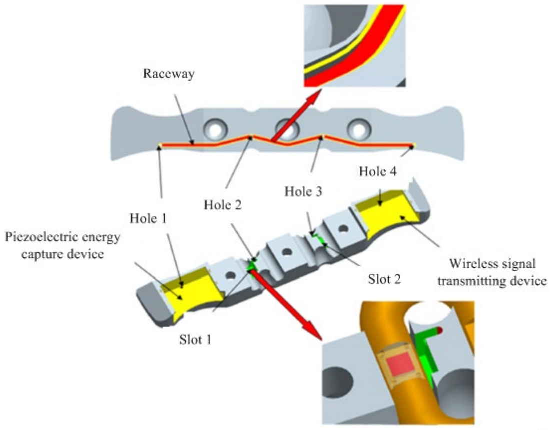


Fig. 7. Schematic diagram of installation method of piezoelectric energy capture device and strain gauge

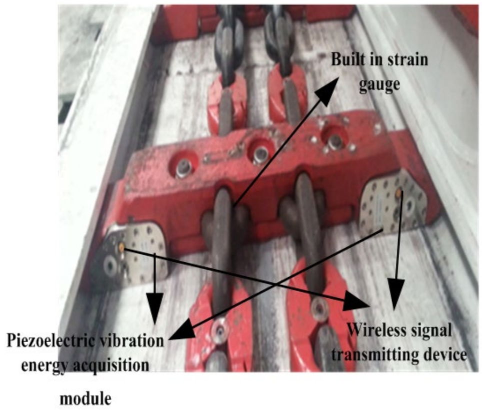


Fig. 8. Field installation and testing

Through the comparison and analysis of the above laboratory experiments, the spatial multi-frequency vibration picking model was selected for detection.

The multi-frequency pick-up energy generation device has been tested by the tension sensor, the power supply performance is stable and reliable, and the power supply output meets the requirements of the tension test sensor and the wireless signal transmission module. The effective tension of the scraper chain is 140kN. After testing, the intact tension value between the scraper chain 1 and the scraper chain 2 is 114kN, and the dynamic tension value between the scraper chain 3 and the scraper chain 4 is 0. Therefore, the device realizes the tension detection of the scraper conveyor, which proves the feasibility of the experimental device [18-22].

4. Discussion

Professor Zhang Qiang proposed a tension detection system of scraper conveyor based on piezo-electric vibration energy capture and self-powered. By collecting vibration energy generated during the operation of scraper, the effective conversion of electric energy was realized to ensure the long-term effective work of tension detection device and wireless signal transmitting device. Zhang Qiang and Guo Tong developed a set of tension testing system of scraper conveyor based on micro-strain detection to solve the bottleneck problems of tension and running resistance of scraper chain in the working process of scraper conveyor, which improved the testing accuracy and reliability. By comparing and discussing with Professor Zhang Qiang's research on the tension detection system of scraper conveyor, this experiment system further optimized the tension detection system of scraper conveyor, proved the power supply reliability of the power generation device, and realized the tension detection of scraper conveyor.

Li Jia [23] proposed a cantilever beam piezoelectric vibration energy harvesting circuit device, which was used to provide power to the passive wireless temperature sensor module, and the power supply of the system was verified by experiments to be effective. Zhao Wei [24] designed a multi-channel piezoelectric vibration energy generation device, which can increase the stress, strain and power generation capacity of the piezoelectric parts through grooving. The simulation model of the power generation unit is established by using the finite element method, and the statics and modal simulation analysis are carried out.

5. Conclusions

In order to realize the real-time stable power supply to the sensor of the scraper conveyor tension detection system and to ensure the sensor electrical energy is stable and sufficient, this paper proposes a spatial type multi-frequency pick-up captive energy supply structure, and conducts experimental analysis and field experiments on the piezoelectric captive energy supply device, and comes to the following conclusions.

(1) Based on the scraper conveyor external environment vibration frequency 20Hz, this paper selects vibration frequency 5Hz, 10Hz, 15Hz, 20Hz, 25Hz, 30Hz for experimental analysis, it is concluded that the voltage peak value of power generation device reaches the highest point within 15-20Hz, in which the maximum voltage generated by spatial type multi-frequency pick-up vibration captive energy generation device is about 4.68V~5.04V, and the maximum voltage generated by planar type multi-frequency pick-up vibration captive energy generation device is about 3.76V~4.08V. The maximum voltage generated by the spatial type multi-frequency pick-up energy generator is about 3.76V~4.08V, compared with the planar multi-frequency vibrator pick-up, the maximum piezoelectric peak value of the spatial type multi-frequency pick-up piezoelectric capacity is increased by about 14.55%~65.79%, which verifies that the spatial type multi-frequency pick-up structure has a stronger power supply capability.

(2) According to the field experiment, the complete scraper chain between scraper 1 and scraper 2 was tested and the tension value of 114kN was obtained, indicating that this part of the scraper chain is in normal operation and in good condition, while the tension value of 0 was measured for the fractured part between scraper 3 and scraper 4, indicating that this scraper chain has been fractured, achieving an adequate and effective power supply to the sensors of the scraper conveyor tension detection system and verifying the feasibility of this power generation device.

6. Acknowledgment

This work is supported by National Natural Science Foundation of China Research on fine modeling method of coal rock interface of Shearer Based on radar prediction and cutting feedback, No. U1810119; National Natural Science Foundation of China Research on preference dynamic identification of coal rock interface of Shearer Based on multi-sensor fusion, No.51774161; National Natural Science Foundation of China The mechanism of rock breaking by induced unloading and multi cutting teeth in high stress hard rock drilling , No.51504121; Sub project of Shanxi provincial key natural fund project, Research on accurate recognition theory of multi information coal rock interface based on Shearer Vision Reconstruction and cutting feedback (cutting feedback identification and virtual simulation of drum cutting trajectory), No.201901D111007(ZD), and Taishan scholar project in Shandong Province, No. tsqn201909113.

R E F E R E N C E S

[1] *Zhang Qiang, Wang Haijian, Mao Jun*. Tension detection system of self powered scraper conveyor based on piezoelectric vibration energy capture. Journal of sensing technology, 2015, 28 (09): 1335-1340

[2] *Mao Jun, Shi Jianguo, Zhang Dongsheng, et al*. Dynamic modeling and Simulation of heavy scraper conveyor. Journal of coal industry, 2008, 33 (1): 103-106.

[3] *MAO Jun, SHI Jianguo, ZHANG Dongsheng.* Simulation Research on automatic tension control system of scraper conveyor. Journal of system simulation, 2008, 20 (16): 4474-4476

[4] *LI Weikang, Mao Jun, LI Jiangang*. Research on the pre tension regulating system of scraper conveyor. Mining machinery, 2009, (7): 11-14

[5] *Deng Guanqian, Chen Zhongsheng, Tao Limin, Zhang Yuguang*. Research on vibration energy capturing behavior based on piezoelectric vibrator. Piezoelectricity and Acousto-optic (6): 939-942.

[6] *Lin L, Pisano A P, Lee A P.* Microbubble powered actuator. International Conference on Solid-State Sensors and Actuators, 1991. Digest of Technical Papers, Transducers. IEEE, 1991: 1041-1044.

[7] *W.J. Li, Z. Wen, P.K.Wong, GM.H. Chan, and P.H.W. Leong*, A micromachined cibration indueed power generator for low power sensors of robotic systems, in world Aytomation Congress: 8'h International Symposium on Robotics with Applications, 2000.

[8] *Weinberg M.S.* Working equations for piezoelectric actuators and sensors. Journal of Microelectromechanical Systems, 1999, 8(4): 529-533.

[9] *Salar C, Hasan U, Aziz K, et al.* An Adaptable Interface Circuit with Multi-Stage Energy Extraction for Low Power Piezoelectric Energy Harvesting MEMS. IEEE Transactions on Power Electronics, 2018: 1-1.

[10] *Kyung-Bum K , Yong C J , Jabbar H , et al*. Optimized composite piezoelectric energy harvesting floor tile for smart home energy management. Energy Conversion and Management, 2018, 171:31-37.

[11] *Kenji U*. Piezoelectric Energy Harvesting Systems. Journal of Physics: Conference Series, 2018, 1052: 012-022.

[12] *Aminur Rashid Chowdhury, Abu Musa Abdullah, Istiak Hussain, Jasmin Lopez, Denae Cantu, Santosh K. Gupta, Yuanbing Mao, Serena Danti, M. Jasim Uddin*. Lithium doped

zinc oxide based flexible piezoelectric-triboelectric hybrid nanogenerator. Nano Energy, 2019, 61.

[13] *Apurba Das, D. Pamu*. A comprehensive review on electrical properties of hydroxyapatite based ceramic composites. Materials Science & Engineering C, 2019, 101.

[14] *Wang Hai, Qiu Wanqun, Zhou Xuan*. Multi mass block broadband piezoelectric energy collector. Piezoelectric and acoustooptic, 2015, 37 (06): 1003-1008 + 1011.

[15] *Zhang Qiang, Niu Qi*. Design and experimental study of a new bi directional piezoelectric energy capture device. Sensors and Microsystems, 2018, 37 (07): 32-34+38.

[16] *Zhang Xuhui, Lin Ran.* Omnidirectional vibration energy collection system. Industrial and mining automation, 2015, 41 (01): 84-87.

[17] *Zhang Xuhui, Wu Zhonghua, Deng Pengfei*. Study on the optimization of replaceable multi-directional vibration energy collection device. Piezoelectric and acoustooptic, 2017, 39 (04): 594-59.

[18] *Zhiqi Li, Wanshen Xiao, Junping Xi, Haiping Zhu*. Anti-plane problem of nanocrack with surface piezoelectricity—a finite-form solution. Archive of Applied Mechanics, 2021 (prepublish).

[19] *Guo San-Dong, Zhu Yu-Tong, Mu Wen-Qi, Wang Lei, Chen Xing-Qiu*. Structure effect on intrinsic piezoelectricity in septuple-atomic-layer [formula omitted] (M=Mo and W). Computational Materials Science, 2021, 188.

[20] *Li Yehai, Feng Wei, Meng Long, Tse Kwong Ming, Li Zhen, Huang Linbing, Su Zhongqing, Guo Shifeng*. Investigation on in-situ sprayed, annealed and corona poled PVDF-TrFE coati ngs for guided wave-based structural health monitoring: From crystallization to piezoelectri city. Materials & Design, 2021, 199.

[21] *Qin Du, Wenli Wang, Zhiguang Wang, Wei Su, Zhiyuan Deng, Jingen Wu, Ming Ma, Zhongqiang Hu, Ziyao Zhou, Ming Liu*. Thermally activated giant piezoelectricity and enhanced interface elastic strainâ mediated magnetoelectric coupling. Journal of the American Ceramic Society, 2021, 104(2).

[22] *Kang Woo Seok, Lee Tae Gon, Kang Joo Hee, Lee Ju Hyeon, Choi Gangho, Kim Sun Woo, Nahm Sahn, Jo Wook.* Bi-templated grain growth maximizing the effects of texture on piezoelectricity. Journal of the European Ceramic Society, 2020 (prepublish).

[23] *Zhao Wei, Zhang Jiantao, He Ming*. Design and analysis of a micro piezoelectric vibration energy generator. Micromotor, 2020, 48 (07): 7-11.

[24] *Li Jia, Pang Zhihua, Liu Li, Li Wanjun*. Research on a wireless temperature measurement s ystem for piezoelectric vibration energy collection. Journal of Beihua Institute of aerospace technology, 2020, 30 (03): 20-22.