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Self-Powered Angle Sensor for Drill Pipe Based on Triboelectric Nanogenerator

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Abstract. Drill pipe angle is one of the key parameters for adjusting drilling technology, which needs real-time measurement. In this paper, an angle sensor based on triboelectric nanogenerator is proposed. The sensor can be set to different resolutions by designing different EVA sheets. Taking 12 EVA sensors as an example, the test results indicated the sensitivity is 0.08°/V, the linearity is 5.2%, and the maximum relative error is 6%. In terms of self-supply capability, the self-supply sensor can output maximum voltage are 29 V, a maximum current are 50 nA, and a maximum load power are 110 nW. In the case of 50000 working cycles, its test performance has not significantly decreased, showing high stability.

Keywords. Drill pipe, Angle sensor, Triboelectric nanogenerator, Self-powered

1. Introduction

Drilling is an engineering technique that uses the drilling tools to drill, and is one of the important means of mining the ground floor or the natural resources of the seafloor , and for drilling tools, the rotation angle is one of the important parameters to control the drilling process of the drilling tools [1]. At present, Angle sensors of the drill pipe are widely used in the market. Common Angle sensors are photoelectric[2], electromagnetic[3], eddy current[4], optical grating[5] and inertial measurement unit. However, these Angle sensors generally have high power consumption and cannot be self-powered. Therefore, it is necessary to develop an angle sensor with self powering function to adapt the well working conditions.

Triboelectric nanogenerator have been widely used in sensor and energy collection fields since they were proposed. In the field of sensors, such as speed sensing[6], flow sensors acceleration sensing, vibration sensing[7] and human movement monitoring. In the field of energy collection, it is applied to the collection of wind energy[8], sound wave energy, rain energy[9], mechanical energy[10] and wave energy. It can be seen that triboelectric generator has great advantages in Angle sensor application. Therefore,

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this paper presents a drilling rod angle sensor based on a triboelectric Nanogenerator. Compared with traditional Angle sensors, the drill pipe Angle sensor based on triboelectric nanogenerators can be self-powered, which provides a solution to the problem of difficult power supply for downhole equipment.

2. Structural design and working principle

2.1. Structural design

The structural model of the sensor is shown in Figure 1. The cylindrical blade angle sensor consists a rotor and a stator. The stator is a large cylinder, and the rotor is composed of a shaft, and a small cylinder and a connecting mechanism. Copper foil is pasted on the outer wall of a large cylinder as a negative electrode, and PTFE (polytetrafluoroethylene) is pasted on the copper foil as a negative friction material. The PTFE area on each EVA sheet is not the same, to produce different output when contacting with the positive electrode to realize the judgment of rotation angle. A rectangular EVA sheet is pasted on a large cylinder tangentially, and copper foil is pasted on the EVA sheet as a positive friction material and a positive electrode. The outer wall of the large cylinder is in close contact with the small cylinder, and the shaft is connected with the large cylinder by bearings. The small cylinder is connected to the middle rotating shaft by a connecting mechanism on the outside. When the rotating shaft rotates, the small cylinder can be driven to rotate. The resolution angle is determined by the number of rectangular EVA sheet. For example, in Figure 1a, where pasted 12 EVA sheets, it can distinguish 360°/12, that is, 30° angle. If the number is larger, the smaller the angle that the sensor can distinguish, that is, the higher the resolution.

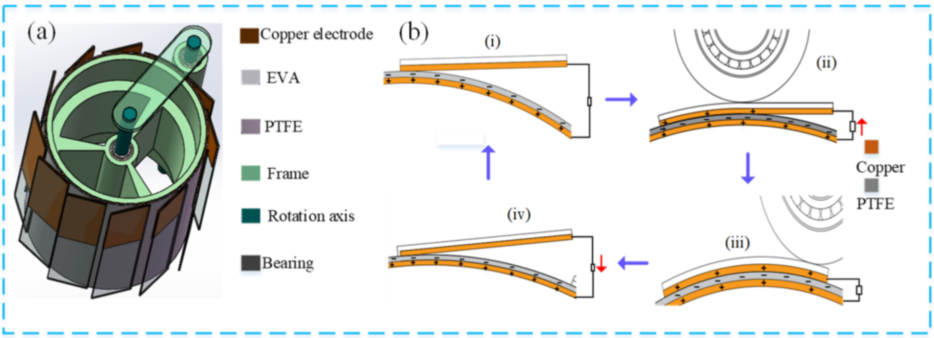

Figure 1. (a) Schematic diagram of the sensor structure; (b) Sensor working principle

2.2. Working Principle

The generating principle of the structure can be attributed to the electrostatic induction and the triboelectric effect. Take a small cylinder touching an EVA sheet once. As shown in Figure 1b (i), when the small cylinder does not contact the EVA sheet, the electronegativity of the two friction layer materials (PTFE and copper foil) on the large cylinder is different. The surface of copper foil has a positive charge, while the surface of PTFE will generate an equal amount of negative charge. When the small cylinder rotates to contact the EVA sheet, the copper foil on the EVA sheet gradually contacts the PTFE, as shown in Figure 1b (ii). At this time, the positive charge is gradually transferred from the negative to the positive. The rotation axis continues to rotate, and the small cylinder presses down the EVA sheet to fully contact the PTFE, as shown in Figure 1b (iii). The negative charge on the PTFE forms a charge balance with the upper and lower copper electrodes again. There is no charge transfer. As the cylinder moves away from the EVA sheet, the EVA sheet gradually separates from the PTFE, and the positive charge is gradually transferred from the positive to the negative. At this point, the small cylinder gradually contacts another EVA sheet, as shown in Figure 1b (i) again, the next working principle is consistent with the above, but the maximum output current is different due to different areas of the friction layer. As the cylinder rotates, it produces several different peaks, depending on how many pieces of EVA sheet.

3. Test results

3.1. Sensor Power Generation Characteristics

As shown in figure 2a shows that the cylinder vane from the experimental process of the power supply Angle sensor, mainly is to use a rotary motor drive motion sensor, the output is connected to the KEITHLEY 6514 types of the electrometer to measure and get the voltage and current of the structure and transfer charge, then by connecting the resistance of the different sizes, and measuring the load output characteristic; Finally, the stability of the material is measured. As shown in Figure 2c, TENG has a maximum

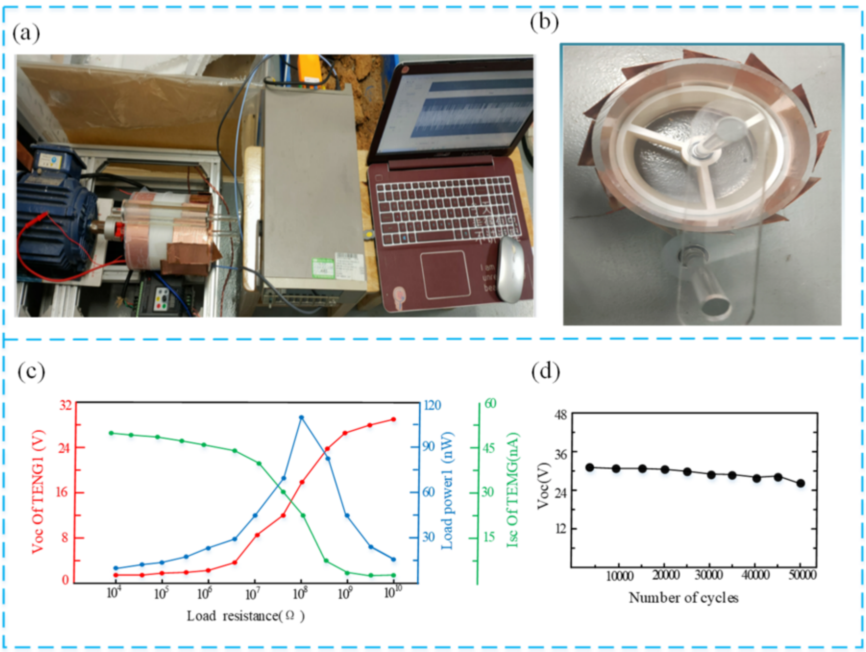

Figure 2. (a) Sensor test device and power generation characteristics. (b) Sensor photographs; (c) Voltage, current and output power of the sensor at different resistances; (d) Sensor stability test

output voltage of 29 V, a maximum current of 50 nA and a maximum output power of 110 nW. Figure 2d shows that the sensor has stable output performance even after 50000 rotations.

3.2. Sensor Characteristics

As shown in Figure 3a, when the rotor drives the small cylinder to rotate, the small cylinder presses the EVA sheet, making the inner copper foil contact with the PTFE outside the large cylinder. The contact area increases from small to large, and the output voltage increases gradually. There will be a process of voltage increase to wave peak every time an EVA sheet is pressed, and because of the different areas of PTFE from different angles, the wave peak shows an increasing trend. As can be seen from Figure 3b, as the rotation angle increases, its current will also increase. Because the large voltage and small current of the triboelectric nanogenerator, the sensor's output voltage and rotation angle are calibrated to obtain a large SNR (signal to noise ratio). As shown in Figure 3c and Figure 3d, the sensitivity of the sensor is 0.08°/V, the linearity is 5.2%, and the maximum relative error is less than 6%.

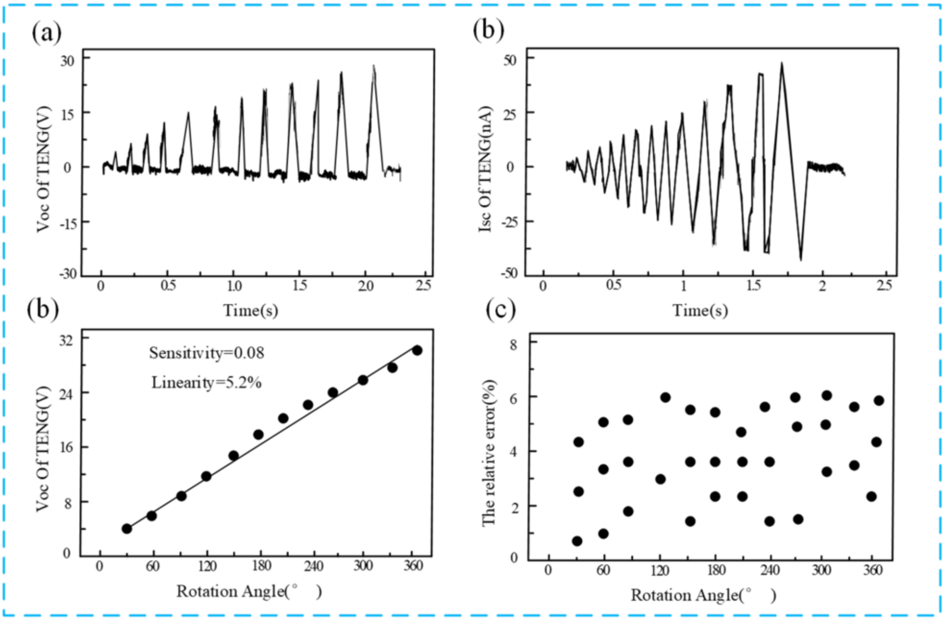

Figure 3. (a) Output voltage waveform of the TENG; (b) Output current diagram of the TENG; (c) Calibration curve of TENG output voltage and rotation angle; (d) Sensor error diagram

4. Conclusions

In this paper, a self-powered angle drill pipe sensor based on TENG is proposed. The sensor can output voltage with different amplitude at different rotation angles. Through the experimental results, the resolution of the sensor was 360°/12, i.e. 30°, with the sensitivity is 0.08°/V, the linearity is 5.2%, and maximum relative error is 6%. In terms of power generation capacity, the sensor can output voltage of 29 V, current of 50 nA, and load power of 110 nW. In the case of 50000 working cycles, its test performance has not significantly decreased, showing a high stability. However, the output performance of this sensor is still low, especially the output current is low, so how to improve the performance of the friction layer materials to improve the output performance of the sensor is the focus of the next research.

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