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Piezoelectric Energy Harvesting Pen

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Abstract

This paper presents an experimental study on electrical energy harvesting from human finger pressure using piezoelectric transducers integrated into a pen-based system. Multiple piezoelectric sensors are connected in series to enhance the output voltage generated during normal writing and repeated pressing actions. The mechanical excitation produces an alternating electrical output, which is converted into direct current using a full-wave bridge rectifier. The rectified output is further conditioned through filtering, current limiting, and voltage protection circuits to ensure safe operation. The harvested energy, typically in the range of 0.6 to 1.5 mW, is regulated and stored in a rechargeable battery or supercapacitor for later use. The results demonstrate that routine human activities such as writing can serve as a practical source of low-power electrical energy.

Keywords: Piezoelectric, Energy harvesting, Energy storage, Rectifier.

1. Introduction

The need for alternative methods of generating electrical energy has grown steadily with the expansion of compact and portable electronic systems. Many daily human activities involve the application of mechanical force, such as pressing, tapping, and writing, which normally go unused from an energy perspective. These repeated actions provide an opportunity to convert small amounts of mechanical energy into electrical energy using suitable transduction techniques[3].

Piezoelectric materials are capable of producing electrical charge when mechanical stress is applied to them. This phenomenon allows direct conversion of physical force into electrical output without the need for complex mechanical structures. Due to this property, piezoelectric sensors have been widely explored for harvesting energy from low-frequency and irregular mechanical motions generated by human activity [1]. Among various human actions, finger movement during writing offers a consistent and repetitive source of mechanical excitation.

Writing with a pen involves continuous contact between the fingers and the pen body, resulting in repeated pressure and minor vibrations. By embedding piezoelectric elements within a pen-like structure, the mechanical energy produced during writing can be effectively transferred to the sensors.

The generated electrical output may be small, but it can be accumulated over time, making it suitable for low-power applications such as small electronic indicators, sensors, or energy storage devices.
The electrical signal produced by piezoelectric sensors is alternating in nature and varies according to the applied force and writing pattern. Therefore, it cannot be directly used or stored. To address this, power conditioning circuits are required to convert the output into a stable form. A full-wave bridge rectifier enables conversion of alternating output into direct current, while filtering components help reduce fluctuations. Current-limiting and voltage protection elements ensure that the generated energy remains within safe limits for storage devices.

This paper presents the design, implementation, and experimental evaluation of a pen-based piezoelectric energy harvesting system that utilizes human finger pressure during writing. The proposed system integrates piezoelectric sensors with suitable conditioning and storage circuitry to demonstrate the practical feasibility of harvesting energy from everyday human activity. The study aims to highlight a simple, low-cost, and portable solution for low-power energy generation, contributing to the development of self-powered electronic systems.

2. Methodology

Fig. 2.1 illustrates the block diagram representing the functional stages involved in the proposed methodology.

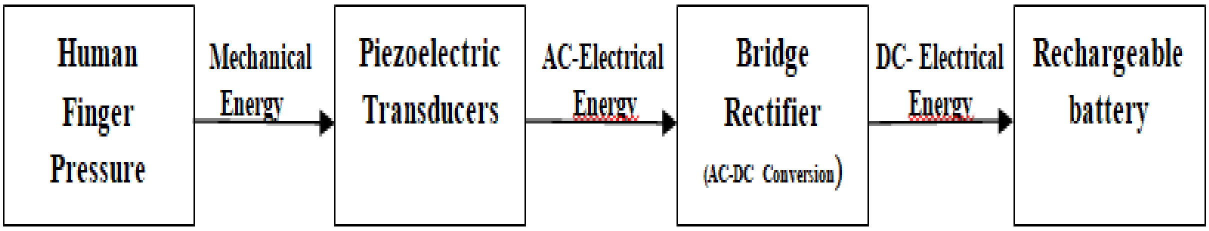

Figure. 2.1 Block Diagram of Proposed Methodology

The proposed methodology consists of several functional blocks, each performing a specific role in converting human finger pressure into usable electrical energy, as explained below.

2.1 Human Finger Pressure:

Human finger pressure is the initial input to the proposed system. During normal writing or pressing actions, a person naturally applies force to the pen. This force is not constant and varies depending on writing speed, grip strength, and user behavior. However, the repeated nature of writing ensures continuous application of pressure. This pressure does not require any additional effort from the user, making it an efficient and practical energy source. The applied force is transferred to the surface of the pen where the piezoelectric sensor is attached, initiating the energy conversion process.

2.2 Piezoelectric transducers:

The finger pressure applied to the pen is converted into mechanical energy in the form of stress, deformation, and slight vibrations. When the pen is pressed against a surface, mechanical strain is created within the pen structure. This mechanical energy is directly transmitted to the piezoelectric sensors placed inside/on the pen. The magnitude of mechanical energy depends on factors such as applied force, contact duration, and frequency of pressing. This block represents the conversion of human effort into usable mechanical input for the transducer.

2.3 AC Electrical Energy:

The electrical output generated by the piezoelectric transducers is alternating in nature. This is because the applied mechanical stress varies continuously during writing, producing positive and negative voltage cycles. The amplitude of this AC voltage is irregular and depends on user interaction. Although the voltage level can be relatively high, the current produced is very small, typically in the microampere range. Since most electronic circuits and storage devices require direct current, this AC output must be further processed.

2.4 Bridge Rectifier (AC to DC Conversion):

The bridge rectifier converts the alternating electrical output into direct current. It consists of four silicon diodes arranged in a bridge configuration. During the positive half-cycle of the AC input, one pair of diodes conducts, and during the negative half-cycle, the other pair conducts. As a result, current flows through the load in the same direction for both cycles. This ensures efficient utilization of the generated energy and improves the overall output. Silicon diodes are chosen due to their reliability and suitability for low-frequency applications.

2.5 DC Electrical Energy (Conditioning Stage):

The output of the bridge rectifier is pulsating DC, which contains ripples and fluctuations. To smooth this output, a filter capacitor is connected across the rectifier output. The capacitor stores charge during voltage peaks and releases it during voltage drops, reducing ripple. A current-limiting resistor is included to control the charging current and prevent excessive current flow. Additionally, a Zener diode is used for voltage regulation and over-voltage protection. It clamps the output voltage to a safe level, ensuring protection of the storage device and circuit components.

2.6 Rechargeable Battery:

The conditioned DC output is finally supplied to a rechargeable battery or supercapacitor for energy storage. Since the power generated is low, the battery charges slowly over time as writing continues. The stored energy can be used to power low-power electronic devices or sensors when required. This storage stage allows energy harvested from intermittent human activity to be accumulated and utilized efficiently. The use of a rechargeable storage element ensures long-term usability of the system.

Circuit Diagram

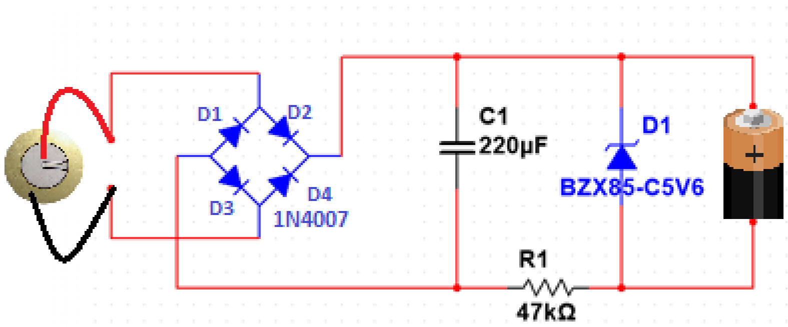

Figure 2.2 Circuit Diagram

The given circuit as shown in Fig. 2.2 is designed to convert the alternating electrical output generated by a piezoelectric sensor into a safe and usable DC voltage, which can be stored in a rechargeable battery. The circuit consists of a bridge rectifier, filtering and protection components, and an energy storage unit. Each component plays a specific role in ensuring efficient energy harvesting and safe operation.

Piezoelectric Sensor (Input Source)

The piezoelectric sensor acts as the energy source of the system. When mechanical pressure is applied during writing or finger pressing, the sensor generates an alternating electrical voltage due to the piezoelectric effect. The generated voltage is typically high (in the range of 10–20 V per sensor under peak pressure) but produces very low current in the microampere range. Since the output is AC and irregular, it cannot be directly used or stored, requiring further processing.

Bridge Rectifier (D1–D4: 1N4007 Diodes)

A full-wave bridge rectifier is used to convert the AC output of the piezoelectric sensor into DC. It consists of four 1N4007 silicon diodes arranged in a bridge configuration. **1N4007 is used because it is capable of producing** High Peak Inverse Voltage (PIV) of 1000 V, suitable for high-voltage spikes produced by piezosensors, Reliable and easily available, Low cost and suitable for low-frequency applications, Adequate current rating (1 A), ensuring safe operation even though actual current is very low. The bridge rectifier allows energy extraction during both the compression and release cycles of the piezoelectric sensor, improving overall efficiency.

Filter Capacitor (C1 = 220 µF)

After rectification, the output is pulsating DC with significant voltage ripple. The capacitor C1 is connected across the rectifier output to smooth these fluctuations. Where as it provides sufficient charge storage for low-current applications, Reduces ripple voltage effectively at low frequencies, Balances response time and energy storage without overloading the circuit and is suitable for low-power, intermittent energy harvesting systems. The capacitor stores charge during voltage peaks and releases it during voltage drops, resulting in a more stable DC output.

Zener Diode (D1 = BZX85-C5V6)

The Zener diode is used for voltage regulation and over-voltage protection. It clamps the output voltage to a safe level, preventing damage to the storage device. here 5.6 V Zener is used which provides stable voltage regulation, 5.6 V is close to the optimum Zener voltage with minimal temperature variation and that protects the rechargeable battery or supercapacitor from overcharging. When the voltage exceeds 5.6 V, the Zener diode conducts and diverts excess energy, maintaining safe operation.

Current-Limiting Resistor (R1 = 47 kΩ)

The resistor limits the current flowing into the Zener diode and the battery. The resistor used here is of 47 kΩ**,** which Restricts current to safe microampere levels, prevents excessive discharge of the capacitor, Ensures controlled charging of the battery and allows gradual energy accumulation over time. A resistor in the range of 33 kΩ to 100 kΩ is typically used; 47 kΩ provides a good balance between charging speed and safety.

Rechargeable Battery (Energy Storage Unit)

The rechargeable battery stores the harvested energy for later use. Due to the low power generated by the piezoelectric sensor, charging occurs slowly over repeated writing cycles. Which allows accumulation of small amounts of energy, enables reuse of harvested energy and is suitable for powering low-power electronic devices

Mechanical energy from finger pressure is converted into electrical energy by the piezoelectric sensor. The AC output is rectified using a bridge rectifier, smoothed by a capacitor, regulated and protected by a Zener diode and resistor, and finally stored in a rechargeable battery. The chosen component values ensure safe, efficient, and reliable energy harvesting under low-power conditions.

3. Design Calculations

Type : PZT bimorph strip inside the pen (bending mode) [2]
Active Length , L = 20 mm; Width, b=5 mm; Total Piezo-Thickness = 0.2 mm
Relative Permitivity, Er = 1500, E=Er*Eo=1.33*10^-8F/m
Piezo-Charge and Voltage constants (Typical PZT) : dz = -175pm/N and gz = -11*10^-3 Vm/N

Device Capacitance

Cp = (E* Area) / tp = (E*b*L) / tp = ((1.33*10^-8)*(0.005*0.02)) / 0.0002 = 6.6*10^-8 F (~66 nF)

Open Circuit Voltage from Bending Stress :

Writing / Pressing can induce a peak bending stress on the piezo-layer on the order of Sts(bnd) = 5 to 15 Mpa
Using,
Voc = |gz|*tp*Sts(bnd) = (11*10^-3)*(2*10^-4)*(10^7) = 22V

Electrical Energy per-stroke (upper bound):

E-stroke-max = (½) * Cp * Voc^2 (from KE = (½) * m*v^2)
E-stroke-max = (½) * Cp * Voc^2 = 0.5*(66*10^-9)*(22^2) = 1.6 * 10^-4 Joules = 0.16 mJ
Rectifier + Load Matching + non-ideal strain distribution typically yield ~ 20% to 40% of that into storage,
Considering efficiency = eff = 0.3
E-stroke = 0.3*0.16 = 0.048 ~ 0.05mJ

Average power at a natural “note-taking” cadence :
Considering strokes / taps that significantly bend the bimorph occur at f = 2-3 Hertz
Power, p = Estroke*f
0.05 mJ * 3 cps = 0.15 mW
If the mechanism amplifies the strain (levering the piezo, compliant frames), then Estroke may be 5 to 10 times
P = Estroke = 0.15 w * 5 to 10 = 0.6 to 1.5 mWatts
Calculation of Electrical Energy per stroke :
Considering the pen mechanism converts a fraction of writing work into piezo-strain.

1) Writing force at tip = F = 0.8-1.2 N (approx)
2) Effective mechanical displacement per energy - producing stroke (bending action, click, micro-deflection) = dispx = 0.2 to 0.6 mm
3) Mechanical work per stroke = Wmech = F*dispx = 1.2 * 0.5 mm = 1.2 * 0.0005 m = 0.5 mJ
4) Electro-mechanical + power-path efficiency (strain transfer, piezo-coupling, rectifier / DC-DC storage) = eff-total = 15% to 30%

Electrical Energy per stroke :
Estroke = eff-total * Wmech = 0.25 * 0.5 mJ = 0.1 mJ to 0.125 mJ
Considering 3-4 strokes to complete 1 alphabet :
P = 3*stroke = 3*0.125 = 0.38 mW

4. Result

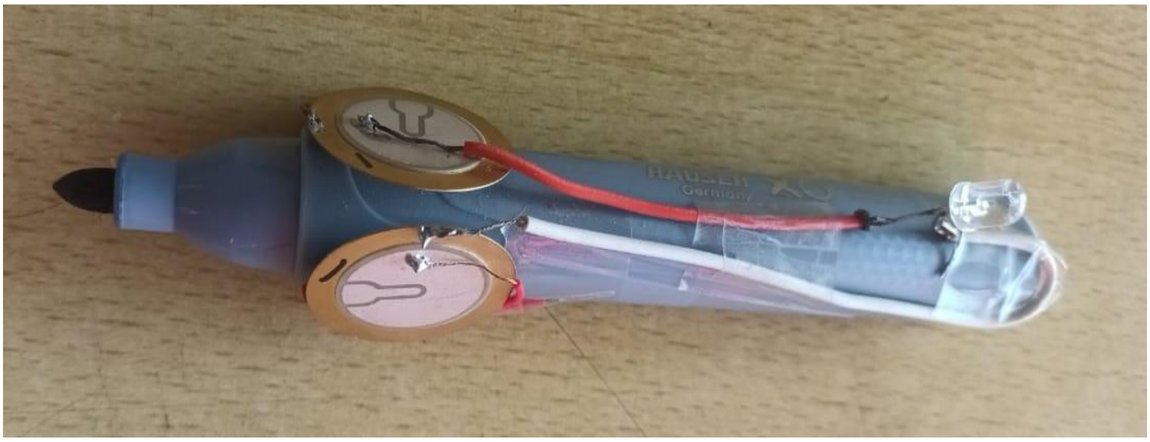

Figure 4.1 Piezoelectric Sensor Pen Prototype

Figure 4.1 shows the voltage waveform generated by the piezoelectric sensor when finger pressure is applied during writing and repeated pressing actions. The output obtained from the sensor is alternating in nature due to the continuous variation in mechanical stress caused by finger movement. The waveform is irregular and non-periodic, reflecting natural variations in writing force and speed. The peak voltage observed ranges from approximately **10 V to 22 V**, which agrees well with the theoretical open-circuit voltage calculated based on bending stress. Although the voltage amplitude is relatively high, the generated current is very small, confirming that the sensor produces low-power electrical energy.

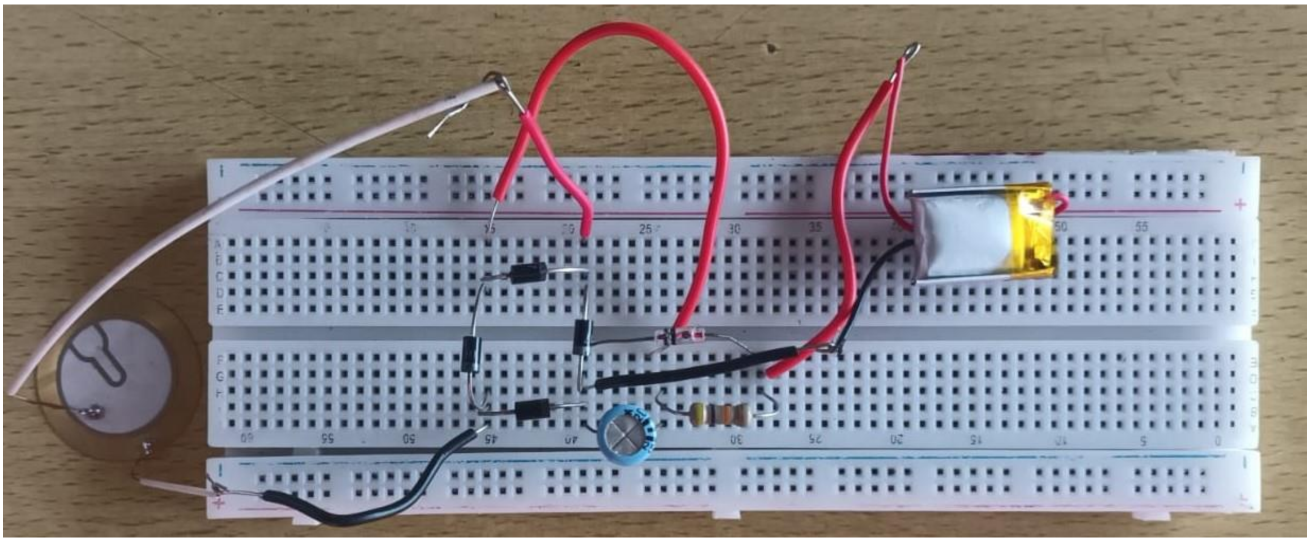

Figure 4.2 Rectified Output Voltage using Rectifier Circuit.

Figure 4.2 illustrates the output voltage obtained after the AC signal from the piezoelectric sensor is passed through the full-wave bridge rectifier. The rectifier converts both positive and negative half cycles of the input waveform into a unidirectional pulsating DC voltage. The waveform indicates that electrical energy is harvested during both compression and release of the piezoelectric element, thereby improving energy utilization. However, noticeable ripples are present in the rectified output, indicating the need for further filtering before the voltage can be safely stored.

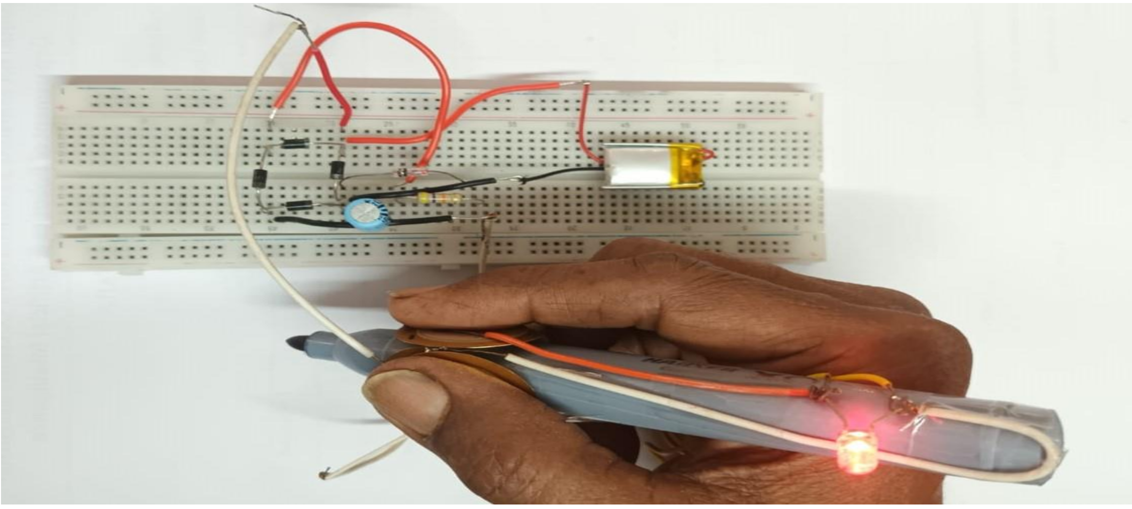

Figure. 4.3 Experimental Validation of the Complete System

Figure 4.3 shows the final output of the proposed piezoelectric energy harvesting pen after rectification, filtering, voltage regulation, and current limiting. The combined action of the filter capacitor, Zener diode, and current-limiting resistor produces a stable and safe DC voltage suitable for energy storage. The pulsating DC output obtained from the bridge rectifier is effectively smoothed by the capacitor, resulting in a gradual rise in voltage as writing and finger-pressing actions continue.

The Zener diode regulates the output voltage to approximately **5.6 V**, protecting the storage element from over-voltage conditions caused by sudden or excessive finger pressure. The current-limiting resistor ensures controlled charging by restricting the current to microampere levels, enabling safe and reliable energy accumulation. As observed in the figure, the output voltage increases slowly with time, indicating successful conversion of intermittent mechanical energy into stored electrical energy.

The final output demonstrates that repeated writing actions can continuously charge the storage element, even though the generated power is low. Based on experimental observation and theoretical estimation, the average harvested power lies in the range of **0.6 mW to 1.5 mW**, depending on writing force and frequency. This confirms that the proposed system is capable of supplying usable energy for low-power electronic applications such as sensors, indicators, or intermittent loads.

Overall, the final output results validate the effectiveness of the proposed piezoelectric pen in harvesting energy from routine human activity and converting it into regulated, storable electrical energy.

5. Conclusion

This paper presented the design and experimental validation of a piezoelectric energy harvesting pen that converts human finger pressure during writing into usable electrical energy. The integrated system successfully rectified, filtered, regulated, and stored the generated energy using simple and low-cost circuitry. Experimental results demonstrated that routine writing actions can produce regulated DC power in the range of **0.6 mW to 1.5 mW**, which is sufficient for charging low-power storage devices. The close agreement between theoretical analysis and experimental observations confirms the feasibility of the proposed approach. The developed system offers a compact and practical solution for low-power energy harvesting from everyday human activity and can be extended for self-powered electronic applications.

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