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Research Article

Piezoelectric Combat Pad: Harnessing Kinetic Energy for Power Generation

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Abstract - *This study investigates the design, development, and performance evaluation of a piezoelectric combat pad that converts kinetic energy from punches into measurable electrical energy. The research will also establish the electrical output produced in the prototype at different punching rates and to test the correlation between the punch frequency and energy production. The system makes use of ten piezoelectric discs which are placed in parallel and connected to a full-wave bridge rectifier which transforms mechanical impacts into electrical signals. Experimental testing is carried out at the rate of punching 20, 40, and 60 punches per minute, and three experiments are carried out in each condition to guarantee data consistency. A digital multimeter is used to measure electrical output in terms of current and voltage. Findings indicate that the prototype has an ability to achieve consistent electrical output in each of the test situations, with an average voltage of about 7 V at 20 and 40 punches per minute and 8 V at 60 punches per minute. The peak mean current output is at a rate of 20 punches per minute (0.21 A). Energy calculations show the highest mean energy to be produced at 20 punches per minute (86.0 J). Pearson correlation analysis An analysis of the relationship between punching rate and generated energy can be seen as having a weak negative correlation (r = -0.272, p = 0.478), which suggests that the frequency of punching is not a key determinant of energy production. The findings demonstrate the potential of integrating piezoelectric technology into sports equipment as a small-scale energy harvesting system, contributing to sustainable energy innovation.*

Keywords - *Energy Harvesting, Kinetic Energy, Piezoelectric, Piezoelectric Sensors, Power Generation, Renewable Energy Technology, Sports Energy Harvesting.*

I. INTRODUCTION

Globally, the increasing demand for electricity has intensified the need for cleaner and more sustainable energy sources. Most of the energy used today still comes from fossil fuels, which significantly harm the environment by releasing greenhouse gases and causing pollution[1]. With the implications of climate change becoming increasingly felt, the need to seek renewable energy options has increased. Because of this, researchers and scientists are exploring innovative ways to generate electricity from natural and sustainable sources that can reduce environmental impact while meeting the rising global energy demand [2].

One promising approach is the use of piezoelectric technology, which can convert mechanical movements such as pressure, vibration, or motion into electrical energy through specialized materials[3]. In most of our daily life settings like roads, walkways, and sports areas, we produce a lot of energy that is mechanical in nature and is wasted. This wasted energy can be harnessed by incorporating piezoelectric materials which can be then transformed into electricity which can then be utilized to power small gadgets such as sensors or lights. The proposed study as per this idea is creating a combat pad that would enable it to produce electricity based on the pressure generated by the punches or blows. The study will focus on proving that basic mechanical activity can be used as a source of clean and renewable energy, as well as help in the process of sustainability and stimulate the development of innovative solutions that integrate technology, energy efficiency, and environmental conservation.

II. MATERIALS AND METHODS

A. Preparation of Materials

Materials for the construction of the piezoelectric combat pad were gathered from local stores and recycling centers, some needed materials unavailable nearby were ordered from online shops. The main components of the combat pad are presented below, along with their corresponding specifications and functions.

Table 1. Piezoelectric Combat Pad Components and Functions

Components	Functions
Piezoelectric Disc	Converts mechanical energy from inpacts into electrical energy.
Foam	Provides cushioning and shock absorption, enhancing user comfort.
Sliding Roller	Facilitates movement back to its original position when punched and distributes impact force evenly across the pad.
Synthetic Leather	Covers the surface for durability and realistic striking texture.
Plyboard	Acts as a strong support layer, maintaining structural integrity.
Steel Base	Provides stability and durability to the overall structure f the pad.
Steel Pole	Supports the combat pad and attaches to the base for stability.
Wires	Connects electrical components.
Jumper Wires	Facilitates connection between components for testing and adjustments.
Schottky Diodes	Used for full-wave rectification, allowing efficient energy conversion.
Spring	Allows the pad to return to its original position after an impact, enhancing responsiveness

B. System Design

a. Circuit Diagram

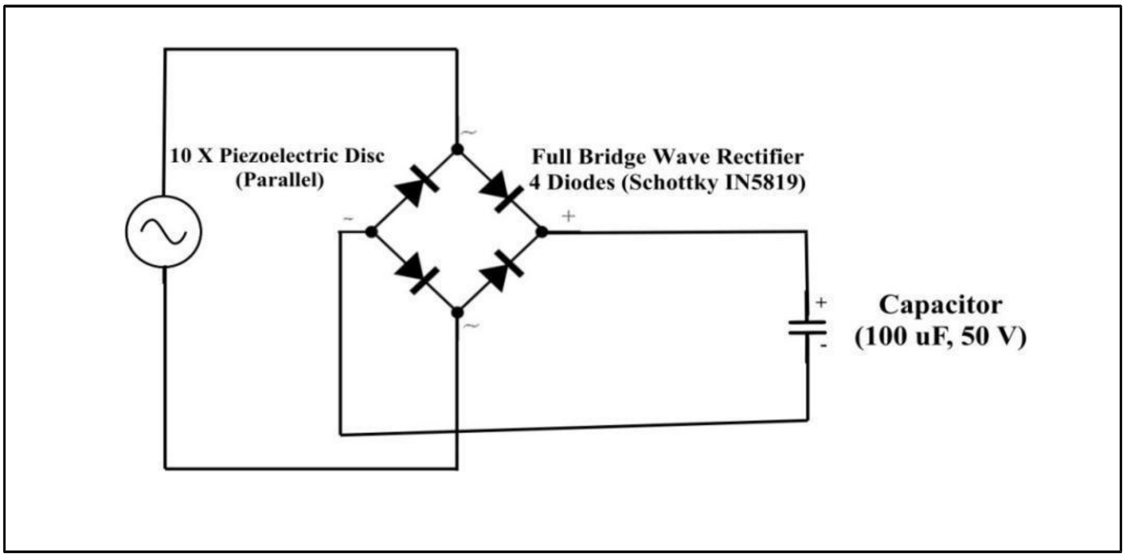

Figure 1. Circuit Diagram of Piezo Electric Combat Pad

Figure 1 represents the piezoelectric combat pad's energy harvesting circuit. Mechanical impacts are converted to AC voltage by an array of 10 piezoelectric discs which are connected in parallel. The AC output is connected to a full-wave bridge rectifier that is made up of 4 Schottky diodes (IN5819), which transforms the AC voltage to DC. The rectified DC is then stored in a 100 μF, 50 V capacitor.

b. Frame

The frame kept the internal layers properly aligned and improves the distribution of force across the pad, allowing the sensors to produce a more stable and consistent electrical output. Overall, the frame increases the durability of the combat pad and makes it easier to mount securely.

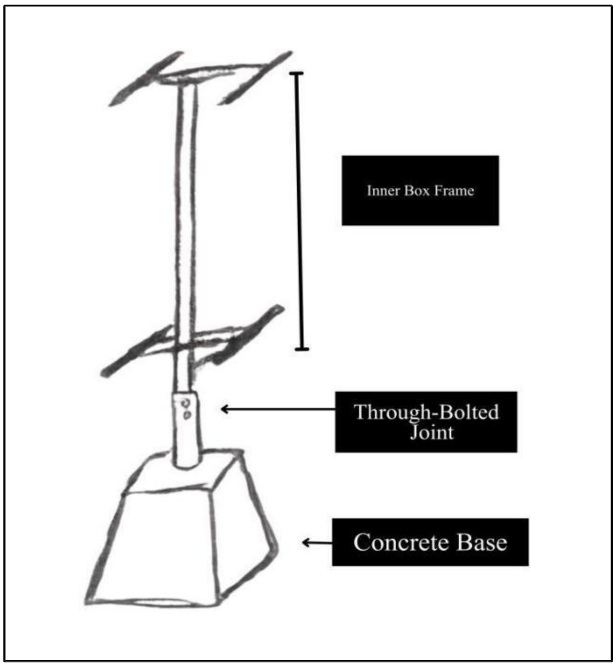

Figure 2. Frame of the Piezoelectric Combat Pad

c. Internal Layer

The sensors and electrical components were mounted in the inner layer. It handles the spring mechanism and sliding rollers which help the pad's return to its original position while enhancing vibrational response.

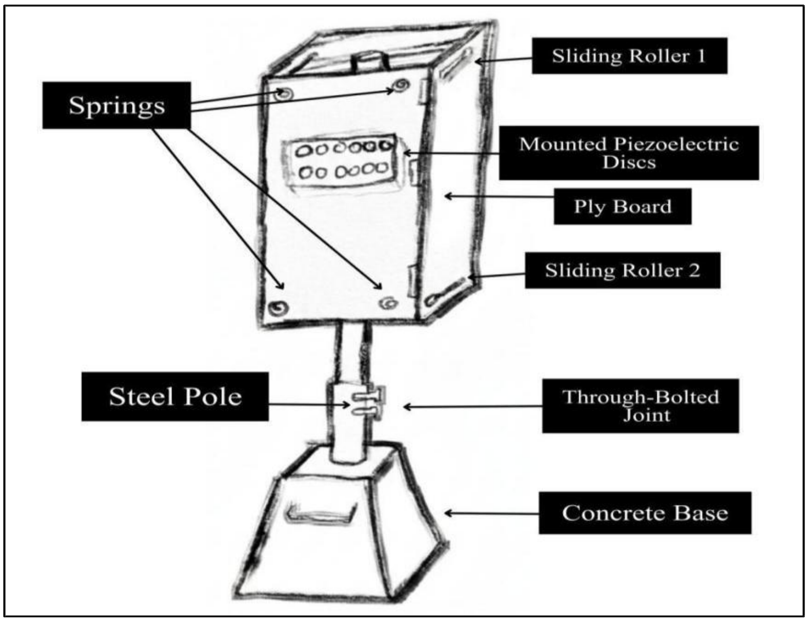

Figure 3. Internal Layer of the Piezoelectric Combat Pad

d. Main Combat Pad & External Design

The main combat pad contains a pair of sliding rollers connected to the inner layer. Its primary function is to receive and absorb punches during use. This is created to be able to endure repeated impact and to transfer forces effectively to the internal components. When hit, the moving rollers assist in dividing the force equally and facilitate easy mechanical action. This mechanism helps the pad to operate successfully by switching on the sensors and retaining structural stability.

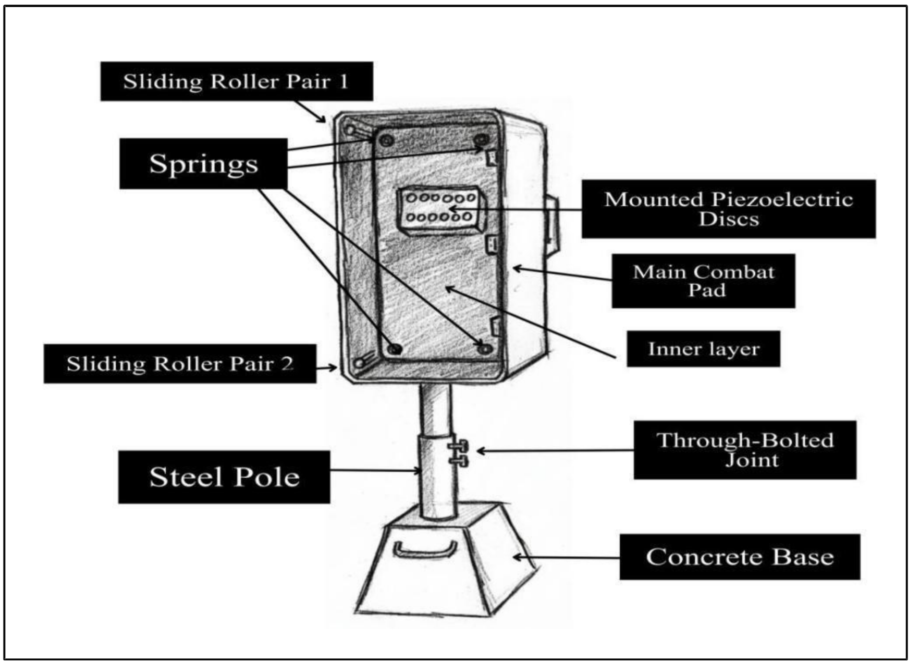

Figure 4. Main Combat Pad

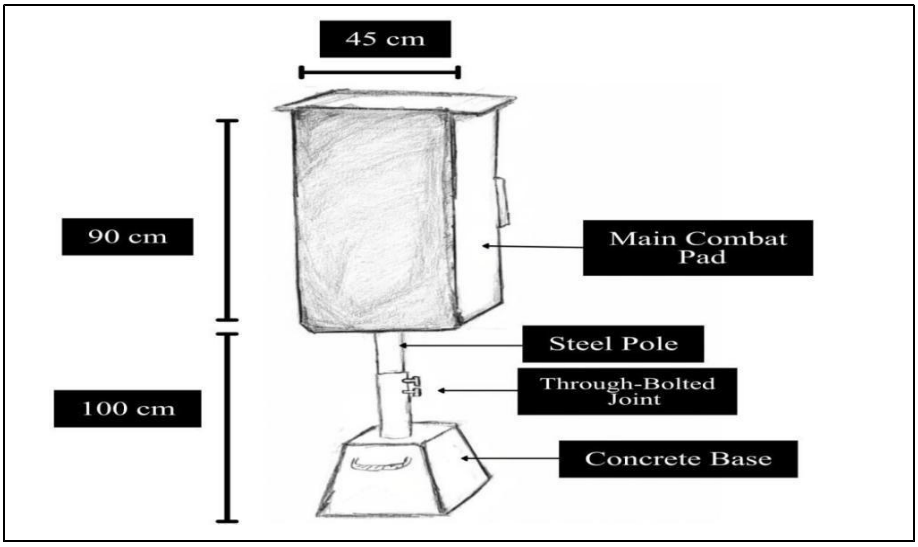

Figure 5. External Design Overview of the Combat Pad

C. Fabrication

a. Mechanical Construction

The design and techniques were created and improved using the information gained in various prior investigations of impact force detection and piezoelectric energy collection, layered transducer structural design, sensor assembly, and mechanical performance of plywood and steel-reinforced structure through repeated impacts [4-11]. The fabrication process began with the construction of the base, that was composed of concrete in order to offer stability and ensure that the base does not move when it is in use. Once the base was done, it was topped with a one-meter hollow steel cross section that was to be attached to the base with a detachable bolt-through joint allowing the combat insert. Also included was a 90 cm steel extension to the combat pad and formed a total structure height of about 190 cm.

Next, the 90 cm steel extension was welded with braces to create the supporting frame of the combat pad. The plyboard after securing the frame was shaped into a prism to suit the overall shape desired of the pad. Once the plyboard was made into a structure, sliding rollers were attached to allow controlled movement during impact. Following this, the spring mechanism was installed, and it was positioned to measure the compression and impact response. The electrical parts were then assembled and attached hinged to get them aligned appropriately. Lastly, the leather cover, that constituted the primary striking surface of the pad, was fitted with its cushioning layers to act as impact absorber and offer durability in the face of repeated strikes.

b. Electrical Integration

The electrical integration began once the mechanical structure and internal mechanisms were fully assembled. An array was formed of ten piezoelectric discs, each in parallel, and connected together to form an array serving as the main sensing layer to impact detection. The piezoelectric array output was fed into a full- bridge rectifier (1N5819) to rectify the alternating current (AC)signals produced by the piezoelectric elements into direct current (DC). The rectified signal was then stored in a 100 μF, 50 V capacitor, which stabilized the voltage and allowed for consistent measurements. All the wiring was secured to the frame so as to not interfere with the moving components within the pad. When the system was assembled a test was done to ensure that the piezoelectric array could reliably produce voltage signals indicative of each strike on the pad.

III. RESULTS AND DISCUSSION

A. Voltage Output

Table 2. Generated Voltage

Punches per Minute (ppm)	Trial 1	Trial 2	Trial 3	Mean
20 ppm	6 V	7 V	8 V	7V
40 ppm	7 V	7 V	7 V	7 V
60 ppm	8 V	8 V	8 V	8 V

Table 2 presents the generated voltage at different punch rates (20 ppm, 40 ppm, and 60 ppm). Trial 1 had the lowest voltage of 6 V at 20 ppm and Trial 3 had the highest voltage of 8 V and the average voltage was 7 V. All the trials at 40 ppm had a consistent 7 V yielding a mean of 7 V. All 3 trials generated 8 V at 60 ppm, which gave the maximum mean voltage between all three punch rates. In general, the findings reveal that the greatest mean voltage was recorded at 60 ppm, and the lowest mean voltage was recorded at 20 ppm and 40 ppm.

B. Current Output

Table 3. Generated Current

Punches per Minute (ppm)	Trial 1	Trial 2	Trial 3	Mean
20 ppm	0.23 A	0. 2 A	0.19 A	0.21 A
40 ppm	0.18 A	0. 2 A	0.11 A	0.16 A
60 ppm	0.20 A	0. 13 A	0.18 A	0.17 A

Table 3 presents the generated current at different punch rates (20 ppm, 40 ppm, and 60 ppm). At 20 ppm, Trial 1 had the greatest value of 0.23 A when the current was 20 ppm and Trial 3 had the least value of 0.20 A giving a mean of 0.21 A. Trial 2 had the highest current of 0.2 A at 40 ppm, whereas the others had 0.18 A and 0.11 A, yielding a mean of 0.16 A. In contrast, at 60 ppm, the recorded values were 0.20 A, 0.13 A, and 0.17 A, resulting in a mean of 0.17 A. These results indicate that the highest mean current was observed at 20 ppm, whereas the lowest mean current was recorded at 40 ppm.

C. Relationship Between Punching Rate and Energy Produced

Table 4 presents the energy generated at different punch rates (20 ppm, 40 ppm, and 60 ppm). Trial 1 gave the lowest energy of 82.8 J, Trial 2 gave 84.0 J, and Trial 3 gave the highest energy of 91.2 J with the mean energy being 86.0 J. At 40 ppm, Trial 1 produced the highest 75.6 J, Trial 2 the highest 84.0 J and Trial 3 the lowest 46.2 J, with a mean value of 68.6 J. Trial 1 gave 84.0 J, Trial 2 gave 60.0 J and Trial 3 gave 86.4 J with a total mean of 76.8 J resulting in the highest mean energy was 20 ppm and the lowest mean energy was 40 ppm.

Table 4. Voltage, Current, Power, and Energy Generated per Trial

Punches per Minute (ppm)	Trial	Voltage (V)	Current (A)	Power (W)	Energy (J)
20 ppm	1	6	0.23	1.38	82.8
	2	7	0.20	1.40	84.0
	3	8	0.19	1.52	91.2
Mean		7	0.21	1.43	86.0
40 ppm	1	7	0.18	1.26	75.6
	2	7	0.20	1.40	84.0
	3	7	0.11	0.77	46.2
Mean		7	0.16	1.14	68.6
60 ppm	1	8	0.20	1.40	84.0
	2	8	0.125	1.00	60.0
	3	8	0.18	1.44	86.4
Mean		8	0.17	1.28	76.8

Correlation Matrix

Correlation Matrix

		PUNCH PER MINUTE	ENERGY GENERATED
PUNCH PER MINUTE	Pearson's r	—	
	df	—	
	p-value	—	
	95% CI Upper	—	
	95% CI Lower	—	
ENERGY GENERATED	Pearson's r	−0.272	—
	df	7	—
	p-value	.478	—
	95% CI Upper	0.478	—
	95% CI Lower	−0.793	—

Figure 6. Pearson Correlation Analysis by Jamovi Cloud

The Pearson correlation analysis was conducted to examine the relationship between punches per minute and the energy generated by the piezoelectric combat pad. The analysis revealed a weak negative correlation (r = –0.272, df = 7, p = 0.478), indicating that increases in punch frequency were associated with a slight decrease in energy output; However, this relationship was very weak and inconsistent. The p-value obtained is more than the level of significance of 0.05 level and this means that the correlation does not have a statistically significant value. Also, the 95 percent confidence interval (-0.793 to 0.478) contains zero, which indicates that there is doubt in the actual direction of the relationship and that the relationship observed could have been obtained by chance, perhaps because the sample was small. In general, the results suggest that the frequency of punching does not exhibit any significant linear influence on the electric energy that the system generates, and other variables like impact force might be more significant in energy generation.

IV. CONCLUSION

The study successfully designed, fabricated, and tested a piezoelectric combat pad capable of converting mechanical energy from punches into electrical energy. The results confirm that piezoelectric materials may effectively utilize kinetic energy at multiple physical bangs and convert it into quantifiable electrical energy. In the prototype, it was shown that the voltage and current were consistent with different rates of punching, which indicated its viability as a miniature type of energy-harvesting device. Findings revealed that an increase in punching rate did result in a slight increase in voltage and current, however there was a weak and statistically insignificant correlation between the frequency of punches and the total energy that was produced.

This implies that the effect of punch force and consistency might be more significant in the production of energy than frequency alone. Measurement consistency was influenced by variations in human punching force, small sample size and component constraints. In spite of these, the research studies show the feasibility of using piezoelectric technology in sports equipment and daily life as a way of enhancing sustainable and innovative sources of energy. In general, the piezoelectric combat pad is an encouraging proof-of-concept demonstrating the exploitation of wasted mechanical energy and is part of the increasingly emerging value of renewable and alternative energy harvesting technologies.

Conflicts of Interest

The authors declare that there is no conflict of interest concerning the publishing of this paper.

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