Application of Human Kinetic Energy to the Power Supply for Wearable Devices

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Abstract. *This research project aims to investigate the feasibility of using an integrated electromechanical transducer to convert the kinetic energy of arm movements into electrical energy for charging wearable devices. The project includes a literature review, an analysis of the transducer's construction and functioning, and an exploration of other relevant experiments. The ultimate goal is to design a compact generator that can store sufficient energy for wearable device charging. The results include an overview of the transducer's principles of operation, efficiency, and potential design solutions, as well as a discussion of encountered challenges. This work contributes to the growing field of energy harvesting and offers insights for developing practical solutions for powering wearable electronics.*

Keywords. Kinetic energy, electromechanical transducer, wearable devices, efficiency, generator

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1 Introduction

Over the last decade, the field of wearable technologies has received increasing attention from industry and academia. This can be seen in the growing amount of research being written and the expanding services available in this area. Most wearable devices have become tools in the wellness field, with many applications in the sports domain that are directly linked to the mobile phone. The main disadvantage of wearables is the limited battery life, the devices need to be constantly recharged, usually every day or every few days. This charging frequency is increasing for more intelligent devices, with a larger sensory field or access to raw data. Ideally, devices could be completely energy independent, so that people can use them conveniently and forget about constant charging. Sadly, the energy consumption of the latest devices is still far from this. To improve devices, a new generation of batteries should be explored or the use of methods such as energy storage should be extended.

There are many ways to harvest energy from the human body, movement, electromagnetic radiation, light or heat. Harvesting energy from environmental sources such as light or human movement is among the most promising. Even small movements in everyday human activities generate a lot of energy that can be stored.

There have been many recent attempts to embed generators in the soles of shoes to generate energy while walking, or to generate energy through the movement of a backpack to charge smart devices. However, it has been concluded that smaller gauges are needed to store kinetic energy.

Energy harvesting is attracting attention as a technology that can replace or improve batteries in the development of various portable electronics. To achieve this, energy storage and electromechanical generators must be used and must be of a weight and size that can be accommodated in a human device. For such devices, a self-charging system should be developed using the stored energy. And they should collect energy from the environment and store it in batteries or supercapacitors. This would be extremely useful and efficient.

2 Related works

The initial prototype is a self-winding mechanical clock mechanism that oscillates when the hand is moved. An analysis of the design solutions and the performance achieved for this type of energy converter described in the scientific literature showed the possibility of obtaining 4.8 mW [3] or even 10.4 mW [2], but the mock-ups described in both papers were too large, with diameters of 65 mm and thicknesses of 18 mm. Given that such a bulky add-on is certainly too large and the power generation benefits it offers will not outweigh the inconvenience of use. Therefore, the aim is to construct the mock-up under investigation with a diameter of 40 mm and a thickness of 5 mm, and a weight of about 20 g, to make the generator analogous to the size of a wristwatch.

3 Experimental results

The main part of the research work is to investigate the applicability of an integrated electromechanical transducer of an electrical device that converts the kinetic energy of hand movements into electrical energy, to analyse the energy quantities obtained and the possible design solutions. It was decided to use coils attached to the housing to capture the energy. Above them, a magnet is used, rotating around the axis from the motion, with a smaller central magnet influencing the glow. This creates an electromagnetic induction. The magnet is known to be a very important component in this phenomenon, as it is partly responsible for the electrical voltage generated. This is also known as the induced electric current.

The generator body was designed in software (AutodeskFusion360). And printed using a 3D printer. For the designed kinetic energy converter to generate electricity, coils are required. During the project, it was discovered that coils of the desired size were not commercially available, so the coils were hand-coiled. For the coils, 3D-printed models of the housing were printed and wrapped with lacquered copper wire (0.12 mm diameter). The generator uses four coils with a circumference of 150 mm diameter and 35 mm thickness. Additional metal cores were inserted in the centres of the twisted coils. These reinforce the magnetic field, allowing more energy to be generated. A steel wire with a diameter of 1mm and a length of 17 mm is used. By using a metal core throughout the coil, the magnet rotating above the coils kept stopping at them from time to time. By shortening the length of the cores to half the length of the coil, the magnet could continue to rotate freely. Also, the total number of windings per coil is estimated to be 780 times. Neodymium magnets are used in the layout as they are very strong. As a result, a higher electric current is generated than with weaker magnets. Two magnets are used in total, a central cylindrical magnet (5x5 mm) placed in the layout of the inverter and a "second cylindrical magnet (10x1.5 mm) rotating around the central cylindrical magnet. To induce an electromotive force, the movement of the magnet is required, which creates a variable magnetic field. To extract it, the magnet needs to be in constant motion with the coils, in this case rotating around a central magnet.

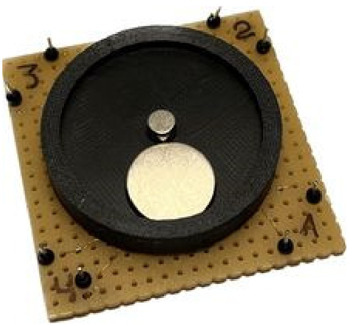

Figure 1. Model of the inverter constructed

Figure 2. Variable speed adjustment testing device

After generator construction is finished the parameters of the coils were measured: inductance, complex circuit resistance and active resistance using a Hioki 3522-50 LCR HITESTER at a fixed frequency of 1 kHz and 1 V output voltage.

Inductance is a property of electric circuits that describes the creation of magnetic flux due to the flow of electric current. It is given by the formula $\Phi = L*I$, where Φ is the magnetic flux, I is current, and L is the inductance, which depends on the dimensions, shape, and magnetic permeability of the circuit. Complex resistance is a concept used in AC circuits to describe the resistance to alternating current. It considers not only the amplitude relationship between voltage and current but also their phase relationship, which refers to the relative timing between them. In other words, complex resistance extends the concept of resistance to AC circuits by describing not only the relationship between voltage and current amplitudes but also their interrelated phases. Active resistance is a fundamental property of conductors and semiconductors that limits the flow of current. It is independent of voltage and current but depends on the physical properties of the conductor and temperature. Active resistance does not consume electricity and exists naturally in conductors and semiconductors. In contrast to reactive components like inductors and capacitors, which store and release energy over time, active resistance converts electrical energy into heat, which is dissipated into the surrounding environment. The active resistance is always constant and does not depend on either voltage or current, but it depends on the physical properties of the conductor itself and temperature.[1]

Table 1. Information about coils

	Inductance	Complex circuit resistance	Active resistance
First	3.18mH	37.37Ω	31.58 Ω
Second	3.42mH	39.03 Ω	32.56 Ω
Third	3.57mH	40.19 Ω	33.30 Ω
Fourth	2.85mH	34.59 Ω	29.56 Ω
General	13.750mH	154.89 Ω	128.56 Ω

For further energy estimations, it was decided to build an appliance that could provide controlled, and stable motion. The adjustable speed device was designed using AutodeskFusion360 software and assembled using 3D-printed parts. The converter fits perfectly into a recessed square space under the propeller and is clamped on all sides, providing stability without movement. A 6 V micro-DC motor with a reduction gear is mounted on top of the converter, capable of rotating at speeds up to 300 rpm. A PWM-type controller capable of 3–35 VDC and 5 A is used to control the motor speed, and the PWM signal allows for easy control of the torque and speed of the DC motor. The device is powered by a power supply that delivers 6 V and 800 mA. An amplitude measurement experiment was performed at different magnet rotational speeds and with different loads. The calculated power output is presented in Table 2.

Table 2. Power output in mW at different load resistances

	100 Ω	130 Ω	135 Ω	140 Ω	145 Ω	150 Ω	160 Ω	200 Ω	300 Ω	500 Ω
72 rpm	0.05	0.04	0.05	0.05	0.10	0.04	0.04	0.06	0.04	0.02
126 rpm	0.12	0.11	0.13	0.15	0.12	0.13	0.12	0.17	0.10	0.07
162 rpm	0.21	0.22	0.23	0.24	0.40	0.26	0.25	0.24	0.18	0.15
192 rpm	0.42	0.41	0.38	0.41	0.41	0.43	0.38	0.45	0.35	0.24
252 rpm	0.59	0.60	0.59	0.62	0.61	0.60	0.63	0.59	0.50	0.34

The results show how the power output varies with different loads and how the increase in power depends on the rotation speed. The chart reveals that the highest power output is achieved with the insert between 145 Ω and 200 Ω. This insert demonstrates the greatest increase in power output compared to the other loads tested.

As the constructed electromagnetic energy generator produces alternating current, a rectifier is required to convert it to direct current. To prevent voltage drop, MOSFET transistors were selected for this purpose. Two n-channel SI2302 transistors with threshold voltages ranging from 0.65 V to 1.2 V are used for low-voltage applications. The remaining two p-channel SI2377 transistors are for high-current applications, with threshold voltage ranges from 0.4 V to 1 V. To store the voltage at the correct level, the ADP5090-2-EVALZ energy harvesting board is used to store the voltage up to 3.3 V. This voltage level was chosen for its reliability and safety, as it is suitable to power most digital components without risk of damage. Furthermore, 3.3 V is the standard voltage for most electronic devices. To measure the signal values at different connection points, a four-channel oscilloscope is connected. The first two channels are connected to the input to measure the differential potentials of the signals, the third channel is connected to the output of the bridge, and the fourth channel is connected to the output of the energy harvesting board, which measures the voltage stored in the supercapacitor. The results indicate that the minimum input voltage to the board must be 236 mV at 17.64 Hz, requiring a current of 1.35 mA. Once the input voltage reaches this limit, the ADP5090-2-EVALZ evaluation board amplifies the input voltage and stores it in the supercapacitor. When fully discharged, the supercapacitor can be recharged to the desired 3.3 V using the minimum set voltage within 145 minutes, as shown in Figure 3. The onboard supercapacitor has a capacitance of 0.1 F and can hold up to 5 V. By connecting a 5 kΩ load to the output, a constant voltage can be maintained across the capacitor if the input voltage is at least 650 mV. With a 1 kΩ load connected to the discharge, the capacitor is fully discharged to 3.3 V in 8.43 minutes.

Also, a study was carried out to see the amount of voltage build-up in the panel using human kinetic energy. The generator was attached to a person's wrist while running on a treadmill at a speed of 7 km/h. The result was recorded using a DMM 506 multimeter, which recorded the variation of the capacitor output voltage every 3 seconds 400 times.

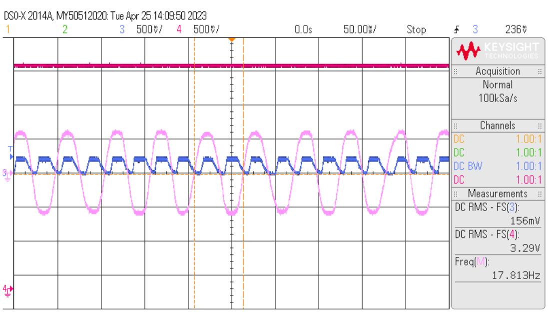

Figure 3. Voltage levels during the test. The pink sinusoid represents the input signal, the blue signal depicts full wave rectification, and the red line indicates the voltage of the storage capacitor

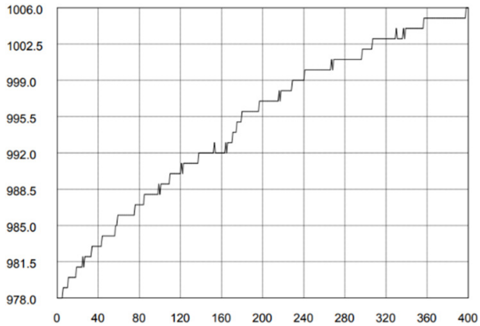

Figure 4. Voltage variation (in mV) in capacitor while running

The measurement started when the capacitor on the board was already charged to 978 mV. From this reference, the increase of 28 mV was obtained over 20 minutes, which is 1.4 mV per minute. Also, the average voltage and current entering the board were measured. The voltage was 143.17 mV and the current was 0.21 mA. This gives a power of 0.03 mW. The energy stored in the capacitor Wc can be calculated over this time using the following formula:

$$Wc = 0.5 * C * (\Delta V)^2 = 0.5 * 0.1 * (0.028)^2 = 39.2 \text{ µJ}. \quad (3)$$

Here C is the capacitance (F) and ΔV is the voltage difference (V).

4 Conclusions

While the designed generator was not able to generate sufficient voltage to fully and independently charge wearable electronic devices, the results of the experiment provide valuable insights into the capabilities of energy harvesting from human movement. The voltage output of 143.17 mV and current of 0.21 mA achieved after the MOSFET rectifier and the 1.4 mV per minute generated by the supercapacitors demonstrate the potential for further improvements and optimizations in the design. These findings can inform future research and development in the field of wearable technology and energy harvesting.

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