Multi-rotating Electromagnetic Power Generation and Energy Storage Using Human Joint Motion for Bikers

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Abstract — **It is unsurprising that many developments are centred on transforming mechanical and human forces into electrical power due to their attractive properties. One main shortcoming of these devices was requiring the user to generate true power. Specifically, this study aims to design a customized kneepad and a compact box that the user can wear during cycling. The proponents aim to have a weight of fewer than 2 kilograms for the device and be able to charge the batteries by achieving a charging current of 0.25-0.5 amperes and a charging voltage of 3.6-3.7 volts. The proponents performed multiple testing and assessments to evaluate the functionality and effectiveness of the device. The Thompson Tau Test shows that the results of the data gathered when the device was used fall within the range and did not deviate significantly from the overall pattern or trend of the data. Overall, the device is fully operational and will undoubtedly contribute to generating energy from the human body.**

Index terms — Multi-rotating Electromagnetic Power Generation, Energy Storage, Human Joint Motion, Energy Harvesting System, Human Mechanical Power

I. INTRODUCTION

Human power is an alluring source of energy. Food is converted into a productive mechanical job with the highest level of around 25%, equivalent to engines with combustion [1]. The task can be done at a rapid clip, with the average person rendering 100 W mechanical and the elite athletes maintaining twice that [2]. Food, the initial source of metabolic energy muscles need, is just as rich as gasoline and about 100 times greater than batteries of the same weight [3]. Unsurprisingly, many developments are focused on converting human, mechanical power into electrical power due to their attractive properties. These include hand cranks, bicycle generators, windup flashlights, radios, and cell phone chargers [4]. One main shortcoming of these devices was requiring the user to generate true power. This limits the time available for power generation and hence the amount of valuable energy that can be produced.

On the other hand, bio-mechanical energy harvesters generate electricity from people as they go about their daily lives [5]. This results in electricity being generated over more extended periods. An excellent example of an energy harvesting system, the self-winding watch, generates sufficient electricity to power the device without needing the user to wind it but is inadequate for most of our portable power needs [4]. A range of devices is based on the same principle as the self-winding watch, such as using an external charger to drive a generator. The most promising concept to date was the spring-charged energy harvesting backpack, which turns the linear motion of the backpack relative to the user into rotational motion generating up to 7 watts [6]. Another energy harvester uses the human inertia of the body to produce as much as 0.8 watts of electricity from the friction of the shoe soles [7].

A system that would produce energy for a more extended period without re-energizing batteries would drastically improve the efficiency of all the above studies. Up to now, advances to maximize power consumption and manufacture batteries with a preferable power density have caused the increase of power density to double per decade [4]. However, the operating consumption time of any mobile off-the-electrical grid device was limited by the imperative need to haul and re-energize batteries [8]. This downside suggests the need for further research into portable electrical generation systems, which can improve both the amount of electrical power and the time of consumption.

This device varies from previous devices because this system takes advantage of the fact that most of the displacement occurs at the body joints and obtains energy from knee movement rather than from an external load or friction of the shoe sole. In the shoe-sole case, a hydraulic reservoir uses the difference in pressure distribution on the shoe sole to generate a flow during the gait cycle. It produces an average power of 250-700 milliwatts and has the drawback of being bulky and heavy [9]. Another case created shoes employing heel striking and toe-off motions to generate piezoelectric materials, which generates an average output of 8.3 milliwatts [10]. From this, another difference can be seen from previous research. Previous ones tend to be heavier, while the proponents' device was less bulky for the user's convenience.

This study aims to develop a mechanism that converts the knees' linear motion, which occurs when cycling, into electrical energy. Specifically, the proponents aim to design a customized kneepad and a compact box that the user can wear during cycling. The kneepads will serve as a converter using mechanical components. The box will hold essential elements like the batteries, charge controller, and voltage regulator. Moreover, the proponents aim to have a weight of fewer than 2 kilograms for the device and be able to charge the batteries by achieving a charging current of 0.25-0.5 amperes and a charging voltage of 3.6-3.7 volts.

A promising safe alternative way of generating power was to take advantage of the heat and motions produced by the human body to generate electrical energy [8], and this approach was investigated and recorded in this paper. As a result, this study aimed to measure the potential power of this source and provide new insights into the idea of energy generation from the human body.

II. MATERIALS AND METHODS

A. *Conceptual Framework*

The idea behind this research is illustrated in Fig. 1. This figure shows the linear motion of the knees while cycling is used as an input, which is then converted into electrical energy by the system with the help of components such as DC motors. The flow of electrical energy coming from the generator is then stored using batteries. The process of designing and fabricating a power generator that utilizes human motion in riding a bicycle is done by considering the constraints needed for maximum output and user convenience, including the weight of the device and the positioning of the main components. With these inputs undergoing their specific process, an output of a kneepad generator and energy storage is achieved.

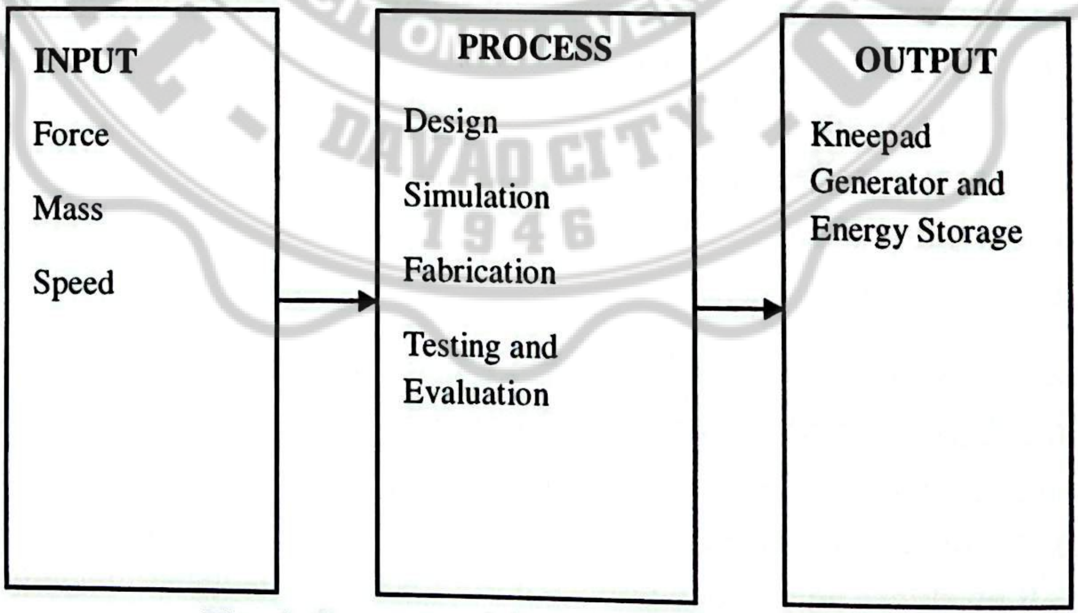

Fig. 1 *Conceptual Framework Flowchart*

B. *Materials and Resources*

The system compromises four main components: DC Motors, a charge controller, batteries, and a voltage regulator. A 220 V, 50 Hz Brushless DC Motor (DT3424D220) is used as the foundation for the generator by simply reversing the motor's operation. Rather than applying an electrical current to the motor to generate rotational motion, the motor was mechanically rotated to generate electrical energy. The simple generator uses a brushless DC motor by spinning the rotor and connecting the output. The quantity of electrical energy produced will differ based on the speed of the motor and the load connected to the generator. A DC motor converts DC electric power into mechanical power [11].

A TP4056 Lithium Battery Charge Controller regulates the amount of electric current that flows between the source and the batteries. The charge controller's primary function is to prevent overcharging and undercharging of the battery, which can cause damage and shorten its lifespan. A charge controller controls battery charging from the generator and ensures power supply to the load [12].

3.7 V, 1200 mAh, (14500) Lithium-Ion Batteries with a charging voltage of 3.6-3.7 volts and a charging current of 0.25-0.5 amps are used for energy storage. The electricity is stored in lithium-ion batteries and used later when needed. This contributes to a steady supply of electricity even without dedicated human resources. Lithium-ion batteries are a potential energy storage technology because of their high energy density, low self-discharge characteristic, almost negligible memory effect, high open circuit voltage, and extended lifespan [13].

An LM317 Voltage Regulator keeps the power source's output voltage enduring changes in input voltage or load circumstances. Voltage regulators are critical components in power generation. The terminal voltage should always be constant to keep the generator's voltage stable [14].

C. *Methods and Procedures*

For the trade-off analysis, the designs were evaluated by referring to manufacturability, economics, socials, and sustainability. For better design results, the proponents used the Pugh matrix during the computation to evaluate and compare various options using the set of criteria. For each criterion, each option is evaluated and assigned a score based on how well it meets that criterion. After evaluating all options, the scores are tallied and compared to determine which option is the best overall [15].

The first design, which can be seen in Fig. 2, was specifically made for walking, providing ample power of up to 50 watts AC. Sprockets, bike chains, and flat bars were used to rotate the shaft. The compact box contained the voltage regulator, inverter, transformer, DC to DC converter, LiPo Battery, LEDs, Arduino, Voltage sensor, and an LCD.

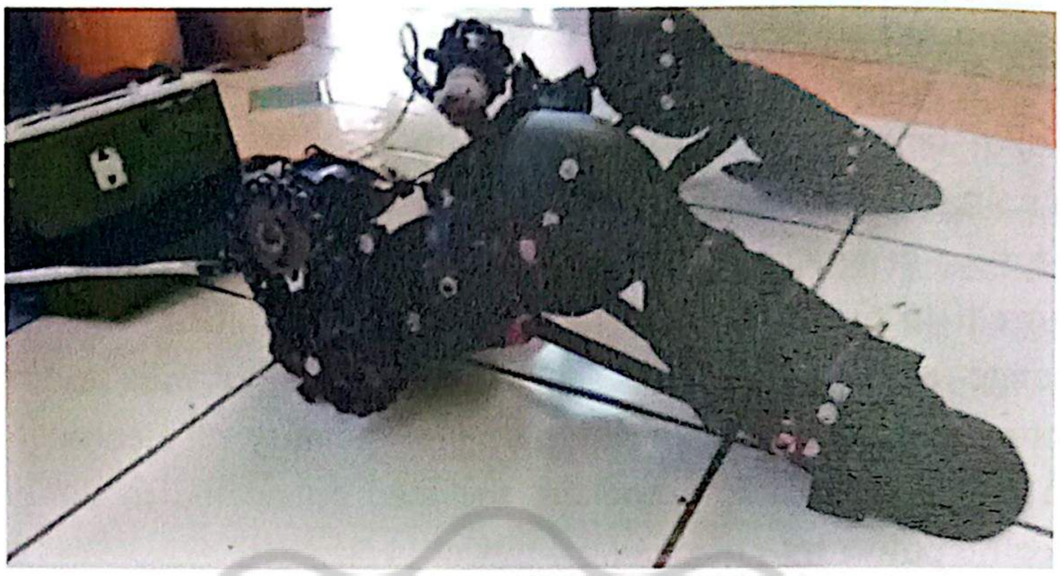

Fig. 2 *AC Design of Kneepad Generator*

The second design, which can be seen in Fig. 3, was specifically made for cycling and is a lighter DC version of the previous design. A meaningful change can be seen in Fig. 2 and 3. The proponents could utilize only one kneepad without compromising any of the target objectives. The proponents attached the motors on top of the kneepad, and instead of using sprockets, bike chains, and a flat bar for the shaft rotation, the proponents opted for springs. A smaller compact box was also attached on the left side of the kneepad, where the charge controller, batteries, and voltage regulator can be found.

Fig. 3 *DC Design of Kneepad Generator*

Based on the information obtained by contrasting the two designs and after careful analysis, the proponents have concluded that the DC Design is the preferable choice considering all study limitations. This is because the DC Design has the highest overall score and a higher Design Concept Score and Weighted Score than the AC Design for all criteria.

D. *Research Design*

The initial design consisted of a long motorcycle kneepad, two motors, two springs, and a compact box. This was designed to keep the device lightweight and free of obstruction when worn. The proponents used two 220V brushless DC motors to achieve the 12 volts DC requirement. A single motor can provide 220 volts, but only on full rotation and at high speed. Since the device can only generate a rotation of up to a 45°-degree angle and is used only at low speed, the proponents decided to use two motors. A pair of springs were also utilized to help rotate the shaft of the two DC motors. Two groups of lithium-ion batteries, consisting of three connected in series, were then connected in parallel. The voltages of batteries connected in series will be added together, coming up with a voltage of precisely 11.1 volts. The capacities of the batteries connected in parallel will be added together, which will then become 2400 milliampere hours [16]. A compact box that can store the other small components was also employed. The batteries, charge controller, voltage regulator, and output outlet can be found here.

Fig. 4 *Design for The Kneepad Generator*

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E. Design of the System

The motor's prime mover is the knees' linear motion that was converted into rotational motion. Moreover, the 12 volts of AC produced by the engine will travel to a bridge diode, rectifying the 12 volts of AC to DC. The charge controller will control the charging process. If the battery is ultimately charged, then the charge controller will help stop the motor's output flow. Afterward, the energy will be stored in the battery. The energy from the battery is adjusted to 12 volts DC using a voltage regulator and is used as a charging port for devices.

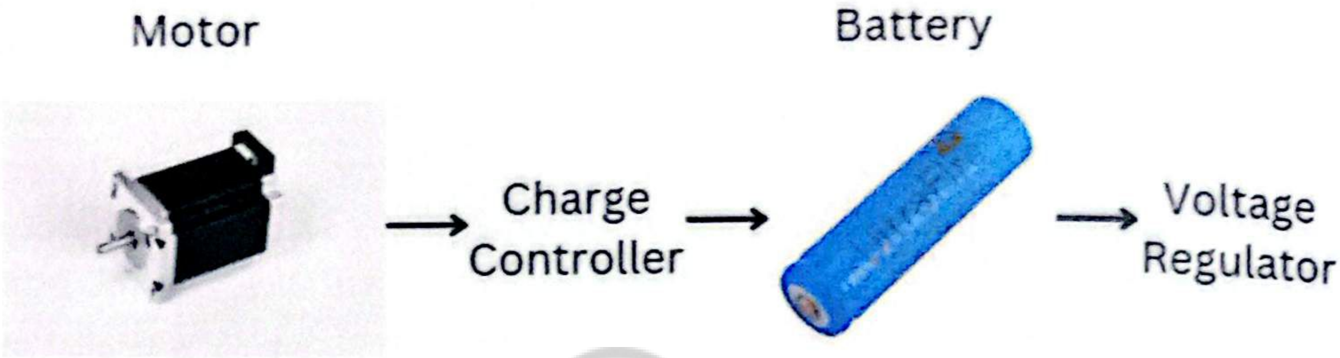

Fig. 5 *System Flowchart*

F. Testing Methods

IEEE std. 113-1985 will be referred to for the electrical measurements of all procedures and the device testing. This standard includes a comprehensive set of DC machine test procedures. Technicians and engineers can ensure that DC machines operate efficiently and reliably over their intended lifespan by following these guidelines [17].

1. *Generator Testing:* The proponents will conduct tests such as the No-load test and the With-load test to identify the power produced by the generator under specific conditions.
2. *No-load test:* In this test, the generator will be tested without any load connected to it. A multimeter was used in parallel to measure the voltage for a cycle speed of either two cycles per second or one cycle per second.
3. *With-load test:* A load was connected to the generator to complete the circuit and to measure the voltage drop across the load for a cycle speed of either two cycles per second or one cycle per second. The load used was a 12 V, 7 W DC lightbulb. The current was obtained by connecting them in series.
4. *Power Measurement:* The watt was used to determine the rate of electrical energy dissipation or the speed of electromagnetic energy radiation, absorption, or dissipation [18].
5. *Power Output:* Obtained by multiplying the supply voltage and current results from the with-load test.

III. RESULTS AND DISCUSSIONS

A. Design of the Kneepad Generator

The kneepad generator consists of different parts to assemble the device. Figure 6 shows the device's actual image, consisting of a singular kneepad with two DC motors attached in front using zip-lock ties. Two springs are connected to the motor's shaft and are held there by a metal bar on the upper side of the kneepad. A small compact box is affixed to the kneepad's left side, which has the other small components. A belt fastener was utilized on the upper side, and a Velcro one for the lower and half sections.

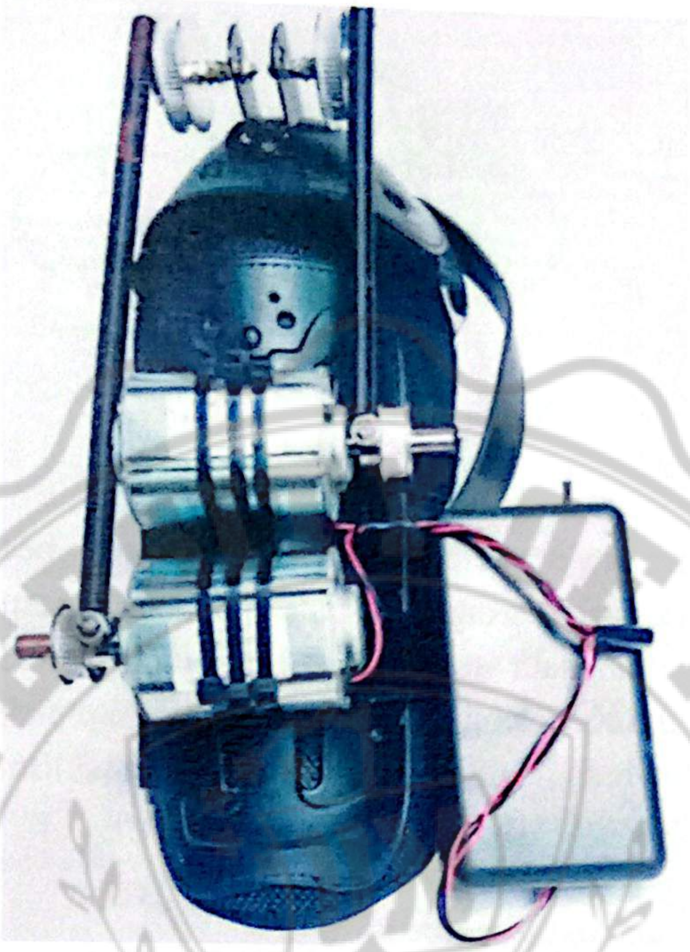

Fig. 6 *Final Output*

B. Proper Cycling Posture for Maximum Output

It is highly recommended to use the proper cycling position to increase efficiency and make the user comfortable while cycling. The following should be observed to attain the best riding position:

1. *Shoulders should stay relaxed.* Shoulders tend to stiffen and rise to our ears when riding strenuously.
2. *Slightly bend the elbows.* This will reduce the strain on the shoulders if the elbows are kept on the sides while turning them.
3. *Maintain a straight line from the elbow to the fingers*. Both wrists should not bend.
4. Maintain a straight line between the hips and shoulders. Where the back should be relaxed while maintaining a neutral spine.
5. *The knees should track over the pedal*. Knees should not go out to the sides while cycling, for it would indeed cause inefficiency and pain for the user.
6. *The saddle height should be raised*. The appropriate saddle height may be determined using the knee's angle at full extension. Males usually hover about 141 degrees, while women may be 1-2 degrees higher [19].

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Fig. 7 *Proper Posture*

C. *Weight of The Device*

A digital weighing scale was utilized for this process because of its advantages over an analog weighing scale. A digital weighing scale has better accuracy, consistency, and capacity than an analog one [20]. This data was collected by placing the device on the scale, waiting for the reading to stabilize, and recording the weight data. Figure 8 shows that the device's weight is equal to 1.624 kilograms which is in line with the proponents' limit of 2 kilograms.

Fig. 8 *Device Weight: 1.624 kilograms*

D. *Generator Testing*

Discuss the results and findings of objective 3 through tables or figures or statistical data analysis. Strictly follow the IEEE guidelines on how to present tables or figures.

1. *No-Load Characteristics*. This data was collected when the device was tested on a bicycle with no load plugged into the system. This voltage reading is known as the voltage in an open circuit, and it is the voltage produced by the machine when no load is applied [23]. A comparison between the voltages is shown using a graph in Fig. 9. The device was tested fifteen times in the same conditions.

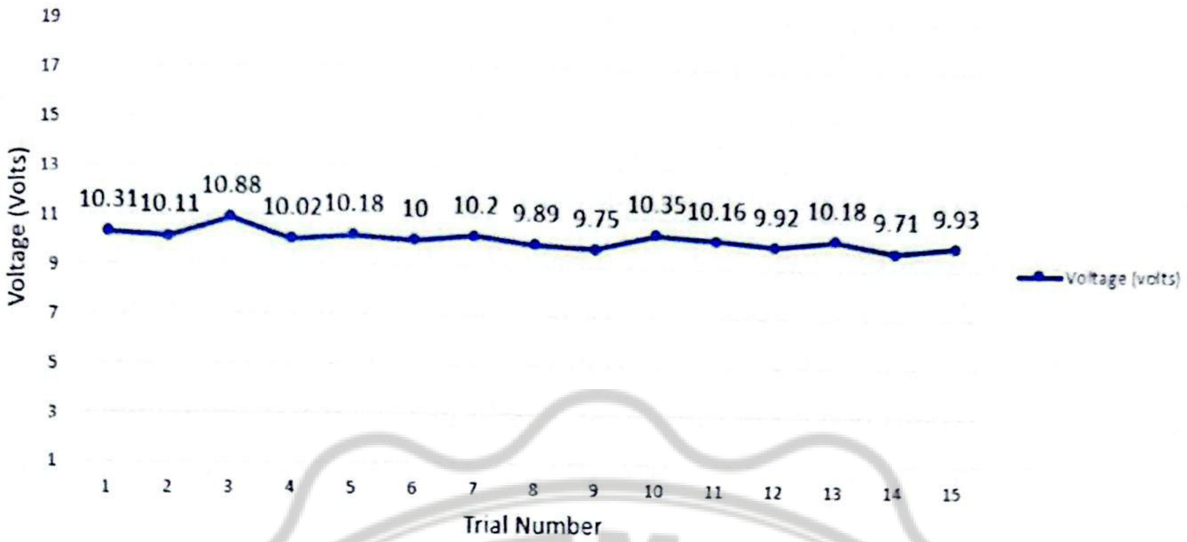

Fig. 9 *No-Load Test Graph*

When measuring voltage in a no-load test, a small or no difference indicates that the measured voltage is close to the expected value of 11.1 volts. This shows that the DC machine is working correctly, producing the desired voltage, can handle the anticipated load, is operating efficiently, and has no prominent faults or issues with the machine's electrical circuitry.

2. *Power Output.* Load testing is essential for determining the generator's capability, ensuring proper operation, confirming efficiency, and ensuring safety. It assists in ensuring that the generator can meet the electrical demands of the system intended to power, as well as identifying any potential issues or hazards. This data was collected when the device was tested on a bicycle with a load connected to the system. A comparison between power is shown using a graph in Fig. 10 regarding two cycles per second and one cycle per second.

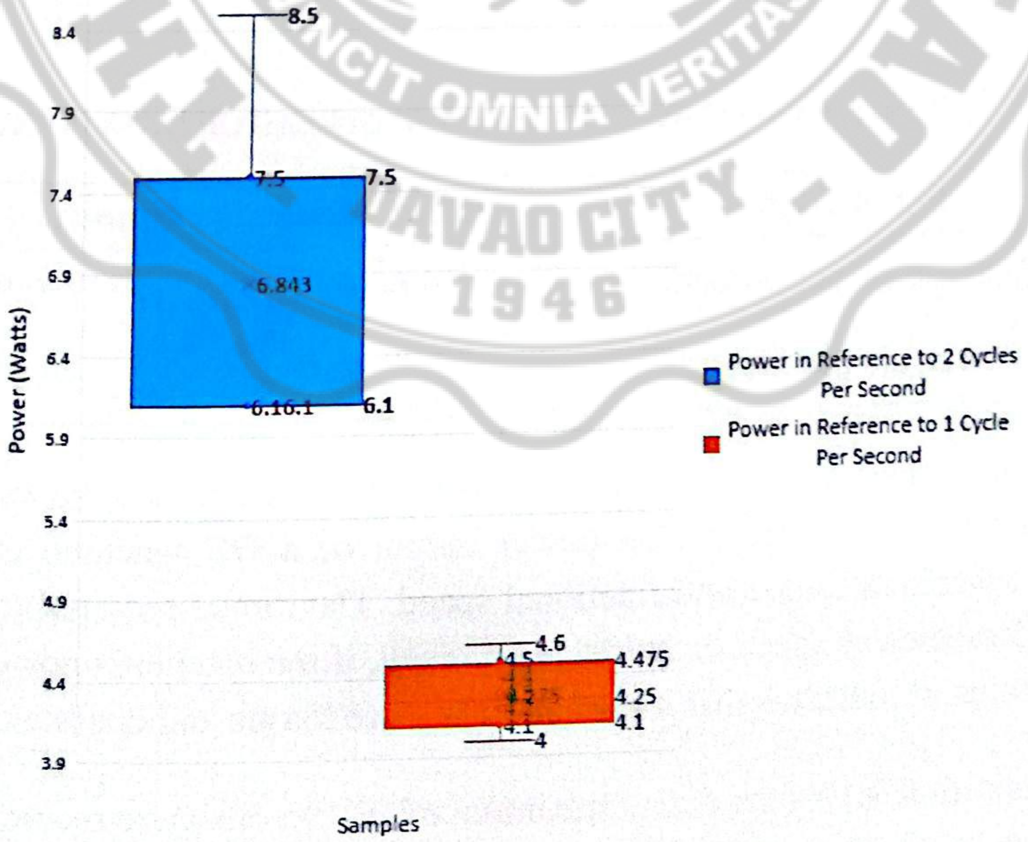

Fig. 10 *With-Load Test Graph*

During the test, an average of 6.843 watts, about two cycles per second, was recorded, showing its central tendency and average value. A standard deviation of 0.985, about two revolutions per second, was also calculated. A less than one standard deviation indicates that the values are more tightly clustered around the mean. Therefore, the data points are consistent, and the sample mean accurately represents the sample values.

During the test, an average of 4.275 watts, about one cycle per second, was recorded. The sample's mean demonstrates its central tendency and average figure, which revolves around the value. A standard deviation of 0.212, about one cycle per second, was also calculated. The standard deviation is again less than one, which indicates that the measurements are more closely banded around the mean. As a result, the data points are dependable, and the sample means precisely represent the sample values.

By following the Thompson Tau Test and repeatedly identifying a potential outlier, and testing its data point, the proponents could conclude that the absolute difference in both sets of data is less than that of their adjusted standard deviation. Hence, none of the data points is an outlier. This concludes that all data points fall within the range and do not deviate significantly from the overall pattern or trend of the data. In other words, no extreme values substantially different from the other data points exist.

Table I summarizes the calculated sample mean and standard deviation as a product of data analysis. The proponents utilized these elements to determine if the two models differed statistically significantly. The sample mean was determined by calculating the arithmetic average of the sample data points for each set of data by using Equation 1. However, it is crucial to remember that the sample mean is variable and might not be a reliable indicator of the underlying population mean. That is why the proponents also calculated their standard deviation in which the variability can be quantified. The standard deviation was calculated by using Equation 2.

TABLE I. CENTRAL TENDENCY AND SPREAD OF DATA POINTS

Set of Data	Sample Mean	Standard Deviation
Two cycles per second	6.843	0.985
One cycle per second	4.275	0.212

It was also observed that as the cycle per second increases, the values for the voltage, current, and power also increase. The power output of a DC machine is proportional to the product of the machine's torque and rotational speed. The torque required to maintain a constant power output decreases as speed increases. As a result, if the machine's power output increases as the speed increases, it indicates that it can produce more torque and operate efficiently.

A minimum of 9.10 volts and a maximum of 10.19 volts were recorded and shown in Fig. 11. A minimum of 0.44 amperes and a maximum of 0.84 amperes were also recorded and displayed in Fig. 12. With these data, the proponents were able to achieve the objective of charging the batteries since they have a charging voltage of 3.6-3.7 volts and a charging current of 0.25-0.5 amperes.

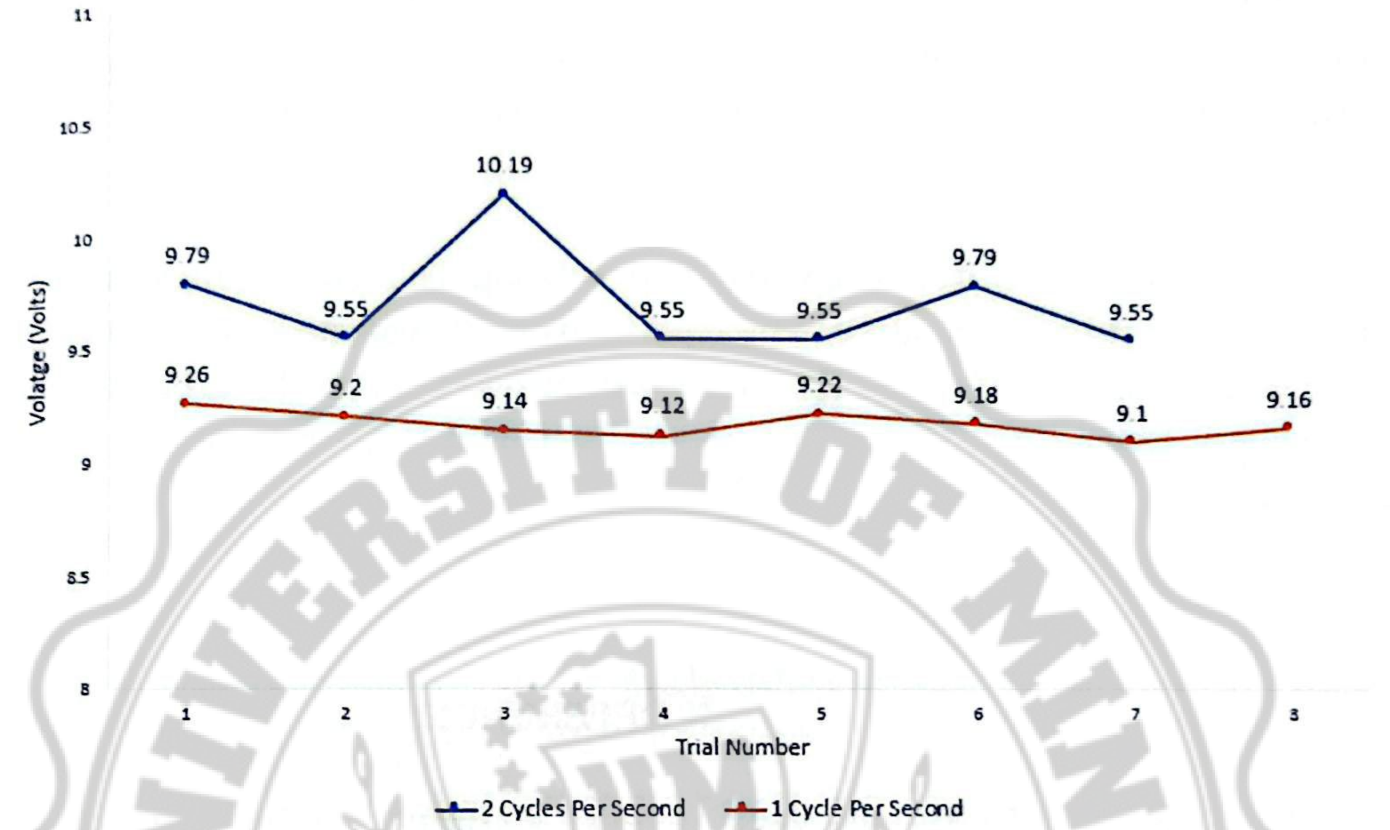

Fig. 11 *With-Load Voltages*

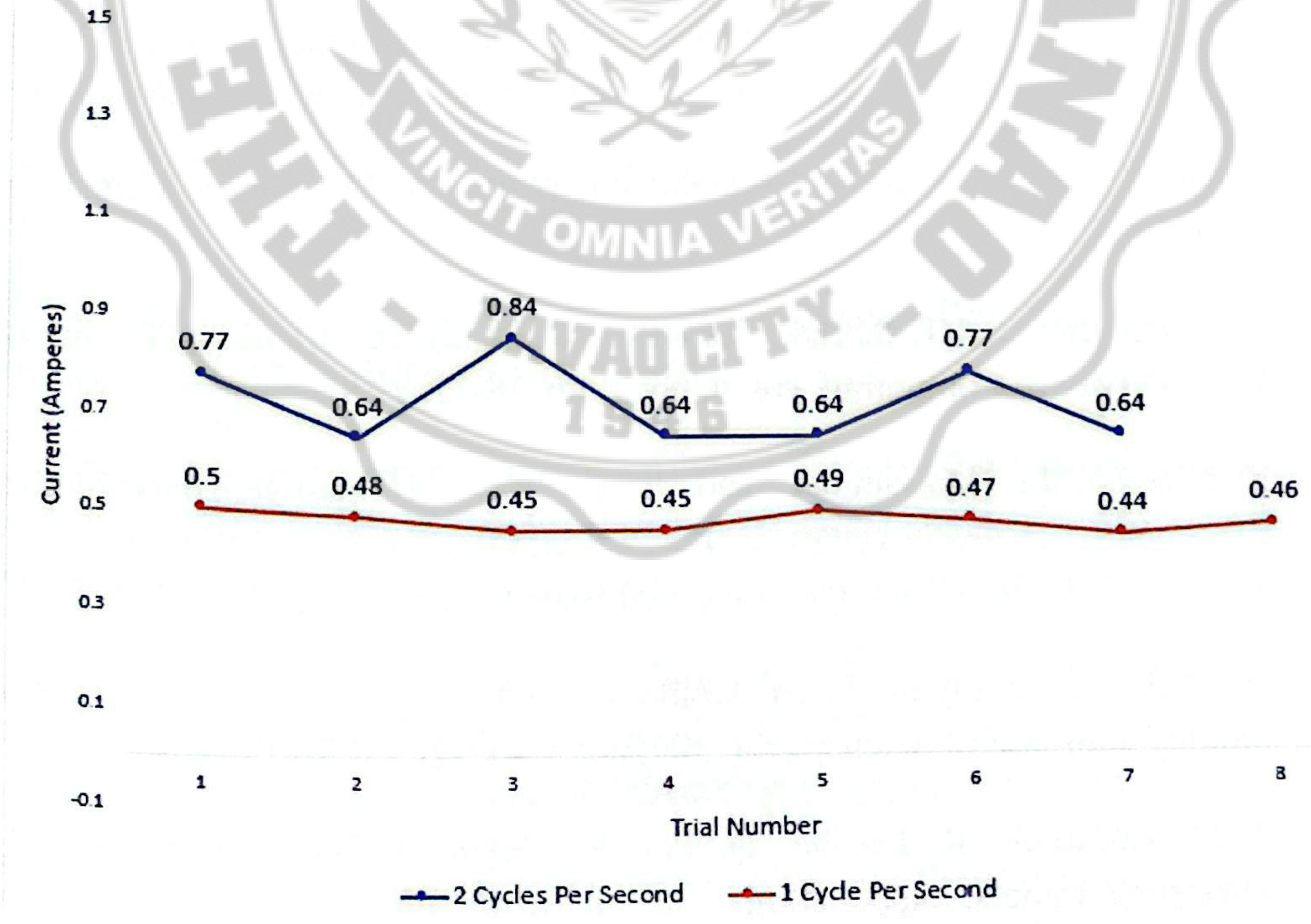

Fig. 12 *With-Load Currents*

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IV. CONCLUSIONS AND FUTURE WORKS

A kneepad generator system that can convert the linear motion of the knees, which occurs when cycling, into electrical energy was designed. By making this device, the researchers were able to limit the weight of the device to only 1.624 kilograms and were able to ensure energy storage. Also, the researchers performed a series of generator tests to determine whether the system was fully operational. It confirms that the DC machine is working correctly and has no major faults or issues with its electrical circuitry.

For future study works, the system for rotating the motor shaft can still be improved. The spring used to drive the motor can be replaced with a light metal bar so that the shaft can turn more easily. Also, an AC version of the device can be developed if a lightweight AC motor and AC battery can be provided with a more efficient system to keep the device light without reducing efficiency.

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