Development of a footstep power generator in converting kinetic energy to electricity

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Abstract. Kinetic energy is considered as one of the renewable energies. Substantial amounts of researches were conducted to investigate the feasibility of converting the kinetic energy into electricity. Nevertheless, most of these previous works emphasized on the selection of suitable materials and the design of power generator which tends to be complicated. In this paper, a simple and yet low cost mechanism has been proposed to enhance the performance and efficiency of energy conversion from kinetic energy to electricity energy by placing a mechanical footstep power generator on the hind foot region. A total of 45 individuals were invited to participate in the experiments and the experiment results are then compared with the theoretical results.

1 Introduction

The deployment of different clean energy systems is a crucial strategy to achieve environment sustainability [1-4]. Most people are spending most of their lifetime in walking. Walking is also known as ambulation, i.e., a fundamental and common locomotion for human in daily life. The contacts between human feet and ground surface is created during the walking. The forces experienced by human feet upon landing on the ground can generate a renewable energy known as kinetic energy. This energy can be converted into electricity through a footstep power generator.

Different types of footstep power generators are available in the market and majority of these devices use piezoelectric transducer to generate power. One of the greatest challenges in designing the footstep power generators with piezoelectric transducer is the selection of suitable ferroelectric material because it governs the efficiency of converting kinetic energy to electricity [5]. Conventionally, the piezoelectric footstep power generator uses ferroelectric materials made up of crystal such as Lead (II) titanate ($PbTiO_3$), Lead (II) Zirconate ($PbZrO_3$), Polyvinylidene Diflurideor Polyvinylidene Fluoride (PVDF) and Lead Zirconate titivate (PZT). While both of the PZT and Polyvinylidene Diflurideor (PVF) are commonly used as piezoelectric, the former material is the best candidate of piezoelectric because it can produce better output voltage than other ferroelectric materials [6]. Despite of its popularity, piezoelectric footstep power generator suffers with some drawbacks such as the infeasibility of this technology under static condition and the limitation of power capacity [7].

Mechanical footstep power generator is an alternative of footstep power generator that can produce electricity

with different mechanisms. Instead of using piezoelectric transducer, delicate mechanisms are designed in the mechanical footstep power generator to convert human motion into electricity. Some notable advantages offered by the mechanical footstep power generator include the simplicity of its assembly process, lower cost, lesser transmission lost and etc. [8].

There are many types of combination for mechanical footstep power generator in the market. For example, rack and pinions with pulley [9], crank shaft with chain drive system [10], fly wheel with gear [11] and etc. However, most of these designs are combined with two mechanism components such as rack and pinion with fly wheel, rack pinion with pulley systems, and rack and pinion with chain drive system.

In this research, a mechanical footstep power generator is designed based on the concept of rack and pinion in order to reduce the complexity of mechanical structure. The components included in the proposed footstep power generator are rack and pinion, shaft, spur gears, bearings, DC generator and battery. The rest of this paper are presented as follows. Section 2 explains the design and fabrication of mechanical footstep power generator. Sections 3 and 4 conducted experiments and discussed the results, respectively. Finally, Section 4 concludes the works of this paper.

2 Design and fabrication

As mentioned in the earlier section, the mechanical footstep power generator in this research is designed based on the rack and pinion concept, aiming to reduce the complexity of mechanical structure. Figure 1 illustrates the design of mechanical footstep power generator.
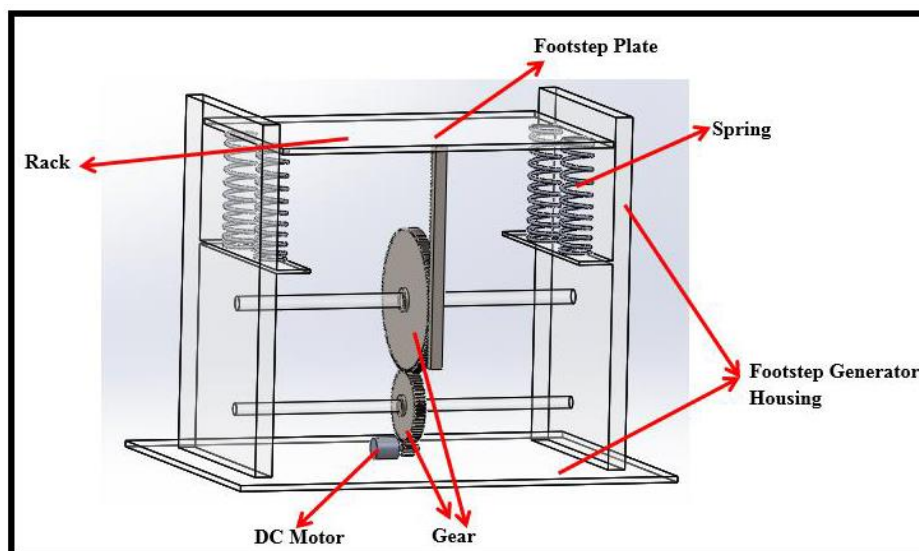
Fig. 1. Proposed mechanical footstep power generator.

Table 1. Ideal specification of major mechanical components in the proposed mechanical footstep power generator.

	Unit	Gear 1 (First Gear)	Gear 2 (Second Gear)	Gear 3 (Last Gear)
Face Width	mm	10	10	10
Base Circle	mm	112.77	56.38	11.25
Addendum	mm	122	62	14
Teeth	-	120	60	12
		Spring		
Wire Diameter	mm	2		
Outer Diameter	mm	44		
Inner Diameter	mm	40		
Total number of coil	Turns	65.69		
Free Length	mm	231.38		
Spring Stiffness	N/mm	4.09		

As shown in Figure 1, the rack and pinion drive the first gear due to the planter force exerted on the footstep plate. The second gear that is attached to a DC generator or dynamo will then be driven by the first gear. The last gear attached with DC generator will eventually transfer the kinetic energy into electricity and store the output in battery through the electronic circuit. The specification of each major component of mechanical footstep power generated is presented in Table 1. These specifications are given based on the design illustrated in Figure 1 and they are considered as the ideal values to be used for the calculation of theoretical results.

3 Experiment setup and data collection

The test subjects in this study involved of nine groups of healthy volunteers with each group consists of five individuals without any foot disorders. The participants in each group can either be kids or adults with the body weights range between 15 kg to 55 kg. The average reading from each group was taken in order to minimize the variation. The test subjects were instructed to use their hind foot to step on the proposed mechanical footstep generator because previous studies done by [12] showed that the hind foot exerts most pressure, i.e., nearly one third of the entire foot pressure, when walking on the flat plane. Furthermore, the previous studies of [13] reported that no significant differences were detected when comparing plantar pressure distribution produced by both foot of men and women on flat surfaces, implying that the negligible impacts of gender factor [13]. Based on these findings, this research assumes that the power generated from each individual can be maximized by using hid foot to step on the proposed mechanical footstep generator.

In this research, different LEDs were used to indicate the intensity of power generated by the proposed mechanical footstep power generator because different ranges of voltage are required for lighting up the LEDs with different colors as shown in Table 2. The generated power can be calculated through the measured values of LED forward voltage and the current flew through it.

Table 2. Voltages required for LEDs with different colors.

Color	Voltage Required (V)
Red	1.6 – 2.0
Green	1.9 – 4.0
Yellow	2.1 – 2.2
Blue	2.5 – 3.7
White	3.1 – 4.4

4 Result and discussion

As compared to the theoretical results using specification in Table 1, the actual results obtained in Table 3 were slightly different. This is because the gears and spring were bought and modified as shown in Table 3, leading to the deviations.

In terms of dimensional sizes, the actual sizes of gear 1, gear 2 and gear 3 are 4.09%, 1.95% and 2.22% larger than the associated ideal values. Nevertheless, the overall performance of the proposed mechanical footstep power generator is not significantly impacted because the tolerance is less than 5% for each gear. As for the stiffness of spring, the difference is up to 13% because

the materials of actual spring chosen for this project is STWC80C steel with 80% of carbon, while the materials chosen for design at the beginning stage was oil temper wire. These differences of materials used in the springs are identified as the main factor that contribute to the deviations between theoretical and actual results.

The differences between the theoretical and actual results for different ranges of mass of individual are presented in Table 4 and Figure 2. It is observed that the

Table 4. Differences between the theoretical and experimental results.

Mass (kg)	Theoretical Power (W)	Experimental Power (W)
15-19	0.0736	0.0603
20-24	0.0981	0.0801
25-29	0.1226	0.1011
30-34	0.1472	0.1390
35-39	0.1717	0.1504
40-44	0.1962	0.1830
45-49	0.2207	0.2012
50-54	0.2453	0.2301
55-59	0.2698	0.2900

Table 3. Actual specification of major mechanical components in the proposed mechanical footstep power generator.

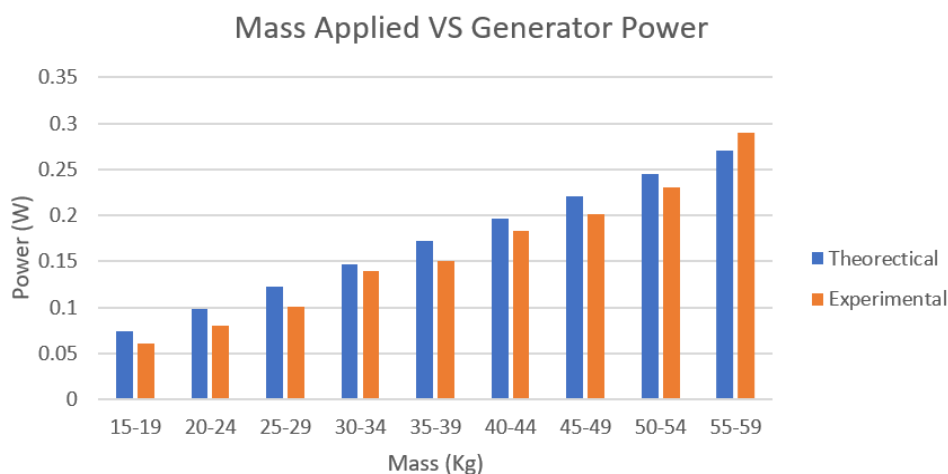|	Unit	Gear 1 (First Gear)	Gear 2 (Second Gear)	Gear 3 (Last Gear)
Face Width	mm	10	10	10
Base Circle	mm	117.5	57.5	11
Addendum	mm	122	62	14
Teeth	-	120	60	12
		Spring		
Wire Diameter	mm	2.95		
Outer Diameter	mm	29.46		
Inner Diameter	mm	23.56		
Total number of coil	Turns	12.75		
Free Length	mm	100		
Spring Stiffness	N/mm	3.53		

Fig. 2. Differences between theoretical and experimental results.

generated power increased proportionally with the mass of an individual. In general, the individual with body mass around 55 kg are the teenager or adults with age above 18 years old. These participants are normally stronger, hence the actual power generated from experiments were higher than the theoretical results. Furthermore, it was also observed that the spring with higher stiffness needs to be installed to the mechanical footstep generator designed for adults to ensure it has higher durability.

5 Conclusion

The conversion of kinetic energy from human footsteps into the electricity energy is considered as one of the renewable energy techniques. This research had demonstrated the feasibility of generating electricity with simple mechanism of rack and pinion. Furthermore, this research proposed to place the mechanical footstep power generator at hind foot region in order to generate higher output power with better efficiency. Experiments were conducted to verify the effectiveness of the proposed design and the experimental findings observed are promising.

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