Design and Fabrication of Mechanical Power Generation Systems Using Footsteps

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***Abstract*—It is well known that our planet population is rising continuously, and it is expected to increase dramatically over the coming years. This has led to an increase in the demand for electric power for the industrial, commercial and living purposes. Currently, fossil fuel has been used as the main source for electricity generation but the amount of these resources is continuously depleting. Besides, renewable technologies are still not quantitively and qualitatively reliable to be considered as the main source of energy. In this study, an alternative power generation method using human footstep was proposed. A new mechanical footstep power generation system using SolidWorks software was designed, fabricated and tested. The stress-strain analysis including the safety factor calculations for the proposed product were conducted in this work. An approximately 34 W per step was generated. All the critical components achieved a minimum safety factor value of 2. In addition, SMART Technology was incorporated into the product to facilitate the monitoring performance of the proposed system. This is also to meet the current technological standards that are globally used.**

***Index Terms*—Footsteps power generation, human footsteps, SMART technology**

I. Introduction

In the current era of globalization, human population has been increased exponentially around the globe. It was reported that the current world population reached approximately 7.6 billion and in Malaysia, the number was about 32 million [1]. It is well-known that the demand for electricity is expected to rise drastically with the increase in population. Moreover, the increase in the urbanization of the current and new cities and the growth in the current industrial revolution may also play a strong role in the rise of electric power demand.

The main sources of energy of fossil fuels have been continuously depleting due to the heavy exploitation during the last few decades [2]. This could also have severe consequences on the global warming of the planet earth. Although many countries have encouraged the researchers and industries as well to adopt more renewable energy systems in their research and investment, renewable energy is still not reliable because its availability depends on nature which is unpredictable.

Many creative power generation systems for flooring applications have been designed and implemented [3]-[5]. Elizabeth Redmond [3] invented a new system that could utilize the mechanical energy of footsteps to generate green energy. His patent comprised two adjacent energy devices installed under a footpath, and they were connected in an arrangement that could respond to the applied footstep effectively and then increase the output power. Moreover, a wireless transmitter system was also adopted to provide an effective communication for the invented system components. A modeling investigation was conducted for a proposed design that could utilize piezoelectric elements to generate output power from the applied forces of the footsteps [4]. In their study, 3.1% of the total floor area of the central hub building at Macquarie University in Sydney, Australia was proposed to be tiled with a piezoelectric harvester. They estimated that about 1.1 MWh can be generated annually.

Roadways are one of the most common civil infrastructures that represented as the structure platform to carry the traffic loads. The vehicle loading and movement could always create mechanical energy in the form of vibration that can be utilized to generate clean energy [6]. Hendrickson B. S., Alvino F. J. and Shani D. *et al*. invented hydraulic electric power generation systems for the roadway installations [7]-[9]. A compressed air method was also used to invent an environmentally friendly power generator for roadway applications [10], [11]. Other concepts such as hybrid, gear mechanism, and electromagnetic induction were also adopted for clean power generation applications in the field of flooring and road [12]-[14]. A piezoelectric energy harvesting technology was used to produce a clean power generator module for roadways installations [15]. The proposed module generated an instantaneous power output of up to 200 mW across a 40 kΩ resistor at the speed of 8 km/h and a weight of 250 kg.

In terms of human life, walking is the most common activity as it is part of a daily routine. In this study, a new design of a power generation system for utilizing the human footsteps was designed and fabricated. This system works by converting mechanical energy generated by human footsteps to a DC electrical power. This system

Manuscript received September 15, 2019; revised November 10, 2019; accepted January 5, 2020.
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doi: 10.18178/ijeetc.9.3.183-188

can be proven to be very effective in crowded public places such as railway station, airport and shopping complex.

II. System Design and Fabrication

A. Operating Principle

The working mechanism of the proposed system mainly relies on an external force that can be supplied by human being's footstep (walking person) on the top tile (power generating tile) and the potential energy that can be stored in the used spring. It is expected that the walking person, who has a normal weight of about 75 kg, could compress the used linear springs via the power generating tile by approximately 6.0 mm. The downward linear movement of the power generating tile could compress the system's rack and springs with a small amount of the mechanical loses. Once the footstep is removed from the tile, the potential energy stored by the springs will be used to push the tile back to its original position. This reciprocating movement of the power generating tile causes the pinion to rotate at a certain angular velocity resulting in a rotational motion of the attached shaft, as shown in Fig. 1. A mechanical clutch was used to maintain the rotational motion (energy) of the attached shaft in one direction only. The rotational speed of the first and second shaft was maintained meanwhile it was gradually increased for the third shaft onwards. This was achieved via using bevel gears with a different teeth number that allows the speed of the rotational shaft to be increased. The rotational speed of the final shaft was designed to be matched with the required generator's rotational speed. Hence, an alternator was used to generate the power that was stored in the adopted energy storage system which comprises a sealed lead-acid battery and charge controller.

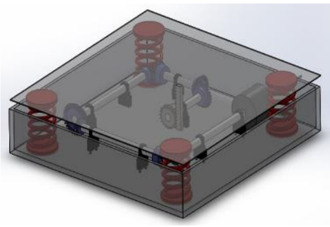

Fig. 1. Proposed model of footstep power generating system.

B. Prototype Design and Fibrication

The model design of the footstep power generating tile has a dimension of 70 cm × 70 cm × 13 cm. This tile is laid on four springs positioned at each corner of the designed system with a gap of 6 mm. A rack and pinion were used as a medium to capture the force from the human footstep, and transfer it to the generator via a power shaft to produce the desired output power from the used alternator. A total of 5 shafts were arranged with 90 degrees from each other to transfer the input power in which the fifth shaft is coupled to the alternator. Bevel gears with a different number of teeth were placed between each shaft to transfer forces from each shaft to the DC generator. The adopted 24 V DC generator in this prototype can produce a maximum output power of 350 W when the shaft rpm is 2700. Brackets were used to hold the shafts in their positions according to the proposed design. Accordingly, a 3D model design was performed using SolidWorks engineering design and drawing software, as shown in Fig. 1 and Fig. 2. The material selection for the proposed design considered the specifications of the proposed design including the number and type of the used components. The selected materials for each component are listed in Table I and Table II.

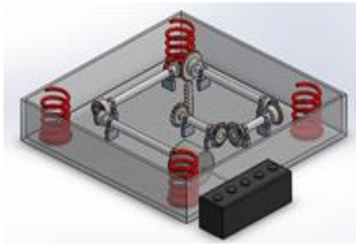

Fig. 2. Inner view of footstep power generation design model.

TABLE I: DESIGN SPECIFICATIONS

Components	No.	Specifications	
Bevel gears	8	**Gear 1-2** Np:23; NG:23	**Gear 3-4** Np:30; NG:15
		Gear 2-3 Np: 23; NG: 15	**Gear 4-5** Np:19; NG:15
Alternator	1	Power: 34W; Speed: 262.3 rpm Efficiency: 85%	
Spring	4	Spring constant K: 33.3 N/mm	
Shaft	5	**Shaft 1 and 2** Length: 15cm; Diameter: 22mm **Shaft 3, 4 and 5** Length: 35cm; Diameter: 22mm	
Rack and Pinion	1	Length of Rack: 13 cm Radius of Pinon: 0.0075m	
Bearing	8	Nominal shaft diameter: 22.22mm	
Sprang Clutch	1	Nominal shaft diameter: 22.22mm	

TABLE II: MATERIAL SELECTION [14]-[17]

Components	Material
Bearing	Chromium steel
Shaft	AISI 1050 Cold Drawn Steel
Bevel gear	
Tile Container	
Tile Plate	
Rack and Pinion	
Spring	Stainless Steel

TABLE III: PROTOTYPE CONSTRUCTION MATERIALS

Components	Material
Tile container and tile cover	Polycarbonate (plastic)
Springs	Stainless steel
Bearings	Chromium steel
Shafts	Polyvinyl Chloride (PVC)
Bevel gears	Polylactic Acid (PLA)
Plywood	Wood

The proposed system in this work was designed and manufactured by using a wide range of the selected materials listed in Table I, Table II and Table III. Fig. 3 demonstrates a real photo of the proposed system of this study. It can be clearly seen that there are groups of differential gears and shafts to transfer the power from the footstep tile to the generator [18]. Four stainless steel springs were used and positioned at the corners of the prototype with a movement clearance of 6 mm at the maximum load conditions. A transparent body and footstep tile were used to demonstrate the internal structure of the proposed system. Moreover, chromium steel bearings were used to reduce the friction losses between the used shafts and the holders to the minimum [19]. A small-scale DC generator was used to generate the maximum possible amount of output power from the minimum limit of the available rotational speeds.

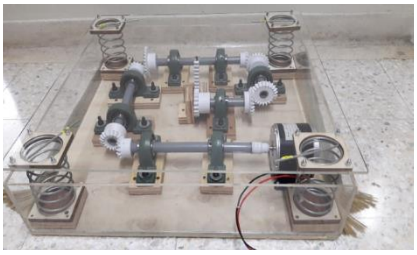

Fig. 3. Image of the constructed prototype

III. Smart Technology

A. Force Sensor and Voltage/Current Sensor

In order to evaluate the real-time performance of the proposed system through the generated power, two sensors were used, as shown in Fig. 4 and Fig. 5, aiming to measure the energy inputs and outputs of the proposed system of this study. Firstly, a force sensor was adopted so that the applied force (input energy) by any person's stepping on the footstep tile could be measured directly. Secondly, a current/volt sensor was used to measure the generated power (output energy) by the alternator of the proposed system. The real-time measured forces and output power were recorded via Arduino IDE software. The used sensors were interfaced with the Arduino micro-controller to read and translate the inputs' analog data from the tile into outputs' digital data at the computer software. Interfacing the force sensor with the Arduino was conducted via home written code by using the Arduino IDE software, as shown in Fig. 6.

Fig. 4. Force sensor.

Fig. 5. Current/voltage sensor.

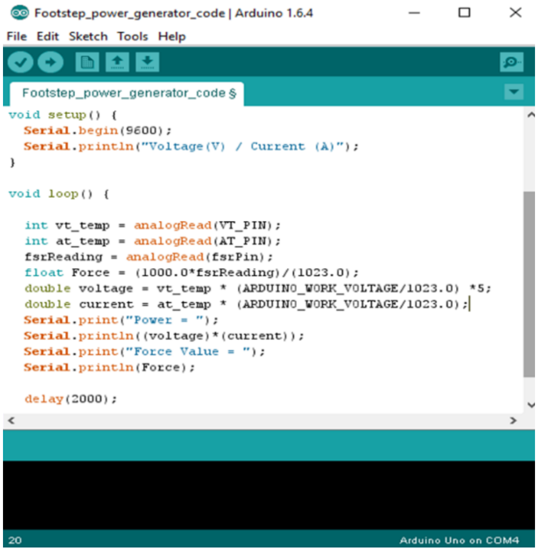

Fig. 6. Arduino IDE code for both sensors.

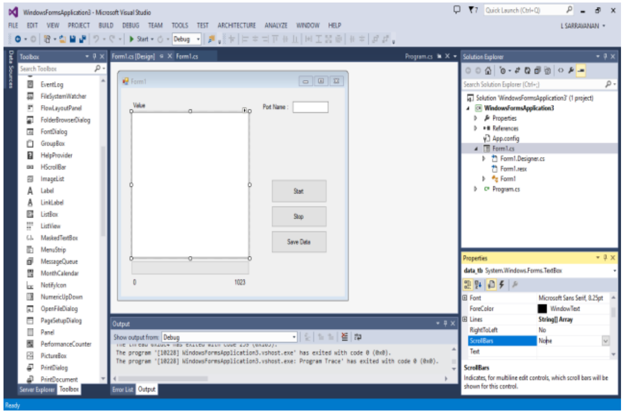

Fig. 7. Developed Graphical User Interface (GUI)

B. Graphical User Interface (GUI)

After completing the design of the power generating model, a graphical user interface (GUI) was developed to monitor the system performance through the input and output data during the operation of the proposed model. Sensors were selected and made to interface with the used microcontroller. For simplicity and viewing purposes, a graphical user interface was created using Microsoft Visual Studio, as shown in Fig. 7.

IV. Design Validation

The proposed system design was validated by comparing the current design with an existed design that was proposed by M. Liu *et al*. [13]. The internal components of the proposed system of this study are quite similar to that of reference [14]. However, the proposed design of this study could operate with a greater shaft rotational speed at the DC power generator. Moreover, the system design was developed so that the shaft speed can be gradually increased starting from the moment of the footstep force was applied and ending at the DC power generator. Theoretically, it was found that the existing design would produce approximately 11.0 W for each applied footstep whereas the newly developed design could produce an approximately 34 W per step.

This shows the superior performance for the proposed design of this study compared with the existing design in terms of power production.

V. Results and Discussions

The prototype was tested by connecting it to a 220-ohm load resistor and applying force by footstep to witness the amount of power generated by the system. In addition, monitoring the amount of the generated power that can be charged in the batteries for further use. The obtained data was recorded in the Table IV.

TABLE IV: POWER GENERATED BY THE PROTOTYPE

Number of Steps	Voltage (V)	Power (mW)
1	0.158	0.11
2	0.097	0.04
3	0.137	0.09
4	0.074	0.03
5	0.086	0.034
6	0.124	0.07
7	0.087	0.034
8	0.144	0.09
9	0.092	0.04
10	0.1	0.05
Average Power (mW)		0.06

TABLE V: AMOUNT BATTERY CHARGING BY PROTOTYPE

No. of Steps	Battery A		
	Initial Voltage (V)	Final Voltage(V)	Amount Charged (V)
10	0.014	0.015	0.001
20	0.015	0.016	0.001
30	0.016	0.016	0.0
40	0.016	0.016	0.0
No. of Steps	Battery B		
10	1.478	1.478	0.0
20	1.478	1.478	0.0
30	1.478	1.479	0.001
40	1.479	1.479	0.0

A battery type AA 1.5 V was used as an energy storage system for the proposed power generation system. It can be noticed from Table IV and Table V, the amount of the electrical charge that the battery can receive is similar for both used batteries, which is at an amount of 0.001V. However, the number of steps used to generate this amount of power is varied for both batteries. This could be attributed to the batteries charging cycle rate because both batteries have a different initial voltage.

Experimentally, as shown in Table IV and Table V, both the generated voltage and power by the prototype are smaller than the designed values. This is mainly attributed to several reasons. Firstly, human errors may occur during the conducted experiments including the vision errors in which the positioning of certain components may differ from the designed position. This may increase the measurements' error and equipment uncertainty. Besides, the construction processes such as drilling, and screwing may need to be more accurate than it is. This may also lead to errors and negatively affect the performance of the prototype. Secondly, the used materials to build up the prototype were not the actual materials as they were proposed in the design. For instance, the plastic bevel gears, which were 3D printed, could not spin effectively due to the material properties that can restrict the rotational motion. A large amount of force could not be applied on the prototype due to the construction of the tile container and cover that were made of polycarbonate plastic. Moreover, the used PVC pipes were not accurately straight due to the weather conditions that caused some bending in the power train pipes. This could also cause some loses in the transferred mechanical power from footstep tile to the DC generator.

When von Mises stress reaches a critical yield strength of a specified mechanical component, this means this part is undergoing yielding. The first component in this analysis was the tile plate which experienced the highest von Mises stress of 38.76 MPa as shown in Fig. 8. By using the formula and referring to the given material properties, the calculated safety factor was more than the optimum value of 2.0. Moreover, the tile plate experienced the lowest von Mises stress of 1.179 MPa.

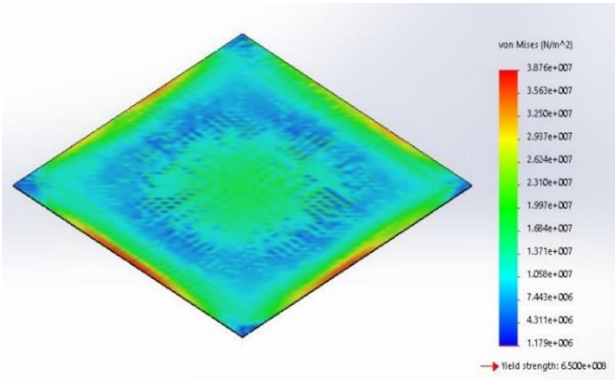

Fig. 8. Stress-strain analysis of tile plate

The second most important part of the proposed design is the powertrain shaft. In this stress-strain analysis, the maximum von Mises stress of the mechanical powertrain shaft was 528.4 kPa and the lowest stress was of 0.5798 kPa. As shown in Fig. 9, the stress can be noticed at the edge area of the shaft which is highlighted with red colour. In this analysis, there are not perpendicular forces directly act on the shaft but indirectly to create a torque force that causes the shaft to rotate. The endurance limit at the critical location and the material ultimate tensile strength are estimated to be 262.2 MPa and 650MPa respectively, the safety factor of the shaft is found to be 2.48.

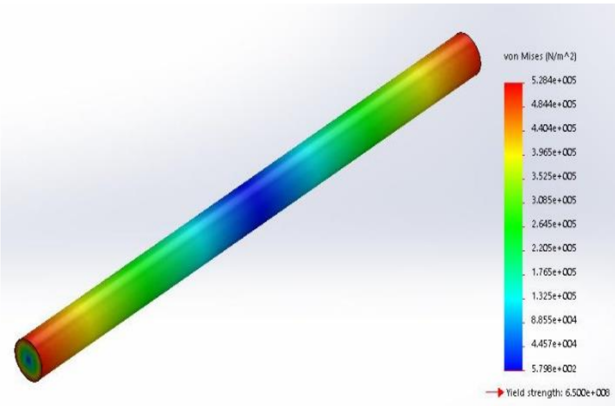

Fig. 9. Stress-strain analysis of the powertrain shaft

VI. Conclusion

An alternative power generation approach using human footstep was proposed. Different working mechanisms of footstep power generation systems were investigated, and the experimental results were analysed. This new mechanical footstep power generation system was firstly designed by using SolidWorks software, before it was fabricated.

In this study, a new developed mechanical footstep power generation system was designed and proposed, and the experimental results were discussed and analysed. An approximately 34 W per step was the amount of power that could be generated. Using SolidWorks software, a 3D model design of the system was made possible. All the critical components achieved a minimum safety factor value of 2. A monitoring SMART technology was implemented for the project that eased the monitoring process of the system. A graphical user interface (GUI) was developed by using a visual studio made the experimental process smoother.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Firas B. Ismail and L Sarravanan conducted the research and analyzed the data while Nizar F. O. Al-Muhsen analyzed the work results and wrote the paper. All authors had approved the final version.

Acknowledgment

The authors would like to express gratitude to power generation unit, institute of power engineering, Universiti Tenaga Nasional (UNITEN) and Tenaga Nasional Berhad (TNB) for providing research grant to carry out this research.

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