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Energy Harvesting from Mechanical Footstep: Design and Optimization

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ABSTRACT

The untapped energy generated by human footsteps is a neglected potential, overlooked by many countries. Despite its abundance in various settings, such as public spaces and walkways, this valuable resource remains largely wasted due to insufficient harnessing measures. The promise of contributing to sustainable energy solutions remains unfulfilled due to inadequate implementation and the absence of effective systems capable of capturing and converting this latent energy into practical forms. This study comprises the design and analysis of a footstep harvesting module under different type of material with same loading using Finite Element Analysis (FEA) simulation. A minimalistic approach has been adopted throughout the design of the footstep harvester. In this paper, the Computer-Aided Design (CAD) model and static structural analysis of the footstep harvester module are run using Solidworks software. The innovative footstep energy harvester concept capitalizes on two power generators tailored to meet exacting criteria: 24V, 2A, and 300rpm. Findings from comprehensive assessments led to the identification of a 5mm-thick aluminium alloy as the optimal material for the top panel. This choice was validated by its exceptional blend of energy conversion efficiency, durability, reliability, and cost-effectiveness. Calculations underscored the device's prowess, revealing its capacity to harvest a formidable 16 watts of energy through the utilization of dual motor generators for each footstep.

1. Introduction

Green technology is the creation and use of products, equipment, and systems that help to protect the environment and nature by decreasing or eliminating the negative effects of human activity. Green Technology is defined as a system that reduces environmental quality degradation, emits minimal or no greenhouse gases (GHG), is safe to use, and creates a healthier and better environment for all living things. It also conserves energy and natural resources while encouraging the use of renewable resources. It's intended to be a renewable energy source that utilizes fewer

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fossil fuels and harms humans, animals, and plants, as well as the environment. The quantity of trash and pollutants produced during manufacturing and consumption should be reduced using green technologies [1].

Global human population has grown significantly in the contemporary era of globalization. It is common knowledge that as the population grows, there will be an enormous increase in the need for power. In addition, the current industrial revolution and the expansion of existing cities' urban populations may both have a significant impact on the rise in the need for electricity. Due to their extensive use over the past few decades, fossil fuels are continuously running out of their primary sources of energy [2]. This might have detrimental effects on the earth's climate, which is already warming. Renewable energy is still unreliable since it depends on nature, which is unpredictable, even though many nations have encouraged scientists and businesses to incorporate more renewable energy systems in their research and investment.

Numerous inventive powers generating systems for flooring applications have been built and put into practice. Footstep harvester is one of the methods to produce renewable energy in a simple way. This is because, energy production will occur if human movement touches the footstep platform. There are some researchers have been used piezoelectric to generated electrical from mechanical vibration energy into electricity. The piezoelectric mechanism is the most promising of all transduction methods to generate energy for microdevices [3-14]. Other method is using motor generator to produce renewable electricity. Based on the previous study from Khatri & Gupta [15] as a result, the concept of employing magnets to generate energy has been around for quite some time. For many years, simple magnets have been utilized to generate electric power due to their magnetic field. They're found inside the cores of motors and generators. The magnetic effect is the fundamental principle of power generation. "A voltage is induced in the conductor when a conductor is spun in a magnetic field," it says. Magnet An engine-free energy generator is a simple device for generating electricity.

In this study focus on 3d modelling and analysis human footstep structure, beside that the calculation of energy produce using motor generator have been calculated. There is numerous researcher research about footstep energy. According to Taliyan *et al.,* [16] had designed a footstep energy harvesting device that uses a DC generator. Their experimental results show that 3–5 J of electrical energy can be generated from each step. However, the paver top panel displacement is 3 cm, which is not only uncomfortable for pedestrians, but also would not conform to the Americans with Disabilities Act (ADA). This act limits the amount of the vertical height difference between pavement joints.

Bhatia *et al.,* [17] design an energy harvesting paver using rack and pinions. They were able to harvest 0.36 W average power. The displacement of the device's top panel varied between 13 and 38 mm, which incurs the same comfort and regulatory code issues as the based on {17]. Furthermore, their overall efficiency, which is less than 20%, is still low. Another company, Waydip came up with an energy harvesting paver called "Waynergy" that can harvest 0.3–0.6 J of energy per step. If there is a sustainable way to extract lost energy into the ground, this could lead to important milestones in the renewable energy sector. Only foot movement steps that follow the mechanism correctly can produce renewable, safe, and environmentally friendly energy.

Elizabeth Redmond's [18] patent involves two adjacent energy devices placed under a footpath, which respond effectively to the applied footstep, increase the output power, and communicate wirelessly. Another design proposed using piezoelectric elements to generate power from applied forces. The study suggested tiling 3.1% of the total floor area of a building with piezoelectric harvesters, which could produce approximately 1.1 MWh of energy annually.

Walking is an integral part of daily routine for humans, making it the most common activity. A novel power generation system was developed and manufactured in this study, which harnesses the mechanical energy produced by human footsteps and converts it into DC electrical power. The system is particularly suited for crowded public places like railway stations, airports, and shopping complexes [19].

2. Design Validation

Regarding on three designs, the researcher took the main attention in terms of the concept used, size, type of power, result, and durability of the structure that can accommodate the maximum weight set by each design, refer Table 1. Out of the three designs compared, the researcher selected the third one as the best design and aims to improve it further. This design employs the rack and pinion mechanism to create an energy harvester that converts the mechanical energy from footstep pressure into electrical energy. When pressure is applied to the top panel, the rack and pinion move, generating mechanical energy that can be supplied to a DC motor generator. The size of the harvester has been reduced to 30 cm x 30 cm x 8 cm to increase the displacement of the footstep, resulting in higher output power and space-saving benefits.

Table 1
Design Validation

Concept	Size	Materials	Output	Description	Limitations
First design of footstep structure (Ang *et al.,* 2019)[20] refer Figure 1	40 cm x 40 cm x 40 cm	Mild steel	Dc motor	- rack and pinion concept, aiming to reduce the complexity of mechanical structure. - Can produce an average of 0.15 W output.	Maximum 55 kg
Second design for footstep structure (Pokale & Deshmukh, 2016) [21] refer Figure 2	40 cm x 40 cm x 40 cm	Mild steel & MDF	Dry battery	- The linear motion due to pressure of footsteps into rotary motion using dry battery. - 380N output can generated in the voltmeter is below 6 Volt.	Maximum 80 kg
Third design of footstep structure (Chakraborty *et al.,* 2015) [22] refer Figure 3	40 cm x 40 cm x 5 cm	Mild steel	DC motor	- Rack and pinions - The energy harvesting paver can produce an average power output of 3.6 W over 0.5 s of the step time, with a peak power of 12 W in walking conditions	Maximum 80 kg

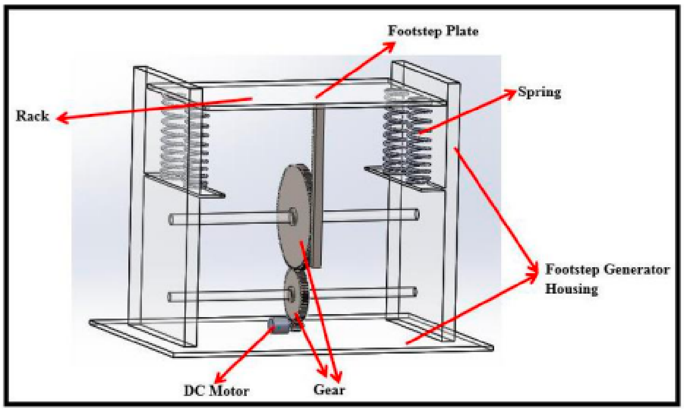

Fig. 1. 1st Design Benchmarking

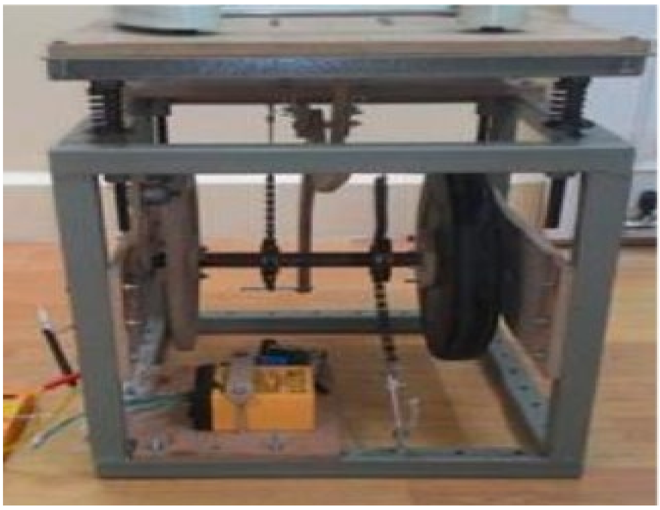

Fig. 2. 2nd Design Benchmarking

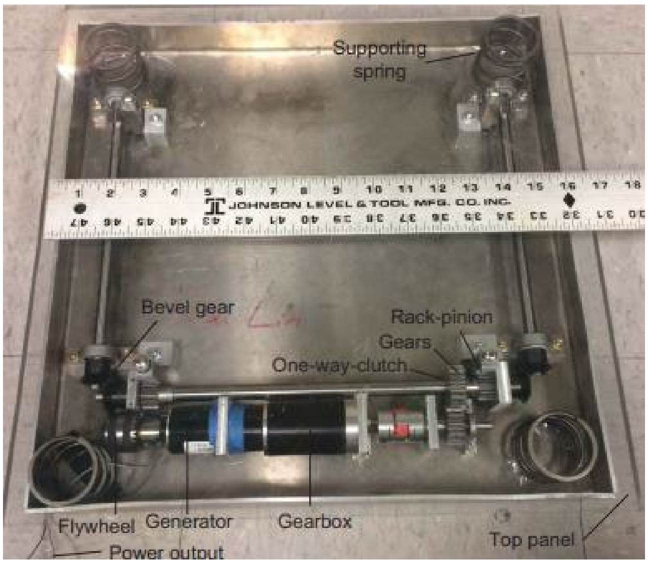

Fig. 3. 3rd Design Benchmarking

3. Working Principal

The footstep energy harvester system works by using the weight of a person's footstep to compress linear springs, which store potential energy that is then converted into electrical energy through the rotation of a shaft connected to a generator, with the rotational speed being increased driven by bevel gears. The generated power is stored in a battery and converted from DC to AC using an inverter, and the system resets to its original position using one-way clutch and springs. A block diagram, as shown in Figure 4, illustrates the working principle of the proposed footstep energy harvester system.

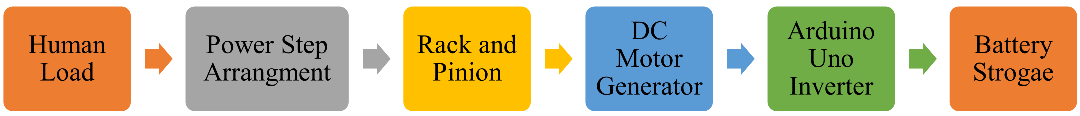

Fig. 4. The block diagram of power transmission

4. Modelling

The footstep structure model design utilizes a rack and pinion mechanism with four compress springs and support in each corner, along with four T-shaped housing bearings and two spur gears combined with a shaft at the centre. The 12 VDC alternator motor can produce a maximum output power of 24W at 900 RPM for one motor, and the design uses two motors to achieve a maximum output power of 48W. A 3D model was created using CAD software refer to Figures 5 and 6, and materials were selected based on design specifications shown in Table 2.

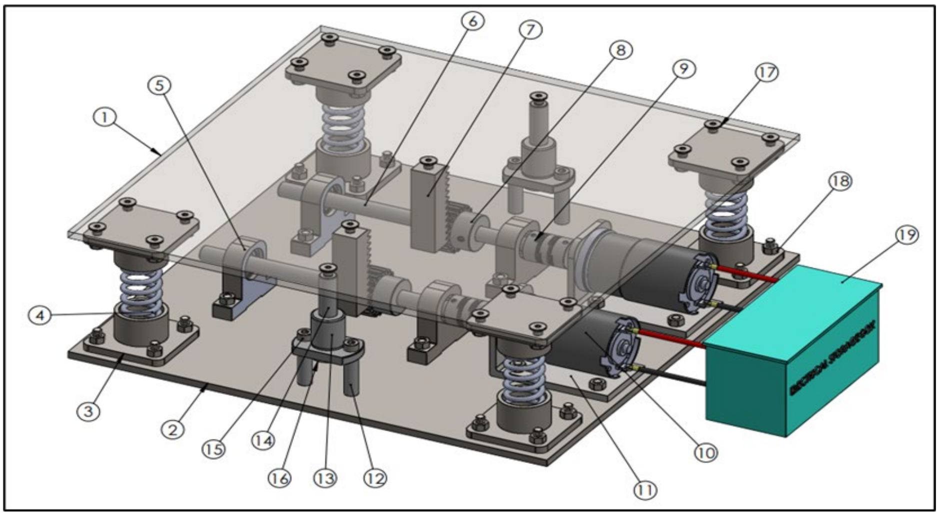

Fig. 5. Inner view of footstep structure design model

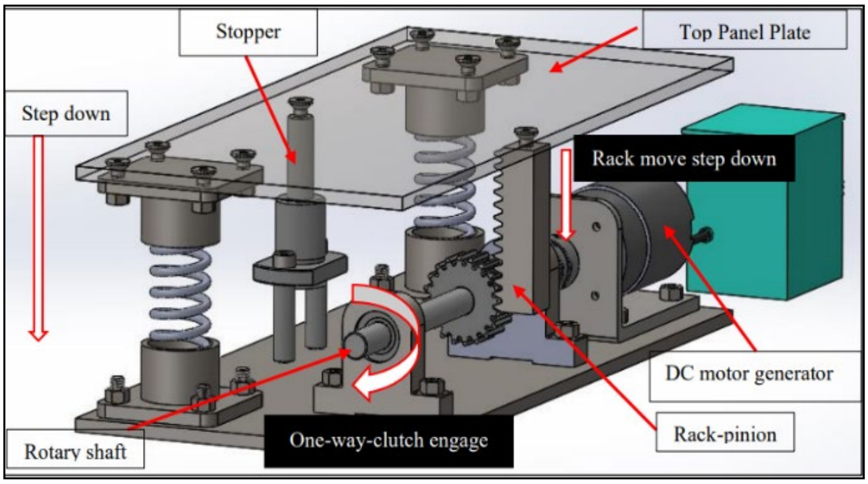

Fig. 6. Cross section for the footstep design

Table 2
Part specification

No.	Components	Qty.	Specifications	Material
1	Top panel	1	300 mm x 300 mm x 5 mm	Aluminum alloy
2	Based	1	300 mm x 300 mm x 5mm	Mild steel
3	Spring support	8	Based: 40 mm x 40 mm x 5mm Height: 20 mm O.D: 25 mm, I.D: 24 mm	Mild steel
4	Compresses spring.	4	Free height: 74 mm Coil O.D :23.2 mm Spring constant K: 13.204 (N/mm)	Stainless steel
5	Housing bearing & bearing	4	T-shaped Bearing I.D: 10 mm Height: 30 mm	Stainless steel
6	Rotary shaft	2	Length: 170 mm, Dia.:10 mm,	Stainless steel
7	Rack	2	60 mm x 15 mm x 15 mm Pressure angle 20°, module 1.5	Mild steel
8	Spurs gear	2	Pressure angle 20°, module 1.5 Shaft bore Dia.: 10 mm.	General steel
9	Shaft coupling	2	Shaft bore D 1: 10 mm. Shaft bore D 2: 6 mm.	Aluminum alloy
10	12 DC motor	2	Length: 68 mm, Dia.: 50 mm Voltage: 12 V Amperage: 2A Rpm:300 Shaft diameter: 6 mm	Metal, Electric part
11	(L) Motor bracket	2	Length: 72 mm, height: 40 mm Thickness: 2 mm, Width: 44 mm	Mild steel
12	Linear bushing support	4	Length: 30, Dia.: 8 mm	Mild steel
13	Linear bushing	2	Length: 29 mm Inscribed circle Dia: 10 mm	Mild steel
14	Shaft support	2	Length: 60 mm, Dia.: 10 mm	Mild steel
15	M5 socket head cap screw	12	Length: 12 mm	Stainless steel
16	Flat washer	2	Outer Dia: 10 mm Inner Dia: 20 mm	Mild steel
17	M5 socket countersunk head screw	40	Length: 12 mm	Stainless steel
18	Heavy Hexagon nut	32	M5 nut type	Stainless steel
19	Electrical storage box	1	Battery Arduino uno Inverter 120 mm x 60 mm x 50 mm	-

5. Material Properties

In order to complete the analysis process, the design of the footstep structure requires the selection of appropriate materials. The top panel of the structure, is define of three different materials, including mild steel (1023), stainless steel (304), and aluminium alloy (1060), with varying thicknesses of 3 mm, 5 mm, and 8 mm as shown in Table 3. However, selecting the appropriate materials for manufacturing is a complex task due to the widespread use of footstep products in the manufacturing industry. The total deformation and equivalent von-mises stress of top panel materials are predicted using FEA method carried out using static structural analysis.

Table 3
Properties of different top panel

Material	Young Modulus (MPa)	Bulk Modulus (MPa)	Shear Modulus (MPa)	Poisson's Ratio
Stainless Steel 304	2.0e + 5	1.6667e +5	76.923	0.3
Mild Steel	2.1e + 5	1.5909e + 5	82.031	0.28
Aluminum	7.0e + 4	6.2000e + 4	0.27	0.33

6. Theoretical of Power Output Calculation

Power can be calculated in terms of obtained voltage and current when the load is applied on the footstep. 100 Kg of maximum load applied on the top panel of footstep, the generated voltage is 12 V and the average current produced is 2 A with 900 rpm. If the maximum rpm motor can generate maximum power is 24 Watt per motor. For this design only use 1/3 maximum rpm motor. The calculation of the energy generated is shown as follows:
RPM = (60 seconds)/ (0.2 per footstep) = 300 rpm

Power = Voltage x Current

Power = 12 x 2 =24 Watt (if max rpm)

1⁄3 rpm is = 1⁄3 power

1⁄3 power = 1⁄3 (24) = 8 Watt for 1 motor

8 x 2 = 16 Watt for 2 motors

Therefore, utilizing a single DC motor generator, the footstep has the capability to generate 24 W of power when the maximum RPM is attained. However, the researcher aims to operate the footstep at only one-third of the RPM, resulting in an output of 8 W per motor generator. Consequently, by employing two motor generators, each footstep can generate a total of 16 W.

7. Result and Discussion

Utilizing specified requirements, a 3D model of the top panel structure is created through CAD software. Static structural analysis is conducted employing the FEA method. For comparative purposes, all three materials, namely stainless steel, mild steel, and aluminium, maintain identical load and boundary conditions. The static structural impact study delineates discretized points of interest to scrutinize stress development, resultant strain, and deformation within each optimized prototype. Von Mises stress is taken into account to provide an overarching view of stress distribution across the footstep harvester module and to simulate the factor of safety (FOS) for each material. Figures 7, 8, and 9 present a comparative analysis of the top panel structure.

7.1 Comparison Analysis to Selection the Top Panel Part

Figures 7 and 8 display the analysis of von Mises stress and displacement for the top panel with thicknesses of 3 mm from mild steel (1023), 3 mm from stainless steel (304), and 5 mm from aluminium alloy (6061). The objective of this section is to select the optimal parameter for the top panel from the three materials and thicknesses shown in the graph, based on the analysis results previously explained. The maximum von Mises stress for each material does not exceed the yield strength, and the maximum displacement is less than 1 mm. Additionally, the factor of safety for all materials is more than 2, except for the 3 mm thickness aluminium alloy, where it is 1.1, which is less than 2, as illustrated in Figure 9.

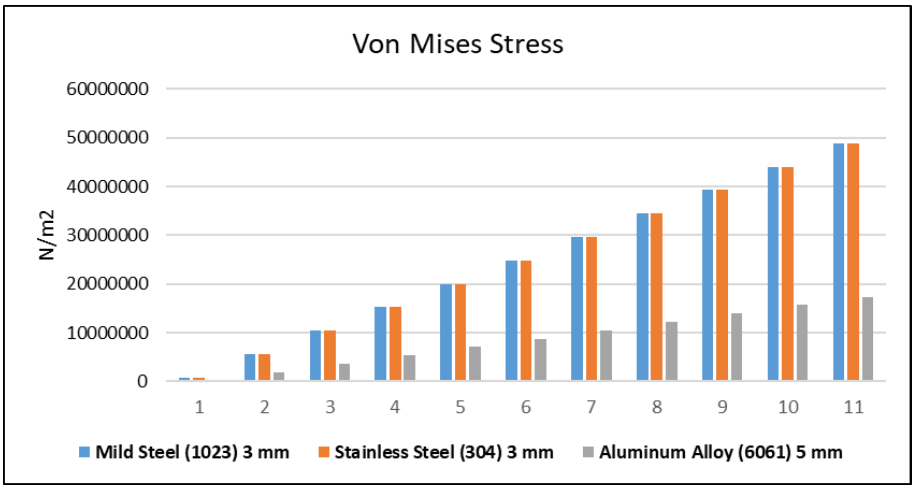

Fig. 7. Graph of von Mises stress analysis for three materials

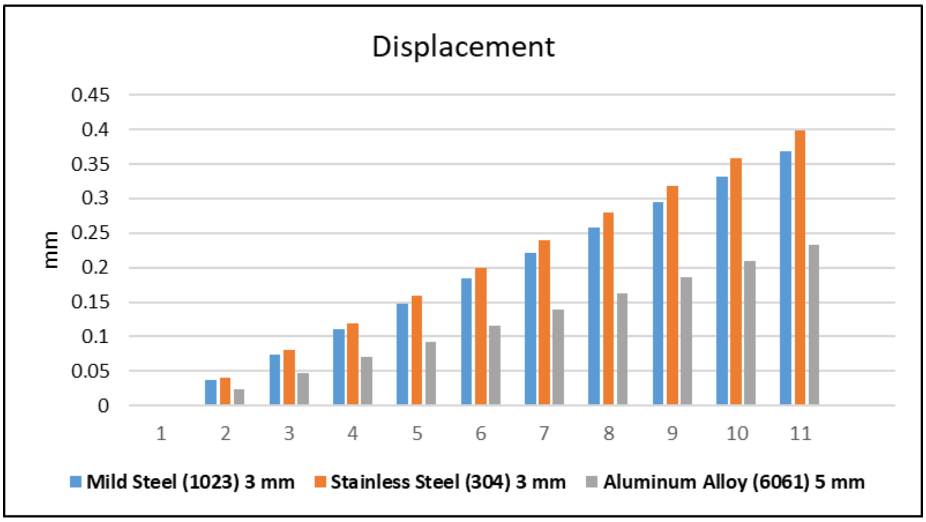

Fig. 8. Graph of displacement analysis for three materials

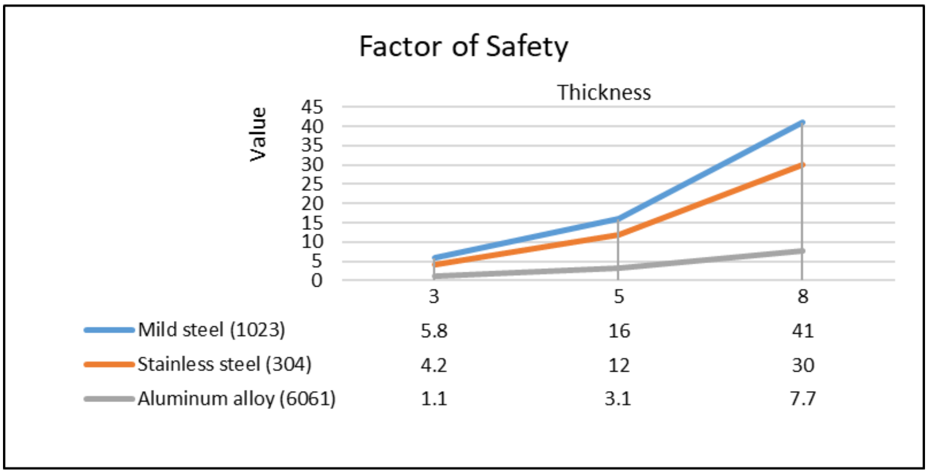

Fig. 9. Graph factor of safety analysis for three materials

According to Akin [23] The factor of safety is a crucial consideration in the design, with many authors advocating for a value greater than one but less than eight, depending on the materials and structure. The top panel for footstep structure design can be made from different materials and thicknesses, but only one material from each group is chosen. The researcher selects the 5 mm thick aluminium alloy (6061) due to its low cost, lightweight, good machinability, and ease of fabrication. Mild steel is inexpensive but prone to rusting. A comparison of the weight for different materials and thicknesses is provided in Table 3. The chosen materials are optimized to create a mechanical device that is less expensive, more effective, and compact.

Table 4 displays the weight differences of top panel parts based on various materials and thickness. Mild steel, stainless steel, and aluminium alloy were compared, and the results showed that the weight of aluminium alloy is significantly lighter than the other materials [24]. The study then focused on determining the best thickness for the aluminium alloy top panel using von Mises stress, displacement, and factor of safety analysis [25], have been discussed at the previous section.

Table 4
Different weights between top panel parts

Materials	Overall weight for top panel (N)		
	3 mm	5 mm	8 mm
Mild steel (1023)	20.65	34.46	55.24
Stainless steel (304)	21.02	35.08	56.21
Aluminium alloy (1060)	77.09	11.84	118.93

8. Conclusion

To summarize, the implementation of finite element analysis (FEA) for static analysis in this study has proven to be a successful approach, as it closely mimics the examination of an actual product. The initial research objectives have been successfully accomplished. Moreover, this cost-effective method solely necessitates the use of a computer and minimal additional materials. As a result, it is highly likely that most engineers will opt for this methodology as a preliminary step before proceeding with the production of a physical product.

A novel approach to power generation utilizing human footstep energy was proposed, employing the rack and pinion concept. Various operational mechanisms for harnessing energy from the human footstep system were explored, and the resulting experimental data were examined. Initially, a CAD software was utilized to design the innovative mechanical footstep device system. In this study, it was found that a maximum power output of approximately 16 W per step could be achieved using two generators. The top plate, a critical component, underwent analysis using an aluminium alloy (6061) material with a thickness of 5 mm, achieving a minimum factor of safety (FoS) value of 2 or higher. The remaining components were also subjected to analysis and referred to standard design components available on the Misumi website to ensure optimal structural design.

This innovative power generation method holds great potential for electricity production. It proves particularly advantageous for households experiencing frequent power outages or for areas where electricity infrastructure is still lacking. Furthermore, it boasts an eco-friendly nature, devoid of pollution, noise, or smoke emissions, allowing for its installation in public spaces and residences without compromise. The versatility of this device enables its deployment in various high-traffic locations such as stairwells, malls, futsal courts, stations, pedestrian walkways, and parks. Embracing this approach can help reduce dependence on fossil fuels while providing self-sustained electricity for everyday needs. The environmentally benign nature of this technology stands as a significant advantage. By embracing cutting-edge advancements, this study's success has the potential to inspire future generations to rectify existing errors and deficiencies. The researcher's ultimate aspiration is to offer substantial benefits to users who can utilize this experiment as a valuable reference.

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