https://doi.org/10.56862/irajtma.v4i3.329

IRA Jurnal Teknik Mesin dan Aplikasinya (IRAJTMA)

Vol. 4, No. 3, 2025, pp. 85-97, e-ISSN: 2962-4290

Available online http://e-journals.irapublishing.com/index.php/IRAJTMA/

Scientific Articles

Simulation and Fabrication of a Prototype Mechanical Footstep Power Generator for Renewable Energy Applications

Simulasi dan Pembuatan Prototipe Generator Listrik Bertenaga Langkah Mekanis untuk Aplikasi Energi Terbarukan

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Diterima: 27-09-2025 **Disetujui: 01-11-2025** **Dipublikasikan: 28-12-2025**

Abstract

The design and fabrication of a Mechanical Footstep Power Generator was developed as an innovative approach to harness kinetic energy from footsteps and convert it into electrical energy. Using a fabrication analysis and Design for Assembly (DFA) method, the prototype was designed to be both efficient and easy to assemble. The system consists of nine primary components, including the top plate, bottom plate, gear plate, gear, pinion, spring, dynamo (DC), long bolt M12, and nut. Fabricated parts were processed through tapping, drilling, milling, grinding, shaping, and chamfering, while other components were commercially purchased. DFA analysis indicated a medium level of assembly complexity, with potential errors mitigated by applying error proofing and systematic assembly guidelines. Experimental testing demonstrated a consistent increase in electrical output with the number of steps, from 2.96 V and 0.0074 W at the first step to 5.71 V and 0.051961 W at the twentieth step. Test results show an increase in electrical output with increasing steps, with system efficiency ranging from approximately 12–15% and influenced by friction, shaft misalignment, fabrication tolerances, and dynamic load variations due to human footstep impact. These results confirm that the prototype can reliably convert mechanical energy into electrical energy, though its application is currently limited to low-power usage. Nevertheless, the system has significant potential for future development to improve efficiency, capacity, and broader applicability in renewable energy solutions.

Keywords: *Mechanical Footstep Power Generator, Renewable Energy, Design for Assembly (DFA), Electrical Output.*

Abstrak

Desain dan pembuatan Generator Listrik Langkah Mekanik dikembangkan sebagai pendekatan inovatif untuk memanfaatkan energi kinetik dari langkah kaki dan mengubahnya menjadi energi listrik. Dengan menggunakan analisis pembuatan dan metode Design for Assembly (DFA), prototipe dirancang agar efisien dan mudah dirakit. Sistem ini terdiri dari sembilan komponen utama, termasuk plat atas, plat bawah, plat gigi, gigi, pinion, pegas, dinamo (DC), baut panjang M12, dan mur. Bagian yang diproduksi diproses melalui pengeboran ulir, pengeboran, pemesinan, penggerindaan, pembentukan, dan pemotongan sudut, sementara komponen lain dibeli secara komersial. Analisis DFA menunjukkan tingkat kompleksitas perakitan sedang, dengan potensi kesalahan diatasi melalui penerapan pencegahan kesalahan dan pedoman perakitan sistematis. Uji eksperimental menunjukkan peningkatan konsisten dalam output listrik sesuai dengan jumlah langkah yang diterapkan, mulai dari 2,96 V dan 0,0074 W pada langkah pertama, mencapai 5,71 V dan 0,051961 W pada langkah ke-20. Hasil pengujian menunjukkan peningkatan keluaran listrik seiring bertambahnya langkah, dengan efisiensi sistem berkisar sekitar 12–15%, dipengaruhi oleh gesekan, ketidaksejajaran poros, toleransi fabrikasi, dan variasi beban dinamis akibat pijakan langkah manusia. Hasil ini membuktikan bahwa prototipe dapat secara andal mengubah energi mekanik menjadi energi listrik, meskipun penggunaannya saat ini terbatas pada aplikasi berdaya rendah. Meskipun demikian, sistem ini memiliki potensi signifikan untuk pengembangan masa depan yang bertujuan meningkatkan efisiensi, kapasitas, dan penerapan yang lebih luas dalam solusi energi terbarukan.

Kata kunci: Generator Listrik Langkah Mekanis, Energi Terbarukan, Desain untuk Perakitan (DFA), Output Listrik.

1. Introduction

The current global energy crisis is one of the biggest challenges facing modern society (Uddin et al. 2023). Continued population growth, rapid urbanization, and the intense use of electronic devices have caused energy demand to skyrocket every year (Cheng et al. 2025; Abdullah et al. 2022). Meanwhile, Fossil fuels still dominate global electricity generation, yet their finite nature and environmental impact — from carbon emissions to global warming (Khan et al. 2025). This situation highlights the urgent need for renewable and environmentally friendly energy sources that can be implemented across different scales, including small-scale applications (Come Zebra et al. 2021). This urgency has made research related to alternative energy increasingly important to develop (Lv 2023).

In addition to energy availability issues, environmental concerns are a major reason for seeking more sustainable energy solutions (Gunawardhana, Wanasekara, and Dharmasena 2020; Saba et al. 2024). Dependence on fossil fuels worsens atmospheric conditions by increasing greenhouse gas levels (Farhat et al. 2022). As a result, climate change threatens ecosystems and human quality of life (Gołąbek and Strankowski 2024). Therefore, the utilization of energy from daily activities is beginning to be seen as an innovative alternative (Sezer and Koç 2021). By harnessing previously wasted energy, such systems not only contribute to energy conservation but also promote inclusive, cost-effective, and easily accessible technologies (Lin et al. 2023; Tabaie and Omidvar 2023).

In this context, mechanical footstep power generators are one potential solution (Zaidi et al. 2024). This technology utilizes the kinetic energy from human footsteps and converts it into electrical energy through specific mechanical mechanisms, such as rack and pinion, flywheel, or chains connected to a generator (Basnet, Ranabhat, and Shrestha 2023). Compared to piezoelectric-based systems, this technology is more economical, easier to manufacture, and has a more stable output power. In addition to functioning as an additional energy source, this system can also be applied in public areas with high pedestrian traffic, such as stations, terminals, shopping centers, and campuses (Islam et al. 2020; Yao et al. 2020). Thus, mechanical footstep power generators are not only relevant from a technical standpoint, but also from a social and environmental perspective (Selim et al. 2024; Brusa, Carrera, and Delprete 2023). A number of previous studies have examined various methods and mechanisms for generating energy from footfalls. The differences lie in the design approach, transmission mechanism, and energy conversion efficiency. A summary of previous studies can be seen in Table 1, which forms the basis for the development of this study.

The novelty of this research lies in its integrated approach that combines design, simulation, and fabrication within a single coherent framework. Unlike previous studies, the simulation was conducted using Autodesk Fusion software with real load analysis and safety factor calculations <2, thereby providing a more realistic representation of operational conditions. The simulation results are not only used as a reference for theoretical calculations, but are also directly applied in the prototype fabrication process. In this way, this research is expected to produce a mechanical footstep power generator system that is more applicable, measurable, and has real implementation potential in public environments.

This research was conducted from February 2025 to May 2025 with a focus on developing a mechanical footstep power generator. The research stages included the design, simulation, fabrication, and prototype testing processes. All activities were carried out using engineering workshop facilities, simulation support software, and fabrication support equipment. The equipment used included metal cutting machines, drilling machines, welding machines, grinders, and measuring tools such as calipers and steel rulers. The main materials used in the design of this system included steel for the frame, shafts, springs, and a DC generator connected via a rack and pinion mechanism to convert the mechanical energy of the footstep into electrical energy.

Tabel 1. Summary of Previous Studies Related to Mechanical Footstep Power Generator

Reference	Methode	Result
(Uddin et al. 2023)	Review of microgrids and outstanding issues	Identifies challenges and future trends in microgrids; highlights role of small-scale generators like footstep systems for localized supply
(Cheng et al. 2025)	Review of distributed energy systems	Classifies and analyzes distributed generation technologies; footstep harvesters included as potential small-scale contributors
(Abdullah et al. 2022)	technical aspects of small engines and electricity.	small-scale generator engines, efficiency, emissions, and combustion characteristics. Found that purified biogas produces lower CO_2 emissions (≈9.1%) and higher O_2 levels (≈16.7%), indicating cleaner combustion.
(Khan et al. 2025)	Comprehensive review of hybrid energy systems	Discusses optimization of hybrid renewable systems; shows integration potential for micro-generation such as footsteps
(Come Zebra et al. 2021)	Review of hybrid renewable mini-grids	Demonstrates potential of combining footstep power with hybrid mini-grid solutions for off-grid electrification
(Lv 2023)	Sustainable energy transition with blockchain	Explores blockchain as energy management; applicable to integrating micro-energy data from devices like footstep harvesters
(Gunawardhana, Wanasekara, and Dharmasena 2020)	Optimization of wearable triboelectric nanogenerators	Shows scalability of TENG for human motion; principles applicable to footstep-based systems
(Saba et al. 2024)	Study on microgeneration in urban spaces	Highlights impact of micro-renewables like footsteps on urban planning; promotes integration into smart cities
(Farhat et al. 2022)	Review on waste heat recovery	Critical analysis of WHR technologies; provides hybridization opportunities with biomechanical harvesting
(Gołąbek and Strankowski 2024)	Review of human-motion nanogenerators	Summarizes recent advances in TENGs, sensors, and self-powered electronics; relevant to footsteps energy
(Sezer and Koç 2021)	Comprehensive review of piezoelectric harvesting	Presents state-of-the-art piezoelectric systems; potential improvement for footstep energy harvesters
(Lin et al. 2023)	Review of human motion harvesting devices	Compares piezoelectric, triboelectric, and electromagnetic methods; footsteps recognized as a key application
(Tabaie and Omidvar 2023)	Thermoelectric generators from body heat	Explores body-heat-driven TEGs; demonstrates alternative biomechanical energy harvesting complementary to footsteps
(Zaidi et al. 2024)	Novel low-cost footstep mechanism	Proposes an affordable design for harvesting energy from footsteps; suitable for public area applications
(Basnet, Ranabhat, and Shrestha 2023)	Feasibility study on mechanical footstep generator	Confirms technical feasibility of footstep-based power and storage; effective for small-scale applications
(Islam et al. 2020)	Hybrid triboelectric–electromagnetic tile	Combines TENG and EMG for biomechanical energy; achieves higher efficiency than single mechanism
(Yao et al. 2020)	TENG-based walking harvester and tracking system	Generates energy while enabling self-powered human tracking system
(Selim et al. 2024)	Piezoelectric sensors pressed by footsteps	Demonstrates energy harvesting from foot pressure; applicable for powering low-energy devices
(Brusa, Carrera, and Delprete 2023)	Review of piezoelectric harvesting: materials and circuits	Provides insights into material design and circuit integration for improving piezoelectric harvesters

The method used in this research is engineering with a mechanical system design and fabrication approach. The research process begins with system design using Autodesk Fusion software to create three-dimensional models and perform force simulations. The simulation results are used to determine the safety factor value, which forms the basis for deciding whether the design can proceed to the fabrication stage or needs to be revised. If the design meets the criteria with a safety factor below 2, it proceeds to the prototype assembly stage according to the working drawing specifications. After the prototype is completed, testing is carried out to assess the system's performance in generating electrical energy from foot pressure, then the data obtained is analyzed as material for evaluating design performance.

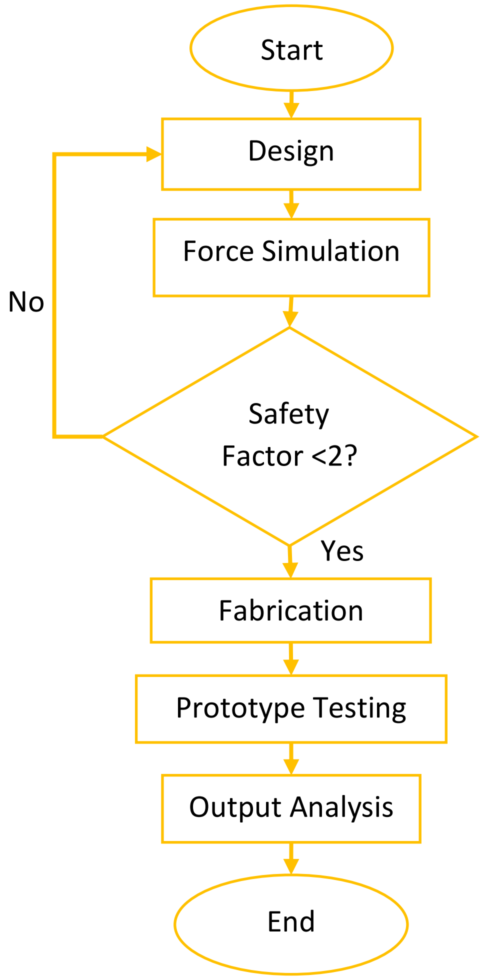


Figure 1. Flowchart of Research on Mechanical Footsep Power Generator

2.1. Prototype Design

The design of the mechanical footstep power generator focuses on converting mechanical energy from foot steps into electrical energy by utilizing a rack and pinion mechanism to convert linear motion into rotational motion, which then drives a DC generator. The system is still in prototype form, so the design is simple, sturdy, and easy to manufacture for the initial testing stage. The main frame uses iron plates, while the footplate is connected to the rack and pinion and equipped with springs as shock absorbers to maintain system stability. Load analysis was performed using Autodesk Fusion software to ensure structural reliability, with a safety factor value below 2 as a reference for material limits against repeated loads. With this design, the prototype is expected to demonstrate basic energy conversion performance efficiently while also serving as a basis for further development in the next stage.

2.2. Prototype System Design

The flowchart of the mechanical footstep power generator research methodology is shown in Figure 2. The research process begins with the design of sketch stage to describe the initial design of the system, including the dimensions of the footstep, the position of the rack and pinion, and the placement of the generator. Next, material selection is carried out by considering strength, availability, and cost, so that the components are able to withstand repeated footstep loads without significant deformation. The next stage is the calculation of pressure force, which serves to determine the average pressure force from human footsteps and how that force is transferred to the energy conversion mechanism. After that, the conversion is determined to ensure the efficiency of the mechanism in converting mechanical energy into electrical energy. The process then continues with mechanical load analysis to analyze the structure's resistance to dynamic loads using simulation software. The final stage is component manufacturing, where prototypes are fabricated according to design specifications so that they are ready to be tested for performance and reliability.

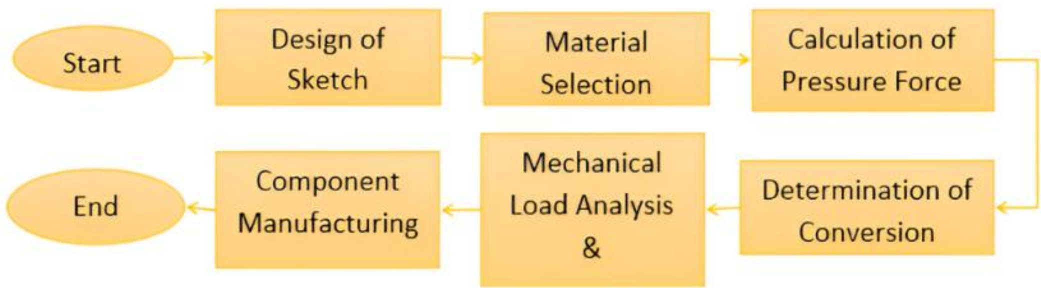


Figure 2. Block Diagram of Research Methodology for Mechanical Footstep Power Generator

2.3. Prototype Fabrication

The fabrication of the Mechanical Footstep Power Generator was carried out after the design and structural simulation met safety standards with a safety factor of less than 2 based on Fusion 360 analysis. This process was carried out in a technical workshop using basic equipment such as metal cutting machines, electric welding machines, hand drills, and grinders to shape and assemble the main components. The materials used consist of iron plates for the support frame, iron shafts for the transmission system, and rack and pinion that function to convert the energy of the footstep into the rotation of the generator. The fabrication stages include cutting materials, welding frames, drilling connection holes, installing transmission mechanisms, and integrating a DC generator as a converter of mechanical energy into electrical energy. After the assembly process is complete, the prototype is initially tested to ensure that each component functions as designed and is ready for the performance evaluation stage.

2.4. Fundamental Equations for Design Evaluation

Calculation analysis is very important in the development process of the Mechanical Footstep Power Generator because it determines the feasibility and performance of the prototype. The evaluation is carried out using basic mechanical and electromagnetic equations, which include the compressive force due to the footstep, voltage distribution in the material, torsional moment in the transmission system, and the mechanical energy produced. In addition, the electrical power converted through the generator is analyzed to determine the potential energy output at each step. The safety factor parameter is also taken into account to ensure that the structure is able to withstand the load safely with a value greater than the actual working voltage. All equations used in this evaluation are presented in Table 2 as the basis for design analysis, simulation, and prototype fabrication.

Tabel 2. Fundamental Mechanical and Electrical Equations of the Prototype

References	Parameters	Equations	Number	Description
(Wang, Lu, and Dong 2025; Anggara 2020)	*Safety Factor* (n)	$n = \frac{\sigma_{ult}}{\sigma_{working}}$	(1)	n = *safety factor* σ_{ult}=ultimate tensile strength of the material (MPa) $\sigma_{working}$ = working voltage (MPa)
(Lopes Coelho 2025)	Compressive Force (F)	$F = m.g$	(2)	F = compressive force (N) m = mass of the user (kg) g = gravitational acceleration (9,81 m/s²)
(Kou et al. 2020; Radhakrishnan et al. 2023)	Normal Voltage (σ)	$\sigma = \frac{F}{A}$	(3)	σ = Normal Voltage (N/m² atau MPa) F = force (N) A= cross-sectional area (m²)
(Türkay and Altun 2023; Jurmu et al. 2025)	Torque (T)	$T = F.r$	(4)	T = torque (N·m) F = force (N) r = radius of gear teeth or pinion (m)
(Lamin et al. 2021)	Mechanical Energy (E)	$E = F.d$	(5)	E = mechanical energy (J) F = force (N) d = vertical displacement distance of the step (m)
(Azahari et al. 2023)	Electrical Power (P)	$P = \frac{E}{t}$	(6)	P = electrical power (W) E = mechanical energy (J) t= contact time of the step (s)
(Sebestyén 2021; Mara et al. 2025)	Generator Voltage (V)	$V = N.\frac{d\phi}{dt}$	(7)	V = induced voltage (V) N= number of coil turns $\frac{d\phi}{dt}$ = rate of change of magnetic flux (Weber/s)

2.5. Prototype Testing and Data Collection Procedure

Performance testing was conducted by applying a repeated footstep load of 20 steps to measure the variation in voltage, current, and power generated. Each test was repeated three times to ensure data consistency, and the average value of the repetitions was used in the analysis. In addition, measurement errors were minimized by calibrating the equipment before each test and maintaining constant environmental conditions during the data collection process. Voltage and current measurements were taken using a digital multimeter with an accuracy of ±0.01 V and ±0.001 A. The overall measurement uncertainty was estimated to be within ±2% of the measured value. The measurement results were then used as a basis for evaluating system performance and ensuring the reliability of the prototype under the given load.

3. Results

3.1. Design Dimensions

The Mechanical Step Electric Generator design consists of several main components, namely a base plate as the system mount, compression springs, an iron shaft, gears and racks as mechanical transmissions, and a generator as a converter of mechanical energy into electrical energy. Based on the final visualization in the form of a 3D technical drawing, the overall dimensions of the prototype are 200 mm × 200 mm × 112 mm in Figure 3(a), with a maximum spring height of 112 mm and a fastener hole diameter of Ø10 mm as shown in Figure 3(b). The main components, such as the frame and base, use iron plate material to withstand the repeated compressive loads from the footrest, while the shaft uses iron to ensure strength in transmitting force from the rack gear to the pinion gear, as shown in Figure 3(c). The selection of dimensions and materials is based on structural strength requirements, resistance to dynamic loads, and ease of fabrication and assembly.

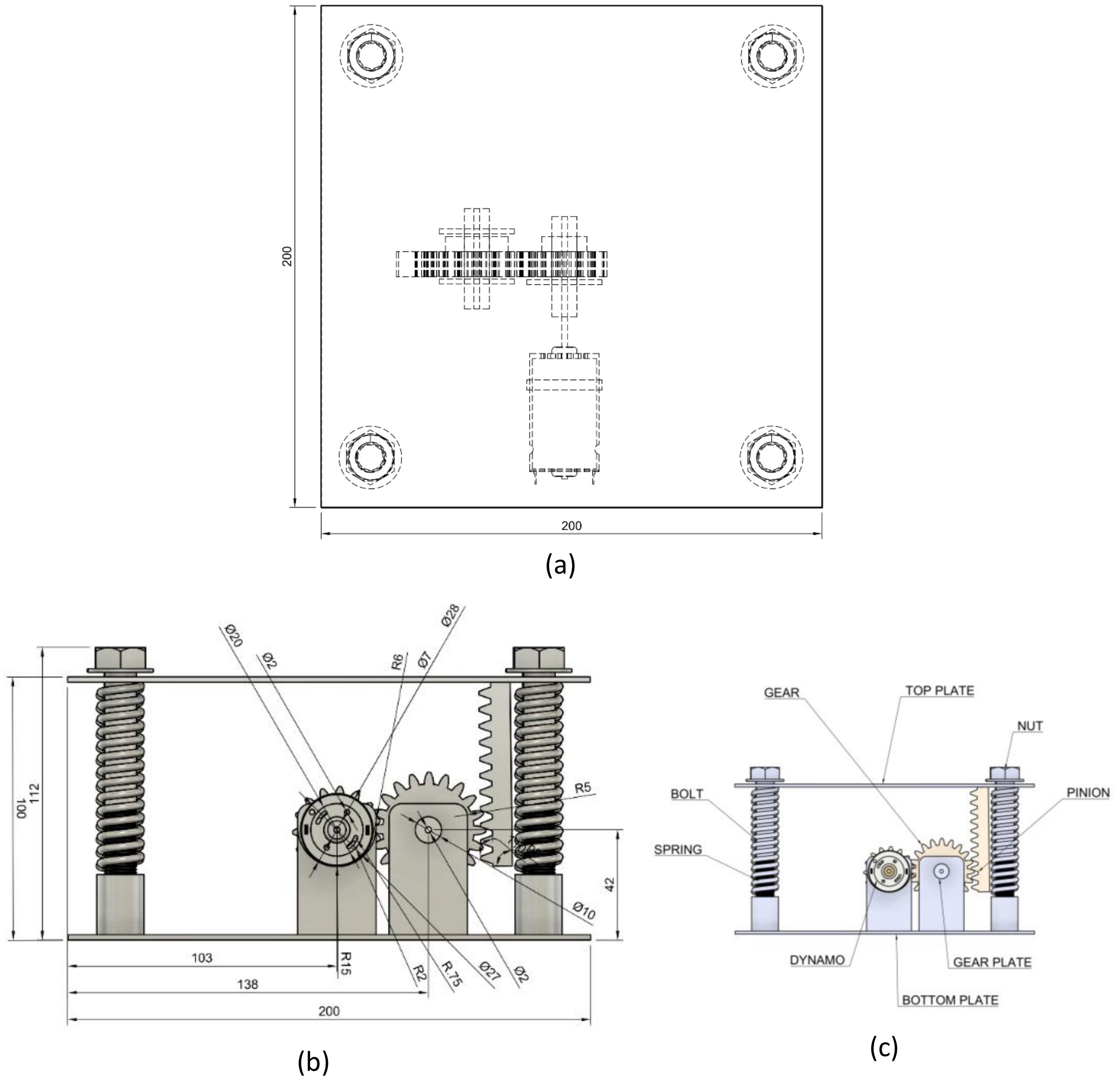


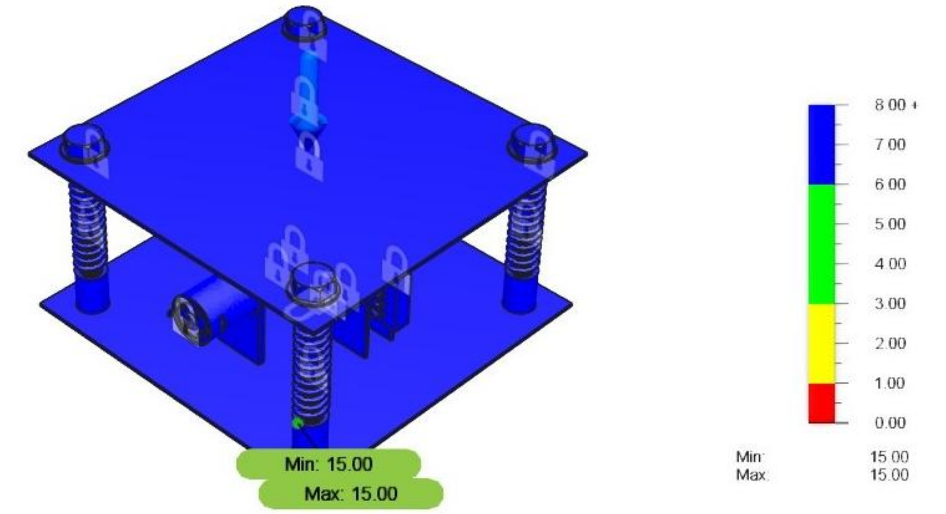
Figure 3. Geometric Representation: (a) Top View, (b) Side View, (c) Component Geometry and Visualization

3.2. DC Motor Selection

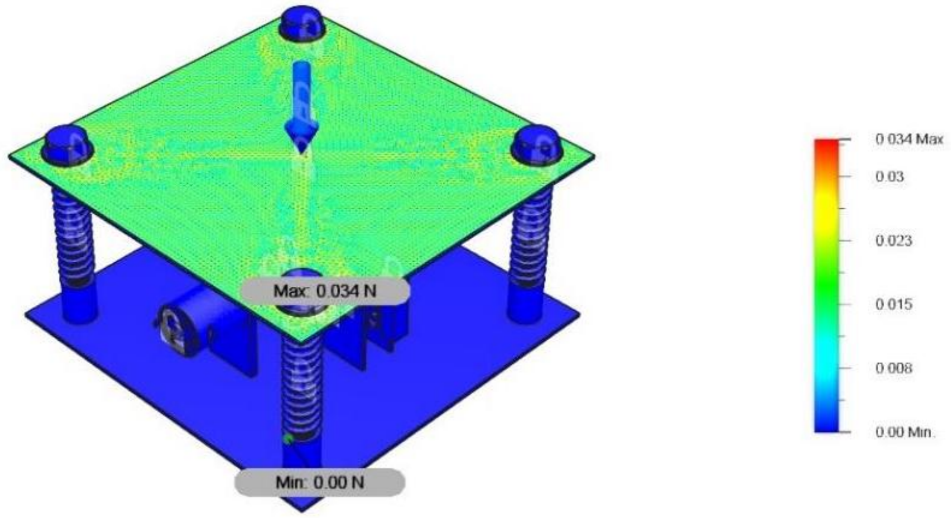
The selection of a DC motor for the Mechanical Footstep Power Generator system is based on the voltage and current requirements that are in line with the mechanical design and the desired electrical energy output. In this study, a 12 V DC motor was used because it has specifications that are suitable for the energy source resulting from the conversion of foot pressure through a rack and pinion mechanism and gears. The 12 V DC motor was chosen because it is easily available, economical, and capable of working well in a prototype scale system. In addition, this type of motor has a fairly high efficiency in converting mechanical energy into electrical energy and is relatively stable at low to medium loads. The use of a 12 V DC motor also allows integration with energy storage components such as batteries or supercapacitors, so that the energy generated can be utilized more optimally for small applications such as LED lights and low-power electronic devices.

3.3. Static Simulation Results

Static simulation analysis on a mechanical footstep power generator was performed using Fusion 360. Four frame support points were given fixed constraints, while compressive force was applied to the upper plate to represent foot steps. The main material is iron plate with a Young's modulus of 210 GPa and a yield strength of 250 MPa. The simulation results show a maximum reaction force value of 0.034 kN, which indicates that the structural reaction force is still within safe limits. In addition, the safety factor reaches 15, so that the prototype has a high level of rigidity and load resistance. At a load of 400 N (≈40 kg), the reaction force value increased but remained safe, with no significant decrease in the safety factor. This proves that the design is capable of withstanding footfalls heavier than the average human load. The visualization of the results can be seen in Figures 4(a) and 4(b).



(a)



(b)

Figure 4. Simulation Results of Mechanical Footstep Power Generator: (a) Safety Factor Distribution and (b) Reaction Force Distribution

However, the simulation results differ from actual testing because in the simulation, the connection is considered perfect without energy loss, whereas in actual conditions there is friction between the rack and pinion that reduces the effective force to the generator. This is in line with the findings of (Li et al. 2023), who reported that fabrication errors and component misalignment in journal bearings can increase frictional losses and reduce system performance. In addition, (Ma et al. 2020) also showed that small deviations in the shaft axis can cause an imbalance in load distribution, thereby reducing mechanical efficiency. Meanwhile, research by (Shin and Palazzolo 2021) found that misalignment in rotating systems can trigger excessive dynamic loading and thermal instability. Therefore, the differences between simulation results and actual testing are mainly due to friction, fabrication tolerances, and dynamic load conditions, while the simulation results remain valid as a preliminary design reference.

3.4. Mechanical Footstep Power Generator Fabrication Process

The fabrication process of the Mechanical Footstep Power Generator is carried out by combining manufacturing activities in a technical workshop and utilizing standard components available on the market. The main components that undergo the fabrication stage are the Top Plate, Bottom Plate, and Gear Plate. These three components require tapping, drilling, milling, grinding, shaping, and chamfering processes to ensure that the dimensions are in accordance with the design and that structural strength is maintained. This process is also important to ensure good integration with the rack and pinion mechanism and generator. Meanwhile, components such as gears, pinions, springs, dynamos, long bolts, and nuts are not produced independently, but are obtained from commercial products (purchased) to be more efficient in terms of cost and processing time. In summary, the list of components and the manufacturing processes applied can be seen in Table 3, which shows a clear difference between fabricated components and standard purchased components. This strategy balances manufacturing precision with assembly efficiency, so that prototypes can be produced with good quality but remain economical.

Table 3. List of components and manufacturing processes for Mechanical Footstep Power Generator

No	Part	Tapping	Counterboring	Drilling	Milling	Grinding	Shaping	Fillet	Chamfer	Other
1	Top Plate	M12	N	40	Y	Y	Y	Y	N	-
2	Bottom Plate	M12	N	40	Y	Y	Y	Y	N	-
3	Gear Plate	M8	N	25	Y	Y	N	N	Y	-
4	Gear	-	-	-	Y	Y	N	N	Y	Purchased*
5	Pinion	-	-	-	Y	Y	N	N	Y	Purchased*
6	Spring	-	-	-	-	-	-	-	-	Purchased
7	Dynamo (DC)	-	-	-	-	-	-	-	-	Purchased
8	Long Bolt M12	-	-	-	-	-	-	-	-	Purchased
9	Nut	-	-	-	-	-	-	-	-	Purchased

The next analysis focuses on the application of Design for Assembly (DFA) presented in Table 4. This evaluation aims to assess the level of complexity, functionality, and potential errors that may occur in the assembly process. The results in Table 4 show that the Top Plate, Bottom Plate, and Gear Plate components have a medium level of complexity because they require precision in alignment during assembly. Conversely, standard components such as gears, pinions, springs, long bolts, and nuts are categorized as having low complexity, as they only require a simple assembly process without additional modifications. The spring component is marked as flexible, so care must be taken to prevent it from slipping out of position, while the dynamo is classified in the high-cost category due to its crucial role in energy conversion. In general, the results of the analysis in Table 4 show that the system can be assembled with a moderate level of difficulty, and the application of appropriate error proofing measures can help reduce the risk of errors. Thus, the resulting prototype is not only effective in terms of fabrication but also efficient in assembly.

Table 4. Analysis of DFA Mechanical Footstep Power Generator

	Part	DFA Compexity		Functional Analysis		Error Proofing		Handling		Insertion								
Part Number	**Part Name**	**Number of Parts (Np)**	**Number of Interfaes (NI)**	**Part can be Standarized**	**Cost (Low/Medium/High**	**Assemble part wrong way around**	**Tangle/Nest/Stick Together**	**Flexible/Fragile/Sharp/Slipery**	**Pliers/Tweezers/Magnifying Glass**	**Difficult to align/Locate**	**Holding down required**	**Resistance to Insertion**	**Obstructed access/visibility**	**Re-oriented Work Piece**	**Screw/Drill/Twist/Rivet/Bend/Crimp**	**Weld/Solder/Glue**	**Paint/Lube/Heat/Apply liquid or gas**	**Test/Measure/Adjust**
1	Top Plate	1	4	N	M	Y	N	N	N	Y	Y	Y	Y	Y	Y	N	N	Y
2	Bottom Plate	1	4	N	M	Y	N	N	N	Y	Y	Y	Y	Y	Y	N	N	Y
3	Gear Plate	1	3	N	M	Y	N	N	N	Y	Y	Y	Y	Y	Y	N	N	Y
4	Gear	1	2	Y	L	N	N	N	N	N	N	Y	N	N	Y	N	N	N
5	Pinion	1	2	Y	L	N	N	N	N	N	N	Y	N	N	Y	N	N	N
6	Spring	4	4	Y	L	N	N	Y (flexible)	N	Y	Y	N	N	N	N	N	N	N
7	Dynamo (DC)	1	2	Y	H	N	N	N	N	N	N	Y	Y	N	Y	N	N	Y
8	Long Bolt M12	4	4	Y	L	N	N	N	N	N	N	Y	N	N	Y	N	N	N
9	Nut	4	4	Y	L	N	N	N	N	N	N	Y	N	N	Y	N	N	N

3.5. Electrical Output

The results of testing the electrical output of the Mechanical Footstep Power Generator are shown in Figure 7, which represents the relationship between the number of steps and the voltage, current, and power generated. Based on the graph, it can be seen that each additional step significantly increases the voltage. In the first step, the voltage generated was 2.96 V with a current of 0.0025 A and a power of 0.0074 W. As the number of steps increases, the voltage value increases to 5.71 V at the 20th step, with a current of 0.0091 A and power reaching 0.051961 W. This increase shows that the system is able to accumulate energy from the footsteps consistently, where the relationship between the number of steps and electrical output is linear with a positive trend. This indicates that the more steps given to the system, the greater the electrical energy that can be converted. Thus, this prototype has proven to be functional in generating electrical energy from simple mechanical activity, although it is still limited to a small scale for low-power applications.

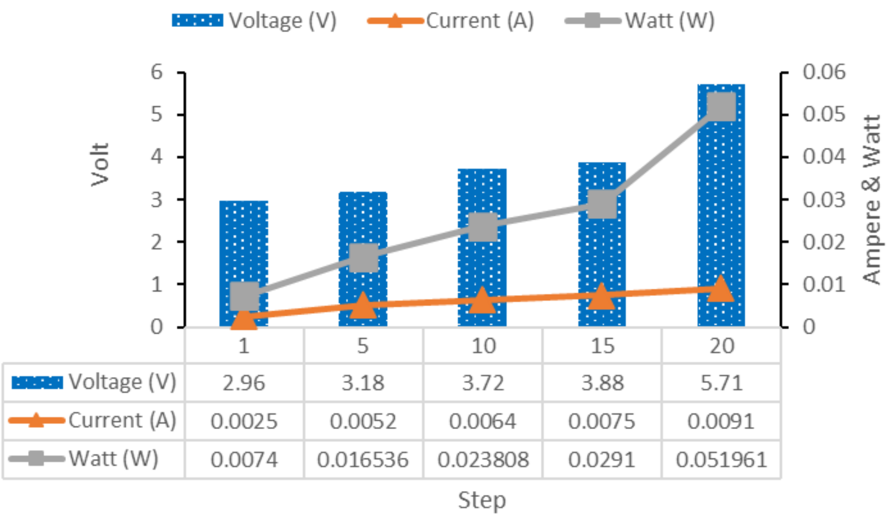


Figure 5. Energi Output of Mechanical footstep Power Generator

4. Conclusion

The Mechanical Footstep Power Generation prototype successfully converts mechanical energy from footsteps into electrical energy through a rack-and-pinion mechanism and a dynamo (DC), with a design involving nine main components and manufacturing processes such as drilling, machining, grinding, and angle cutting. The Design for Assembly (DFA) evaluation results indicate moderate complexity with potential assembly errors that can be minimized through clear instructions. Although testing shows an increase in electrical output as the number of steps increases, the overall system efficiency is still limited to around 12–15%, influenced by friction, shaft misalignment, fabrication tolerances, and dynamic load variations due to human footsteps. The differences between the simulation results and actual testing are mainly due to these factors, although the simulation remains valid as an initial design reference. This analysis emphasizes the importance of geometric and material optimization to reduce friction losses and mechanical misalignment. In the future, system efficiency can be improved through friction reduction, rack-pinion geometry optimization, and the integration of energy storage mechanisms to expand the capacity and application of the electricity generated.

Acknowledgments

This research was conducted as part of the Project 2 course in the Power Plant Engineering Technology Study Program, Faculty of Vocational Studies, State University of Malang, Indonesia. The authors would like to sincerely thank Mr. Royb Fatkhur Rizal, M.Eng., as the course supervisor, for his valuable guidance and support throughout the completion of this project. Appreciation is also extended to the academic staff and laboratory facilities that provided assistance during the design, simulation, and fabrication stages of this study.

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