Generating Electricity with Footsteps: Analysis of the Proposed Mechanism

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***Abstract*—This document examines the plausibility & efficiency of generating power via footsteps, which could be used on pavements to generate electricity used for various purposes, depending on the user's preferences.**

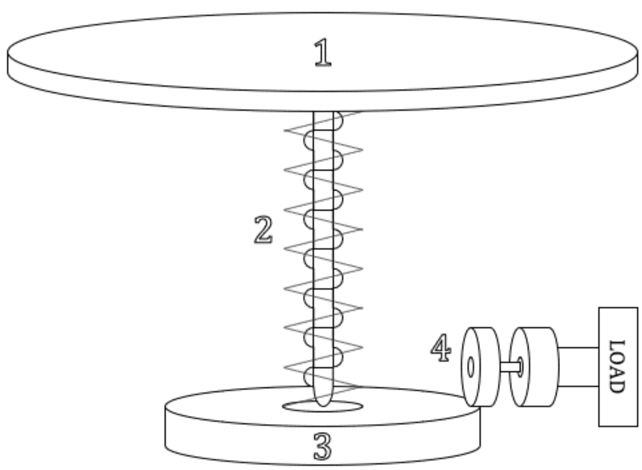
I. Mechanism Proposal

The proposed mechanism to generate electricity is comprised of multiple stages, and such operate in unison to provide the output voltage at the output stage.

A. Components Analysis

The mechanism itself involves a button/plate that, when pressed, would push a spiral down an entry point, compressing a spring. When such button/plate (thus, the spring) is released, the spiral is released to its initial position, in turn spinning the flywheel disc/gear that such spiral is fixed to, causing such to move in a rotational manner.

Fig. 1. Diagram of proposed mechanism to generate electricity from footsteps



Such mechanism is shown in Fig. 1 and is comprised of the following components (refer to labels on Fig. 1):

1) Plate which individual steps onto - such is supported by a compression spring
2) Spiral rod which inserts into Component 3's axle - such is attached to Component 1
3) Flywheel which Component 2 inserts into via an opening fitting the size of the spiral's rectangular body
4) Motor with additional gears connected to Component 3, where such is repurposed as a generator; such gears may include transmission stages

B. Operations of Mechanism

The mechanism is intended to operate per the following procedures (refer to labels on Fig. 1):

1) One steps onto Component 1, pushing Component 2 downwards & compressing the support spring
2) Component 2 moving downwards passes through slot in Component 3
3) One steps away from Component 1, resulting in the spring being released; such results in Component 2 moving upwards to its original position
4) Component 2 moving upwards now results in Component 3 rotating, causing Component 4's axle to also be rotated (due to the gear connection)
5) The rotation of Component 4's axle results in EMF being generated at its output

One can surmise that power from **linear motion** (due to Steps 1 and 2) is converted to that of **rotary motion** (given by Step 4), and later converted via **induction** (per Step 5).

II. Theory

This section concerns the generator's output characteristics & how such is linked to the mechanical stage prior. Such refers to [1] in regards to theory & formula behind such operations.

A. Assumptions of System

Given reality, that the system will encounter losses, and thus will not be 100% efficient. This therefore warrants for a number of assumptions to be made, to allow easier calculations & analyses of the system.

- An individual steps onto the slab & pushes the spiral to its maximum length
- There is no friction within the spiral - this results in the flywheel rotation a full revolution per one successful spiral turn
- Thermal losses (due to friction or thermal dissipation by the components) are neglegible
- The material themselves do not wear down or permanenently change form, thus allowing for sustained usage
- The tangential force on the flywheel is fully transferred to the motor/generator

- The flywheel and its opening component is regarded as a singular entity

B. Known Quantities

The following electrical values are either known or determined by the chosen equipment.

- The **electromagnetic constant**, **reluctance** and **voltage rating** of the motor/generator
- Desired voltage at load (i.e. 5V for a rechargeable battery)

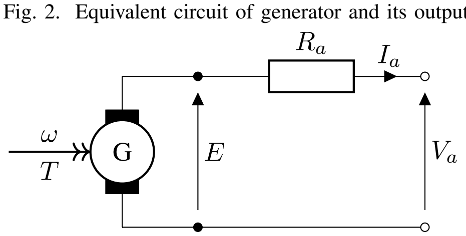
Similarly, on the mechanical domain one understands that the number of **spiral turns** is controlled by the spiral rod, and thus is a known value.

C. Generator Output Characteristics

The generator's output mechanism can be modelled as an equivalent circuit per Fig. II-C, where the following terms are defined:

- ω/T: Angular speed & torque of generator's input axle, dictated by its transmission gear & stages
- E: Output EMF of generator
- R_a: Generator reluctance
- I_a/V_a: Current & voltage at load output of generator

Fig. 2. Equivalent circuit of generator and its output



Such is governed by the equations given by (1), where k_e is the **electromagnetic constant** of the motor/generator.

$$T = k_e I_a \tag{1a}$$
$$E = k_e \omega \tag{1b}$$

Given Fig. II-C one can surmise the following information given by (1).

$$\begin{aligned} V_a &= E - I_a R_a \\ &= k_e\omega - \left(\frac{T}{k_e}\right) R_a \end{aligned} \tag{2}$$

where ω and T are determined by the prior stage, specifically the mechanical input stage.

D. Mechanical Input Characteristics

The following assumptions are to be made in regards to the mechanical stage, to alleviate calculations.

- The mass of the flywheel is represented as an arbitrary cylindrical mass of M_f kg with a radius of r_f metres
- The mass of the slab is, similarly, represented as a point mass of M_s kg
- The spring continuously obeys Hooke's Law

1) Force Exerted by Spring: Given the operations of the mechanism, compressing the spring to a certain distance x from its original position results in a force being exerted outwards (with intent of returning to its original shape), and thus obeys Hooke's Law per (3).

$$F = -kx \tag{3}$$

where x is the total distance compressed by the spring.

2) Tangential Force of Flywheel: As the spiral rod passes through the opening gap inside the flywheel, force is exerted by the spiral rod incident to the opening's sides (assumed here to be point incidents). It can be assumed that, during upward motion, the flywheel and the spiral port moves as a single object, and thus is abstracted as a single entity in the flywheel itself.

The expression for tangential force on the flywheel is given per (4), where

$$F = T\omega \equiv \frac{T\theta}{t} \tag{4}$$

where F is (assumedly point) tangential force exerted onto the flywheel, and ω is the angular velocity of the flywheel. In addition, θ is the total angle which flywheel travels (in radians), and t is the time at which the spring reverts to its original length, and is variable by the person stepping onto the slab.

It is to be noted that θ is given to be $2\pi Q$ per q spiral turns.

3) Equating: Provided that (3) and (4) equate, one could obtain the expression for the raw torque obtained at the flywheel's edge, per (5).

$$T = \frac{-tkx}{2\pi Q} \tag{5}$$

However, the motor itself is to be connected via a buffer gear, which would allow one to vary the torque and angular velocity of the motor.

E. Mechanical Output Characteristics

Since connecting the flywheel and the motor together results in the same tangential force, one could equate F and obtain an expression in terms of torque & angular velocity of the motor, where such are T_m and ω_m, respectively.

$$F = T_m \omega_m$$

Given that the flywheel's attributed are controlled variables, one could only change the motor's gear and, provided the attributes of the flywheel's gear, could determine the ratio of turns between such gear connections.

$$\Gamma = \frac{N_{motor}}{N_{flywheel}}$$

And thus, one could then obtain the expression for the motor's torque & angular velocity in terms of the flywheel's.

$$F = T_{motor}\omega_{motor} = (T\Gamma)\left(\frac{\omega}{\Gamma}\right) \tag{6}$$

Per (6) one could observe that a decrease in the number of gear 'teeth' on the motor's, such reduces the coefficient, and thus reduces the motor's torque while increasing its angular velocity. Vice versa applies.

Sufficient information has been provided to return to (1b); now that one has obtained the motor's characteristics, one could then equate such to those that one has explored prior as follows.

$$
\begin{aligned}
V_a &= k_e(\omega_f \Gamma) - \left(\frac{T_f \Gamma}{k_e}\right) R_a \\
&= k_e \left(\frac{2\pi Q}{t}\Gamma\right) - \left(\frac{1}{k_e}\right)\left(\frac{-tkx}{2\pi Q}\Gamma\right) R_a
\end{aligned}
$$

Given this, the only independent variable (provided components are static, thus its values fixed) to determine the output voltage of the mechanism is the time duration taken to reload the spring mechanism back to its original position.

REFERENCES

[1] N. Simpson, *Electro-Mechanical Energy Conversion*. Bristol, United Kingdom: UNIVERSITY OF BRISTOL Department of Electrical and Electronic Engineering, 2017.