Energy harvesting from seismic waves for electricity production

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Abstract. In this paper, the generation of clean energy using the waves of telluric movements is studied. The characteristics of earthquakes are described, including the types of waves and the power of these waves. Following, the equations that describe how the kinetic energy of the earthquakes transforms into potential energy, and a mechanism that takes advantage of this effect to produce energy is described. The physical properties for this mechanism are determined, and an approximation of the electricity that this mechanism could produce is computed. Currently, after a seism, the affected areas remain without electricity for several days. This energy source could partially solve this issue, in the short and long term.

1 Introduction

The nature produces energy, and human beings have always wanted to control this source for their own benefit. Over time, different methods for achieving this objective have been generated. This document explores a different source of electricity, due to the little explored and great potential energy that could be obtained from earthquakes; capturing it and transforming it into electricity, a new type of generation would be achieved.

The use of seismic mechanical waves as source of energy is a very little-known topic, and the literature related to the topic is scarce. Usual databases show no results when the topic is searched, and only few undergraduate papers about this concept can be found. Amongst these, in 2016 the University of Leicester [1] in England highlighted the proposal of a group of students which consists in the use of a type of generator in the basement of buildings to store its energy and then use it once the seismic event is over. They proposed that, if the foundations of a certain building in San Francisco, California were built using generator blocks, a 7.2 magnitude earthquake would be able to generate approximately 770 W.

Prior to this date, the Scientific American [2] magazine published an article debating whether the motion of earthquakes could be used to generate electricity. This article emphasizes that it is not likely since it would be a great challenge in terms of logistics to carry it out. Besides drawing this conclusion, no attempt to define a technical method for capturing this energy is made.

The lack of studies on this topic is partly due to the logistical complexity of bringing it to reality. According to Kasahara [3] 75.4% of the seismic energy released by the Pacific Ring of Fire corresponds to a superficial release, and the studies that exist are only a reference of how an earthquake of a given magnitude compares to the

atomic bombs of Hiroshima and Nagasaki. There is currently no hypothesis on how to harness this power.

The main objective of the Paris Agreement [5], signed in 2015 by the United Nations Framework Convention on Climate Change, is to reinforce responses of all countries in the face of the increase in the planet's temperature, and another proposal mentioned is to increase the capacity of countries to face the effects of climate change. To achieve this feat, it is necessary to propose a new technological framework that is accessible to developing territories.

In Spain, it is highlighted the great need for exploration in new energy sources due to the depletion of oil reserves worldwide [6]. And not only oil, also water, wood and other natural resources are already exhausted, as the population becomes indebted to the planet due to the belief in infinite sources of resources.

Taking advantage of seismic waves as a way to generate electricity could be a solution for the future. These mechanic waves occur around the world, this aspect brings the possibility to transport and produce electricity in countries that have no access to common ways of energy generation but have seismic potential to generate their own energy.

This paper proposes a mechanism based on the Faraday Law for generating electricity by converting the kinetic energy of earthquakes into electrical energy. In the first section, the dynamic properties of seisms are reviewed; next, the mechanical equations for the design of the generation mechanism are described. Later, the physical dimensions and characteristics of a prototype are calculated, and finally the electricity that could be generated by this prototype is computed. The numerical simulations indicate that this prototype could generate 87,5 MW of electricity according to the frequency of seisms in Costa Rica. This value is expected to always be different to 0 MW but could increase or decrease depending on the annual seismic activity of the country in a period of one year.

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2 Earthquake features

An earthquake is a powerful movement of the terrestrial crust, occasioned by a big energy liberation. This natural phenomenon can be generated by subduction of the tectonic plates, collisions between them, or volcanic activity. These plates have an approximate thickness of 70 kilometres, and they are found throughout the earth's surface [7].

2.1 Types of seismic waves

In the earth's crust, mechanical waves are generated, which are called seismic waves, this is produced by a great release of energy, from a point called the hypocentre [8].

These waves have velocity depending on the type:

- P waves have a speed of 7 km/s,
- S waves have a speed between 4 and 6 km/s,
- L waves have a speed of 2 km/s to 3 km/s,
- R waves speed is equivalent to 90% of S waves.

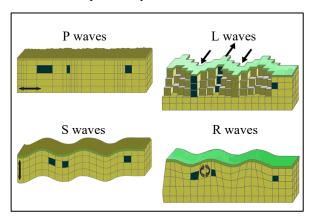


Fig. 1. Seismic waves.

These will move with different physical variations depending on the environment, in the case of this study it was based on the type of rock that is abundant in Costa Rica such as limestone and basalt. According to the National University of Colombia [9], the speeds of the primary and secondary waves are shown in Table 1.

Table 1. Wave speed in different types of rock [9].

Type of rock	Primary wave speed (m/s)	Secondary wave speed (m/s)	
Basalt	6400	3200	
Limestone	2400	1350	

In this study, reference was made to secondary waves, because according to Rojas [8], these represent 90% of surface waves.

2.2 Calculation of the seismic forces

The magnitude of earthquakes is represented by the unit erg, which can be transformed into the unit of joules. This indicates the energy to carry out work over a distance, which leads to the analysis of how much force it generates based on the hypo central distance, according to its magnitude. By means of Gutenberg's equation [4],

$$E_{\rm s} = 10^{11.8 + 1.5 \times M} \tag{1}$$

the energy dissipated E_s in the unit used in seismology the erg is obtained, where M represents the magnitude of the event, and the constants of 11.8 together with 1.5 are predisposed by the creators of the formula Beno Gutenberg and Francis Richter in 1956.

2.3 Arrival power

Because Costa Rica has, in the region of Guanacaste, the type of stone called limestone, and the presence of rocks of volcanic origin, such as basalt, in seismic waves, specifically secondary ones, which have a large percentage from the surface ones, their speeds are different, due to the composition of the environment in which they move. According to the National University of Colombia [9], these have the values shown in Table 1, which will position the mechanism in an area with the same composition as where the earthquake originated, shown in Figure 2.

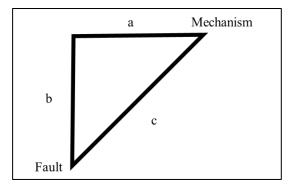


Fig. 2. Vectorial description of the incoming power.

By means of the average of forces according to the seismic magnitudes, f_{sis} , the force is obtained up to the necessary distance, in this case an average already established by the OVSICORI data [10]. This force multiplied by the speed of the mechanical waves, v_{os} , corresponding to the displacement medium, will indicate the initial power, P_i , in the ranges of magnitudes, shown by

$$P_i = f_{sis} \times v_{os} \tag{2}$$

The area that the earthquake will hit is equal to the area of the magnet or the A_m plate, because both have the same dimension in the case of magnitudes not considered as microseisms; therefore, to solve for the final or arrival power, P_f , it would be expressed as

$$P_f = \frac{P_i * A_m}{A_e} * \cos \alpha \tag{3}$$

Remembering Figure 2, this formula will be multiplied by the adjacent angle, up to a completely perpendicular position; Being in the second quadrant, the

only variable it will be the sign, which indicates the direction of the analysis. The initial power is calculated based on equation 2, together with the data in Table 1 of the theoretical framework, where it indicates the speed of the seismic waves in the rocks under study, such as limestone and basalt. In the case of so-called microseisms, the area that will receive the magnitude cannot be that of the magnets, it should have a diameter of 1.70 m. Due to the almost-zero movement that it will carry out, this must be a hypothetical value, because the mechanism does not have an external structure.

3 Mechanism design

Due to the mechanical behaviour of seismic waves, together with their physical magnitudes, based on the principle of linear electric generators, a prototype capable of producing electricity through the vibrations of seismic events is designed according to the magnitude of the event. Based on a mathematical model, the dimensions, and behaviours of the system in the event of an earthquake are demonstrated, and its application ranges according to the geology that makes up Costa Rica.

3.1 System motion

The operation of this mechanism is made up of a pair of springs located in parallel, shown in Figure 3. Seismic events have a very high frequency, and this will cause an oscillation of the mass, which in turn will generate eddy currents, known as eddy currents.

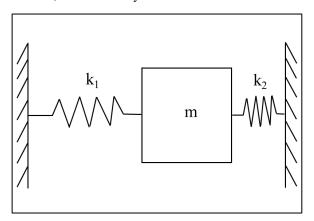


Fig. 3. Parallel arrangement of springs.

In this type of mechanism, the mass will not exert any force on the springs; on the contrary, it will be affected by the elastic forces applied by them.

3.2 System behaviour

To demonstrate the stretching and contraction of the spring system in parallel, with respect to the average arrival power in the ranges of magnitudes studied, the arrival seismic power is converted into work, W_{sis} , which would be the one performed by the earthquake in its displacement from the point of origin, in this case the tectonic fault until its arrival at the mechanism, and this is demonstrated by

$$W_{sis} = P_{ll} \times t \tag{4}$$

The variable P_{ll} is identified as the average of the arrival power, for time t. To find out this, equation 5 is applied first, which is the frequency H with which the earthquake travels, it will be the speed of the seismic wave in the middle, v_{os} , divided by the distance c to be used in this case it is used the distance obtained from equation 1 as in

$$H = \frac{v_{os}}{c} \tag{5}$$

This energy conversion would be from kinetic to potential energy. Because the system is at rest before an event, it will be affected by the work done by the earthquake, shown in equation 6, which in turn will displace the springs, causing them to stretch and compress

$$W_{sis} = W_{R1} + W_{R2} (6)$$

This equation is composed of the elastic potential energy U, which is a function of the elastic constant k multiplied by the final elongation X_f or the initial elongation X_o of the spring, and is represented by the expression

$$U = \frac{1}{2} \times k \times X^2 \tag{7}$$

The variable k is the elastic constant of the spring, X_f and X_o represent the positions of the spring, in this case final and initial, because the length of the spring used is the free length, and it will not be working in compression; therefore, its initial potential energy in both cases is expressed

$$U_0 = \frac{1}{2} \times k \times X_0^2 = 0 \tag{8}$$

The initial potential energy of both springs will have a value of 0 N, as they are in their initial length, and it is represented by

$$W_{sis} = \frac{1}{2} \times k_1 \times X_f^2 - \frac{1}{2} \times k_2 \times X_f^2$$
 (9)

Through a clearing of variables, a differential of the final positions of both springs is denoted, by means of the use of an equivalent elastic constant. This is represented by

$$W_{sis} = \frac{1}{2} \times k_e \times \Delta X_f^2 \tag{10}$$

3.3 Spring design

For microseisms, the k value must be very low due to sensitivity; in these it is taken considering the maximum elongation of the spring based on a load P. The elastic force used for the design of the springs used for microseisms is equivalent to the displacement to its minimum length, which will act as a load on spring 2 and on its namesake; this equates for spring 1 to 35 N, and spring 2 will support up to 27 N. Their forces are different, due to the elastic constant of each one. The characteristics of each one of the springs are shown in Table 2.

Table 2. Springs for microseisms.

Feature	Spring 1	Spring 2	
Material	Steel A227	Steel A227	
k (N/m)	291	334	
Free length (cm)	10.0	10.0	
Min. length (cm)	2.54	2.54	
Load (N)	35.0	27.0	
Coil calibre	16	17	
Hole Diam. (cm)	1.30	1.30	
Number of turns	9	8	
Total turns	11	10	
Exterior Diam. (cm)	1.40	1.40	

For earthquakes of a magnitude of 4.0 to 4.9 Mw, their springs will have higher elastic constants k, due to the force expelled by the event being higher. Their data is shown in Table 3.

 Table 3. Springs for earthquakes.

Feature	Spring 1	Spring 2
Material	Steel A227	Steel A227
k (N/m)	700	848
Free length (cm)	13.0	13.0
Min. length (cm)	2.54	2.54
Load (N)	45.0	40.0
Coil calibre	15	16
Hole Diam. (cm)	1.50	1.14
Number of turns	7	11
Total turns	otal turns 9	
Exterior Diam. (cm)	1.68	1.30

The displacement and compression of the springs, depending on the magnitude, is shown in Table 4.

Table 4. Displacement of the springs.

	Final position (cm)			
Magnitude	Limestone		Basalt	
	Spring 1	Spring 2	Spring 1	Spring 2
1.0 a 1.9	0.110	0.0900	0.110	0.0900
2.0 a 2.9	0.156	0.044	0.155	0.045
3.0 a 3.9	0.118	0.082	0.118	0.082
4.0 a 4.9	0.180	0.0800	0.180	0.0800

The mechanism was modelled in SolidWorks, and it is shown in Figure 4.

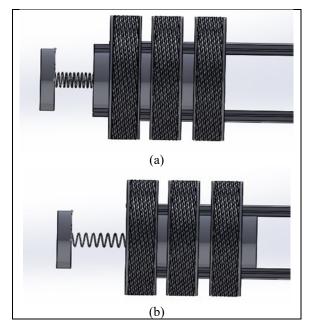


Fig. 4. Spring motion. (a) Compression, (b) elongation.

3.4 Plates, magnets, and screws

Neodymium magnets, grade N52, are used for this clean energy mechanism. These have the characteristic of being the most powerful magnets on the market, as they have the capacity to lift 10 kg, and their operating temperature is 80 °C, but in specific cases they can be manufactured to withstand between 100 and 120 °C. As this mechanism is based on the principle of Faraday's Law, a large source of magnetic field is necessary for the generation of an electromotive force. Magnets of this grade have a magnetic field of between 14200 and 14800 G [11], and the dimensions of the magnet are 100 mm in diameter and 20 mm thick.

These will be held by interspersed aluminium plates, they have the same diameter, but with a thickness of 40 mm. Aluminium was chosen, because the mechanism for microseisms is located under the surface and its temperature would not affect these plates, because it can withstand temperatures above 600 °C, and its density corresponds to 2700 kg/m³ [12]. Together, the 25 plates and 24 magnets will weigh 46 kg.

These aluminium plates are fastened to the slide, which is 1.50 meters long and 2.0 cm thick, by means of a screw, which is designed to SAE grade number 7 to support 4450 N; in this design it was assumed that it corresponds to 77.5 MPa, and the modulus of elasticity of the material chosen in this case, aluminium, corresponds to 207 MPa [13].

It should be noted that, for the chosen grade, its test resistance corresponds to 7.2 MPa and its head has a hexagonal shape; its torsion area has a value of 0.685 cm^2 and a standard pitch of 60° [13].

The maximum effort that the screw will support will be equivalent to 64 kPa, and its dimension is 3 cm in length.

The reason behind the use of aluminium is the lightweight of this metal and its low cost, as well as the possibility of recycling this component once its life cycle is over.

3.5 Coil

Its internal diameter is equivalent to 14 cm. Due to the presence of two sliders, one at the base and the other at the top inside the coil, the maximum width of the coil will be equivalent to that of the aluminium plates, so that the frequency of oscillation of the magnet when entering and leaving of this is elevated. Its inductance will have a value of 200 $\mu H_{\rm h}$, and the number of turns it has will be 2000. The magnetic field produced by the coil has a value equivalent to 0.030 Tesla.

The complete mechanism is shown in Figure 5.



Fig. 5. View of the full generator assembled.

4 Electricity generation

This mechanism will generate an electromotive force, for production in Watts, by

$$P = V \times I \tag{11}$$

The electrical power P would be equal to the product of the voltage, or in this case the electromotive force V produced by the magnetic change in time, based on the principle of Faraday's Law, multiplied by the current I of the coil wire according to its gauge, based on the AWG Table. This value is multiplied by the number of daily and annual earthquakes n to know the electrical production of the system, P_e , according to its register magnitude, which is represented in the form

$$P_e = P \times n \tag{12}$$

The generation through Faraday's Law in volts and watts is shown in Table 5.

Table 5. Electricity generation.

Magnitude	Limestone		Basalt	
	FEM I		FEM (V)	Power (W)
1 a 1.9	735	3822	735	3822
2 a 2.9	805	4186	801	4165
3 a 3.9	735	3822	735	3822
4 a 4.9	1470	7644	1470	7644

The annual production, according to the frequency of appearance of the magnitudes under study, for the year 2020, is shown in Table 6.

Table 6. Electricity generation in Costa Rica in 2020.

Magnitude	Number of seisms	Limestone		Basalt	
		Daily (kW)	Annual (MW)	Daily (kW)	Annual (MW)
1.0 to 1.9	5513	57.7	21.1	57.7	21.1
2.0 to 2.9	4446	51.0	18.60	50.7	18.5
3.0 to 3.9	852	8.92	3.26	8.92	3.26
4.0 to 4.9	114	2.39	0.871	2.39	0.871

If a summation of the generation is made between the two types of rock under study, Costa Rica in 2020 generated 87.5 MW of electricity, coming from seismic waves.

5 Conclusions

In this research, a calculation model for the generation of energy based on seismic waves is presented, and the design of a mechanism that allows the use of this energy to produce electrical energy.

The generation of electricity, through the so-called microseisms, is possible, due to the analysis of forces and speed variables according to the type of rock that predominates in Costa Rica, its generation will be 87.5 MW in a period of one year based on the principle of Faraday's Law which makes it a clean energy.

The size of the designed prototype makes it a transportable mechanism, with 1.70 meters long for the case of microseisms, and 1.76 meters, for seisms of 4.0 to 4.9. It can be located in remote areas or in countries than may not have the resources for a common type of electricity generation.

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