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Modelling Piezoelectric System for Powering the Fans in Railway Stations

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Abstract: Nowadays, piezoelectric becomes popular in entire world. Increasing of electricity consumption in Malaysia caused the people to pay more for the usage of electricity. Excessive energy from the environmenttakes over the usage of power supply to generate a voltage for any electrical appliances. The excessive energy from human walking through via vibration or human movement during entering the ticket entrance in railway stations can be used by scavenging this energy using piezoelectric generator. Piezoelectric generator is the conversion of mechanical energy into electrical energy. In this research, modelling the piezoelectric system for powering the fans in railway stations has been invented. The results obtain from this research is based on current and voltage output for the system. Thus, there have been analyse by varied the length and thickness of piezoelectric plate. Type of piezoelectric used in this research is piezocomposites. All the systems and the subsystems of this research simulate by using MATLAB/SIMULINK software and the outcome is to produce a voltage output more than $24V_{dc}$.

Key words: Pulse generator · Resonator · Input force · Piezoelectric generator · Rectifier circuit

INTRODUCTION

Piezoelectric effect was founded by the Curie Brother's in the late 19th century. They realized that the effect of piezoelectric can convert mechanical energy to electrical energy [1].

Piezoelectric device react as a sensor for the applied force to generate electricity. When the stress or pressure applied on the piezoelectric material produced an electrical output or potential differences.

However, the voltage produced by piezoelectric was AC thus rectifiers are needed to convert AC into DC output. The DC-filter rectifier used to reduce noise and distortion of waveform [2].

Piezoelectric principle has experienced a constant growth in many applications and appliances such as in aerospace, medical and nuclear instrumentation. Piezoelectric materials are properties that can create electric field when stress is applied to the material. There are some piezoelectric materials such as crystal and ceramics.

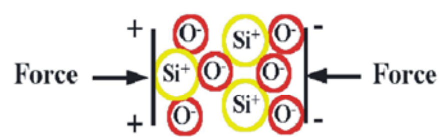

Fig. 1: Piezoelectricity of quartz [3]

MATLAB/SIMULINK has been used in this research to simulate all the systems and the subsystems of the research. The results expected to produce more than 24Vdc to powering the DC cooling fan in railway stations. Thus, there have been analyse by varied of length and the thickness of piezoelectric. Type of piezoelectric use in this project is type plate with piezocomposites material. Piezocomposites used are PZT5A1 Navy Type II from Morgan Technical Ceramics. Figure 1 shows internal of piezocomposites which is quartz (SiO_2) tetrahedron.

Figure 1 explain when force is applied to the tetrahedron which is one example of piezoelectric element a displacement of cation charge to towards to the centre of the anion charges occur [2]. Thus, the electricity produces from this pressure.

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MATERIALS AND METHODS

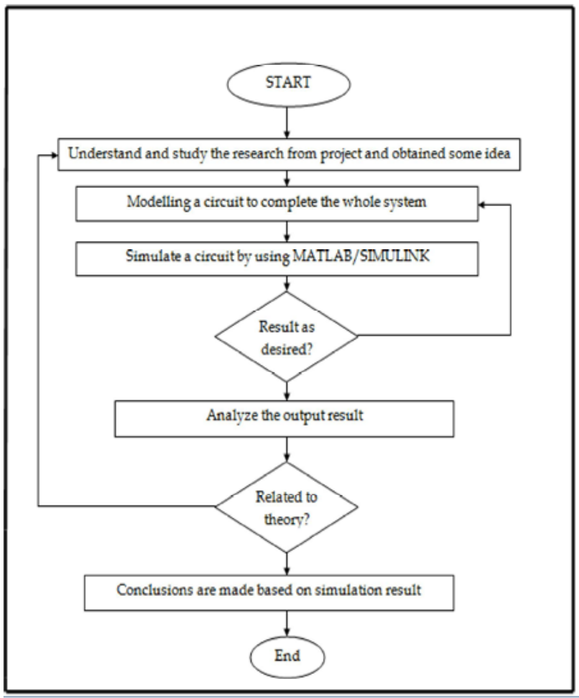

Fig. 2: Flowchart of research

Pulse Generator: A square wave pulse can be generated by pulse generator block at regular intervals. In order, to determine the shape of the output waveform, it can refer to the block's waveform parameter such as amplitude, pulse width, period and phase delay. Simulink software support pulse generator block outputs real signals of any numeric data. For this research, input of the system is based on the movement of people walking through the ticket entrance at LRT Bandar Tasik Selatan since electricity to generate. Thus, pulse generator has been chosen to measure the input for the system.

Pulse type set to "Timed based" and the time (t) set to "use simulation time". The amplitude in this source block set as gravity acceleration which is at 9.81m^2/s and the period (sec) set at 0.2905s considering the mean time frequently of people walking through the ticket entrance.

Input for the System: Input to this system is a dynamic movement from the people walking through the ticket entrance in railway stations. Pulse generator has been used to generate the force or vibration for this research.

The data have been taken from Bandar Tasik Selatan LRT station. The data are the numbers of people walking through the ticket entrance during the peak hours which is in the morning during people were going to work. The time has been taken during 8.00 am until 8.30 am in the morning. Table 1shows thesummarizesof data that have been taken at Bandar Tasik Selatan LRT Station.

Table 1: Number of people walking through ticket entrance

Time	No. of People	Mean Time (s)
0800-0805	90	0.30
0805-0810	88	0.293
0810-0815	92	0.3067
0815-0820	94	0.3133
0820-0825	87	0.29
0825-0830	72	0.24

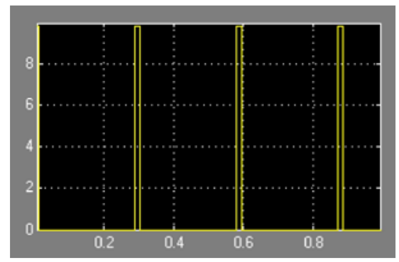

Fig. 3: Output from pulse generator

Pulse type set to "Timed based" and the time (t) set to "use simulation time". The amplitude in this source block is set as gravity acceleration which is at 9.81m^2/s and the period (Sec) set at 0.2905s considering the mean time frequently of people walking through the ticket entrance.

Figure 3 shows at 0s there is triggering pulse at an amplitude of 9.81m^2/s. This waveform sets to trigger every 0.2905s. Thus, its use as input for the system.

Resonator: Resonator for this research responds as spring to produce an oscillating waveform and continuous for piezoelectric generator. For this extend the wet mass of spring is kept constant and the mass of individuals walking through the ticket entrance, take as considerations since the mass of individuals walking through not vibrate along the spring.

For this research resonator reacts as mechanical part for the piezoelectric generator. Type of piezoelectric is type plate of the piezoelectric ceramic crystals which is Navy type II. The mechanical configuration of piezoelectric generator is shown in Figure 4 that consists of one or more piezoelectric material. The force is applied to the generator in parallel with the poled heading of the PZ material[8].The connected force is accepted to be quickly and consistently circulated all around the device, which permits the simple mass-spring systemof Figure 4 to be utilized.

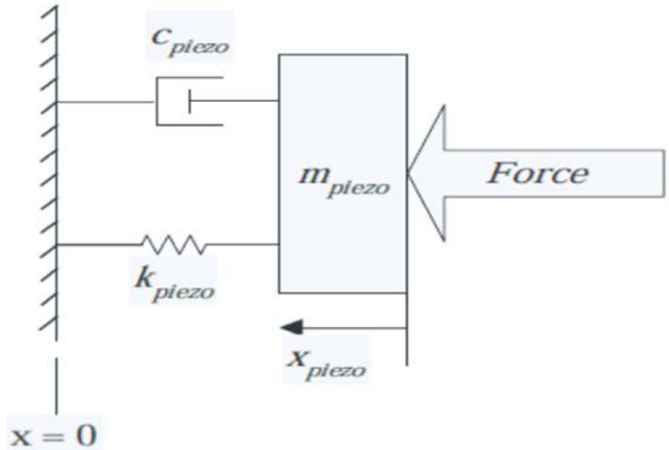

Fig. 4: Mass-spring model of piezoelectric generator [8]

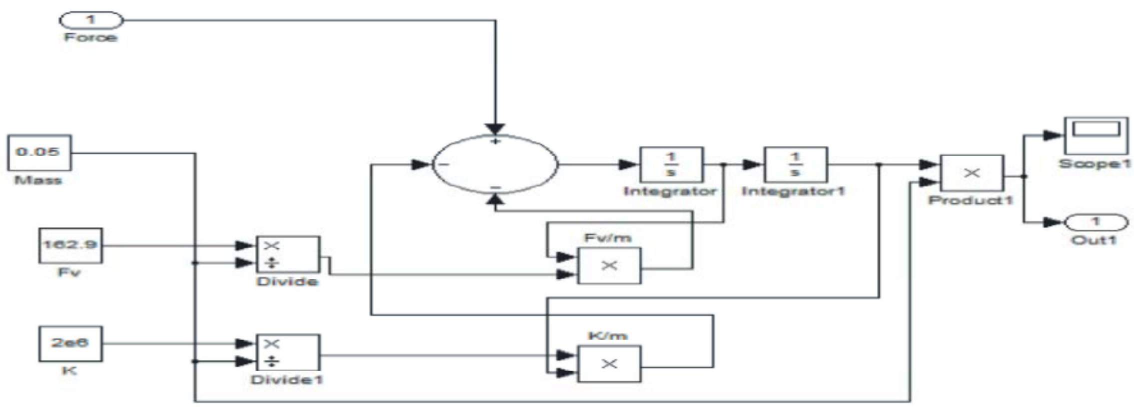

Fig. 5: Resonator model for the system

The resonator system in Figure 5 is described by thesecond order equation [6]:

(s^2+ ☻s +☻) X(s) = ☻ F(s) (1)

x□ +☻ x□ + ☻ x = ☻f (2)

x_1 = x□ (3)

x_2 = x□ (4)

x□$_1$ = x_2 (5)

x□$_2$ = - ☻ x_1- ☻ x_2 + ☻ f (6)

x = x_1 (7)

- ☻ (x□ + ☻ x□ - ☻ F(t)) = x(t) (8)

where M equal to mass, K as a spring constant, f_v as damping constant and f(t) as an input force.

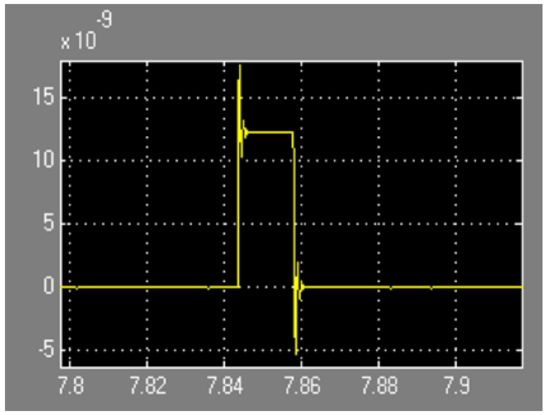

Fig. 6: Output from the resonator

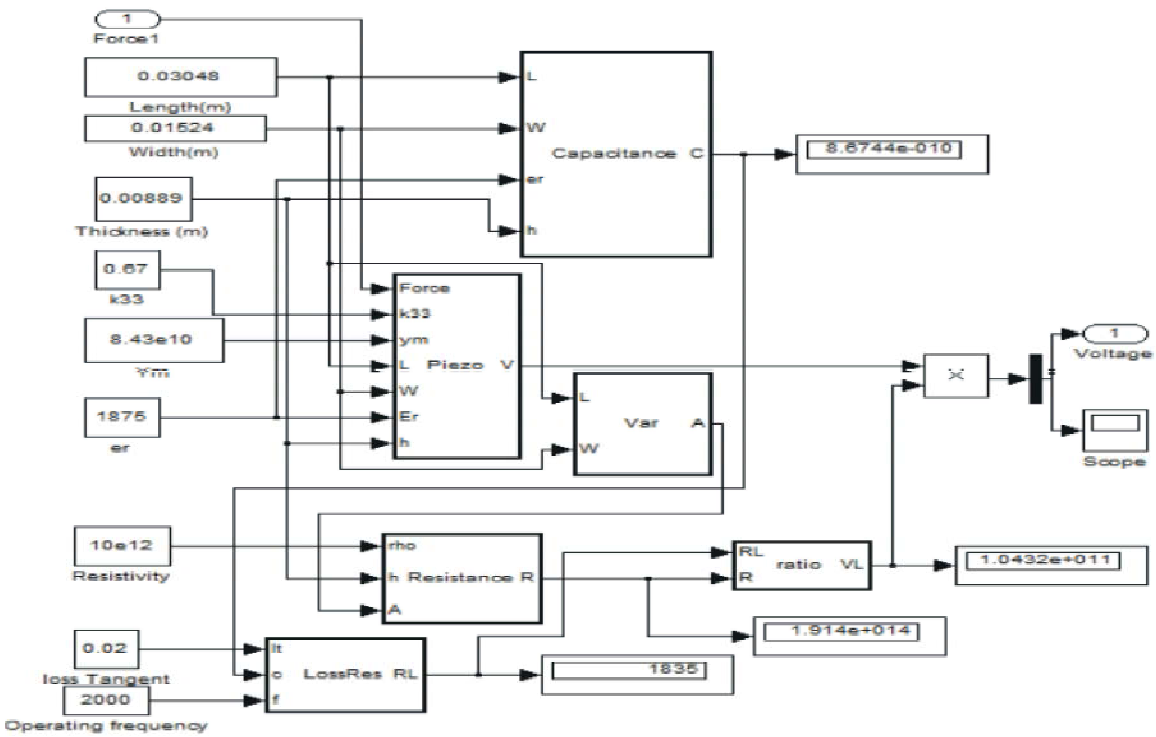

Fig. 7: Piezoelectric Generator

From Figure 6, shows that the input of the pulse generator has been oscillate due of resonator. Thus, the main function of the resonator is to improve the oscillating for the system.

Piezoelectric Generator: Matlab/Simulink use to simulate and analyse the thickness and length of piezoelectric plate for this research. Morgan Technical Ceramics (MTC) Navy type II characteristic has been used as the piezoelectric ceramic crystal while modelling the piezoelectric element using Matlab/Simulink.

The result obtained from this research must greater than $24V_{dc}$ for powering DC cooling fan in railway stations. Full bridge rectifier has been used to convert AC voltage produced by a piezoelectric element into DC voltage also used to filter all the distortion and the ripple.

There are two types of parameter of the piezoelectric elements to simulate and analyse which is length and thickness of piezoelectric plate. Thus, it can be used to produce an output voltage more than $24V_{dc}$ for powering the DC cooling fans in railway stations. Figure 7 shown piezoelectric elements of the system.

Table 2: Output produce at thickness 0.40”

Length (inch)	Length (m)	Width (inch)	Thickness (inch)	Thickness (m)	Voltage (V)	Current (A)	Power (W)
0.60	0.01524	0.60	0.40	0.0106	65.00	6.50	422.50
0.80	0.02032	0.60	0.40	0.0106	48.00	4.80	230.40
1.00	0.0254	0.60	0.40	0.0106	38.00	3.80	144.40
1.20	0.03048	0.60	0.40	0.0106	30.00	3.10	93.00
1.40	0.03556	0.60	0.40	0.0106	27.00	2.70	72.90

Table 3: Output produce at thickness 0.35”

Length (inch)	Length (m)	Width (inch)	Thickness (inch)	Thickness (m)	Voltage (V)	Current (A)	Power (W)
0.60	0.01524	0.60	0.35	0.00889	55.00	5.50	302.50
0.80	0.02032	0.60	0.35	0.00889	42.00	4.00	168.00
1.00	0.0254	0.60	0.35	0.00889	38.00	3.80	144.40
1.20	0.03048	0.60	0.35	0.00889	26.00	2.60	67.60
1.40	0.03556	0.60	0.35	0.00889	22.00	2.20	48.40

As a rule, loss resistance is relatively small and the leakage resistance is high, this value is depending on the thickness of the material. Loss resistance represents the losses from the current travelling across the surface of the material to the electrical leads. Leakage resistance represents the losses as current travel through the material [8].

There are lot of sizes and common shapes of piezoelectric. Since, this research based on electrical energy has been produced by people walking through the ticket entrance at railway stations, piezoelectric ceramic crystal type plate very suitable for this research. Table 4 shown common shape and size of piezoelectric type plate and the width of plate kept constant at 0.60” for this research.

Figure 8 shown example shape and sizes for the research. This type of piezoelectric is selected because rectifier and filter has been developed at size 0.60” thus the width of plate remains constant.

Resistance leakage must be greater than loss resistance to produce a high voltage output. There are also constant values for piezoelectric ceramic crystal and this value was taken from Morgan Technical Ceramics. Table 5 shown property and value for each constant value.

Rectifier: Piezoelectric produced an AC output voltage [2]. Thus, rectifier has been used to convert AC-DC for powering the fans in railway stations. Besides, the rectifier used to reduce noise and distortion from the voltage output produce. Since DC cooling fan need a DC voltage, RC filters has been chosen for this research.

Besides, RC filter able to stabilize the output voltage and reduce the ripple of the waveform. Figure 9 shown the full bridge rectifier and RC filter has been developed for this system.

Table 4: Common shapes and sizes of piezoelectric ceramic crystal [7]

Shapes	Range(inch)	Description
Length	0.080”-1.900”	-
Width	0.080”-1.900”	-
Thickness	0.008”-0.400”	Based on material

Table 5: Property and value of the piezoelectric generator [7]

Property	Value For PZT5A
Relative Permitivity	1875
Dielectric Loss	0.02
Resistivity(at 25°C)	10^{12}
Coupling Factors (k_{33})	0.67
Frequency Constants	2000
Young Modulus	$8.53e^{10}$

Fig. 8: Examples of shape and sizes for piezoelectric type plate

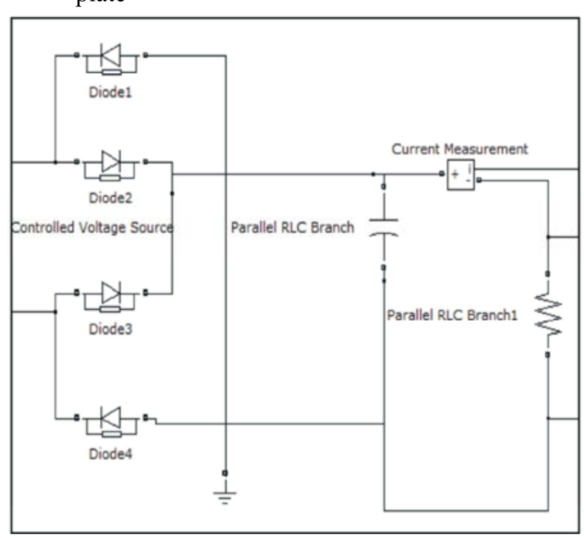

Fig. 9: Rectifier and RC filter circuit

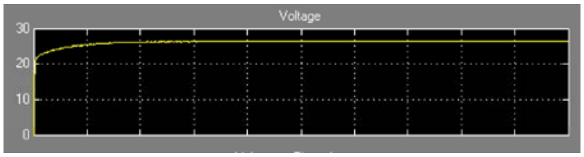

Fig. 10: Voltage output at thickness 0.35” with 0.60” and 1.20” for width and length respectively

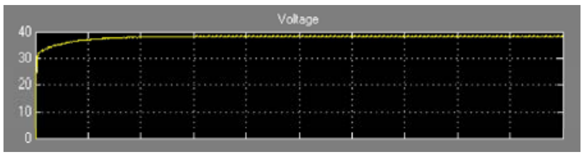

Fig. 11: Voltage output at thickness 0.40” with 0.60” and 1.00” for width and length respectively

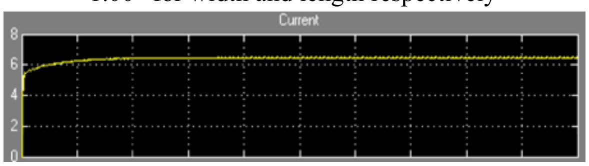

Fig. 12: Current outputs at thickness 0.40” with 0.60” and 0.60” for width and length respectively

Simulations: In this part, the present simulationsrelating the output voltage when the length and thickness of piezoelectric has been varied. Table 2shown the voltage and current produce when the length range 0.60”-1.40” with its thickness 0.40”.

Besides, Table 2 proves that smallest the area of the plate, higher the voltage and current produce from the piezoelectric ceramic crystals.

Table 3 shown the voltage and current produce when the length range at 0.60”-1.40” with its thickness 0.35”.

The voltage output for the system triggered at every 0.2905s due number of people walking through the ticket entrance at LRT Bandar Tasik Selatan.

From Figure 9 shows the current output produced by the system when thickness of piezoelectric at 0.40”, 0.60” for both width and length respectively.

Since the voltage and current output produce shows at Figure 11 and Figure 12 proved that the system produces a DC output, although the piezoelectric generator intend to produce an AC output. Since, the full bridge rectifier and RC filter used to the system the output intend to produce a DC output for powering DC cooling fans at railway stations.

CONCLUSIONS

As conclusions, piezoelectric generator produced an AC output. For this system, resonator reacts as an important partof the system to increase the oscillating for the output for the system.

Rectifier has been used to produce a DC output and stabilize the output voltage and reduce the ripple of the waveform.

When the area of piezoelectric plate was decreased and increasing the thickness of piezoelectric plate, the higher voltage and current output produce for the systems. In the future, another input force should be taken as considerations for this project such as vibrations at the railway or the movement of the train.

Thus, the main objective for this project has been achieved. This researchoutcome is to produce an output more than $24V_{dc}$.

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