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Application of modern piezoelectrics in street lighting

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Abstract: The article is devoted to the efficient use of the energy obtained from the people and cars moving on the pedestrian crossings by turning it into electricity through piezoelectric generators in street lighting. The article provides information on energy produced from piezoelectrics, equipment used in lighting, and charging batteries with modern charging modules.

Key words: Piezoelectric generator, Pedestrian crossing, Battery, Comparator.

1. INTRODUCTION

Current technologies used in street lighting lead to increased lighting efficiency and automatic control without human intervention. In modern times, the use of alternative energy sources is also used in street lighting. Examples of these applications include solar and mechanical energy. Obtaining electricity from the intensive movement of people and vehicles on the streets has recently become an object of research. The most suitable option is to use piezoelectrics on streets and sidewalks to convert mechanical or step energy into electrical energy [1].

Dielectrics that produce an electric field as a result of mechanical deformation are called piezoelectrics. As a result of the external force F, the piezoelectric plate is deformed, polarization charges are created on that plate, and an electric field is formed there. This effect is called direct piezoelectric effect. The reverse of this process is also true and the resulting effect is the reverse piezoelectric effect.

However, it is not the only piezoelectric material that should be considered here that has sufficient output power. For this, the piezoelectric elements that will perform the function of the generator must be connected in series-parallel with each other and the corresponding parameters must be selected preferentially [2]. This application, which will be used in street lighting, is installed in pedestrian crossings where people are more intensive in the form of piezoelectric matrices. The resulting high-value output power is used to charge batteries. The lighting is intended for typical traffic signs located near pedestrian lanes, and this lighting uses a rechargeable battery or accumulator as the power source. Also, in order to increase the efficiency of energy consumption, in accordance with the day-night mode, lighting is planned to be carried out only at night, and a corresponding system has been developed for this.

2. EXPERIMENT DETAİLS

In this article, suggestions have been put forward regarding the recharging of the power source used in street lighting, as well as the productive use of the energy from human and traffic movement to obtain electricity from it. Piezoelectric generators are used to convert mechanical energy generated during human movement into electrical energy [3].

The equivalent circuit of the piezoelectric generator is presented in figure 1. High values of piezoelectric element capacitance and output voltage are required to charge the produced energy into batteries [4-10].

Also, the brand of the diode used in the rectifier circuit should be selected so that the voltage drop on the rectifier is less. After determining the battery to be used, the appropriate charging module required to charge them must be selected. At the same time, in order to save energy, it is required that the lights turn on at night and turn off automatically during the day without human intervention [1-11]. For the circuit elements used here to operate at low power, the components should be selected with appropriate parameters. We consider that this application used in street lighting is more efficient to be installed in pedestrian lanes where people are more active (Fig. 2).

The material of the piezoelectric element used to convert the mechanical energy obtained during movement into electrical energy should be selected in such a way that the value of its relevant parameters is high.

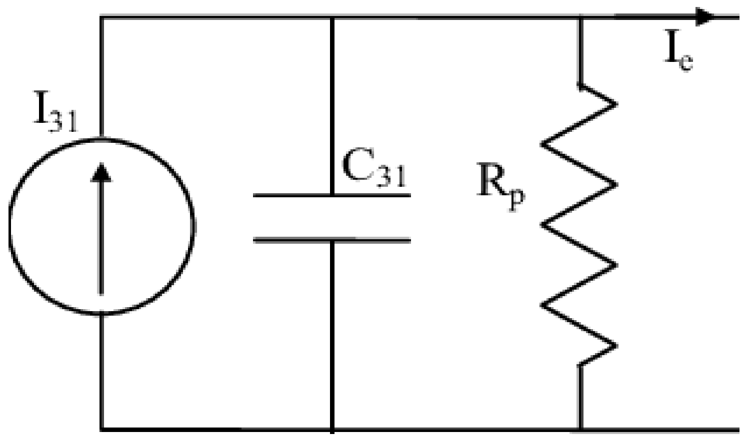

Figure 1. Equivalent circuit of a piezoelectric generator

Figure 2. Pedesterian crossing

For this, it is considered appropriate to use PCR-73 piezoelectrics. PCR brand piezoelectrics manufactured from ceramic piezoelectric materials whose parameters are presented in table 1 are made by hot pressing method [4].

Table 1.The main parameters of PCR-73 piezoelectric

Type of piezoelectric	d_{33}	g_{33}	ε_{33}
PCR-73	860×10^{-12} C/N	16.1×10^{-3} Vm/N	531×10^{-10} F/m

The piezoelectric material to be used is disc-shaped and its diameter is d=20 mm and its thickness is h=0.3 mm. When the material is deformed, the output voltage varies depending on the mechanical force F applied to the piezoelectric element [4]

$$V_{out} = \frac{g_{33}Fh}{\pi r^2} \quad (1)$$

Here g_{33} is the electrical coefficient due to voltage; r = d/2. In the pedestrian crossing where the piezoelectric generator is applied, the width of each lane is 30 cm, the length is 200 cm, and the number of lanes is 10.
Considering the areas of strips and piezoelectric elements, we can place 1000 parallel connected piezoelectric elements in one strip and 10000 in 10 strips (Fig. 3). Rectifier diodes to be used when rectifying the alternating current with a leap obtained from a piezoelectric generator should be selected in such a way that the voltage drop across them is small [5]. We achieve this by using 1N5820 series Schottky diodes. The voltage drop of this diode during forward bias is 0.475 V, and the maximum current it can release is 3 A. The stabilization voltage of the stabilitron at the output is 5.1 V (Fig. 4).

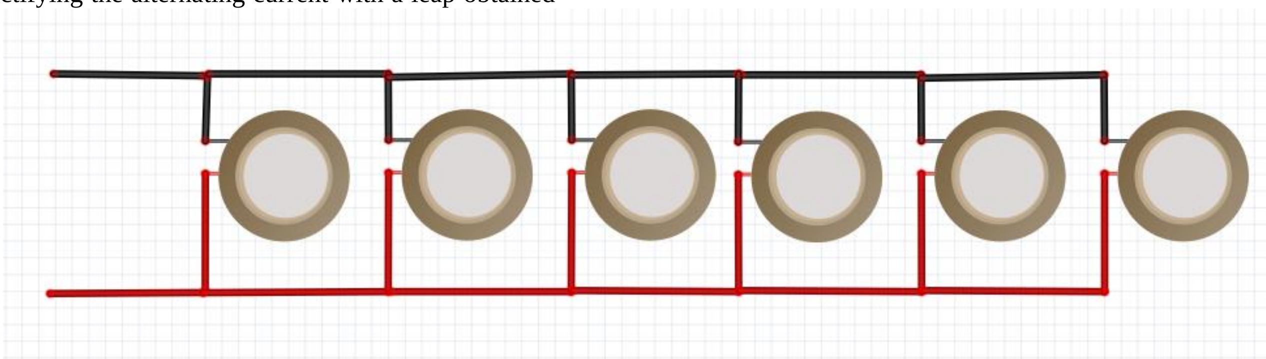

Figure 3. Parallel connected piezoelectric plate

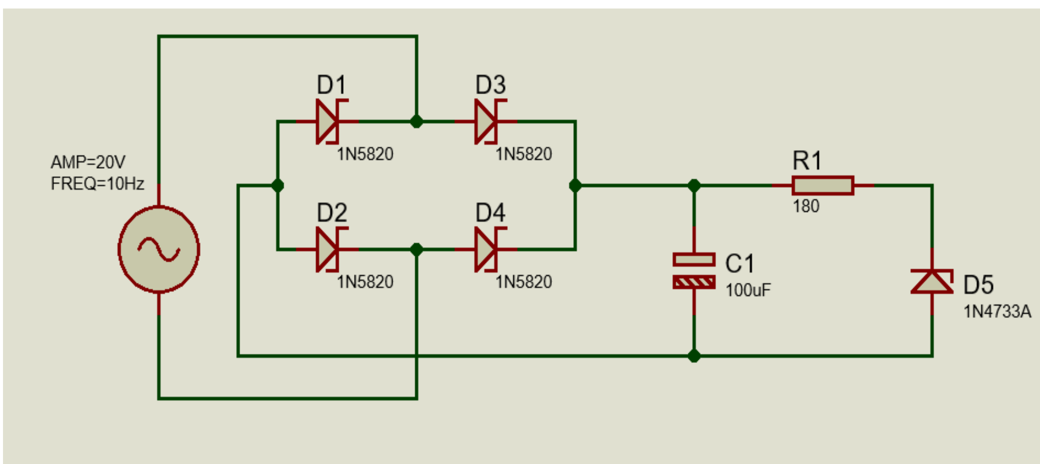

Figure 4. Rectifier circuit on Schottky diodes

Lithium-Ion batteries were used as the battery to be used in the street lighting (Fig. 5), and the capacity value was increased as a result of connecting several batteries in parallel to provide enough energy during the dark hours of the day. The module used to charge these batteries is the TP4056 charging module (Fig. 6).
Due to the protection circuits on the main feature of the use of this module, the failure of the battery as a result of supplying power to the output load at a low voltage after long-term operation is prevented.

New generation filament LEDs with high brightness at low voltage can be used for lighting (Fig. 7).
We consider it important to ensure that the lights automatically turn on only at night, prioritizing the increase of energy savings and the simplicity of the control circuit [6]. For this purpose, a comparator circuit was developed on the operational amplifier and photoresistor working at low currents presented in figure 8.
The two-channel OP282 series operational amplifier is capable of operating at currents below

250 μA. By using such an operational amplifier, we achieve that the comparative circuit consumes less energy during clear hours of the day.

Figure 5. Lithium-İon battery

Figure 6. TP4056 charge module

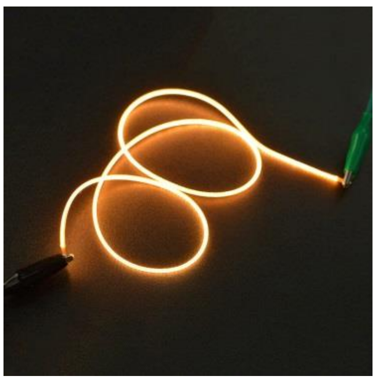

Figure 7. Neon filament led

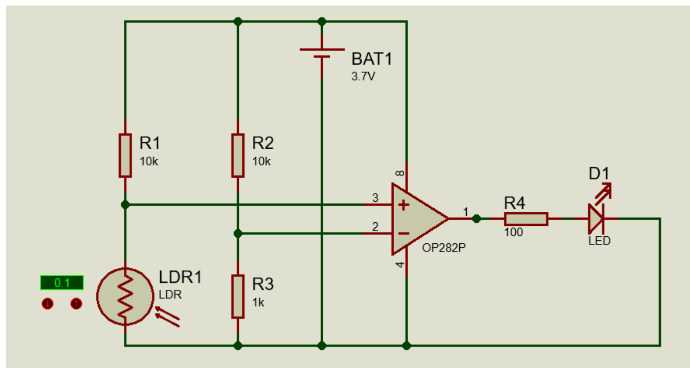

Figure 8. Comparator circuit designed for automatic lighting

In the application of piezoelectric generators in regulated pedestrian crossings, the first 60 seconds of the traffic light are intended for pedestrians, and the other 60 seconds are for cars.

Using the expression (1), the voltage generated on the piezoelectric elements when pedestrians pass through the passage is equal to $V_{out\,p} = 10.8\,V$. The voltage $V_{out\,c} = 271.3\,V$ when cars pass over the passage. Since the values of the resulting voltages are different, it is proposed to use two-channel Lithium-Ion batteries: one channel is designed to collect the energy generated when pedestrians and the other vehicles pass over the crossing.

The electric charge Q caused by the mechanical force F in a piezoelectric element can be determined by the following expression [4]

$$Q = d_{33}F \qquad (2)$$

Here d_{33} is the quantity characterizing the piezomodule.

Using the value of piezomodulus presented in table 1 and expression (2), we find the value of the charge generated in a piezoelectric element: for pedestrians $Q_p=0.6\cdot10^{-6}$ Kl , for cars $Q_c=1.52\cdot10^{-5}$ Kl. Taking into account the parallel connection of piezoelectric elements and assuming that the crossing works for 3 hours during the day in the peak mode, the value of the load generated in the piezoelectric elements of the crossing is $Q_{gp}=64.8$ Kl for pedestrians, and $Q_{gc}=652.3$ Kl for cars.

These loads are accumulated during the day in two-channel batteries. It is required to synchronize the operation of the traffic light in order to adjust the operation of the two-channel batteries alternately for pedestrians and vehicles. Using the obtained results, it was determined that by using the loads stored in the batteries in one channel at night, we can provide the lighting of LED lamps with a voltage of 10.8 V and a current of 18 mA and various street signs for 1 hour through the energy generated in the crossing at the expense of pedestrians. It is possible to ensure the operation of various street equipment with a voltage of 271.3 V for 3 hours, consuming a current of 60 mA, or with a voltage of 271.3 V for 1 hour, consuming a current of up to 180 mA, through the energy generated in the transition at the expense of machines in the second channel.

3. CONCLUSION

In order to efficiently use the energy obtained from the heavy traffic of people and cars on the streets, it was proposed to apply piezoelectric generators on pedestrian crossings and use them to illuminate neon filament LEDs with low energy consumption. Rechargeable lithium-ion batteries were used as the power source, and a TP4056 type reliable charging module was used to charge them. In addition, a comparator circuit was developed on the OP282 series operational amplifier operating at low currents to realize automatic lighting. It has been shown that by using the loads stored in the batteries in one channel at night, we can provide the illumination of LED lamps with a voltage of 10.8 V and a current of 18 mA and various street signs for 1 hour through the energy generated at the crossing at the expense of pedestrians. In the second channel, it is possible to operate various street equipment with a voltage of 271.3 V for 3 hours, consuming 60 mA of current, or consuming up to 180 mA of current for 1 hour, through the energy generated in the transition at the expense of machines.

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