Feasibility Of Power Generation Using Piezoelectric Devices On A California Highway

Abby Vaux
Electromechanical Engineering Technology,
Penn State Altoona,
3000 Ivyside Park, Altoona,
PA 16601

Dr. Sohail Anwar
Department of Engineering
Penn State Altoona,
3000 Ivyside Park,
Altoona,
PA 16601

***Abstract*—Piezoelectric devices are able to convert kinetic energy, in the form of vibrations, into electrical energy. This technology is being considered for usage in smart highways for collecting the wasted kinetic energy from passing traffic. Reduction of wasted energy and utilizing reusable energy resources consequently reduces carbon emissions. Looking at the US-101 N in California, this paper considers the energy outputs based on traffic volumes and speeds collected for one day. As observed by the results, the output power decreases with a decrease in speed, and increases with an increase in traffic volume. This being considered, this technology would be better developed on high speed, high traffic areas and roads.**

Keywords—Piezoelectric, Smart Highway, Carbon Emissions, Traffic, Speed, Traffic Volume

1. Introduction

Renewable energy is in high demand. Smart highways, such as a piezoelectric smart highway, contribute to the world's energy situation by collecting wasted kinetic energy released by moving vehicles. Piezoelectric plates installed in a road system would effectively take the kinetic energy from the vehicles and transform that energy into electrical energy which can be used to power lights, signs, and more. Roads like this are being studied and tested in places like California, Israel, India and Italy. According to the California Energy Commission, one lane of a one mile stretch of road could produce 72,800 kilowatt-hours of energy per year using piezoelectric road energy harvesting systems [1]. Energy production for piezoelectric roads depends on the force of the traffic, the speed at which the traffic is moving, and the volume of traffic on the road. Based on these variables, different roads would produce differing amounts of energy.

The significance of road energy harvesting systems consists of sustainable energy growth which enables power generation, creating a self-sustaining system to maintain the road lights, signs, etc. By utilizing another renewable energy source, smart highways, in the context of energy harvesting, will help reduce the greenhouse gas emissions and air pollution emitted by other energy sources.

1.1 The Piezoelectric Effect

Simply put, piezoelectric effect is the ability to turn mechanical stress into usable electric energy. When mechanical stress is placed on a piezoelectric material, such as a vibration, positive and negative charges shift which generates an external electrical field [6].

In turn, the piezoelectric effect is also reversible. If an electric field is applied to the material, it causes mechanical stress such as contractions and expansions. Piezoelectric crystals are often used in lighters to spark gas to ignite [7]. Other applications include cell phones, ultrasonic transducers, vibration sensors, musical greeting cards and more [8].

Hence, if piezoelectric materials were to be integrated into roadways, mechanical stress from the vibrations and force of vehicles would be able to produce useable electrical energy.

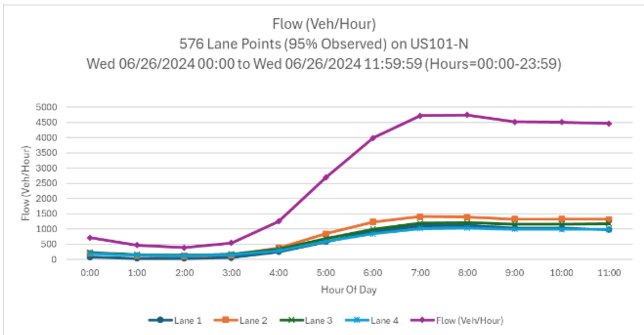
1.2 Existing Smart Road Development

In Mumbai, India, TATA Projects Limited has recently inaugurated two smart roads with the developing energy harvesting technology. One of these roads, Road Number 2, has a length of 465 meters (about 1525.59 ft) and runs from Zero Point Bridge to Gyaneshwari Mata Temple. The other one, Road Number 4, is 412 meters (about 1351.71 ft) long and is from Bela Patra Mahadev Temple to Jain Mandir. India has budgeted trillions of dollars to create more than 100 smart cities [4]. The United States has already invested about $2.3 M on projects related to piezoelectric roads. In the UK, there is a research program at Lancaster University dedicated to power generation using piezoelectric roads; their goal is to generate between 1 and 2 MW/km with around 3000 vehicles per hour. In Japan, the East Japan Railway Company recorded generating about 10 K Watt-second per day and that is used to power electronics at the Tokyo Marunouchi North Exit station. In Italy, there are piezoelectric floors for the Venice-to-Trieste Autostrada [5].

Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 11 Issue 12, December - 2024

2. Methodology

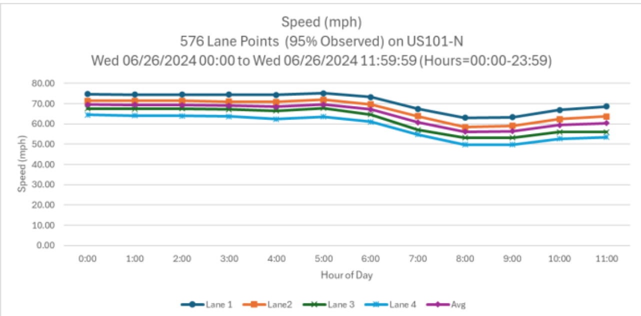
This study was done as an analysis of the traffic patterns on California 101-N highway to understand the possible power outcome of piezoelectric energy collection technology. By obtaining speed and volume data of the traffic from the Caltrans Performance System [2] for the single day of 06/26/2024, we were able to calculate possible outcomes of power per hour per lane. The highway data consisted of four lanes throughout the hours of 00:00 to 11:00. This information can be observed in the figures below.



Graph 1: Above displays the vehicle flow per lane per hour [2].

Hour	Lane 1	Lane 2	Lane 3	Lane 4	Flow (Veh/Hour)
0:00	80	207	234	195	717
1:00	37	130	161	141	469
2:00	29	104	135	121	389
3:00	56	151	178	160	545
4:00	250	380	339	284	1253
5:00	579	843	682	586	2691
6:00	912	1233	995	845	3985
7:00	1108	1402	1190	1015	4715
8:00	1114	1391	1211	1032	4747
9:00	1031	1322	1162	999	4515
10:00	1025	1325	1164	990	4503
11:00	983	1318	1176	984	4461

Table 1: Above displays the flow of vehicles per lane per hour as shown in Graph 1 [2].



Graph 2: Above displays the average speed of vehicles per lane per hour [2].

Hour	Lane 1	Lane 2	Lane 3	Lane 4	Average
0:00	74.68	71.36	67.61	64.55	69.55
1:00	74.49	71.37	67.41	64.17	69.36
2:00	74.49	71.40	67.51	63.98	69.35
3:00	74.48	70.98	67.12	63.77	69.09
4:00	74.34	70.82	66.49	62.38	68.51
5:00	75.08	71.89	67.79	63.60	69.59
6:00	73.26	69.66	64.69	61.10	67.18
7:00	67.47	63.82	57.11	54.84	60.81
8:00	63.02	58.39	53.21	49.78	56.10
9:00	63.34	59.03	53.26	49.79	56.35
10:00	66.89	62.41	56.08	52.67	59.51
11:00	68.65	63.66	55.96	53.49	60.44

Table 2: Above displays the average vehicle speed per lane per hour as shown in Graph 2 [2].

3. Results and Discussion

Piezoelectric devices within the roadway converts the vibrations from the speed and force of the vehicles and converts it into electrical energy to be stored and used [3]. This research is based on a previous study that used a piezoelectric transducer integrated into a road surface that collects the strain and vibrations from the moving vehicles and generates electrical power [9]. The equation used to calculate the total output power based on average vehicle speed per lane is shown below.

$$P = Fv$$

F is a constant (about 4944.4 N) that represents the average weight of a vehicle, v is representative of the average speed per lane per hour (mph), and P is the total output power based on the average vehicle speed. The equation to calculate the total output power based on the total volume is given below.

$$P_{out} = PV$$

P is representative of the total output power based on the average vehicle speed, V is the volume of vehicle flow per lane per hour, and P_{out} is the total output power per lane per hour based on the total volume of traffic flow.

The tables below (Tables 3-6) show the results of these calculations for each lane by the hour. The leftmost column shows the hour at which the data represents, the middle column shows the total output power based on the average vehicle speed (in watts), and the rightmost column shows the total output power based on the total volume of traffic flow (in watts).

Hour	Lane 1 Total Output Power Based on Average Speed (Watts)	Lane 1 Total Output Piezo Power Based on total Volume (Watts)
0:00	369229.9372	29651215.24
1:00	368306.2958	13583852.34
2:00	368306.2958	10847131.95
3:00	368254.7917	20550663.23
4:00	367564.6358	91778847.54
5:00	371225.552	214857100
6:00	362235.0917	330363434.7
7:00	333613.0892	369682687.7
8:00	311579.6067	347218687.9
9:00	313172.8022	322920305.7
10:00	330711.6878	338905988.5
11:00	339422.7592	333697357.2

Table 3: Output powers per hour for lane 1.

Hour	Lane 2 Total Output Power Based on Average Speed (Watts)	Lane 2 Total Output Piezo Power Based on total Volume (Watts)
0:00	352810.4089	73193459.41
1:00	352868.7803	45821481.41
2:00	353040.4608	36605882.78
3:00	350935.6572	52937669.07
4:00	350156.2275	133166358.6
5:00	355452.916	299792445.1
6:00	344451.3049	424753907.4
7:00	315569.4628	442391132.1
8:00	288718.6239	401483296.4
9:00	291870.6789	385893575.1
10:00	308578.6306	408834541.9
11:00	314769.4314	414949174.7

Table 4: Output powers per hour for lane 2.

Hour	Lane 3 Total Output Power Based on Average Speed (Watts)	Lane 3 Total Output Piezo Power Based on total Volume (Watts)
0:00	334282.6433	78059640.03
1:00	333307.4978	53600011.99
2:00	333808.805	45029416.92
3:00	331879.1156	59178194.79
4:00	328761.3967	111413584.4
5:00	335180.876	228735343.8
6:00	319851.3096	318363112.5
7:00	282397.3458	335921448.3
8:00	263090.1506	318485243.4
9:00	263337.3706	306078488.8
10:00	277284.6989	322755538.3
11:00	276673.5161	325423773.9

Table 5: Output powers per hour for lane 3.

Hour	Lane 4 Total Output Power Based on Average Speed (Watts)	Lane 4 Total Output Piezo Power Based on total Volume (Watts)
0:00	319167.25	62392022.11
1:00	317278.03	44801471.15
2:00	316355.79	38148324.83
3:00	315281.10	50444606.26
4:00	308407.97	87663245.46
5:00	314463.84	184382688.8
6:00	302078.12	255160425.9
7:00	271171.01	275361780.8
8:00	246151.51	253972707.4
9:00	246177.11	246022127.2
10:00	260419.03	257696744.4
11:00	264454.77	260162644

Table 6: Output powers per hour for lane 4.

4. Conclusion

Based on the results, the output power decreases with a decrease in speed, and increases with an increase in traffic volume. This being considered, this technology would be better developed on high speed, high traffic areas and roads. Considering these observations, the California 101-N highway is a good example of an efficient road for piezoelectric technology implementation.

As this research is based on a past study [9], the numbers achieved throughout this project is validation for continuation of this research in the future of piezoelectric smart highways and their development.

Further study may include using these power outputs and determining the effect the technology would have on things such as energy waste, greenhouse gas emissions, and other affected areas.

Sources:

[1]. Commission, C. E. (current-date). *Ultra-High Power Density Roadway Piezoelectric Energy Harvesting System*. California Energy Commission. https://www.energy.ca.gov/publications/2023/ultra-high-power-density-roadway-piezoelectric-energy-harvesting-system

[2]. Caltrans PeMS. (n.d.). Retrieved June 23, 2024, from https://pems.dot.ca.gov/?dnode=search&content=cnt_search&view=e#37.740754,-122.431383,14

[3]. Development and application performance of road spring-type piezoelectric transducer for energy harvesting—IOPscience. (n.d.). Retrieved June 10, 2024, from https://iopscience-iop-org.ezaccess.libraries.psu.edu/article/10.1088/1361-665X/ac0c2d

[4]. India Smart Highway Market 2022-2027 | July 2024 Updated. (n.d.). Retrieved July 23, 2024, from

https://mobilityforesights.com/product/india-smart-highway-market/

[5]. Toh, C. K., Sanguesa, J. A., Cano, J. C., & Martinez, F. J. (2020). Advances in smart roads for future smart cities. Proceedings. Mathematical, Physical, and Engineering Sciences, 476(2233), 20190439. https://doi.org/10.1098/rspa.2019.0439

[6]. The Piezoelectric Effect—Piezoelectric Motors & Motion Systems. (n.d.). NANOMOTION. Retrieved July 23, 2024, from https://www.nanomotion.com/nanomotion-technology/the-piezoelectric-effect/

[7]. THE CREATIVE SCIENCE CENTRE. (n.d.). Retrieved July 23, 2024, from http://www.creative-science.org.uk/piezo1.html

[8]. Sekhar, B. C., Dhanalakshmi, B., Rao, B. S., Ramesh, S., Prasad, K. V., Rao, P. S. V. S., Rao, B. P., Sekhar, B. C., Dhanalakshmi, B., Rao, B. S., Ramesh, S., Prasad, K. V., Rao, P. S. V. S., & Rao, B. P. (2021). Piezoelectricity and Its Applications. In Multifunctional Ferroelectric Materials. IntechOpen. https://doi.org/10.5772/intechopen.96154

[9]. Rall, K. C., Bailen, K. L., Bender, E. N., Taha, L. Y., Abdeltawab, H. M., & Anwar, S. (2023). Smart Highways Based Vehicle Speed Sensor With Piezoelectric Energy Harvesting: A Progress Report. 2023 IEEE International Conference on Industrial Technology (ICIT), 1–6. https://doi.org/10.1109/ICIT58465.2023.10143163