

Development of regenerative shock absorber using the piezoelectric patch for electric vehicles

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Abstract

In the era of electric vehicles, a regenerative shock absorber can be equipped in the place of normal shock absorbers which continuously produces electricity and can be amplified and fed to the battery, a piezoelectric generator can be used that harvests mechanical vibrations energy available on an electric vehicle. The piezoelectric material can be placed in shock absorber housing above the piston head. Due to bumps and pits on road, continuous generation of electricity is possible. It can be then amplified and fed back to the battery regeneratively. The 3D cad model of piezo housing was modelled and the force acting on the housing of piezoelectric materials was analyzed and found to be 103.5KN and equivalent power produced was calculated. Various Piezoelectric materials were studied and PZT 5A was found to be the best to act as transducer and quartz was the best material to act as Actuator. A proof of concept developed showed the power produced by piezo material and comparison study of that with PZT 5A was done and power produced was 19J which is 9% of power produced by the charger of electric vehicles. The calculation for mileage showed an increase of 3 km which is 4% of the maximum distance covered by the average electric bike.

Keywords: Electric vehicle (EV's), Regenerative, Shock absorber, Transducer, Quartz, Actuator

1. Introduction

Most of the fuel present in the earth is depleted and gasoline engine causes many problems to the environment like SO_x and NO_x emission. The automotive industry is changing rapidly from gasoline to electric powered vehicles. So as a remedy for this several people like scientists' engineers used several equipment's charge the car like, Solar panels, Wind turbines, Dynamos, Shock absorber.

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Since these devices were used individually, they have to afford an external source to charge the car which again results in some economic as well as resource problem that led to the failure of the model. Re-generatively charging the battery by harvesting energy from shock absorber through piezoelectric materials is one of the ways to increase the energy efficiency, mileage and discharge capacity of the battery. Vibration in vehicle is undesirable so shock absorber acts as a damping element reducing the vibration but these vibrations are nowhere used in the vehicles. Energy loss from shock absorber is nowhere utilized in electric vehicles. The energy losses that occur during driving of vehicles and subsequently for the reduction of these losses to the possible lowest level [2]. In order to increase the discharging time, if battery capacity is increased it eventually increases the size of the battery, space occupied and weight. This reduces the mileage of electric vehicles. Overall Cost of vehicle increases if battery with high capacity is used. Charging time increases with big batteries so fast charging technology has to be incorporated, which again increases the cost.

A. Why India needs a switch to electric vehicles

There is a need to make people understand that electric vehicle holds a permanent solution for cleaner, sustainable India. Many countries formulated many technologies in electric vehicles but India is still lagging in it. By incorporating many technologies in EV's mobility sector one can promote for greener ecology. China is the leading producer and stake holder of EV mobility and US stands the next as shown in Fig1. India has an aim to become electrical vehicle manufacturing spot as per information given by Nitin Gadkari, Union Minister of Road Transporting sector and Highways. Even in the outbreak of COVID people tend to avoid public transport and prefer individual vehicles. This led to increase in price of gasoline engine and many people cannot afford such price hike. So, EV will be a solution for such problem. This can travel the same distance with reduced cost when compared to gasoline vehicles. So, advancements and technologies in EV sector is of most important. Though there are EV, many localities don't have enough charging hubs. So regeneratively harvesting the power from the vehicle will be the possible solution to increasing the mileage. This paper shows one of the methods of regeneratively harvesting the power from shock absorber and storing it in battery dynamically.

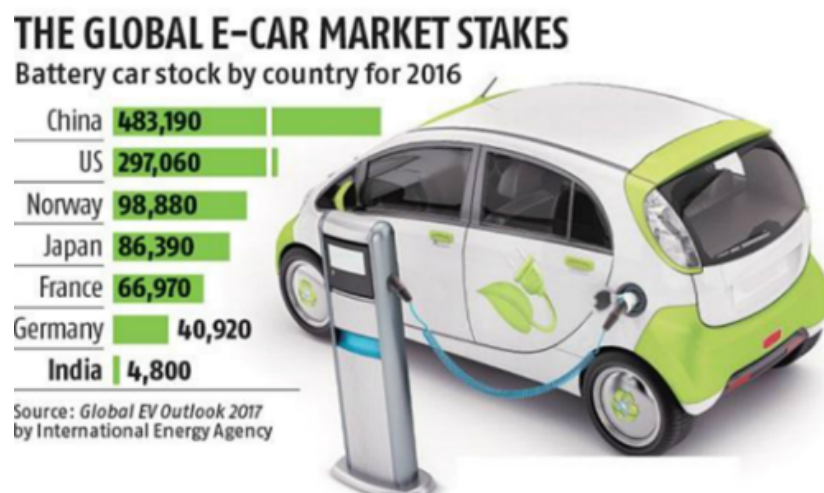


Figure 1: The global E-vehicle market stake

India has to become a sustainable green ecosystem for this a constant pull towards cleaner mobility is much needed. Only electric vehicles can do this. Well known fact is that the fossil-fuel engines contribute to 60 percent of particulate matters atmospheric pollution, and over 20 percent of CO₂.

The Electric vehicles, , is smoke free. They don't choke India with hydrocarbon pollutions, the UNICEF aptly said as "danger in the air." The petrol and diesel vehicles are hugely in-efficient as they nearly 70% of the precious fuel is simply wasted. It can neither be recycled nor be recovered or reused. Well known that it takes millions of years to create the natural fossil fuel again, unlike the battery that is made and used when needed. On the other hand, the Electric vehicles are rechargeable and involving zero wastage of energy. They don't even have a single (a few) harmful effects on human health and ecology. The heavy petrol and diesel trucks alone cause over 30% of vehicular particulate pollution. However, government support to promote electric vehicles is dismal and disappointing. It has to be promoted as far as possible.

Various researchers have proposed different models to regeneratively harvest power from vehicles some of them are discussed below. B.lafarge et al. [4] states low power output from the piezo plate is converted to high power. Piezoelectric material is mounted on the surface of the shock absorber Lead Zirconate Titanate (PZT-5H) is the power harvester used to generate electricity. a bond graph model of piezoelectric patch placed in the quarter vehicle system is proposed. Power is produced when the car is travelling at 30kmph on road and the Results show that approximately 0.5-milliwatt electrical power is harvested regeneratively while varying the key parameters like location, characteristics of the piezoelectric device.

Albert Chawanda et al. [6] states that COMSOL Multiphysics finite element analysis software was used to study the piezoelectric effect. an external load is applied on the free end of a composite beam. single crystal lead magnesium niobate-lead titanate (PMN32) is the material used and three other lead zirconate titanate ceramics PZT-5A, PZT-5H, and PZT-4. For each material three analyses has been performed they are static, eigenfrequency and transient analysis. A common geometry for all materials and similar excitation conditions were given. results clearly says that the new crystal material PMN32 is superior than other existing PZT material. The COMSOL analysis procedure and method was studied from this paper.

Sivani Mohapatra et al. [5] states that design methods of piezo electric transducer. From the property of PZT and BNN air displacement, compliances and polar graph are simulated. COMSOL Multiphysics software is used to simulate this. It is concluded that the air displacement and compliance shown by PZT is higher than the BNN material. PZT is most preferred as a piezoelectric transducer material. An investigation with the lead contact PZT with lead free BNN materials is also carried out.

Doaa Al Yafeai et al. [1] states That piezoelectric material is mounted on different locations such as suspension springs, dampers, and tires. The technique which is to be used for harvester and the maximum amount of power harvested from each location are studied. The evaluation of the electrical power converting and amplifying circuits and various storage devices like capacitor, battery for the harvested power are also discussed.

Min Wang et al. [8] Describes a power harvesting circuit for piezoelectric energy harvesting from suspension system. 8 pairs of piezo electric patches were attached to either surfaces of leaf spring. This can magnify the force from working condition to load acting on the surface of piezo electric patches. The results indicate that the resonance frequency 25.2 Hz experiment is close to the simulation result 26.1 Hz. Impedance correlation experiments show that sum of output power is 1.7 mW, and the max single layer reach 0.6 mW with impedance matching 610 KW & power density is 3.82 mW/cm^3 .

Białkowski et.al. [3] States the damage to shock absorbers of a passenger car at normal road operation condition with the use of vibration response FFT and PSD measurement is described. Accelerometers are mounted on the CG point of car. The test was carried for several variety of shock absorber damages. The resonance frequency was studied from the obtained results.

From the literatures, various possible methods of power amplification circuit to convert low power output to high power output was studied. Methodology to proceed in COMSOL and Random vibrational analysis in ANSYS with various materials and various possible locations where a PZT patches can be placed are studied.

2. Selection of piezo material and ITS shape

A. Selection of piezo electric material

Best suitable piezoelectric material was chosen by studying various materials. Analysis of circular and square plater was carried out and square plate made of PZT 5A was found to be optimum for power extraction. Some crystals generate electrical energy when mechanical stress is applied and deform when electrical field is applied. Such behavior is called piezoelectric property. The charge thus produced can be called as piezoelectricity.

Piezo-electricity can be defined as the electrical polarization produced by mechanical strain on certain class of crystals. The factors determining the selection of piezoelectric material are the electromechanical coupling factor k , Piezoelectric strain constant d , Piezoelectric voltage constant g , Mechanical quality factor QM , Acoustic Impedance Z . These properties are studied for various materials like PZT5A, PZT5H, Quartz and barium Titanate. The properties of the PZT5A are given in table 1.

Table 1: Properties of PZT5A

DATA	Lead Zirconate Titanate				
	Sp-4	SP-8	SP-5A	SP-5J	SP-5H
Piezoelectric coupling coefficient K_p	0.6	0.5	0.61	0.63	0.63
K_{33}	0.68	0.63	0.70	0.71	0.73
Piezoelectric charge constants $D_{33}(x10^{-12}C/N)$	300	215	400	460	550
$D_{31}(x10^{-12}C/N)$	-122	-97	-170	-195	-247
$G(x10^{-12}Vm/N)$	27	24	26	22	20
$G(x10^{-12}Vm/N)$	-11	-11	-11	-9	-9
Relative dielectric constant K^T	1250	1000	1750	2450	3100
Dissipation factor $\tan\delta$	0.004	0.004	0.02	0.02	0.02
Density $\rho(kg/m^3)$	7600	7600	7650	7500	7500
Curie Temperature $T(^{\circ}C)$	325	330	360	260	190
Mechanical Quality Factor Q_m	500	1000	75	70	65
Figure of Merit $d_h \times gh (x10^{-15})$	150	110	65	150	07
Elastic constants					
$S_{11}^E(x10^{-12}m^2/N)$	12	12	16	14	15
$S_{33}^E(x10^{-12}m^2/N)$	18	13	21	19	21
Frequency Cnstants (Hz-m)					
N_p	2200	2270	1950	2000	1950
N_t	1905	2032	1800	1950	2000
Ageing Rate, % change er time decade					
K_3^T	-2.5	-4.6	-0.1	-0.4	-0.4
K_p	1.6	-2.0	-0.7	-1.5	-0.9
N_P	1.0	0.8	0.1	0.2	0.15

Ceramic lead zirconate titanate also known as PZT Due to the larger electromechanical coupling coefficient, PZT is used in an application where mechanical stress has to be converted to electrical energy. Three parameters to be considered for selecting piezoelectric materials for applications working under mechanical resonance are the mechanical quality factor, electromechanical coupling factor, dielectric constant. Higher the magnitude of these parameters best is the material for the application. So PZT finds application in this area. Based on the properties of various materials PZT 5A has the properties suitable to act as a transducer. Quartz should be selected in applications where electric input has to be converted into equivalent mechanical motions or vibrations. Coupling factor, charge constants are high for PZT when compared to barium Titanate.

B. Selection of shape of piezo electric material

There are two modes by which power is produced from piezo plates. In D33 mode Potential is extracted in the same direction to that of force applied. In D31 mode Potential is extracted in the direction opposite to that of force applied. Here D3 mode is chosen because the charge produced in this mode is high. The planes C, F remains the same but the planes B, D and A, E are interchanged. i.e., in first case C, F, D, E are the active plane and in second case C, F, A, E are the active planes. The model was discretized into elements with finer mesh. Tetrahedral finer mesh with minimum element size of 0.5mm and maximum element size of 1mm is generated. Element growth rate is 1.4 and probes are placed in the plane. The probes are shown in the Fig2. The output voltage, surface charge accumulated for given force was analyzed. The governing equations for the piezoelectric analysis in stress-charge and strain-charge form is

$$\begin{array}{ll}
 \text{Stress - Charge Form} & \text{Strain - Charge Form} \\
 T = c_E S - e^T E & S = s_E T + d^T E \\
 D = e S + \epsilon_s E & D = d T + \epsilon_T E
 \end{array}$$

T = stress, S = strain, E = electric field, D = electric displacement, C_E = elasticity matrix, e = coupling matrix, ϵ_S = permittivity matrix.

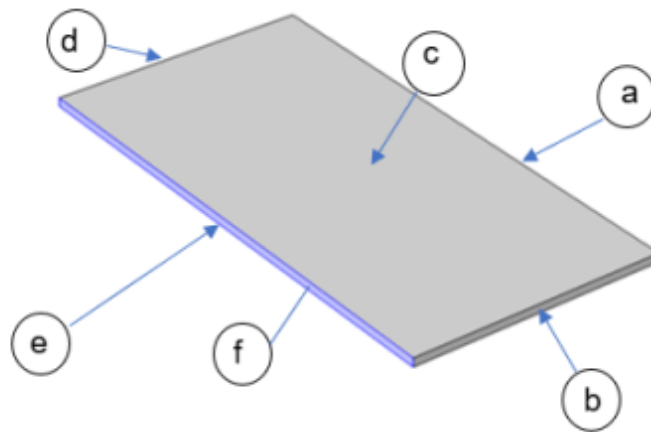


Figure 2: Boundary probes

d = Boundary probe 1, c=Force Boundary probe 5, a= Electric potential (+) Boundary probe 4, b=Boundary probe 2, f= Support Boundary probe 6, e= Ground (-) Boundary probe 3. Material shape for power harvesting was selected by doing analysis on COMSOL Multiphysics software. Square

of dimension 40 * 40 * 2 mm and circle of diameter 45mm was initially chosen for analysis such that it has same area. The boundary conditions were set initially such that bottom of the plate is fixed because the bottom seats into the housing of shock absorber. The force is given in perpendicular direction to that of power output. Analysis is carried per unit newton of force. Two pairs of perpendicular faces are there for which individually analysis was performed given as case1 and case2 as shown in Fig3.

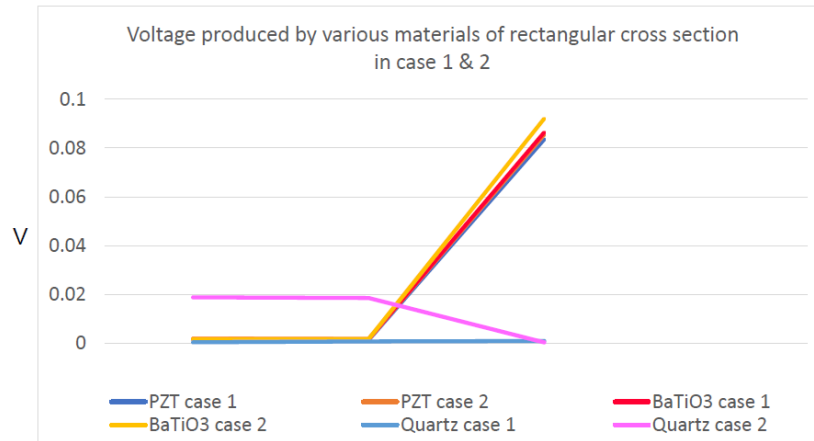


Figure 3: Voltage produced by various materials of rectangular cross sections

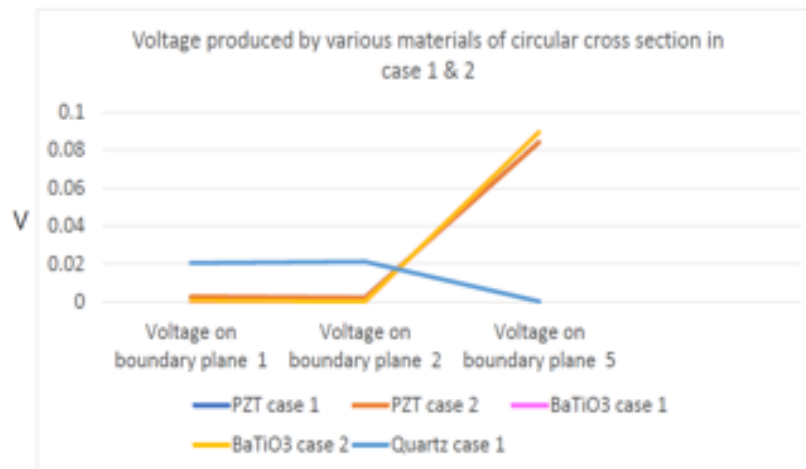


Figure 4: Voltage produced by various materials of circular cross sections

Surface charges are accumulated on the outer most area so placing the output terminals on the edges would extract the maximum charges possible. The voltage on the probes 3, 4, 6 remained 0 in both the case irrespective of the plane in which force applied but the charge was accumulated in the probe 3 and 4. Since the fixed face is f, the voltage in that plane is 0 but opposite face showed a potential difference. The surface charge produced in square plate made of PZT acting in case 2 has the maximum charge produced per unit square area so it is chosen such that C, F, A, E are the active planes. Rectangular BaTiO3 piezo plate produces more voltage for applied force when compared to circular disk of same cross section as shown in Fig4 but the charge developed is more in PZT and its voltage is also nearer to BaTiO3 so PZT of rectangular cross section is chosen.

3. Development of proof of concept

A proof of concept was developed and calculation of efficiency of piezoelectric plate and increase in mileage due to regeneration on power from shock absorber was observed. The current output from the piezoelectric plate is AC it should be converted to DC before storing it into the battery. So, the bridge rectifier does this job. When AC is given in one pair of nodes it is rectified and DC is given on the other pair of nodes. Diode IN4007 is used for bridge rectifier and the circuit diagram is shown in Figure 5. The output from the rectifier is not uniform. It produces intermittent DC current so to get a constant voltage it is connect to capacitor of 25V and 100 micro farads. Since the diode is a unidirectional device that allows the current flow in one direction only. With this configuration of diodes in the rectifier, it doesn't allow the power to vary depending on the load requirement. So, this type of rectifier is used in constant or fixed power supplies. The constant output is shown in Fig 5 along with capacitor.

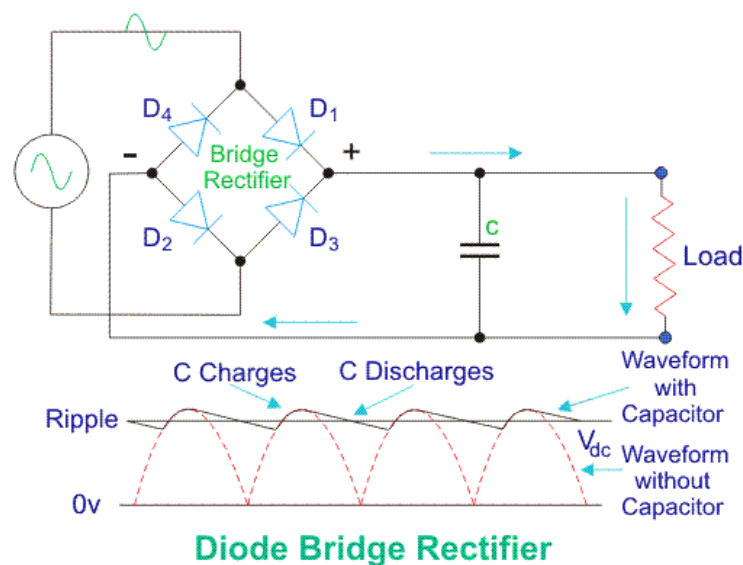


Figure 5: Bridge rectifier with capacitor circuit

A. Construction and working

The shock absorber consists of 4 piezo plates two are placed on the top end of shock absorber and two are at bottom as shown in Fig 6. The output from the piezo is rectified from AC to DC through diode bridge rectifier and voltage is made constant with capacitor then stored in battery. Piezo plate in shape of circular disk and size 30 mm was used. It is continuously tapped which is analogues to the force produced in shock absorber through vibration. The AC current from the piezo is rectified and stored in capacitor. It is connected to LED to show the constant current from the piezo plate. The piezo gradually charges the capacitor. 5V LED is used to check the circuit. The output from the piezo material is found using a multi meter.

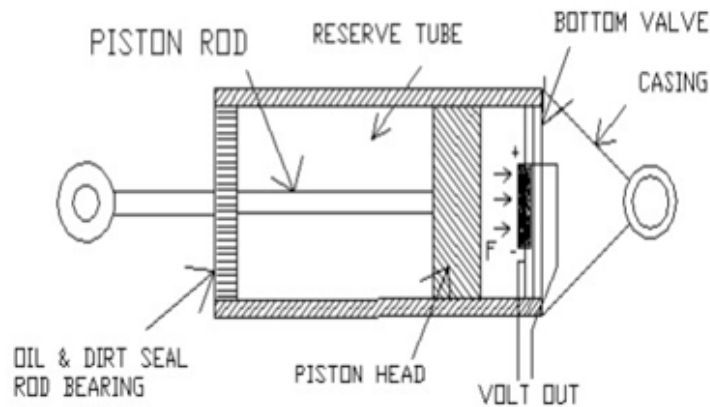


Figure 6: Position of PZT inside the housing in shock absorber

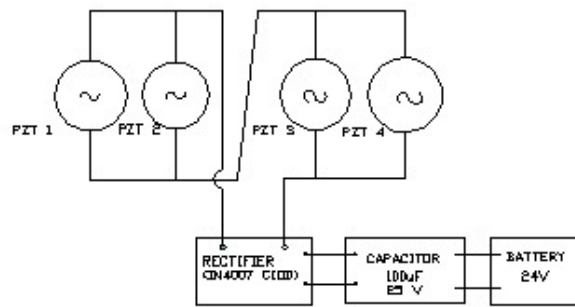


Figure 7: Position of PZT inside the housing in shock hardware amplification circuit

Power from the piezoelectric material is small which is to be amplified before giving it to battery. Amplification with electric circuit is not feasible because an additional voltage has to be given to compensate the drop in current during amplification so amplification with hardware components with parallel and series connection were performed as shown in Fig 7. Circuit when connected in parallel, current adds up and voltage remains constant and Circuit when connected in series, voltage adds up and current remains constant. With this method, the 2 piezo plate on the top end and bottom end individually are connected in parallel. The piezo plates in the top and bottom end of shock absorbers are connected in series. Thus, making possible of increasing both current and voltage.

B. Calculation of efficiency of quartz

When two plates are connected in parallel maximum voltage produced = 2.7 V, maximum current produced = 0.061 A. Piezo plates on the upper and lower end of shock absorber are connected in series.

$$V = V_1 + V_2 = 2.7 + 2.7 = 5.4V \tag{1}$$

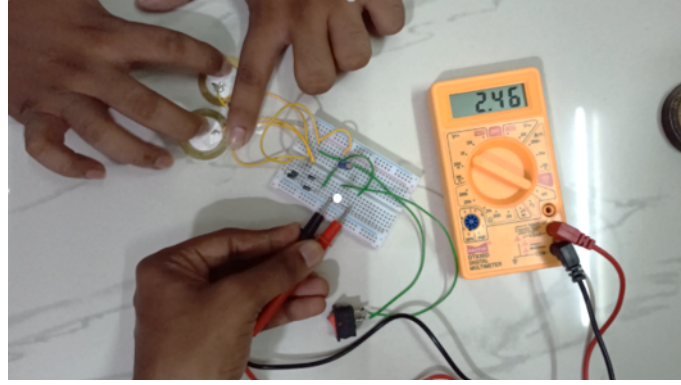


Figure 8: Testing of Quartz piezo plate

Current Remains constant

$$I = I_1 = I_2 = 0.061A \quad (2)$$

Power produced from 1 shock absorber = $V * I$

$$P = 5.4 * 0.061 = 0.33J/s \quad (3)$$

Power produced from 2 shock absorber = $2P = 0.66J/s$ Power given by charger of electric of Electric Vehicle Minimum output from the charger required is 3 A and 48V

$$P = V * I = 3 * 48 = 144J/s$$

$$\text{If } 144J/s = 100\% \text{ then } 0.66J/s = 0.47\%. \quad (4)$$

The same procedure for PZT5A is carried out using ABAQUS and COMSOL software. The electric potential value and surface charge were taken from the results as shown in Fig 9 and Fig 10. The current produced is 70 micro amp and 25.8 volts by single PZT 5A patch of $40 * 40 * 2$ mm for a pressure of 170 pa. Bore diameter of shock absorber will be 60 mm the maximum area that can be fitted is 1800.3 mm^2 .

Maximum voltage and current produced = 25 V & 0.14 A Piezo plates on the upper and lower end of shock absorber are connected in series.

$$I = I_1 = I_2 = 0.14A \text{ and}$$

$$V = V_1 + V_2 = 25 + 25 = 50V$$

Power produced from 1 shock absorber = $V * I = 7 \text{ J/s}$

Power produced from 2 shock absorber = $2P = 14 \text{ J/s}$

If $144 \text{ J/s} = 100\%$ then $14 \text{ J/s} = 9.72\%$.

Hence with PZT 5A there will be an output of 9%.

The sample material available was quartz which is poor material as a transducer but it can produce a power of 0.47 % of output from charger. If the material is replaced with PZT 5A there will be an output of 9%. Amplification with circuit is not feasible because it needs additional voltage from battery to amplify and to compensate the drop in voltage while amplification.

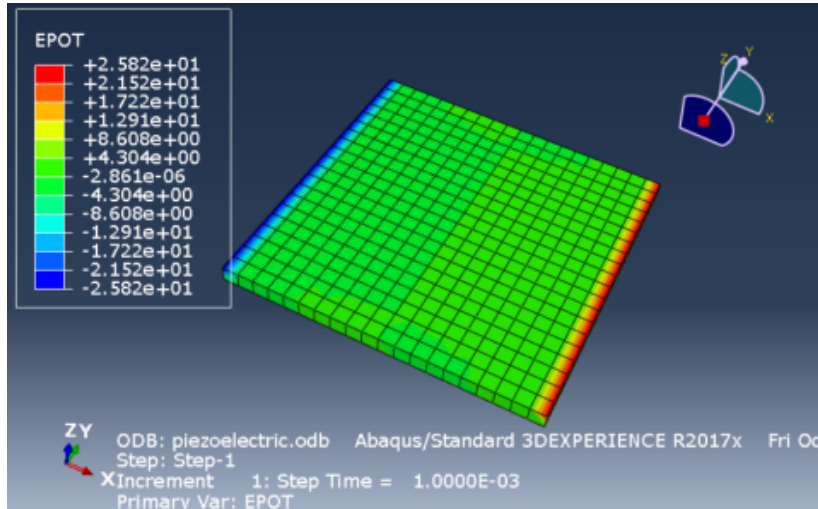


Figure 9: Electric potential of PZT patch

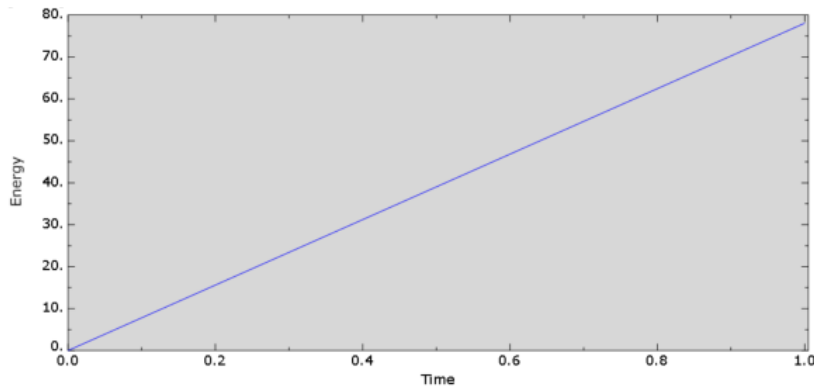


Figure 10: Charge produced by PZT patch

4. Modelling of housing for PZT plate

A. Modified piston rod and guide cylinder

The housing for piezo plates was modelled in Solidworks software. The existing shock absorber head is slightly modified to place the piezo plate inside. Two plates were introduced on both end of shock absorber. The groove for wire output is taken to facilitate the design. The model of top end and bottom end modified are shown in Fig 11 and Fig 12. This plate has threads which can be screwed easily into the existing shock absorber end plates without any major modifications. Their dimensions were given in Fig 13, Fig 14 and the exploded view is given in Fig15. The standard dimension for the shock absorbers was taken from the literature survey [7].

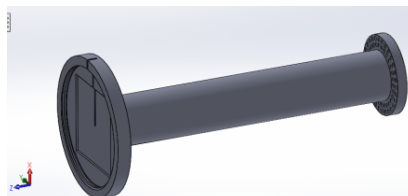


Figure 11: Modified top end in piston rod

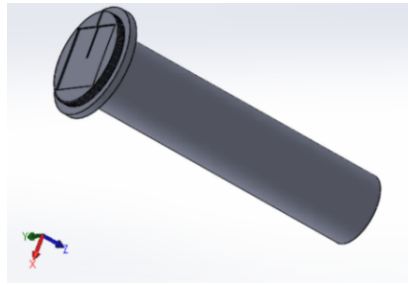


Figure 12: Modified bottom end in piston rod

B. Dimension of top and bottom housing for the PZT plate

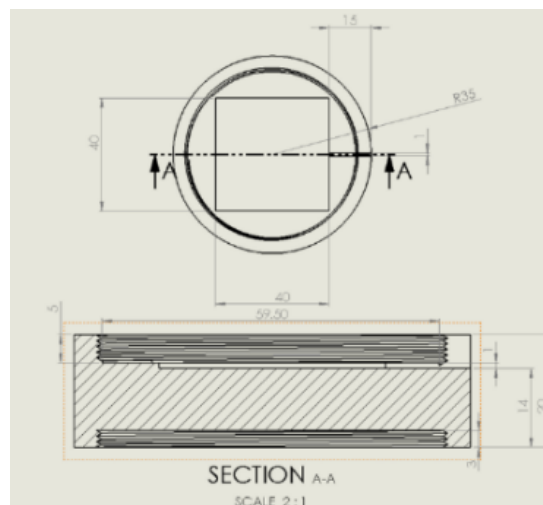


Figure 13: Dimension of plate for housing piezo electric material on top end

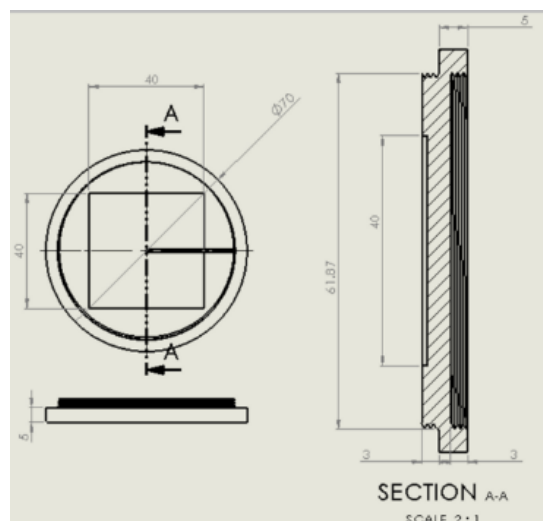


Figure 14: Dimensions of plate for housing piezo electric material on bottom end

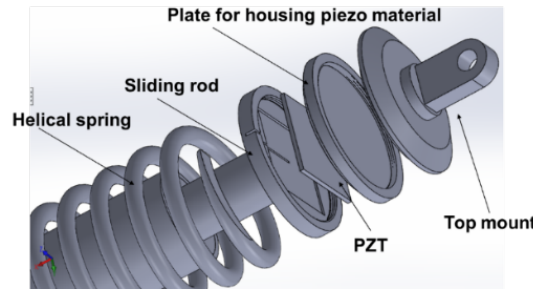


Figure 15: Exploded view of piezoelectric plate assembly at top end

5. Analysis

A. Analysis of force acting on housing of PZT plate

The analysis of force in housing was carried in Ansys software. The probe is placed on the housing. Bottom end of the shock absorber is given cylindrical support and the other end has force acting axially on the shock absorber. Lateral deflections were arrested by giving displacement support and only compression is permitted. 89.393MPa of stress was induced on the housing of PZT material on area of 2336.56 mm² shown in Fig16 and Fig17. So, the force which is acting on the plate on one side is 103.5kN.

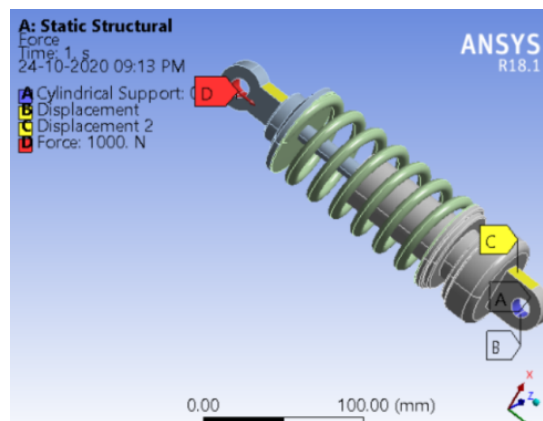


Figure 16: Boundary conditions

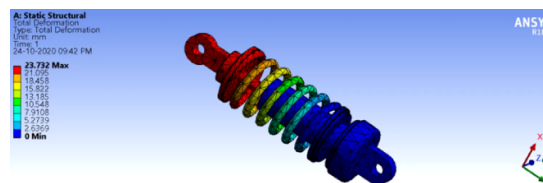


Figure 17: Total Displacement

B. FFT transform and Random vibration analysis

Random vibration of shock absorber is carried using the vibration data of a truck. The data is captured by using accelerometer placed on the chassis of the truck. Vibration data Collected from Truck at Sampling Frequency of 1000 Hz. The accelerometer should be placed at shock absorber for

accurate results. Raw data consist of time domain data as shown in Fig 18, which is to be converted to frequency domain data as shown in Fig 20. Here MATLAB is used as a tool to do FFT and PSD analysis. Natural frequency of the shock absorber is calculated by doing modal analysis in ANSYS it was ranging from 64 Hz to 330 Hz. This is the prerequisite for random vibration analysis. Mode super position method is followed. The Frequency Vs G-acceleration data is given as input to Random vibration analysis and PSD load data can be taken as output. From the PSD load curve, the average load can be obtained from rms as shown in Fig19. For that average load, voltage and current that can be produced from PZT is studied using ABAQUS software further.

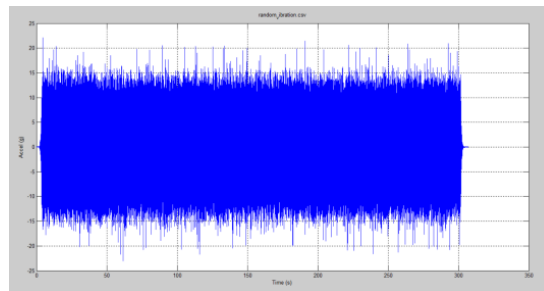


Figure 18: Time domain Data

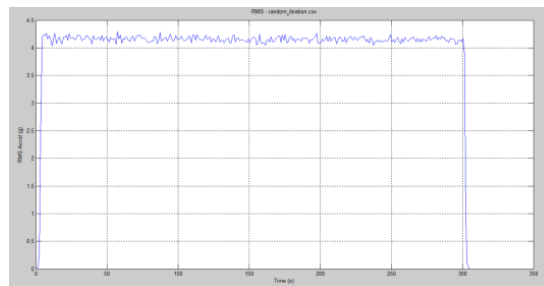


Figure 19: Rms Acceleration

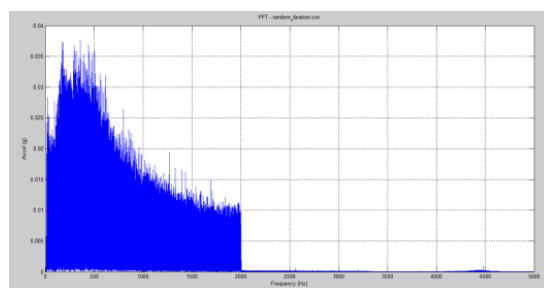


Figure 20: Frequency domain data

The values obtained from the PSD Curve is given as input to Random vibration analysis along x direction after solving for results we can get a response PSD curve in the same direction at desired location. Here the response PSD is taken at the point where is PZT is to be placed. The stress produced on the housing of shock absorber is 7.25MPa and in random vibration the results are given as probability distribution function and for 68.29% of time the stress is below the above value.

6. Results and discussion

The current produced is 70 micro amp and 25.8 volts by single PZT 5A patch of 40*40*2 mm for a pressure of 170 Pa. The storage capacity of the battery varies from 3200 mAh to 3500mAh and the time taken to charge the battery is 4 hours on average. 144 J/s takes 4 hours to charge completely.

$144 * (4 * 3600) = 2073600$ J this energy is stored in battery. The energy supplied by piezoelectric plates are 9J/s. $144/9 = 16$. This takes $16*4$ hours to charge the battery only by piezoelectric material without supply from main power charger. Mostly electric vehicles have 60-75 kilometers per charge and maximum speed varies from 25 to 40 kmph. In average considering 70 km per charge and vehicle and speed as 25 kmph for calculation. It takes 2.8 hours to cover the maximum milage of vehicle I.e.,70 km. If a piezoelectric plate produces a power Continuously for 2.8 hours $9*2.8*3600 = 90720$ J energy is produced.

If 2073600 J of energy can cover a distance of 70 km then 90720 J of energy would cover

$$(90720 * 70) = (x * 2073600)$$

$$X = 3.0625km$$

When compared to maximum range of 75km that an electric vehicle can travel 3.0625 km in addition which is 4% increase in terms of mileage per charge.

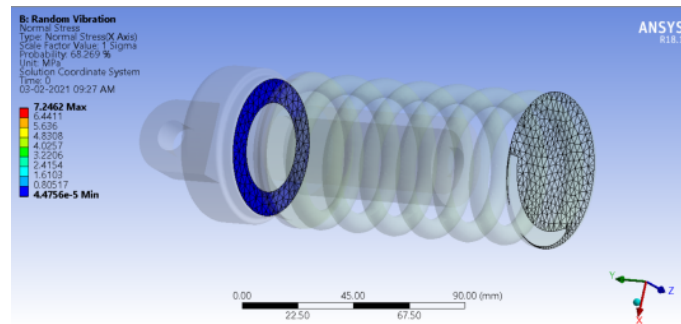


Figure 21: Stress produced due to random excitation

The resonance conditions for all the components were analyzed and the natural frequency is far apart from the induced frequency. To obtain the response it has been probed at the location of PZT plate for accurate values. The input PSD curve and the Response PSD curve is obtained to be similar for both top and bottom plate. which shows there is no induced frequency in the natural frequency range. There is one resonance condition occurring at the spring at 171 Hz. Since the random vibration is unpredictable and occurs for a very short period of time this can be overcome on accelerating the vehicle.

A. Analysis of PZT 5 A from random vibration analysis

For a PZT 5A material Elasticity property is orthotropic, Dielectric permittivity is anisotropic, Piezoelectric property is orthotropic. These properties are specified so that the stiffness matrix is generated for FEA calculations. Boundary conditions are specified Bottom face of the PZT is fixed as it rests on the housing. 7.25MPa of stress which is produced in the housing as shown in Fig 21 is divided to top and bottom faces and applied on the surface of PZT material as shown in Fig22. The element size of 2mm was used to mesh.

When 2 plates are connected in parallel Maximum voltage produced = 17 V as shown in Fig 23. Maximum current produced = 0.07 A Piezo plate on the upper and lower end of shock absorber are

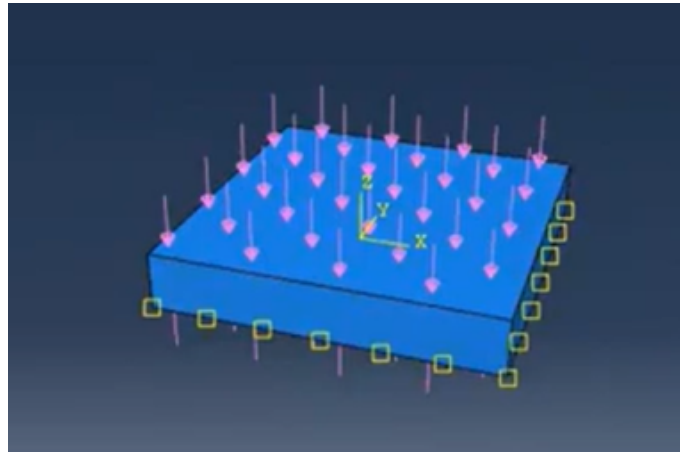


Figure 22: Load and support

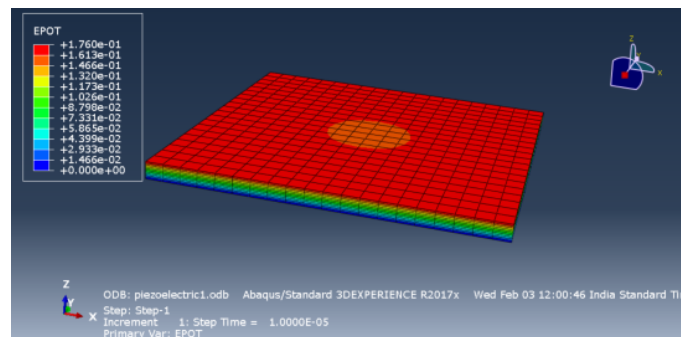


Figure 23: Electric potential plot

connected in series. Current Remains constant $I = I_1 = I_2 = 0.14A$. Total voltage $V = V_1 + V_2 = 17 + 17 = 34V$. Thus, the power produced from shock absorber is 6.6% when compared to the power produced on power adapter by using the vibrational data of truck. Since the truck is heavier than vehicles, g load is also higher and it can be expected that power produced will be less than 6%.

B. Comparison of various material at different locations

A comparative study of various materials like PZT-5A, PZT-5H, PZT-4 and PZT-8 was studied by placing it in different locations like top and bottom surface of the shock absorber, housing which was designed previously and outer surface of piston guiding cylinder.

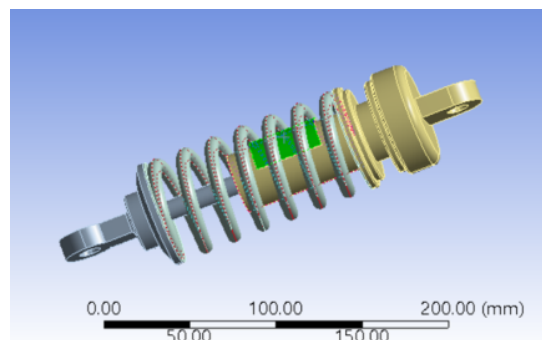


Figure 24: PZT on guide surface of piston rod

PZT on guide surface of piston rod. The Fig 24 shows the PZT patch placed on the surface of piston rod. It is bent to a curved shape and bonded to the surface of guide cylinder. One end of the shock absorber was fixed and the stress values obtained from the random vibration analysis was given on the other end to find corresponding voltage and surface charge density produced. Tetrahedral element with 5mm mesh size was used. Displacement support on all the direction except compressing direction was given as boundary condition. Lateral displacements were arrested in this way. The electric potential plot Fig25 shows 1.5 V of potential.

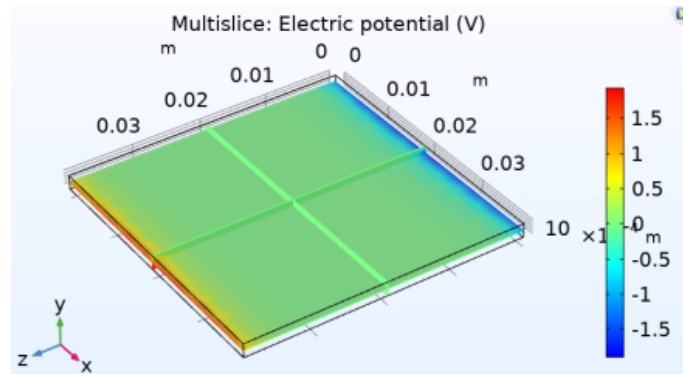


Figure 25: Electric potential plot

Electric potential: 1.5V

Surface charge = $10 \times 0.040 \times 0.040A = 0.016mA$

Surface energy density: $14J/m^3$

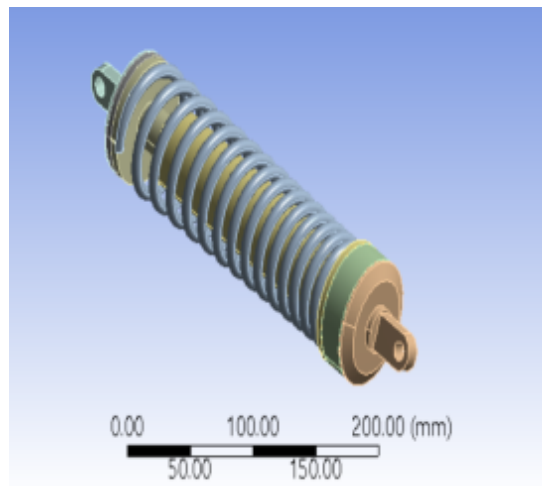


Figure 26: PZT on Top & bottom housing

PZT on Top & bottom housing. The Fig26 shows the PZT patch placed inside the top and bottom housing. The dimension and exploded view are shown previously. In all the cases maximum voltage was produced on the extreme edge of PZT which shows placing the probes at that position will extract maximum potential and surface charge density. The electric potential plot Fig27 shows 21V of potential.

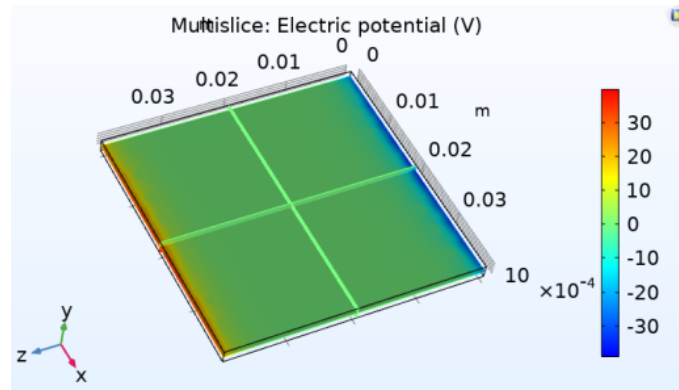


Figure 27: Electric potential plot

Electric potential = 21 V
 Surface charge = $35 \times 0.040 \times 0.040 = 0.056 \text{mA}$
 Surface energy density = 10J/m^3

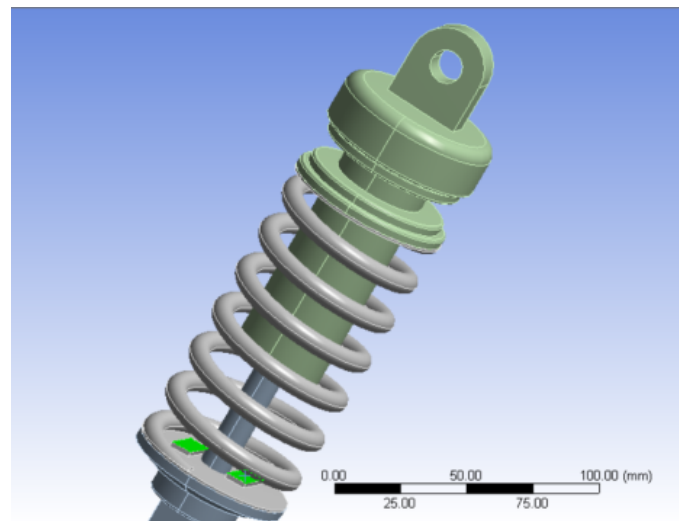


Figure 28: Pzt on top & bottom surface

PZT on top & bottom surface. The Fig 28 shows the PZT patch placed on the top and bottom surface of Shock absorber. PZT is split into 2 halves in order to accommodate the piston rod which is at the centre. In real time the potential output leads are exposed to ambient when PZT is placed on the surface of shock absorber which cause reduction in potential developed due disturbances. The electric potential plot Fig 29 shows 3V of potential.

Electric potential= 3 V
 Surface charge = $24 \times 0.040 \times 0.040 = 0.0384 \text{mA}$
 Surface energy density = 0.06J/m^3

Upon studying voltage, surface charge, surface energy density of PZT 5H & PZT 5A, PZT5H shows maximum voltage and surface energy density of 21V and 10J/m^3 on placing it inside the top and bottom housing as shown in graphical comparison Fig30. The PZT 5A is more stable than PZT5H while generating electric potential for longer period of time. Probing the output leads at extreme ends results in harvesting maximum possible power from the system as shown in previous analysis results.

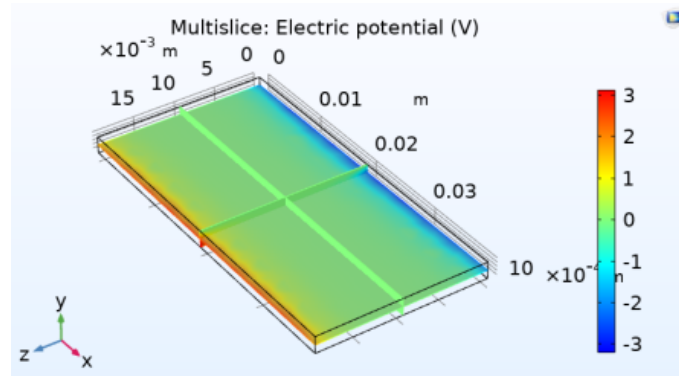


Figure 29: Electric potential plot

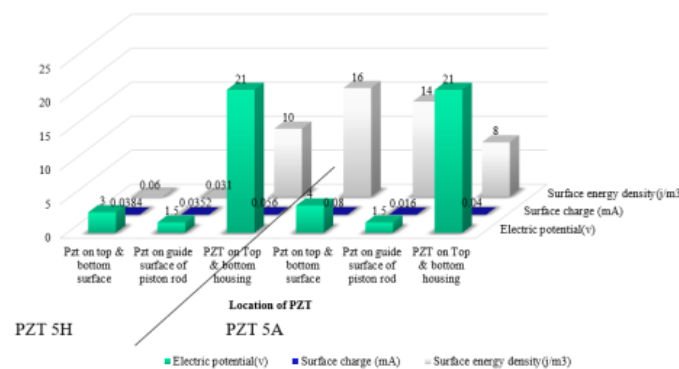


Figure 30: graphical representation of electric potential, surface charge and surface energy density for various materials.

7. Conclusion

The regenerative from shock absorber will be able to Recover energy from suspension vibration and charge the battery, increasing the mileage by 4%. Space for additional gadgets like mobile charging hub, health monitoring system. The weight of the system is not much high it does not affect the load carrying capacity Energy is produced near the speed breakers as well as on even slightly uneven roads. The power output from two shock absorbers of electric vehicles is 14 J/s which is 9% of power produced from charger. 90.720 kJ of energy from shock absorbers travels for a distance of 3 Km therefore mileage can be increased by 4 %. Rectangular PZT piezo plate produces more charge for applied force when compared to circular disk of same cross section PZT of Rectangular cross section is chosen. Amplification with circuit is not Feasible because it needs additional voltage from battery to amplify and to compensate the drop in voltage while amplification so hardware amplification was done. For the housing of piezo plate, the top and bottom plate of shock absorbers has to be modified which was designed and modeled.

References

- [1] D. Al-Yafeai, T. Darabseh and A. Mourad, *A state-Of-the-art review of car suspension-Based piezoelectric energy harvesting systems*, Energies 13 (9) (2020).
- [2] U. Aks and r. Halicioglu, *A review study on energy harvesting systems for vehicles*. Tehnicki Glasnik 12(4) (2018) 251–259.
- [3] P. Bialkowski and B. Krezel, *Diagnostic of shock absorbers during road test with the use Of vibration FFT And cross-sSpectrum analysis*, Artykul-Szczegoly 18(1) (2017) 79–86.

- [4] B. Lafarge, C. Delebarre, S. Grondel, O. Curea and A. Hacala, *Analysis and optimization Of a piezoelectric harvester On a car damper*, Int. Cong. Ultrasonics, 2015 ICU Metz. Elsevier. (2015) pp.970–973.
- [5] S. Mohapatra, S.K. Kamilla, P. Pattnaik and G.Bose, *Comparative study of different piezo-electric materials based ultrasonic transducer model*, COMSOL Conf. 1 (2011).
- [6] A. Nechibvute, A. Chawanda and Pearson Luhanga, *Finite element modeling of a piezoelectric composite beam & comparative performance study of piezoelectric materials for voltage generation*, ISRN Materials Sci. 4 (2012).
- [7] P. Poornamohan and T. Lakshmana Kishore, *Design and analysis of a shock absorber*, Int. J. Eng. Res. Technol. 1(4)(2012) 578–592.
- [8] M. Wang, Y. Xia, H. Pu, Y. Sun, J. Ding, J. Luo, Sh. Xie, Y. Peng, Q. Zhang and Z.Zh. Li. *Piezoelectric energy harvesting from suspension structures with piezoelectric layers*, Sensors. 20(13) (2020) .