Power Generation from Leaf Springs Using Piezoelectric Materials

Mohibb E Hussain Jamadar[1], Dr. B. S. Manjunath[2]

[1]*M. Tech. Student, Department of Mechanical Engineering, KLE Dr. MSSCET, Belagavi, Karnataka, India*
[2]*Professor, Department of Mechanical Engineering, KLE Dr. MSSCET, Belagavi, Karnataka, India*

Abstract:*This paper introduces a concept of using piezoelectric material in leaf springs so that some amount of power can be generated to feed the battery onboard the vehicle. A conventional leaf spring with spring steel as material will be modeled in SOLID EDGE ST8 and analyzed in ANSYS WORKBENCH 15.0. Procedure will be repeated for spring with piezoelectric material and results will be compared with those of conventional material leaf spring. Amount of power generated will be theoretically calculated and power harvesting circuit will be designed and simulated in NI MULTISIM 14.0 to obtain the waveform of generated voltage signal.*

Key words:leaf spring, spring steel, piezoelectric, PVDF.

1. INTRODUCTION

Dependency of mankind on technology has been increasing exponentially since the time immemorial. Electricity is an essential part of this technology. Therefore, the demand for electricity has been increasing exponentially. And to fulfil this demand nearly every known source has been exhausted and people are now seeking new sources. One of those resources is piezoelectric materials.

When certain materials are applied with load they generate electric current. This phenomenon is known as piezoelectric effect and the materials possessing this property are known as piezoelectric materials. Since these materials require some amount of load to operate, they are placed in the suspension system of the vehicle since it is always under load even when the vehicle is at rest.

Piezoelectric power generation is not a new concept. Power generation from shoe sole and stair case are some of the examples.

2. LITERATURE REVIEW

W. Hendrowatti et. al. in 2012 designed a vibration harvesting system with multilayers of piezoelectric material. The aim here was to use the vibrational energy from the suspension system of the vehicle, amplify it and use in to generated electricity using piezoelectric materials. The experiment turned out to be successful with 2 to 5 volts of average voltage generated.

V. Prasannabalajiet. al.[8] from Sri SriRam college of engineering, Chennai proposed a design in 2013for piezoelectric power generation from staircase.

Kiran Boby et. al.[7] from MACE, Kothamangalam in 2014 proposed a design to generate piezoelectric power from shoe sole. The experiment turned out to be successful and they were able to produce about 40V of energy promising a bright future in piezoelectric power generation.

Inspired form the above literature review this paper makes an attempt to introduce the concept of generating power from leaf springs via piezoelectric materials.

3. METHODOLOGY

First a simple problem is selected involving designing a leaf springs with conventional spring material. Based on the permissible stresses in this spring the dimensions are calculated. A CAD model is developed using SOLID EDGE ST8. The stress analysis of this CAD model is carried out in ANSYS 15.0 to find the error in theoretical and software solutions. The same stress analysis is repeated but now with the cad model containing the piezoelectric material. These results are now compared with those with the spring steel to determine whether the modified spring can withstand the loading conditions. Finally, the amount of power generated will be calculated based on the data obtained from the simulation of the power harvesting circuit in NI MULTISIM 14.0.

4. THOERETICAL CALCULATIONS

Problem statement:

A car weighing 9000N has a capacity of 5 passengers each weighing 600N. It has wheel base of 2000 mm has its center of gravity at 1100 mm behind the front axle. The car is to be supported on 4 similar long semi-elliptical carriage springs of each 840 mm between shackle pins. Design a suitable spring using a factor of safety of 1.5 on proof stress of 0.84 GPa. The static loads are to be multiplied by a load factor of 2.5 to allow the impact load. The maximum deflection of the leaves equal to 50mm. Number of full length leaves are 2 and graduated leaves 8. Take E= 210 GPa.[1]

Solution:

→ Load calculation:

Total load W = (9000 + 5x600) x 2.5 = 30000 N

Load on rear axle = R_A can be found as

R_A x 2000 = 30000 x 1100, RA = 16500 N

load on front axle F_A = 30000 -16500 = 13500 N

Thus the spring design is based on the rear axle load.

Load on each spring = 2F = R_A / 2 = 8250 N

F = 4125 N.

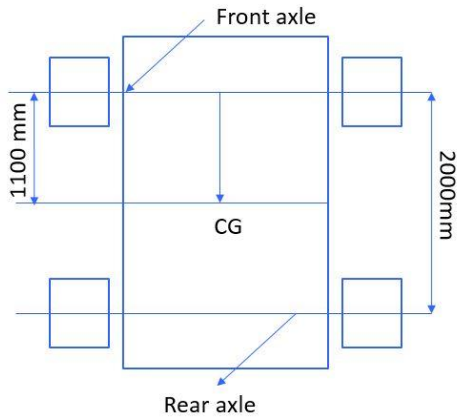

Fig-1: Schematics of vehicle for load calculations

→ Spring dimension calculations

$$\sigma_f = \frac{1.5\alpha FL}{nbh^2}, \delta = \frac{\beta FL^3}{Enbh^3} \quad (4.1)$$

where σ_f, δ are the stress and deflection, b and h are the width and thickness of each leaf and E is the Elastic constant of material used (spring steel).

Taking the stress and deflection values from given problem the only unknown values are b and h. After calculation the following values were obtained and the designed cad model is as shown below.

Spring width = 60 mm, Leaf thickness = 6.5 mm, Master leaf span = 840 mm, Number leaves = 2+8 = 10.

The amount of stress and deformation in the above designed spring is calculated from the below formulae taken from one of the references mentioned at the end.

$$\sigma = \frac{6WL}{nbt^2}, \delta = \frac{6WL^3}{nEbt^2} \quad (4.2)$$

Now the CAD model of the designed spring was analysed for stress in ANSYS 15.0 and the results thus obtained were compared with those calculated theoretically. This comparison allows the user to determine how much the software is dependable for analysis.

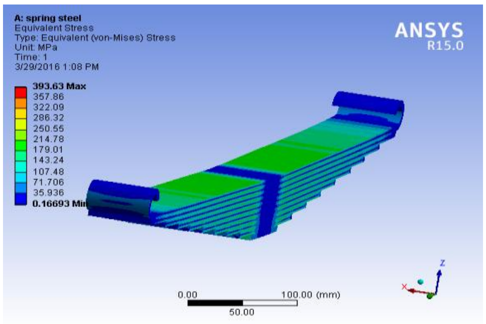

Fig-2: Stresses developed in spring steel leaf spring

Table-1: Comparison of theoretical and Software results

	Permissible values	Theoretical values	ANSYS solution	% Error
Maximum stress (N/mm^2)	560	410.06	392.64	4.2
Maximum deflection (mm)	50	26.49	22.02	16.8

5. MODIFIED DESIGN

The piezoelectric materials are mainly ceramics and hence are quite brittle in nature, hence their limited use. But one of these materials is actually a polymer which goes by the abbreviation PVDF that stands for PolyvinyledeneFlouride. Polymers are mostly plastic and so is this one. The elastic nature of this material make it acceptable to be used in leaf springs. But this material is more elastic than that of the spring steel itself.

Table-2: Properties of PVDF

Property	Value
Density (kg/m^3)	1780
Elastic Modulus (GPa)	2.4
Poison's ratio	0.34
Flexural strength (MPa)	20-50

From the above properties it can be seen that this material is more elastic than the spring steel itself. If all the leaves in the leaf spring are replaced with this material, the deformation will be higher than the permissible value. Therefore, only some of them will be replaced with the material. The below figure give an idea about which of the leaves will be replaced.

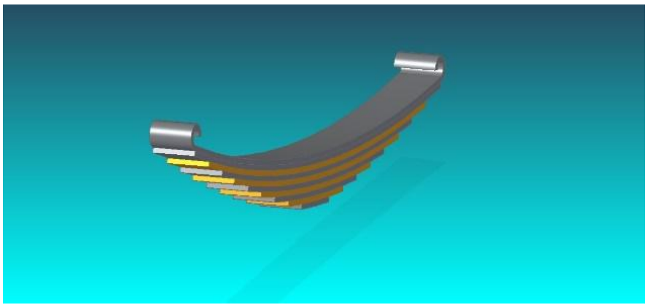

Fig-3: Modified design of leaf spring

In the above figure, the grey leaves are made of the conventional spring steel and the yellow ones are made of PVDF. To determine the effect of this modification, earlier CAD model was also modified and same analysis was carried out and following results were obtained.

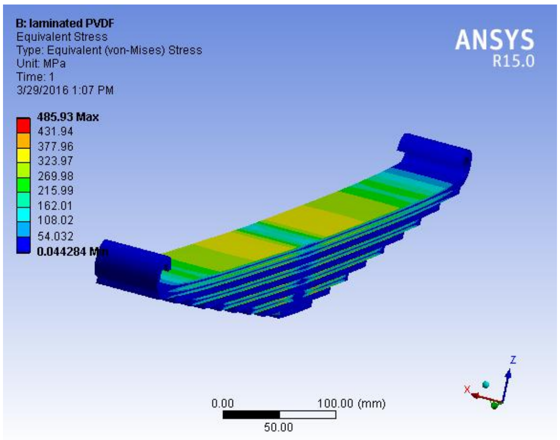

Fig-4:Stresses developed in spring with PVDF

In the above figure it can be observed that the stress developed in the PVDF leaves is homogeneous and at the minimum as compared to the spring steel leaves. Therefore, this value of the stress will be used in further calculations for amount of voltage generated.

Table 3:Comparison of results of conventional and modified design

	Spring steel	**PVDF**
Stress (MPa)	393.63	485.93
Deflection (mm)	22.82	40.42
Stiffness (N/mm)	180.76	102.05

From the above table it can be clearly seen that the stresses generated in the spring with PVDF are higher than the one with only spring steel indicating probable early failure than the one with only spring steel material. And the stiffness has also reduced as an obvious result of the lower Young's modulus.

6. MODAL ANALYSIS

Modal analysis determines the comfortability of a suspension system. When material of some of the leaves in the spring was changed, it comfortability also changed. Hence, modal analysis was carried out for both the conventional and modified design in ANSYS 15.0 and frequencies for different mode shapes were obtained and upon comparison following results were drawn. The average frequency of the road was assumed to be 12 Hz (Yu and Kim, 1988) which forms the base to determine the comfortability.

Table-4: Mode shape frequencies

Mode shape	Spring (Hz)	PVDF(Hz)
1	229.38	211.67
2	377.85	275.72
3	443.71	350.36
4	714.72	568.8
5	853.52	666.31
6	1016.3	733.48

7. CALCULATIONS FOR POWER GENERATED

When the stresses developed in a piezoelectric element are homogeneous, the voltage generated will depend only on the thickness of the element which is given by,

$$V = -g_{31} \times \sigma \times t$$

Where σ is the stress developed (0.44 MPa), g_{31} is the piezoelectric constant that determines the amount of voltage generated based on the amount of load applied whose value for PVDF is 0.22 Vm/N and t is the thickness of the element (6.5mm). The amount of voltage generated for one leaf in the spring turned out to be 630 Volts. This raw voltage cannot be directly used to feed the battery onboard hence a circuit needs to be designed to modify it.

8. POWER HARVESTING CIRCUIT DESIGN

The amount and consistency of the voltage generated from piezoelectric element are dependent on the load that is acting on the element and since the contour of the road is unpredictable, therefore the voltage generated will also be unpredictable. Thus a circuit needs to be designed so that voltage available for the battery is continuous.

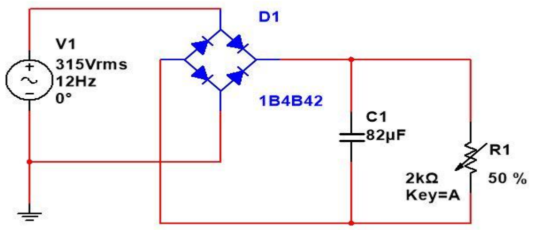

Fig-5: Power harvesting circuit

The above figure shows the schematic of the circuit was used to simulate the voltage in the software NI MULTISIM 14.0. The piezoelectric element is represented here in the form of AC source with half of the calculated voltage value as the RMS value with 12 Hz frequency which is the average value assumed to be of the unevenness of the road. This change is because, apparently, there is no software to represent in such a way that induced stress can be given as input and voltage generated can be obtained as output. It mainly consists of AC power source (represents piezoelectric material), a full wave bridge rectifier to convert the variable voltage to continuous DC voltage, a capacitor to store the charge and a variable resistor to act as load on the circuit.

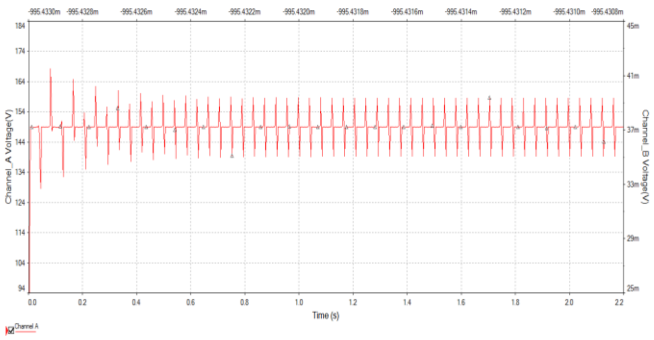

Fig-5: Waveform of voltage generated

Simulation of the above circuit showed that the amount of power generated is about 20 Watts, continuous DC voltage generated varies between 138 V-158 V and the amount of current generated is about 220 milliamperes. These reading belong to only a single piezoelectric leaf. Now, according to modification made in the design there are totally 16 piezoelectric leaves. If these are connected in series, a source of 3.2 Amperes will be available.Now, the amount of time required to charge a battery mainly depends on the current rating of a source which is very low in this case. Therefore, theoretically, it was found that it takes about 15 hours to charge a cellphone battery, hence it can be safely said that it will take much longer to charge a four-wheeler battery. The only expensive element in the above mentioned circuit is the piezoelectric material. After some calculations the total cost of the circuit along with piezoelectric material was found to be Rs 2220/- for 4 leaf spring each consisting of 4 piezoelectric leaves.

9. CONCLUSION

The stress analysis concludes that, a leaf spring with PVDF can sustain the load conditions (theoretically) but at the cost of stiffness and comfortability. The amount of voltage generated also seems to be enough to charge the battery onboard the vehicle but the value of current generated reveals that it will take a huge amount of time to fully charge the battery. Moreover, many assumptions have been made on the way. Thus, to determine feasibility of this concept experimental study needs to be done in all the aspects discussed till now.

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