A STUDY ON DESIGN OF POWER GENERATION FROM SPEED BREAKER

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ABSTRACT

Innovations and their applications stand at the root of developments for any nation. With increasing population and depleting reserves of natural resources, it is getting more difficult to satisfy the public needs. The shortage of various resources has caused a rise in prices. Many renewable sources of energy are available in abundance like solar, wind, tidal, etc. Generation of energy using such resources that are present in ample amounts is a new highway towards a better tomorrow. The force exerted by vehicles on the speed breakers is one such source that can help in generating energy in lower budget. Design and Fabrication of Power Generation from Speed Breaker is one such practice towards the usage of renewable sources of energy to generate power. Using rack and pinion mechanism helps converting force by vehicles into power and this in turn helps the nations from facing scarcity of resources. Piezoelectric cells also play a vital role in absorbing the force on speed breakers. The design and analysis done on Autodesk Inventor has shown us, the virtual representation of the system we are so eager to put forth.

KEYWORDS: Power generation, Rack and Pinion, Piezoelectric cells, Autodesk Inventor

INTRODUCTION

Modernization has given rise to the need to innovate and improvise. Conventional sources of energy have been used for many decades. This has caused the reserves of energy to decrease with passing time. The generation of power using non-conventional sources can allow us to create power without being concerned about that issue. These sources are present in huge amounts and are most likely never seizing to exist. Such a source of energy is the force exerted by vehicles on speed breakers when they are in contact [1-3]. The potential energy from vehicles is first converted into mechanical and then into electrical energy. By using this method, power can be generated for the longest time without having to worry about shortage of resources. The springs under the speed breakers get compressed when pressure from vehicles is applied on them [4-5].

The Piezoelectric crystals create an effect where they convert the exerted mechanical force input into electrical output. These crystals when under force will detect the deformation in them and convert it into
electricity. Piezoelectric effect is a reversible process for the materials that can directly exhibit piezoelectric properties [6-9]. The material Lead Zirconate Titanate (PZT-4) carries direct piezoelectric properties and hence showcases reversible effects for the same [10-11].

The generation of power is vital for survival of human race. Over decades, many developments have been made to ease our living. The system for generating power using speed breakers can be made by application of the following mechanisms.

- Roller mechanism
- Rack and Pinion mechanism
- Lever mechanism

The research done on numerous papers published till date showed that the rack and pinion mechanism was proven the most efficient in power generation [12-13]. Like every attempt made up until now, the rack and pinion mechanism is used. The metal sheets along with the springs perfectly carry out the task of putting the rack and pinion mechanism to its use. The process of creating an electric current using this system utilizes the potential energy from vehicles which is wasted everyday due to lack of technologies that use this energy for better outputs. Various applications of such systems can help avoid wastage of such sources of energies which are non-conventional and present in huge quantities thus maintaining the economy as well.

**METHODOLOGY**

In this work, following mentioned block diagram Fig.1 of proposed methodology is used. Whenever the vehicle is allowed to pass over the dome, it gets pressed downwards. With downward motion of dome, springs attached to the dome are compressed. Springs help the dome to come up again when there is no load, so that too and fro motion is continued.

![Figure 1: Block Diagram](image)

The rack which is attached to the bottom of the dome moves downward in reciprocating motion. Since the rack has teeth connected to gears, there exist conversion of reciprocating motion of rack into rotary motion of gears, but the two gears rotate in opposite directions. A flywheel is mounted on the shaft whose function is to regulate the fluctuation in the energy and to make the energy uniform. So, that the shafts will rotate with certain constant R.P.M. These shafts are connected through a belt drive to the dynamos. Dynamo converts the mechanical energy of the reciprocating rack into
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electrical energy. Whenever an armature rotates between the magnetic fields of south and north poles, it cuts the magnetic lines of force of the dynamo and an E.M.F (electromotive force) is induced in it. So, for inducing the E.M.F, armature coil has to rotate. For rotating this armature, it is connected to a long shaft. By rotating, same E.M.F. is induced. For this rotation, kinetic energy of moving vehicles is utilized. The reciprocating motion of dome also leads to the compression and expansion of the piezoelectric crystals. This piezoelectric crystal is a transducer which produces E.M.F due to strain in it. This can also be used as energy generating source if induced with speed breaker and generate electricity.

APPLICATION

Local power generation, Local display board, Street lightening, Charging the battery; two protocols of this type of speed breakers are developed in India, not practically implemented until date, practically implemented in New Jersey, China and Indonesia. It can be fitted onto the entry gate of Roll-on and Roll-off ship where on an average around 2000 vehicles enters and exits and each vehicle has at least two wheels, therefore, on an average, the speed breaker can be pressed around 4000 times at a given loading/unloading time. The energy so produced can be stored in a large capacity battery and can be used to operate gate of the Ro-ro ship or some local lighting provision can be made available.

Standby charging booth can be developed for electric bicycles and delivery scooters.

DESIGN ANALYSIS

Spur Gears

The gears are the most important part of the project. The work of converting linear motion beneath the bump of speed breakers into rotational motion is done by these racks and pinion spur gears. The specifications of rack and pinion gear used for the project are as follows:

- Material = Alloy steel
- Module = 4mm
- Number of teeth, on pinion \( z_1 \) =2, on rack \( z_2 \) =80
- Width of gear \( b \) =48mm
- Pitch diameter \( d_1 \) =80mm
- Pressure angle (\( \Phi \))=200 full depth involute.

![Figure 2: Rack and Pinion Spur Gears](image)

The Rack and Pinion Spur Gears is illustrated in Figure 2. Since pinion is the weakest member, safe design of pinion will ensure the safety of rack. So, analysis on pinion is carried out in Autodesk Inventor software which ensures a
minimum factor of safety of 2.36 everywhere in the pinion as shown in Figure 3. Hence, the design is considered to be safe.

![Figure 3: Safety Factor of Pinion by Analysis](image)

**SHAFT**

The shaft is the torsion member of the assembly. There are two shafts present in the assembly. On the first shaft, pinion and bigger sprocket are mounted and on the other shaft flywheel, smaller sprocket with freewheel is mounted.

- The specifications of the shafts are as follows:
  - Material = Alloy Steel ($\sigma_y=250$MPa, $\sigma_{ut}=400$MPa)
  - Diameter = 45mm

  Analysis done in the Inventor shown in the Figure 4 shows that the factor of safety for the overall shaft of minimum 6.08. Hence, the design is considered to be safe.

![Figure 4: Safety Factor of Shaft by Analysis](image)
SPRINGS

The important part in the project is played by the springs. Once the rack gets the downward motion due to the weight of the vehicle, the speed breaker needs to retrace the same upward path so that it can continue to generate the downward linear motion. The spring shown in Figure 5 retracing the upward path and resets the rack to original position without shock. Thus, it is very necessary to select spring of stiffness such that it can give effective deflection as well as should have enough compressive strength to withstand heavy loads.

The specifications of spring selected are as follows:

- Material = Stainless steel (440C), \(\sigma_y=689\text{MPa}, \sigma_{ut}=861\text{MPa}\)
- Spring Index = 10
- Wire diameter = 11mm
- Mean coil diameter = 110mm

![Figure 5: Spring](image)

When a modeled spring is analyzed on the Inventor software, it is obtained that it has the minimum factor of safety as 2.14 as shown in Figure 6. Hence, the design is considered to be safe.

![Figure 6: Safety Factor of Spring by Analysis](image)
CHAIN AND SPROCKET WITH RATCHET

The chain and sprocket are used for transmitting the torque on the first shaft to the second shaft which is connected to the motor. The smaller sprocket and second shaft are attached with each other by the ratchet mechanism. After downward motion of the rack, it retraces its path in upward direction which rotates the shaft in the opposite direction. So, to avoid the rotation of shaft attached to motor in the opposite direction, ratchet mechanism is used between second sprocket and shaft. The specifications of sprockets used are as follows:

- Material = Mild Steel
- Number of teeth, \( Z_1 = 12 \)
- \( Z_2 = 26 \)
- Pitch \( (p) = 15.875 \text{mm} \)
- Pitch Diameter, \( d_1 = 61.34 \text{mm} \)
- \( d_2 = 131.7 \text{mm} \)

Figure 7: Chain-Sprocket with Ratchet

Freewheel/Ratchet specifications:
- Material = Mild steel
- Number of teeth = 14
- Freewheeling = one direction
- Chain specifications:
  - Pitch \( (p) = 15.875 \text{mm} \)
  - Roller diameter \( (d) = 10.16 \text{mm} \)
  - Width \( (w) = 9.55 \text{mm} \)
  - Breaking Load = 4440 kgf (min, ISO Standards for chain number 10 A-2)

SHEET METAL

The sheet metal is shaped as the replica of the speed breaker. The sheet metal is connected to the rack. When vehicle passes over the speed breaker (i.e. over a sheet metal), the weight of the vehicle displaces the sheet metal which in turn displaces the rack to generate power. So, sheet metal should be strong enough to withstand the load of vehicles acting on it so that it can impart linear motion to the rack to generate electricity.
The specifications of sheet metal are as follows:

Material = High strength, low alloy

Steel ($\sigma_y = 275.8$ MPa, $\sigma_{ut} = 448$ MPa) The analysis report of sheet metal speed breaker says that the model made has the factor of safety of 4.51 minimum over the entire sheet metal as shown in Figure 8. Hence, its design is considered as safe.

![Figure 8: Safety Factor of Sheet Metal by Analysis](image)

**ASSEMBLY AND WORKING PRINCIPLE**

The generation of power from speed breakers is the system that works on rack and pinion mechanism. The breaker bump is covered by metal sheet underneath which one side of the bump is fixed, whereas the other side consists of springs attached to them. The vehicles passing over the bump apply pressure on the metal sheet and the springs are thus compressed. Once the vehicle loses its contact with the breaker, the springs expand to their original position. This compression and expansion of springs provides motion to the rack and pinion mechanism.

![Figure 9: Safety Factor of Spring Analysis](image)

Safety factor of spring analysis is shown in Figure 9. The simple linear motion by springs is then converted into rotary motion by the gears. The two gears rotate in opposite directions with respect to each other. Flywheel is mounted on the shaft to prevent fluctuation of energy keeping it uniform. Dynamos are connected to shaft through belt drives. Dynamos convert the mechanical energy from rack and pinion into electrical energy. The rotation of armature cuts through the magnetic lines of force of the dynamo creating an E.M.F. which is ultimately the output electrical energy. The compression and expansion of the springs also affect the piezoelectric crystals. This movement causes deformation in the crystals that impose strain on them resulting in formation of E.M.F. within the system.
The piezoelectric crystals respond to the slightest deformation, which results in detection of motion over a small movement. This ensures the smallest force exerted on the bump to be detected by the system and used in converting it into electrical energy.

**OUTPUT CALCULATION FROM PIEZOELECTRIC CELL**

Output Voltage from piezoelectric cell is given by,

\[ V = \frac{\varepsilon_r \varepsilon_0 \Delta V}{d} \]

Where,

- \( V \): Output Voltage
- \( d \): Thickness
- \( \varepsilon_r \): Relative Permittivity
- \( \varepsilon_0 \): Dielectric Permittivity
- \( \varepsilon_r \): Piezoelectric constant
- \( F \): Force applied
- \( A \): Area
- \( r \): Radius of piezoelectric cell
- \( \gamma \): Relative Permittivity
- \( \varepsilon_0 \): Dielectric Permittivity

Material: PZT-4

Properties of PZT-4:

- \( d = 295 \times 10^{-12} \) m/V
- \( \varepsilon_r = 8.85 \times 10^{-12} \)
- \( \varepsilon_0 = 1300 \)

Dimensions of piezoelectric cell:

- \( r = 10 \) mm
- \( t = 1 \) mm

Let the force of 100N be applied on piezoelectric cell.

Then,

\[ V = \frac{295 \times 10^{-12} \times 100 \times 10^{-3}}{8.85 \times 10^{-12} \times 1300 \times 3.14 \times 10^{-4}} \]

\[ V = 8.16 \text{ V} \]

Using the above equation, calculation of voltage shown in Table 1 for different loads is tabulated below:
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Table 1: Voltage Calculation

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Load (N)</th>
<th>Output Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>8.16</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>16.33</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>24.49</td>
</tr>
<tr>
<td>4</td>
<td>400</td>
<td>32.66</td>
</tr>
<tr>
<td>5</td>
<td>500</td>
<td>40.83</td>
</tr>
</tbody>
</table>

OUTPUT POWER CALCULATION FROM RACK AND PINION MECHANISM

Let us consider,

The mass of a vehicle moving over the

Height of speed brake = 200mm

Equivalent stiffness of the springs (K)

=\( n \times 13.492 \text{N/mm} \)

=\( 3 \times 13.492 = 40.496 \text{ N/mm} \)

where,

\( n \) is number of springs (as here 3 springs are taken in parallel, thus here \( n = 3 \))

Work done = Force \times\ Displacement = \( F \times s \)

where,

Force = Weight of the Body = \( M \times g \times F = M \times 9.81 \text{m/s}^{2} \)

Displacement of the speed breaker (s) = \( F \div K \)

Output power = \( \frac{F \times s \times 0.001}{60} = P(\text{in min}) \text{ Watts} \)

(This is power developed for 1 vehicle passing over the speed breaker arrangement for one minute)

Power developed for one hour (\( P(\text{in hr}) = P(\text{in min}) \times 60 \text{ watts} \))

Power developed for one day (\( P(\text{in day}) = P(\text{in hr}) \times 24 \text{ watts} \))

Using all above derived information finding values for various values of power at various loads and tabulating them.

Power calculation shown in Table 2.

Table 2: Power Calculation

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>M (in kg)</th>
<th>( F = 9.81 \times M ) (in N)</th>
<th>( s = F \div K ) (in mm)</th>
<th>( P(\text{in min}) = \frac{F \times s \times 0.001}{60} ) (in watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>981</td>
<td>24.22</td>
<td>0.396</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>1962</td>
<td>48.45</td>
<td>0.792</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>2943</td>
<td>72.66</td>
<td>1.187</td>
</tr>
<tr>
<td>4</td>
<td>400</td>
<td>3924</td>
<td>96.88</td>
<td>1.584</td>
</tr>
<tr>
<td>5</td>
<td>500</td>
<td>4905</td>
<td>121.1</td>
<td>1.98</td>
</tr>
</tbody>
</table>
RESULT

The output obtained at different load condition for piezoelectric and rack and pinion mechanism is tabulated above. As load increases, deflection of spring increases, which results in increasing torque in the shaft and thus, power generation by mechanism increases. In piezoelectric, when pressure on the piezoelectric cell increases the voltage also gets increased. The total output will be the combination of both these output, i.e. from piezoelectric cells as well as rack and pinion mechanism. This combination helps in harnessing power at the speed breakers.

CONCLUSIONS

The proposed work is an attempt towards generating power using combination of piezoelectric cells and rack and pinion mechanism. One of the goal is to make the design compact which can be easily maintained and placed anywhere on the road. This project is a step towards technology created using nonconventional source of energy to create a better opportunity for future applications. The main setbacks of economy and space have been taken into consideration while making of the whole project. With some changes in design, the efficiency of the overall system can be increased to obtain greater output with time.

REFERENCES

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