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Analysis of Power Generating Speed Breaker Based on Modified Slider Crank Mechanism

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Abstract

The project focuses on producing energy through non-conventional sources. Ever increasing energy demand may not be satisfied by fossil fuels or other conventional energy sources in coming future. Also burning fossil fuel to extract energy for various uses is a major concern in today's scenario as it is polluting our environment .This project aims to extract energy from vehicles through the speed breaker without polluting the surrounding. A lot of benefits are mentioned like uses of renewable resources, eco-friendly. But what make this project interesting and unique is the use of piezoelectric discs which acts as transducers and convert force into electrical energy. At last it also discusses the parameters and calculations necessary for making this project and working model.

Keywords: Speed Breaker, Slider Crank Mechanism, Rack and pinion Mechanism, Piezoelectric sensor, Piezoelectric Mechanism

1. Introduction

Energy plays a great role in developing a nation. But the sources of energy are limited. Conventional sources are diminishing in amount at a rapid rate due to increased demand. Also sustainable development requires limited use of polluting fossil fuels. Hence need of the hour is to find innovative and ecofriendly ways to produce energy. This work makes an attempt to harvest the kinetic energy of huge traffic to obtain useful energy. The kinetic energy of the moving traffic remains unutilized and in fact is wasted at speed breaker. This kinetic energy can beutilized to produce power by using modified SPEED BREAKERS incorporating piezoelectric effects. Slider crank mechanism along with rack and pinion is used to convert kinetic energy of vehicles into electrical energy. In addition to this pressure force of spring is additionally exploited through a piezoelectricmaterial. It directly converts force into electricity.

Speed Breaker Energy Generation (SPEG) have been explored as a non-conventional method of energy generation. ShraddhaDeshpande et al. [1] have assessed SPEG; however the voltage output generated by this power generation has found to be inadequate. G.Prabhu et al. [2] and Laukik et al. [3] have utilized rack and pinion mechanism in SPEG; however output voltage is only 1.5V. Dave [4] has incorporated Air compression method to build SPEG. Ali et al.[5] and Kafi et al.[6-8] also employed rack and pinion mechanism to extract energy from vehicles. Present work makes an endeavor to explore new method of design of SPEG. Earlier, some research studies based on simple rack and pinion mechanism have been attained; however, past literature doesn't apply

engineering concepts rigorously to reach the results in a systematic and theoretical manner.

2. Components Used

S. No.	Components	Specification
1.	**Piezoelectric Sensor**	Weight-50gram Dimension- 5x5x1 cm
2.	**Rack and Pinion arrangement**	Length of rack =30 cm Pitch circle radius of pinion =50 mm (spur gear of 20° involute system)
3.	**Springs**	Length of spring =30 cm Material used – steel
4.	**Flywheel**	Made from steel and rotate on conventional bearings
5.	**DC Generator**	Low speed Output voltage 12 V
6.	**Connecting Rod**	Material Used – Aluminium
7.	**Crank and Crankshaft**	Crank: Material used- steel Crankshaft: Material used- forged steel

3. Piezoelectric Materials

Ceramic materials exhibit the unusual phenomenon of piezoelectricity — electric polarization (i.e., an electric field or voltage) is induced in the ceramic crystal when a mechanical strain (dimensional change) is imposed on it. The inverse piezoelectric effect is also displayed by this group of materials; that is, a mechanical strain results from the imposition of an electrical field.

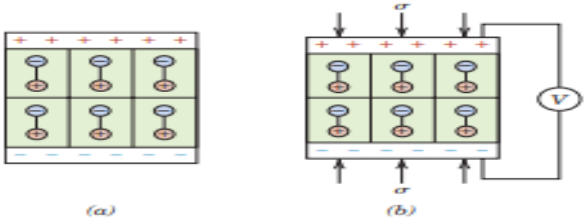


Fig 1: (*a*) "Dipoles within a piezoelectric material. (*b*) A voltage is generated when the material is subjected to a compressive stress" [7].

Now the concept of piezoelectricity can be described using the Barium Titanate crystal:-

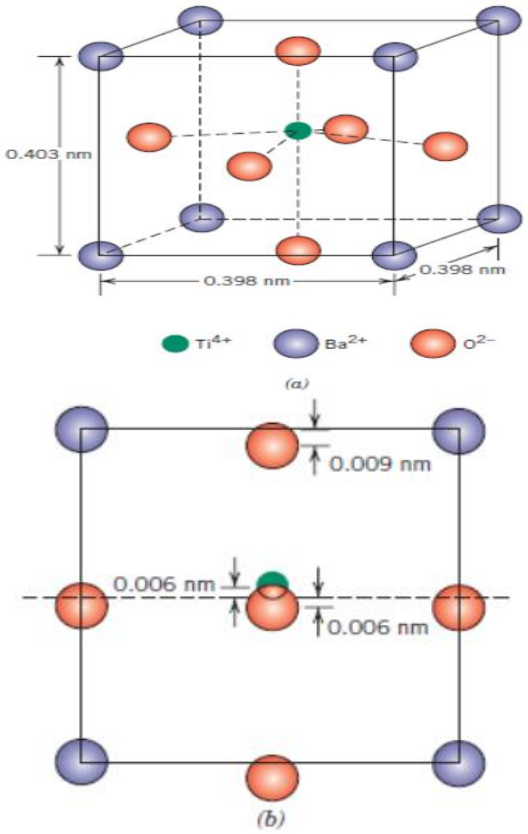


Fig 2: "A barium titanate ($BaTiO_3$) unit cell(*a*) in an isometric projection, and (*b*) looking at one face, which shows the displacements of Ti^{4+} and O^{2-} ions from the center of the face"[7].

Barium Titanate has tetragonal symmetric crystal structure. Here titanium is at the core of it and the Bariums are here at the vertices and oxygen are at all the phase centres. Now, what happens is that this particular structure is stable in a very small margin, the moment the structure is deform .For example compressive load is applied on it then the

crystal will actually get shifted from its location by a little bit because one can never apply very perfect force system, so at that atomic level it will get deformed .And that small deformation is good enough to disturb the structure, so that one get electricity out of it because titanium is electron giver and oxygen is electron taker, so this titanium at the Centre is just pseudo-stable and it will generate a dipole moment, the moment one actually deform it. It was found later on that it is not only Barium titanate, but materials like lead zirconatetitanate, lithium niobium, lead niobium, yttrium magnesium family, NH4CD family, etc, all of them show this kind of phenomenon called Piezo electricity.

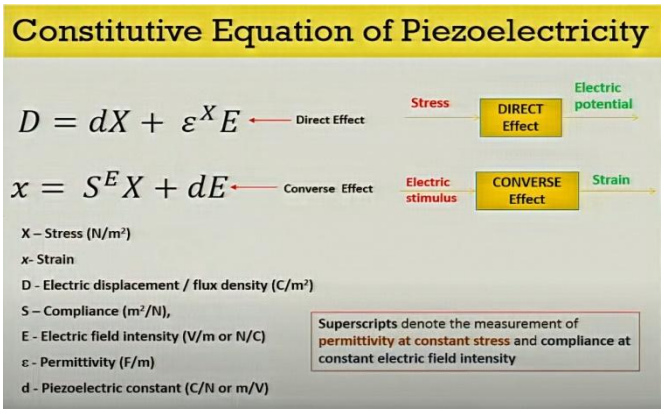


Fig.3 Constitutive equations of Piezoelectricity [8]

4. Design and working

There are two power producing units in our design:

1. Modified slider-crank mechanism
2. Piezoelectric Sensors

Following is the theoretical design of above mentioned units along with working:-

The base plate is the lower most part which would lie underground. Piezoelectric sensors are fitted on the base plate. Then the springs are fitted on the sensors inside the guidance pipes of the base plate and the fixed rack is also connected to the base plate. The pinion is messed between the movable and fixed rack. The connecting rod transmits the linear to and fro motion of the pinion to the rotary motion of the crank. Crank is further connected to PMDC motor with the help of crank shaft. The top plate is fitted into the springs using guidance pipes. This acts as the actual speed breaker. Then the movable rack is fitted at the center of the top plate so that it can absorb maximum force of the vehicle. Piezo transducer generates AC voltage when pressure is applied on it. As AC voltage cannot sum up each other it is to be converted into DC voltage. But in this conversion process we may lose some energy. On using Full Wave Rectifier Bridge for converting AC to DC we get approximately 80% of the energy generated by the transducer. To overcome this loss we will use a voltage multiplier also called Villard cascade. By connecting the voltage multiplier the output will be in DC with some voltage boosting. The output of the piezoelectric will then be coupled with the output of DC generator.

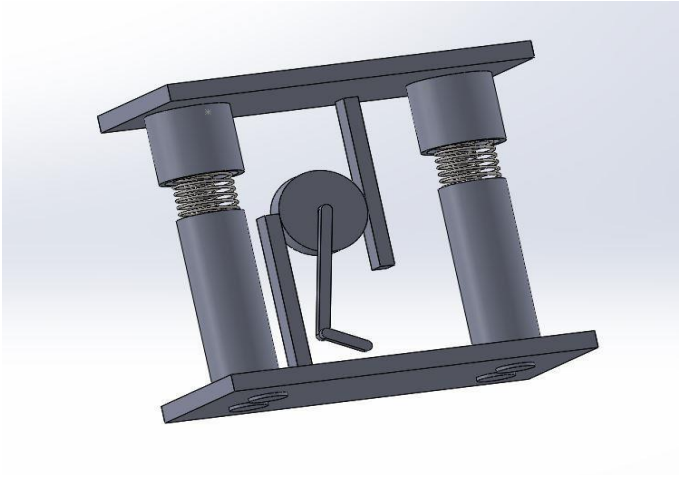


Fig 4: 3-D CAD Model

5. ENERGY FLOW DIAGRAM

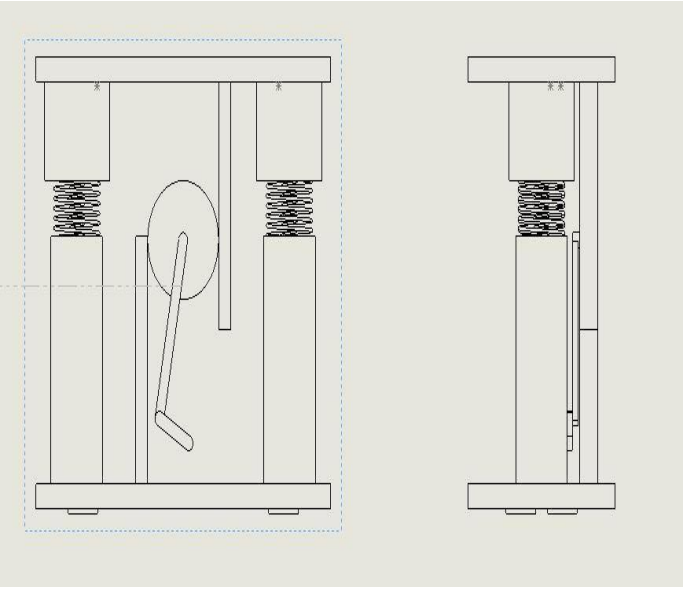
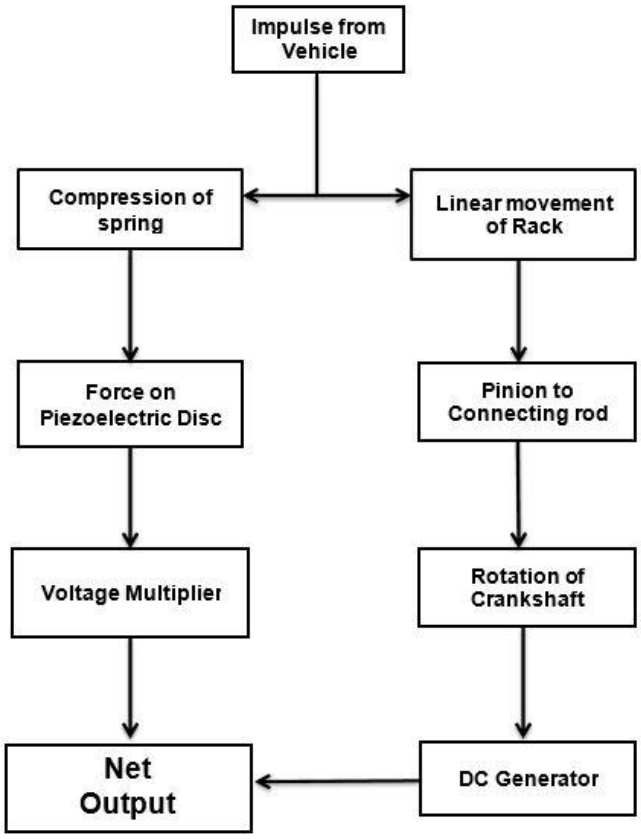


Fig 5 (a): Front View Fig 4.2 (b): Side View



6. Analysis and Calculations

Since ultimately energy is transferred to the shaft which drives the motor ,therefore a more rigorous kinetic analysis is needed to obtain the angular velocity of the shaft or the crank (as crank is attached to the shaft, both have same angular velocity).Consider the schematic diagram of the model:-

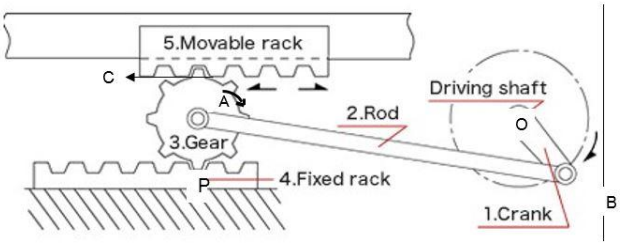


Fig.6: Schematic diagram of mechanism

Here,
Pitch circle radius of gear = r (m)
Length of the connecting rod AB (Rod) =L (m)
Length of the crank OB =*l* (m)
Let at an instant
Velocity of the movable rack is $\mathbf{v}_m$towards right (assume known)

Linear velocity of center of gear (point A) be **v** towards right
Angular velocity of gear be $\boldsymbol{w}_g$clockwise
Angular velocity of connecting rod AB be$\mathbf{w}_{AB}$= w_{AB} (rad/sec)
Angular velocity of crank OB be$\mathbf{w}$ =w **k**(rad/sec)
Assumption:-
-All bodies are assumed to be rigid.
-Gear is pure rolling on the fixed andmovable rack.
As gear is pure rolling on fixed rack, therefore velocity of contact point P is zero

Hence $\mathbf{v}_p = 0$

Also $\mathbf{v}_p = \mathbf{v}_A + \boldsymbol{w}_g \times \mathbf{r}_{AP}$, here $\mathbf{v}_A = \mathbf{v}$

$\therefore 0 = v - rw_g$

$v = rw_g$(1) Velocity of point C is$\mathbf{v}_c = \mathbf{v}_m$

Also $\mathbf{v}_c = \mathbf{v}_A + \mathbf{w} \times \mathbf{r}_{AC}$ $\therefore v_m = v + rw_g = v + v = 2v$Using Eq (1)

Hence $v_A = v = v_m/2$(2)

Now consider the Connecting Rod AB

$\mathbf{v}_B = \mathbf{v}_A + \mathbf{w}_{AB} \times \mathbf{L}$(3)Consider crank OB

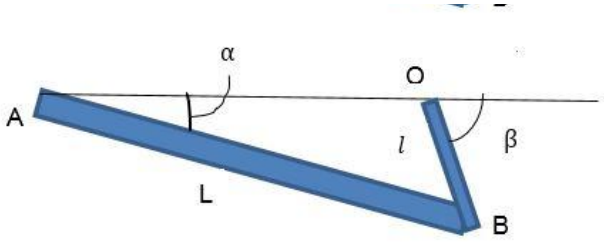
$\mathbf{v}_B = \mathbf{w} \times \mathbf{l}$(4)

From eqns (3) and (4)

$$\mathbf{w} \times \boldsymbol{l} = \mathbf{v}_A + \mathbf{w}_{AB} \times \mathbf{L}$$

This equation has two unknowns**w**and$\mathbf{w}_{AB}$ and while,$\boldsymbol{l}$ and $\mathbf{v}_A$are known quantities. This is a vector Equation, which can be further divided into two directions i and j respectively. Thus it consist of two equations and two unknowns, therefore value of **w** and $\mathbf{w}_{AB}$ can be calculated.
Thus angular velocity of crank**w** has been determined. But its value is changing with time because load on speed breaker is varying with time. So to eliminate fluctuations in angular velocity of shaft a flywheel is connected to it. Flywheel having large moment of inertia produces less fluctuation in angular speed of shaft and thus shaft runs smoothly.

Let due to weight of vehicle upper plate of speed breaker moves down in one sec=10 cm (approx.)
Then velocity of movable rack is $v_m = 0.1$ m/sec
Using (2):$v_A = \frac{v_m}{2} = 0.05$ m/sec and direction is towards right therefore $\mathbf{v_A} = 0.05\,\boldsymbol{i}$
Let connecting rod and crank makes angle α and β with positive x direction as shown:



$$\mathbf{L} = L\cos\alpha\,\mathbf{i} - L\sin\alpha\,\mathbf{j}$$
$$\mathbf{l} = l\cos\beta\,\mathbf{i} - l\sin\beta\,\mathbf{j}$$

Also $\mathbf{w}_{AB} = w_{AB}\,\mathbf{k}$ and $\mathbf{w} = w\,\mathbf{k}$

Substituting in eqn (5)

$$w\,\mathbf{k} \times (l\cos\beta\,\mathbf{i} - l\sin\beta\,\mathbf{j}) =$$
$$v_A\,\mathbf{i} + w_{AB}\,\mathbf{k} \times (L\cos\alpha\,\mathbf{i} - L\sin\alpha\,\mathbf{j}) \text{ or}$$
$$wl\cos\beta\,\mathbf{j} + wl\sin\beta\,\mathbf{i} =$$
$$v_A\,\mathbf{i} + w_{AB}L\cos\alpha\,\mathbf{j} + w_{AB}L\sin\alpha\,\mathbf{i} \text{ or}$$
$$wl\sin\beta\,\mathbf{i} + wl\cos\beta\,\mathbf{j} =$$
$$(v_A + w_{AB}L\sin\alpha)\mathbf{i} + w_{AB}L\cos\alpha\,\mathbf{j}$$

Now comparing i and j direction terms on RHS to LHS, we get

From i direction:- $-wl\sin\beta = v_A + w_{AB}L\sin\alpha$ (6)

From j direction:- $-w_{AB}L\cos\alpha = wl\cos\beta$

$$\therefore w_{AB} = wl\cos\beta / L\cos\alpha$$

Now substitute w_{AB} in the equation (6),

$wl\sin\beta = v_A + wl\cos\beta\sin\alpha / \cos\alpha$ or

$w = v_A\cos\alpha / l\sin(\beta - \alpha)$

Here $v_A = 0.05$ m/sec and l = 0.1 m

Thus value of angular velocity of shaft, w is not constant and it varies with both α and β. Therefore average value of w can be calculated as:-

Sl.No.	α	β	$\cos\alpha/\sin(\beta-\alpha)$	w
1	0	30	2	1
2	15	45	3.732	1.866
3	30	50	2.532	1.266
4	40	60	2.240	1.120
5	45	75	1.414	0.707
6	40	100	0.866	0.433
7	30	150	0.884	0.422
8	20	180	1.880	0.940
9	15	240	1.366	0.683
Average w = $\{(\sum_{k=0}^{9} w_k)/9\}$ = 0.940 rad/sec				

where, $w = (v_A/l)(\cos\alpha/\sin(\beta - \alpha))$ (in radians/sec)

α, β are in degrees

Hence w = 0.94 rad /sec or 9 rpm

Therefore the shaft rotating at around 9-10 rpm when couple with standard DC generator will produce 12 V which is much larger than 1.5 V as shown in some earlier researches.

In addition to it each piezoelectric disc generates 2mW when a vehicle moves over the speed breaker. Though output from piezoelectric disc is small, it can be readily increased by connecting several piezoelectric discs in series.

7. Applications

1. To light nearby streetlights.
2. To operate traffic signals.
3. Energy stored can be used to charge Electric Vehicles.
4. As vehicle applies force on the speed breaker, equal in magnitude of this force is transferred back to its suspension which can also be utilized to generate power within the vehicle.
5. The speed breaker can be used to compress the air .And this compressed air after passing through **FLR** unit (filter, regulator and lubricator).This filtered air is then made to pass through the nozzle where kinetic energy of the compressed air is increased. This high velocity air is made to strike the buckets of runner and thus runner rotates the shaft connected to the motor and ultimately energy is produced.

8. Conclusion

The paper describes an efficient method to extract energy from speed breakers. Part of kinetic energy of traffic is converted to electrical energy by modified slider crank mechanism and piezoelectric discs. The output from slider crank mechanism is 12 V. Four piezoelectric discs contribute 8m W power .This project introduces an innovative approach to harvest energy, which goes un utilized in conventional speed breakers .The energy thus extracted is utilized to lighten the street lights on highway ,toll both etc.

Acknowledgement

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