DESIGN AND DEVELOPMENT OF ENERGY HARVESTING MECHANICAL MOTION RECTIFIER

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Abstract: Shock absorber dissipates the vibration energy which is converted into heat energy and this is waste energy. In this work attempt has been made to convert dissipated energy into electrical energy by employing transmission mechanism. The innovative design of the mechanical motion rectifier is proposed in this work, for improvement of energy harvesting efficiency. The mechanical motion rectifier having compact size is introduced and prototyped. The prototype converts linear vibratory motion into unidirectional motion of DC generator. Rack and pinion arrangement is used to generate power along with one way clutch bearing and bevel gear. This system replaces the damper in the shock absorber. The design based on the mechanical motion rectifier can also be used for other applications for energy harvesting.

***Index Terms* - Mechanical Motion Rectifier, Unidirectional Motion, One Way Clutch Bearing, Rack and Pinion.**

I. INTRODUCTION

The suspension system isolates the vehicle body from the disturbances coming from road. Also the weight of the vehicle is supported by suspension system. The suspension system consists of three main elements i.e. mass, spring and damper. The spring stores the kinetic energy into potential energy. The function of damper is to dissipate the vibrational energy. The energy dissipated by the vibration is important loss in the suspension system. The vibrations are reduced by the damper by converting vibrational energy into heat energy due to viscosity of oil in damper. Harvesting of vibration energy is possible from the suspension system; such suspension system is called regenerative suspension system.

There is relative linear motion between coil and magnet in the linear electromagnetic harvester. But these linear vibrations can be converted into bidirectional oscillatory motion or unidirectional rotational motion by incorporating DC or AC generator, which can harvest waste energy. Such mechanical mechanism consists of rack and pinion, ball screw and hydraulic mechanism. The electrical energy can be generated in rotary energy harvester by converting up and down vibrations into unidirectional rotary motion. Zonggjie Li et.al [1] has proposed design of regenerative energy harvester mechanism which improves the vehicle efficiency. The mechanism introduced converts up and down vibrations into unidirectional rotational motion of DC generator. Zhang Jin Qui et.al [2] reviewed that mechanical vibration energy of conventional suspension system is dissipated in the form of heat which is waste energy. Mohamed A.A. Abdelkareem et.al.[3] presented analytical and statistical study of vehicle regenerative suspension and reviewing the concepts, designs, simulations, test rig experiments and vehicle road tests. G.P.Dhalwar et.al.[4] proposed a design of mechanical motion rectifier. The modal and vibrational analysis is also carried out.

Figure 1 shows proposed 2D model of energy harvesting mechanical motion rectifier. Rack is fixed to the base which is vibrating continuously. Pinion which is mounted on shaft and connected to rack will rotate bidirectional due to vibratory motion. This bidirectional motion is need to be converted in to unidirectional motion to get more energy density. Hence, one way bearings are mounted on same shaft and this one way bearing converts bidirectional rotary motion into unidirectional rotary motion. The unidirectional rotary motion is again feed to the generator through the bevel gear.

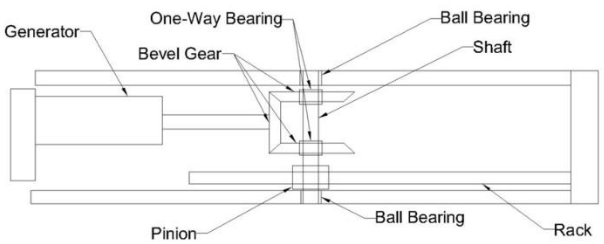

Fig-1: Proposed 2D Model of Energy Harvesting Rectifier

II. DESIGN OF COMPONENTS

DESIGN OF PINION:

Pinion is toothed wheel which transmit power and motion from one shaft to another by means of engagement of teeth. The material used for the manufacture of gears depends upon the strength and service conditions like wear, noise etc.

Gear material: 50C8

Ultimate tensile strength (S_{ut}): 900MPa

Lewis factor(Y): 0.32
Number of teeth (T): 20 (assumed)
Pressure angle: 20°
We know that the maximum energy that is available for harvesting is the amount that is dissipated by the viscous damping. Therefore, instant power dissipation is

P= $C_2 * (U_2 - U_1)^2$ (1)

Where,
C_2= suspension damping coefficient and its value for car is 1388 Ns/m [9]
U_2 and U_1 Are RMS suspension velocities, its values are 0.13 m/s and 0.265 m/s for car.
From equation (1),
P=1388*0.13^2 =23.45 watt
P=1388*0.265^2 =97.47 watt
Hence, the power dissipated by each shock absorber is nearly equal to 25 to 100 watt.
We know power transmitted by gear is given by following equation,

P=$\frac{2\Pi N M_t}{60}$ (2)

200=$\frac{2\Pi*300*M_t}{60}$

M_t=6366 N-mm
Beam strength equation is give as,
P_t=S_b=m*b*σ_b*Y
Where, m is module of pinion. b is face width of gear tooth and is assumed as ten times of module.
Therefore,
b=10 m
12732/D=m*10m*300*0.32

$\frac{12732}{D}$=$\frac{D}{T} * \frac{10*D}{T} * 300 * 0.32$

D=17.44 mm
D= 20 mm (approx...)
We know the relationship between diameter and number of teeth and are given as,

D = m*T (3)

20=m*20
m=1

DESIGN OF SHAFT:

Shaft is rotating machine element, circular in cross section, which supports transmission elements like gears, pulleys and sprockets and transmit power. Shafts are made of medium carbon steels with carbon content from 0.15 to 0.40 per cent such as 30C8 or 40C8.
The maximum shear stress theory is applicable to ductile materials. Since the shafts are made of ductile materials.
Based on maximum stress theory, diameter of the shaft can be found out from following equation.

τ_{max}= $\frac{16}{\pi d^3}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}$ (9)

Now,
Shaft material= plain carbon steel
Ultimate tensile strength (S_{ut}) = 770 MPa
Yield strength (S_{yt}) = 580 MPa
K_b=K_t=1.5 (Load suddenly applied or minor shock)
Where,
K_b, K_t= Combined shock and fatigue factor applied to bending and torsional moment respectively.

τ_{max}= $\frac{16}{\pi d^3}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}$

138.6= $\frac{16}{\pi d^3}\sqrt{(1.5 * 40676)^2 + (1.5 * 6370)^2}$

d = 12 mm (approx...)

DESIGN OF BEVEL GEAR:

Bevel gears are used to transmit power between two intersecting shafts. A bevel gear is in the form of frustum of cone.
The beam strength equation of bevel gear is given as,

S_b=P_t= m*b*σ_b*Y [1- $\frac{b}{A_0}$] (11)

Where,
S_b= Beam strength of bevel gear
P_t= Tangential load on tip of tooth
m= Module of gear
b= Face width of bevel gear
σ_b= Permissible bending stresses
A_0= Cone distance

S_b=P_t= m*b*σ_b*Y [1- $\frac{b}{A_0}$]

$\frac{2*12732}{D}$=m*10m*300*0.389*[1- $\frac{10m}{D/\sqrt{2}}$]

$\frac{2*12732}{D}$=m*m*10*0.389*0.646*300

2*12732=$\frac{D*D*D*10*0.389*0.646*300}{40*40}$

D=37.8 mm

D=40 mm (approx.)

III. Working of setup

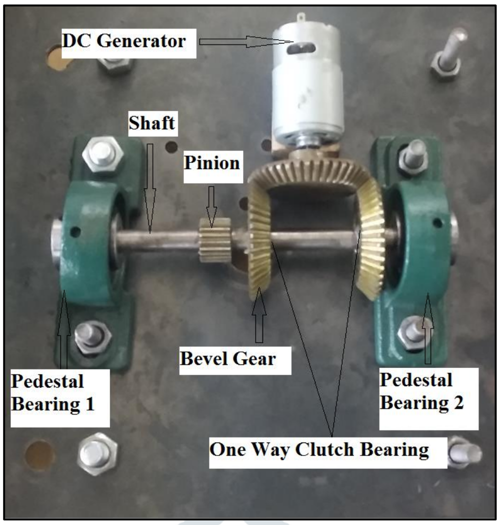

Fig-2: Assembly of Prototype

Fig. 2 shows assembly of energy harvesting mechanical motion rectifier prototype. Above prototype consist of two pedestal bearings which are bolted to the metallic plate through nut and bolt arrangement. The bore diameter of pedestal bearing is 12 mm. The shaft is mounted on the pedestal bearing and one pinion of 20 mm pitch diameter and two bevel gear of 60 mm pitch diameter are mounted on the shaft as shown in above figure. The third bevel gear is attached to other two bevel gears in such a way that it gives only unidirectional rotational motion.

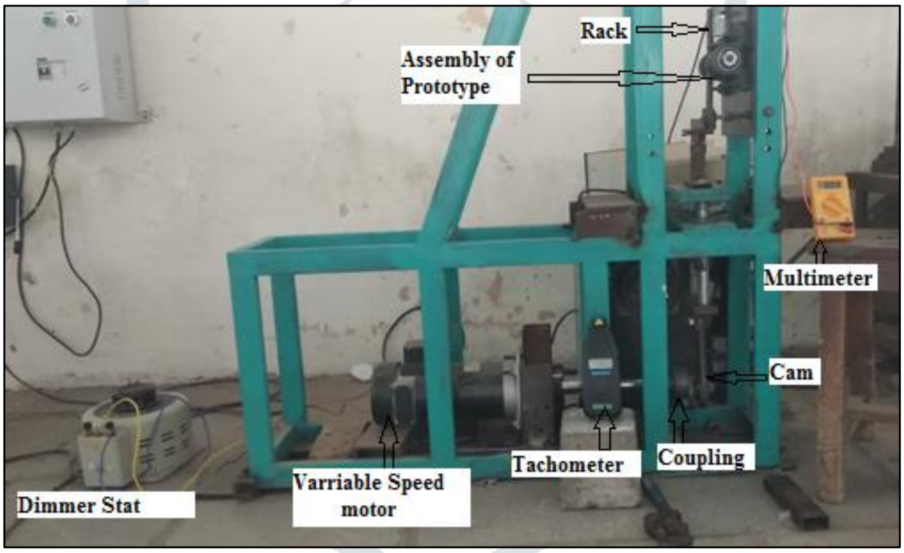

Fig-3: Setup of Energy Harvesting Mechanical Motion Rectifier.

Figure 3 shows setup of energy harvesting mechanical motion rectifier. It consists of dimmer stat, variable speed motor, coupling, cam, rack, pinion, bevel gear, dc generator, tachometer and multimeter.

Dimmer stat is variable voltage supplier device which is used to change the rpm of motor. Dimmer stat changes the rpm of motor by changing it voltage. It is having range from 0 volt to 270 volt. The motor is connected to cam through the transmission shaft and coupling. Coupling has arrangement to adjust eccentricity so that we will get different stroke length of cam.

The cam is attached to the rack through nut and bolt arrangement. The eccentricity of cam give to and fro motion to the rack. The tachometer is used to measure the rpm of motor so that it gives directly the frequency of excitation. The tachometer used is noncontact type tachometer. The multimeter is also used to measure the voltage across the two terminals of dc generator.

IV. Results and discussion

Experimental results are obtained by keeping the stroke length constant and varying the load resistance which is connected to the dc generator in the series across two terminals. Graphs plotted below shows the effect of excitation frequency on the open voltage and output power of dc generator.

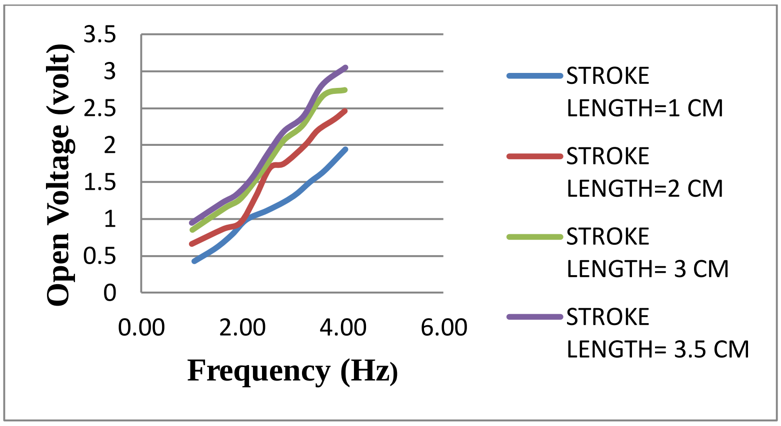

Fig-4: Effect of Frequency on Open Voltage

Fig. 4 shows the graph of frequency of excitation for different rpm of motor to the open voltage across the two terminal of dc generator. It shows that for constant stoke length as the frequency increases the open voltage also increases linearly. As the stroke length increases the open voltage also increases. Hence output power increases.

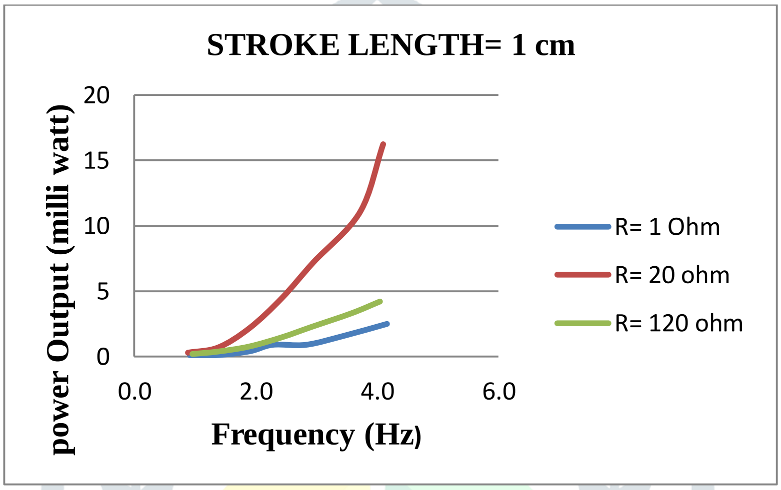

Figure 5: Effect of Frequency on Power Output

Fig. 5 shows the graph of excitation frequency for different rpm of motor to the power output of dc generator when stroke length of 1 cm is given to the rack by adjusting the eccentricity of cam. Different load resistances are connected in series with the two terminals of generator. It shows that maximum output power is obtained when the load resistance is equal to the internal resistance of DC generator. As the frequency increases, the output power increases.

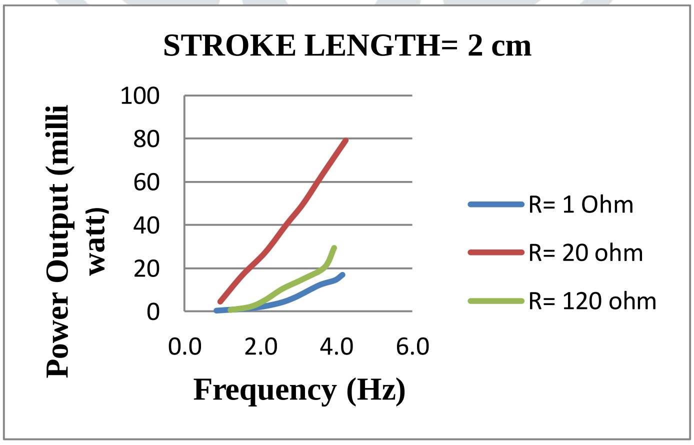

Figure 6: Effect of Frequency on Power Output

Fig. 6 shows the graph of excitation frequency for different rpm of motor to the power output of dc generator when stroke length of 2 cm is given to the rack by adjusting the eccentricity of cam. Different load resistances are connected in series with the two terminals of generator. It shows that maximum output power is obtained when the load resistance is equal to the internal resistance of DC generator. As the frequency increases, the output power increases.

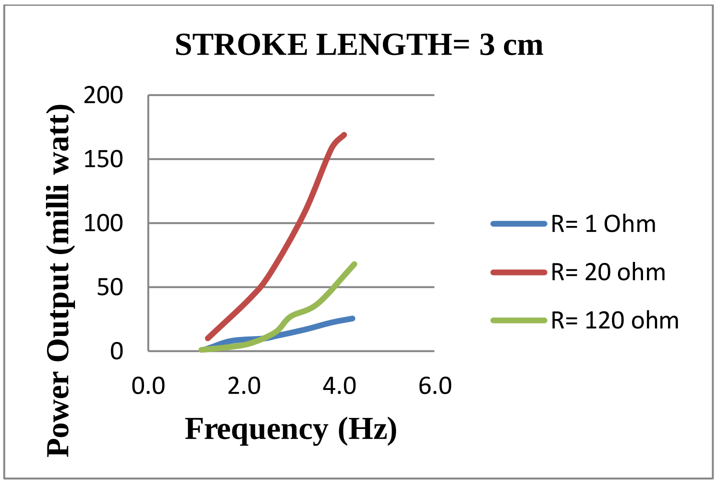

Fig- 7: Effect of Frequency on Power Output

Fig. 7 shows the graph of excitation frequency for different rpm of motor to the power output of dc generator when stroke length of 3 cm is given to the rack by adjusting the eccentricity of cam. Different load resistances are connected in series with the two terminals of generator. It shows that maximum output power is obtained when the load resistance is equal to the internal resistance of DC generator. As the frequency increases, the output power increases.

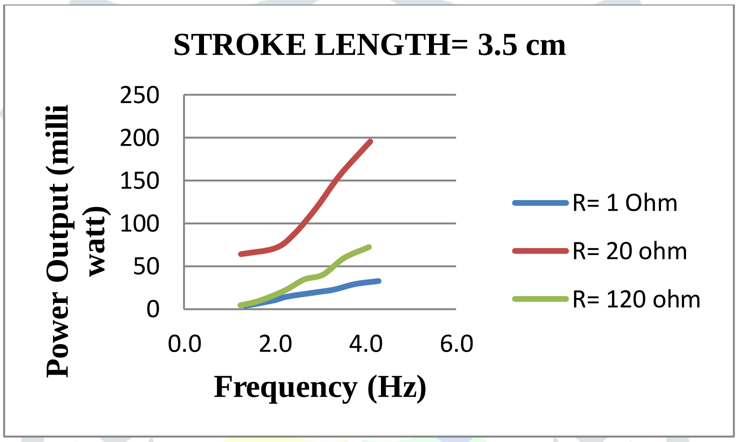

Fig- 8: Effect of Frequency on Power Output

Fig- 8 shows the graph of excitation frequency for different rpm of motor to the power output of dc generator when stroke length of 3.5 cm is given to the rack by adjusting the eccentricity of cam. Different load resistances are connected in series with the two terminals of generator. It shows that maximum output power is obtained when the load resistance is equal to the internal resistance of DC generator. As the frequency increases, the output power increases.

V. Conclusion

Experimental results show that as the frequency of excitation increases, the open voltage also increases. It means that the RPM of motor is directly proportional to the open voltage of the generator. For constant stroke length of the rack, as the excitation frequency increases, the output power also increases. It is found that the maximum power is harvested when the load resistance across DC generator is equal to the internal resistance of DC generator. The maximum power of 200 milliwatt was harvested when stroke length of 3.5 cm and load resistance of 20 ohms.

The input speed to the generator can be increased by employing the gearbox between DC generator and bevel gear.

VI. References

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