Design and Fabrication of Load Applied Power Generator

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Abstract-* The main purpose of this study is to construct load applied power generator and test the results. In this study, the principle used is the conversion of the forced mechanical energy into electrical energy. The mechanism carries main components like upper plate supported with two springs, rack and pinion and D.C generator. Rack and pinion mechanism is used to change linear motion of rack gear into rotational motion of pinion gear. The power generated can be stored by means of battery and can be used for activating the connected LED. This model can be installed in bus stations, airports and highways where the load to be applied on the upper plate is easily available. In this study, by using the kinematic relationship between linear velocities of large gear (95 teeth) and small gear (20 teeth), the rotational speed of output shaft is found to be 570 rpm. Theoretically, the large gear and small gear mesh at the pressure angle of 17.59°. Input shaft diameter is estimated by using maximum shear stress theory and maximum normal stress theory. From two results, larger value is selected, the estimated diameter of rotating shaft is 20 mm. Theoretical effective stress, Von-Mises stress, is 271.54 MPa and effective strain is 1.83×10^{-9}. The maximum output electrical energy is found to be 2 W.

***Index Terms-* Shaft Diameter; Rotational Speed; Pressure Angle; Stresses; Strains**

I. INTRODUCTION

Man has needed and used energy resources at rapid rate for his living and well-being ever since he came on earth. Humans are facing energy crisis due to two reasons, the first one is the population of the world has been increased rapidly and the second one is the increasing of living standard. The adverse environmental and social consequences of fossil fuel use, such as air pollution by emission of carbon dioxide and other green-house gases, or mining accidents have been voiced intermittently for several centuries. To improve the power generation technologies and to make them more sustainable, non-conventional technologies have been discovered.

As the availability of conventional energy declines, there is need to find alternate energy sources. When it is difficult to divert the energy for public needs, alternative sources must be discovered, many people proposes for solar energy, but it is going to be a costliest affair, moreover availability of solar energy is poor ,particularly in rainy and winter seasons, as a result it is not dependable. Hence non-conventional technology is preferable. The non-conventional technology used in this study is safe and does not pollute the environment. If there is a tremendous increase in the crowd, the load applied on the upper plate by the people will cause generation of non-stop electrical energy, which can be stored and utilized to energize the street lights. In this study, the concept used is to convert the mechanical energy into electrical energy.

The objective of this study is about creating the electrical energy by utilizing mechanical energy created by the weight of human body or transferred from kinetic energy that gone wasted while vehicles move. At first, the load will be applied on the upper plate. The rack and pinion gear system is used to convert linear motion into rotational motion. Because of two springs, rotational motion will also be converted into linear motion, vice versa. Spur gear with larger teeth drives another spur gear with smaller teeth. That makes the revolution of motor to be increased, and the power output from the DC motor will be increased.

II. MAIN COMPONENTS OF FABRICATION

A. *Shaft*

Figure1. The design of shaft

The designate shaft, figure 1, is a rotating mechanism which is used to transmit power from one place to another. The power is delivered to the shaft by some tangential force and the resultant torque or transmitting torque set up within the shaft permits the power to be transferred to various mechanisms linked up to the shaft. In order to transfer the power from one shaft to another, the various members such as pulleys or gears are mounted on it. These members along with the forces exerted upon them causes the shaft to bending.

B. *Fabrication of Bearings*

Figure2. Fabrication of four bearings

A bearing is a machine element which supports another moving machine element. It permits a relative motion between the contact surfaces of the members, while carrying the load. Figure2 shows four bearings used in load applied power generator, for supporting shaft rotation, reducing frictional resistance and wear, and to carry away the heat generated. Two bearings are used for the input shafts and the latter are used for output shaft.

C. *Rack and Pinion*

Figure3. Rack used in load applied power generator

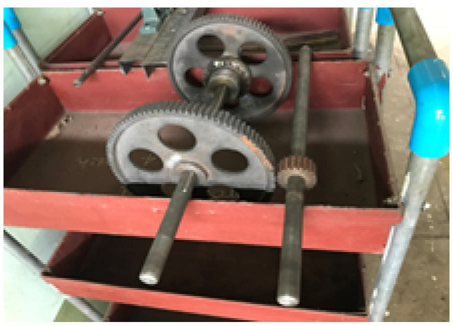
This gear system in figure 5 is composed of two gears. Normal round gear is the pinion gear and the straight or flat gear is the rack. It is a type of gear in which a shaft meshes externally and internally with the gears in a straight line. Figure 3 is a straight line gear called rack and the circular wheel is called pinion as shown in figure 4. A consideration is that with the help of a rack and pinion, linear motion of rack gear can be converted into rotary motion of pinion, vice-versa. And then, the shaft meshing internally with the pinion will rotate.

Figure4. The design of small gear on shaft

D. *Assembly of Gears*

(a)

(b)



(c)

Figure5. (a) Large gear; (b) large gear with sprocket; and (c) assembly of gears

E. *Spring*

Figure6. The design of spring

A spring in figure 6 is defined as an elastic body, whose function is to distort when loaded and to recover its original shape when the load is removed. The important application of spring in this study is to do cushion, absorb or control energy due to either shock or vibration as in car springs, railway buffers, air-craft landing gears, shock absorbers and vibration dampers.

F. Beams for Frame

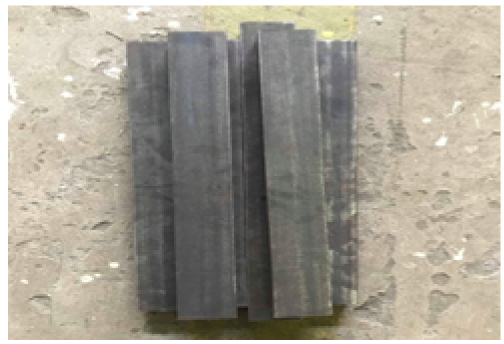


Figure7. The design of beams for base frame

Figure 7 shows the required beams for construction of base frame for the load applied power generator. For obtaining the beams in specified and required dimensions, cutting process is done by means of grinding machine or grinder manually. Moreover, arc welding process is also used to join and arrange these cut-off beams together in a satisfactory configuration.

G. *Complementary Machine*

Figure8. The desired model of load applied power generator

Figure 8 shows sketch of base frame, on which gear assembly supported on shafts are presented. Firstly load will be applied manually on upper plate. Then rack will move in linear motion, and the pinion will rotate in angular motion. After that, rotation of input shaft is happened, which causes the output shaft to rotate. The output shaft will rotate in clockwise direction only because sprocket avoids its counterclockwise rotation during the upward moment of rack. Rotational speed of output shaft is 570 rpm while rotational speed of input shaft is 120 rpm.

III. METHODOLOGY

A. *Estimation of Shaft*

When the shaft is subjected to combined twisting moment and bending moment, then the shaft must be designed on the basis of the two moments simultaneously. For combined torsion and bending, the equivalent twisting moment equation is as follows,

$$T_e = \sqrt{(K_m \times M)^2 + (K_t \times T)^2} \tag{1}$$

The equivalent bending moment equation is as follows,

$$M_e = \frac{1}{2}\left[(K_m \times M) + \sqrt{(K_m \times M)^2 + (K_t \times T)^2}\right] \tag{2}$$

A bending moment diagram shows in figure 9 is the variation of bending moment along the length of the shaft. If two concentrated loads act on a simple beam, expressions for the shear forces V and bending moments M can be determined for each segment of the beam between the points of load application. In this study, at input shaft, there are two bearings at A and B. At C, there is a total weight of large gear, sprocket and human. At D, there is a weight of large gear only. The portion after point B is omitted because this portion will not affect in design.

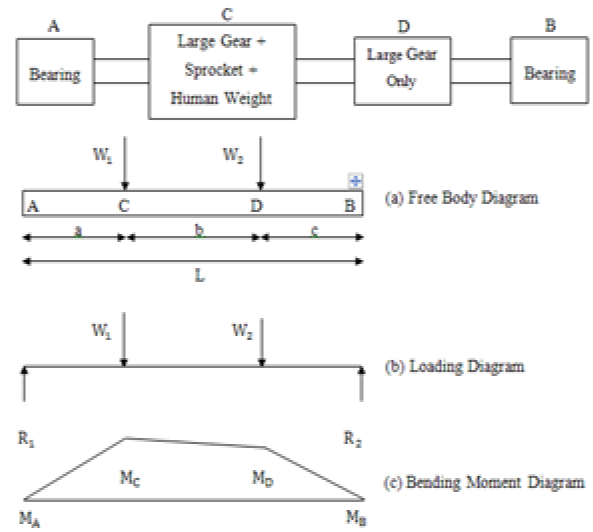


Figure9. The moment consideration on a shaft

The figure 9 can be explained as follows;

W_1 = total weight of large gear, sprocket and human

W_2 = weight of large gear

R_1 = reaction force acting at bearing A

R_2 = reaction force acting at bearing B

M_A = bending moment at bearing A

M_C = bending moment at point C

M_D = bending moment at point D

M_B = bending moment at point B

The torque transmitted by the shaft is shown in equation 3.

$$T = \frac{P \times 60}{2\pi N} \tag{3}$$

According to maximum shear stress theory, the maximum shear stress induced due to twisting moment is as follows;

$$\tau = \frac{16 T_e}{\pi d^3} \tag{4}$$

According to maximum normal stress theory, the maximum normal stress induced due to bending moment is as follows;

$$\sigma_b = \frac{32M_e}{\pi d^3} \tag{5}$$

The tangential force acting on gear rotating on shaft is as follows;

$$F_t = \frac{T}{R} \tag{6}$$

The relation between rotational speed and teeth of gears is,

$$\frac{N_1}{N_2} = \frac{T_2}{T_1} \tag{7}$$

Teeth on pinion (small gear) to avoid interference is given by;

$$T_p = \frac{2A_w}{G\left[\left(\sqrt{1+\frac{1}{G}\left(\frac{1}{G}+2\right)\sin^2\phi}\right)-1\right]} \tag{8}$$

B. Stress Analysis

Stress can be defined as the internal resistance offered by a unit area of a material to an externally applied load. The basic types of stress analysis are torsional shear stresses, bending stresses, and stresses due to combined torsional and bending loads. Axial loads are usually comparatively very small at critical locations where bending and torsion dominate, so the following equations are left out. The fluctuating stresses due to bending and torsion are shown in figure 10.

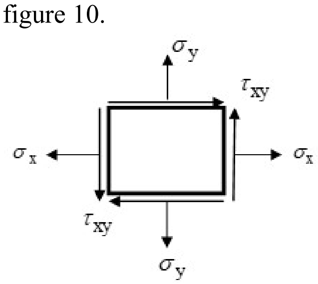


Figure10. Stresses in XY plane

Bending stress, $\sigma_x = \sigma_b = \dfrac{32M}{\pi D^3}$ (9)

Centrifugal stress, $\sigma_y = \sigma_c = \left(\dfrac{3+\nu}{8}\right)\rho\omega^2 r^2$ (10)

Shear stress, $\tau_{xy} = \dfrac{16T_e}{\pi D^3}$ (11)

Principal stresses can be calculated as follows;

$$\sigma_{1,2} = \frac{1}{2}\left(\sigma_x + \sigma_y\right) \pm \frac{1}{2}\sqrt{\left(\sigma_x + \sigma_y\right)^2 + 4\tau^2_{xy}} \tag{12}$$

Von-Mises stress (or) Effective stress is given by equation 13.

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\left[\left(\sigma_1 - \sigma_2\right)^2 + \left(\sigma_2 - \sigma_3\right)^2 + \left(\sigma_3 - \sigma_1\right)^2\right]^{\frac{1}{2}} \tag{13}$$

Effective strain can be defined as follows;

$$\bar{\varepsilon} = \left[\frac{2}{3}\left(\varepsilon_1^2 + \varepsilon_2^2 + \varepsilon_3^2\right)\right]^{\frac{1}{2}} \tag{14}$$

C. *Design Specifications*

The required data for design estimation of shaft are included in table 1.

Table 1. Specification data for shaft design

Material used for shaft and gear	cast iron
Pitch circle diameter of large gears	197.88 mm
Pitch circle diameter of pinion gear	88.8 mm
Length of shaft	45.72 mm
Diameter of shaft	1.9 mm
Weight of pinion gear	0.163 kg
Weight of large gear with sprocket	2.445 kg
Weight of large gear without sprocket	1.956 kg

IV. RESULTS AND PERFORMANCE TEST

The estimated results for shaft in this study are included in table 2. The pressure angle of gears and rotational speed of generator are also calculated. Test results measured are output voltage from motor, output current from motor, output electricity from motor, which are measured at different rotational speeds of output shaft (from 100 rpm to 500 rpm). The table 3 shows the 5 times performance test data.

Table 2. Theoretical result data for shaft design

Item	Marking	value	Unit
Equivalent twisting moment	T_e	183.99×10^3	N-mm
Equivalent bending moment	M_e	170.63×10^3	N-mm
Pressure angle	ϕ	17.59°	
Torque transmitted by the shaft	T	79.58×10^3	N-mm
Shaft diameter	d	20	mm
Output rotational speed	N_2	570	rpm
Bending stress	$\sigma_x = \sigma_b$	133.49	MPa
Shear stress	τ_{xy}	117.13	MPa
Principal stress	σ_1	238.11	MPa
Von-Mises stress	$\bar{\sigma}$	271.54	MPa

Table 3. Performance test result data

Rotational speed of output shaft N_2 (rpm)	Output voltage from motor V (Volt)	Output current from motor I (Ampere)	Output electricity from motor P (Watt)
100	0.5	0.6	0.3
200	0.6	0.7	0.42
300	1	0.8	0.8
400	1.4	0.8	1.12
500	2	1	2

Figure11. Testing of load applied power generator

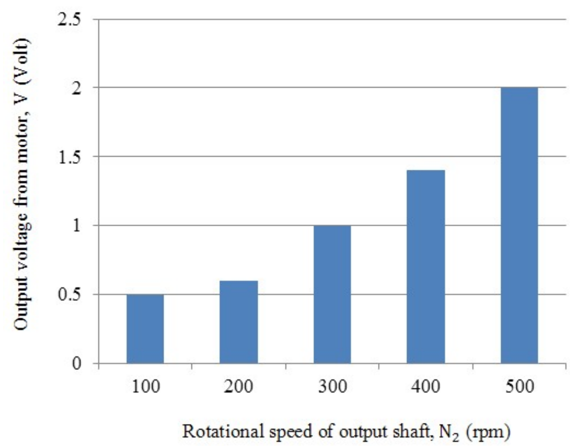


Figure12. Output voltage at different rotational speeds of output shaft

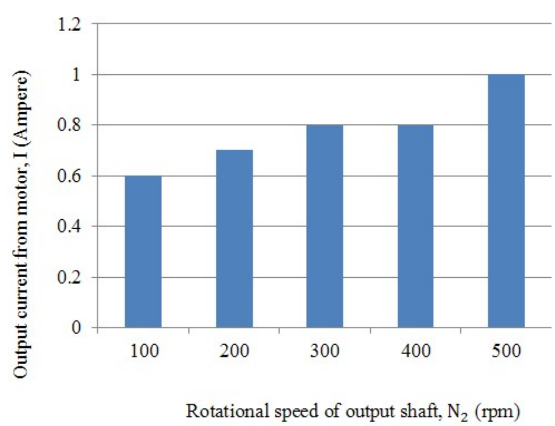


Figure13. Output current at different rotational speeds of output shaft

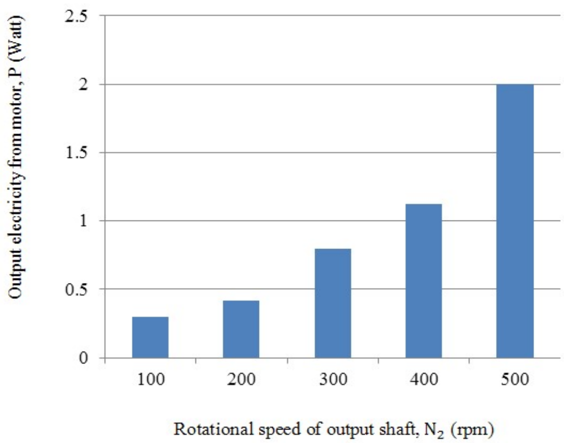


Figure14. Output electricity at different rotational speeds of output shaft

The performance testing as shown in figure 11 are resulted the voltage, current and power of electricity at different speed of shaft in figures 12, 13 and 14 respectively.

This research can be implemented on railway stations, bus stops, airports to generate electricity by human physical activity. Energy generation capacity in this load applied power generator can be increased by using flywheel. The ratchet can also be used instead of sprocket so that do not occur reverse rotation of shaft, for higher electrical output, rotational speed of output shaft should be increased. Flywheel should also be added in constructing further load applied power generators, because it will increase rotational speed of output shaft.

IV. CONCLUSION

In this research, electrical power is generated by simply walking on the step. This can also be done by the use of wasted kinetic energy of vehicles. This does not need fossil fuel input, so it is a pollution-free energy generation, suitable for our world. But it is noisy to operate it. The electrical power generated is just in small amount, but it can be used for street lighting system. For initial installation, the cost is high, but reliable, economical, eco-friendly. Battery can be used to store generated power. It is only applicable for the particular place. The maximum electrical output is found to be 2 W.

In this load applied power generator, the pushing power is converted into electrical energy by proper driving arrangement. The rack and pinion and spring arrangement are fixed between the upper plate and the frame. The spring is used to return the plate in original position by releasing the load. This is because of the ability of spring, being able to recover to initial position. Sprocket is used not to occur reverse rotation of shaft. DC generator is used to generate power.

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NOMENCLATURE

W_1	: Total weight of large gear, sprocket and human (N)
W_2	: Total weight of large gear (N)
R_1	: Reaction force acting at bearing A (N)
R_2	: Reaction force acting at bearing B (N)
M_A	: Bending moment at bearing A (N-mm)
M_c	: Bending moment at point C (N-mm)
M_D	: Bending moment at point D (N-mm)
M_B	: Bending moment at point B (N-mm)
V	: Shear force at cross-section (N)
K_m	: Bending moment factor
K_t	: Twisting moment factor
T_e	: Equivalent twisting moment (N-mm)
M_e	: Equivalent bending moment (N-mm)
T	: Torque transmitted by rotating shaft (N-mm)
N	: Rotational speed of rotating shaft (rpm)
N_1	: rotational speed of driver gear (rpm)

N_2 : rotational speed of driven gear (rpm)

P : Power transmitted by rotating shaft (W)

τ : Maximum shear stress (MPa)

σ_b : Maximum normal stress (MPa)

d : Diameter of rotating shaft (mm)

F_t : Tangential force acting on gear (N)

m : Module of gear

T_p : Number of teeth on pinion

A_w : Fraction by which the standard addendum for the wheel

G : Gear ratio or velocity ratio

ϕ : Pressure angle or angle of obliquity

ρ : Density of shaft (Kgm^{-3})

ω : Angular velocity (rad/s)

σ_b : Bending stress (MPa)

σ_c : Centrifugal stress (MPa)

$\sigma_{1,2}$: Principal stress (MPa)

$\bar{\sigma}$: Von-Mises stress (or) Effective stress (MPa)

ε_1 : First principal strain

ε_2 : Second principal strain

ε_3 : Third principal strain

$\bar{\varepsilon}$: Effective strain

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