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Design and Analysis of Electricity Generation using Contactless Magnetic Coupling

Aniket Madwe[1], Abhinav Deshmukh[2], Nachiket Dhange[3], Rutuja Godse[4], K. R. Jagtap[5]

Mechanical Engineering Department, Sinhgad Institute of Technology and Science, Savitribai Phule Pune University, Pune, Maharashtra-411041, India

aniketmadwe95@gmail.com
abhinavdeshmukh615@gmail.com
shivamdhange01@gmail.com
godserutu1110@gmail.com
Krjagtap_sits@sinhgad.edu

Abstract

The renewable energy sources are rapidly depleting across the planet. There is a continuous need of new methods and ideas of generating energy without harming the environment. This paper aims to produce electricity in railway bogies using non-contact magnetic coupling mounted on the axles of the bogies. The main focus of the model was to generate electricity using a magnetic coupling. The torque was transmitted from the axle to the generator shaft without any physical contact, thus reduced the friction losses in currently being used mechanical couplings for torque transmission. Computer aided modeling (CAD) of the system is done using CATIA software. The model was validated for its design feasibility and structural analysis is done using Ansys software.

Keywords: Electricity generation, Magnetic coupling, Non-conventional energy, Finite Element Analysis (FEA)

I. INTRODUCTION

The planet is rapidly running out of conventional fuels, and non-conventional sources of energy are becoming our future. Natural resources like wind, tides, solar, biomass, etc., generate energy which is known as Non-conventional resources. These are pollution free and hence we can use these to produce a clean form of energy without any wastage. There is a need to secure the energy supply for the future since the prices of gas and oil keep rising with each passing day. We need to use more and more renewable sources of energy.

In India, the major transportation system is railways which consume high-grade energy like electricity. Most of the system in railways works on electricity, which need a continuous supply of power. To deal with this demand we were proposing an electricity generation system for railway bogies which offer a continuous supply of electricity for all required purposes. The main goal to build such a system was to replace the conventional methods of electricity production in trains and introduced a non-conventional and eco-friendly way of electricity production which will be both continuous and free of cost.

Electric Power Generation using Contact-less Magnetic Coupling was a system proposed to generate electricity in railway coaches. The electricity produced by this system is free-energy and the method used was very eco-friendly. The system was driven by the axle of the coach using a non-contact

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magnetic coupling. An electric motor, which drives the primary or input shaft, demonstrates the rotation of an axle. The torque and motion transmit by a magnetic coupling to a secondary shaft. The magnetic coupling works on the principle of attraction and repulsion of magnets. The secondary shaft transmitted the torque to the generator shaft through a gear mechanism. It was not possible to directly connect the generator shaft to the magnetic coupling hence the gear mechanism used for this purpose.

Yi-Chang Wu and Chih-Wen Wang [1] investigated the magnetic field and the transmitted torque of an external magnetic gear set with rectangular magnets by using the current sheet model and finite element analysis (FEA). The analytical expression of torque transmitted is compared with the magnetic material properties and geometric dimension of magnetic gear mechanism graphically.

T. Meenakshi et al. [2] proposes a novel technology to convert rotational energy into electrical using a technique called repulsion magnetic technique. The system uses permanent magnet to produce repulsion and this repulsive force produces a torque which drives a direct current (DC) generator and matlab Simulink model of a single-phase 2kVA UPS system based voltage controlled. The repulsive magnet disc consists of two magnetic discs of which one is mounted on rotating machine and other is mounted on generator shaft. The power output from the direct current (DC) generator is fed to uninterrupted power supply (UPS).

S. R. Trout [3] investigated the permanents magnets and studied thermal properties of the same. He examined four families of permanent magnets namely ferrite, alnico, Samarium-cobalt, neodymium iron boron along with their properties such as remanance, curie temperature, Intrinsic coercive field, etc. he proposed a new definition for the maximum operating temperature and advised on which properties are most important in various design situations.

S. M. Hatturkar [4] aims toward generating electric power through non-conventional method by train running on a railway track.The main aim of the concept is to utilize the train crossing time on a railway track. The power is produced by the railway track power generation equipment. The principal of operation is a flat strip held on the axle of a train which will be touching the roller on the track, and the roller starts rotating according to the rotational energy transformation features generating electricity through generator.

V. Thirumalairaj et al. [5] proposes a technology to produce electrical energy using repulsion magnet technique. The system uses magnetic disc made up of plastic which contains a number of permanent magnets arranged on a circumferential portion of the magnetic disc. Magnets used are Neodymium. The magnetic disc and larger size driver plastic gear are connected by the shaft, rotates freely with the help of bearing which is rigidly fixed with stand. The same polarity of magnet is placed on the surface of the motor shaft which is placed near the magnetic disc. The output from the generator is increases by the voltage booster.

A. Working Principle of Magnetic Coupling

The working principle of magnetic coupling is based on the theory of attraction and repulsion of north and south poles of a magnet. The magnetic coupling is used to transfer torque and motion from one shaft to another in axial direction. There is a maximum of 10mm gap between the two discs of coupling on which north and south pole magnets are mounted alternately. When the driver shaft

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rotates the magnetic coupling tends to pull the other shaft in the same direction, resulting in rotation of the driven shaft. Magnetic coupling is a contactless coupling which does not need any physical contact to transmit torque or motion. This contactless motion transmission provides a friction free and leak proof environment which is very useful.

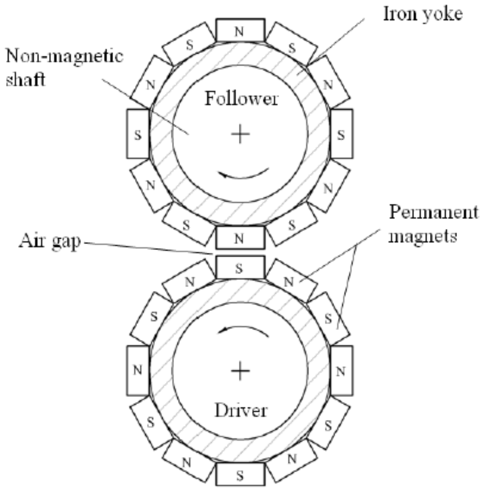

Figure 1: Parallel axis magnetic gears [3]

B. Working of Proposed Model

The system works on the input provided by a 12V battery to a 12V and 100 RPM wiper motor which drives the input shaft on which a wheel and magnetic coupling are mounted. The wheel is mounted so as to demonstrate the rotation of railway wheel and also it stores the inertial energy from the rotational motion. The input shaft is mounted on the frame using bearings at the two ends. The output shaft is perpendicular to the input shaft which mounted using bearings on the frame and the other end of the output shaft is connected to the generator.

The magnetic coupling is two discs attached to the input and output shaft. On the outer periphery of the discs permanent magnets are attached in an alternate manner, i.e., north and south poles alternately. The coupling disc on the input shaft rotates and implies torque on the other disc of coupling based on attraction and repulsion. Thus the output shaft rotates without any physical contact between the shaft or the magnetic coupling. This provides a frictionless torque and motion transfer without any mechanical contact.

The output shaft drives the generator which in turn produces electricity. The electricity, thus generated can be stored in the batteries and can be used as per requirement. The generator and battery are fitted to the frame using attachments.

II. CALCULATIONS

A. Selection of Pulley and V- Belt.

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Selection of pulley is done on the basis of power and input speed.
Power = 0.036 KW
Input Speed = 100 RPM
Centre Distance = 400 mm

Minimum pulley pitch diameter (d) = 75 mm

Assuming speed ratio (i) = 2

$\therefore$ i = $\frac{D}{d} = \frac{n}{N}$

$\therefore$ D = 150 mm

V belt is selected instead of flat belt as the chance of slip is less.

Pitch Length of V belt (L) = $2C + \frac{\pi}{2}(D + d) + \frac{(D-d)^2}{4C}$ [7]

L = 1156.94 mm

Selecting the corresponding length from the design data book,

$\therefore$ L = 1204 mm

Nominal inside length = 1168 mm

Correcting the center distance (C) = $A + \sqrt{A^2 - B}$ [6]

Where, A = $\frac{L}{4} - \pi \times \frac{(D+d)}{8}$

B = $\frac{(D-d)^2}{8}$

$\therefore$ C = 423.62 mm ≅ 425 mm

Number of belts required for a given application is calculated by following relation; [6]

$$n = \frac{P \times Fa}{Pr \times Fd \times Fc}$$

Where,
n = number of belts
P = drive power to be transmitted (KW)
F_a = correction factor for industrial service
P_r = power rating of single v-belt
F_c = correction factor for belt length

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F_d = correction for arc of contact

F_a = 1.1 [6]

F_c = 0.92 [6]

Velocity of smaller pulley (V) = $\frac{\pi DN}{60}$

$\therefore$ V = 0.392 m/s

P_r= 0.13, Corresponding to the velocity

Arc of contact =$180° - 60° \times \frac{\mathrm{D-d}}{\mathrm{C}}$ [7]

Θ =169.37°

F_d = 0.78, Corresponding to the velocity

$\therefore$ No. of belts $(n) = \frac{0.036\times1.1}{0.13\times0.78\times0.92}$ = 0.42 ≅ 1

From this, A-46 size belt is selected from manufacturer's catalogue.

B. Design of Shaft

Shafts are subjected to axial tensile force, bending moment or torsional moment or their combinations. Most of the shafts are subjected to combine and torsional moments. The design of shaft consists of determining the correct shaft diameter from strength and rigidity considerations.

1) Calculating the tension on pulley on input shaft.

From general equation of power, $P = \frac{2\pi NT}{60}$

T = 3.43 N.m

Equivalent torque transmitted by pulley = $i \times T$
= 6.86N.m

Equivalent torque is given by, $\mathrm{Te} = (\mathrm{T1} - \mathrm{T2}) \times \mathrm{R}$

Also, $\frac{T1}{T2} = e^{\mu\theta}$

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Where,

$\mu = 0.297$

$\Theta = \pi + 2\sin^{-1}\left(\frac{D-d}{2C}\right) = 3.49$ rad.

$\therefore \frac{T1}{T2} = 2.819$

$\therefore T_1 = 141.75$ N
$\therefore T_2 = 50.25$ N

2) Calculating the diameter of input shaft for combine bending and twisting.

Material selected for the shaft is AISI 1118 having following properties
$S_{ut} = 525$ MPa
$S_{yt} = 315$ MPa
FOS = 7.5

- Shear force diagram and bending moment diagram

Shear force diagram (SFD) & Bending moment diagram (BMD) is calculated by using MD solid 4.0 software.

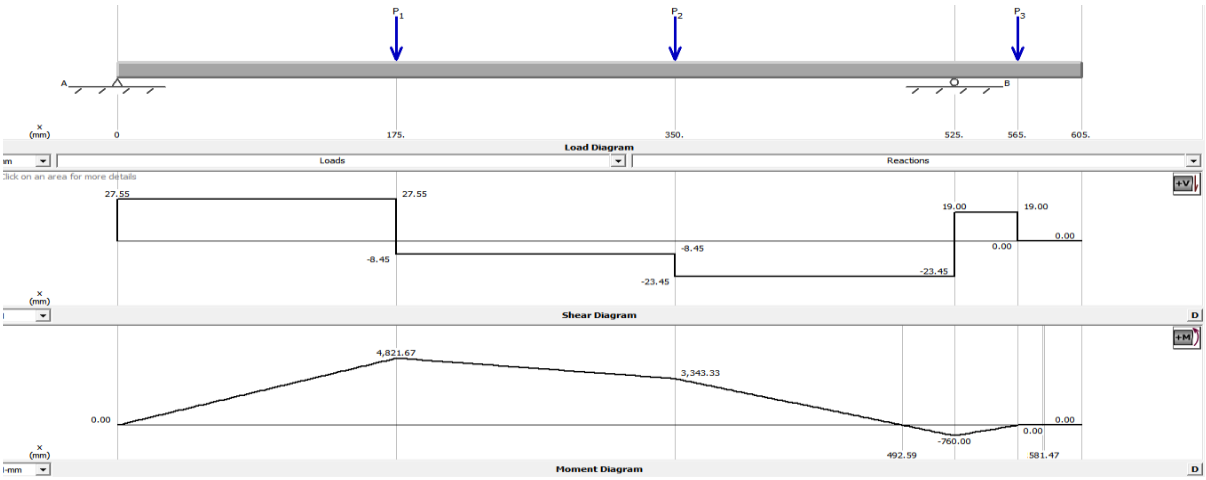

Figure 2: Schematic diagram showing SFD and BMD of vertical loading diagram of input shaft using MD Solid software

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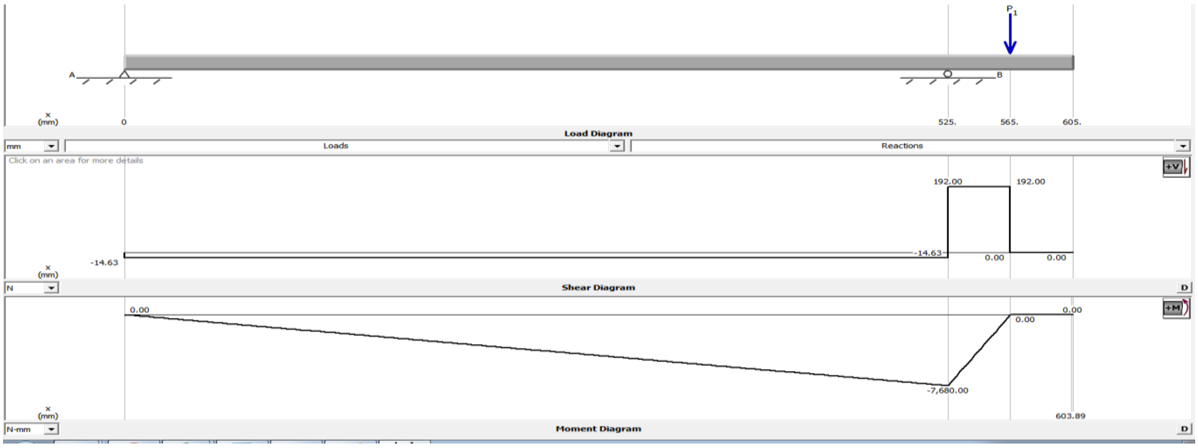

Figure 3: Schematic diagram showing SFD and BMD of horizontal loading diagram of input shaft using MD Solid software

- According to maximum shear stress theory, [7]

$$\tau = \frac{16}{\pi d^3} \times \sqrt{(Mb)^2 + (Mt)^2}$$

Where,

M_b = Maximum bending moment on the shaft
M_t = Maximum torque acting on the shaft

Value of M_b = 4821.25 N.mm (From Fig 2)

And M_t = 6875.49 N.mm
∴ d = 12.67 mm
∴ d = 16 mm is selected

As there is less magnitude of load and torque acting on the output shaft than the input shaft, the diameter of output shaft selected is also 16 mm.

III. RESULT AND DISCUSSION

Details of the analysis:

- Product Version: ANSYS 18.2
- Specimen geometry: 16 mm diameter and 605 mm length (input shaft) 16 mm diameter and 410 mm length (output shaft)
- Material: Carbon Steel
- Mesh element size: 3mm
- Analysis type: 3D
- Solver target: Mechanical APDL
- Solutions obtained:

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1) Y-axis directional deformation.
2) Equivalent Stress distribution along the specimen.

A. Analysis of input shaft

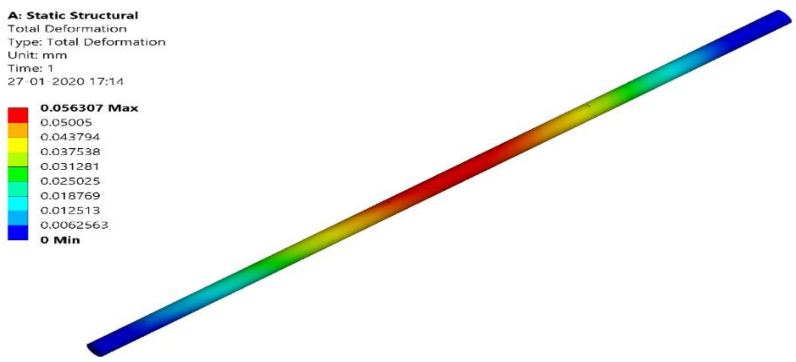

Figure 4: Total Deformation of input shaft

- From figure 4 it is observed that the total deformation of the input shaft is equivalent to zero, this means the input shaft sustain all the loads and torque without any deformation. The red color shows the maximum possible deformation.

Figure 5: Equivalent Stress distribution on input shaft

- Figure 5 shows that the maximum stress is directed over the keyway. The maximum and minimum values of induced stresses are 87.909 N/mm^2 & 0.0014 N/mm^2.

B. Analysis of output shaft

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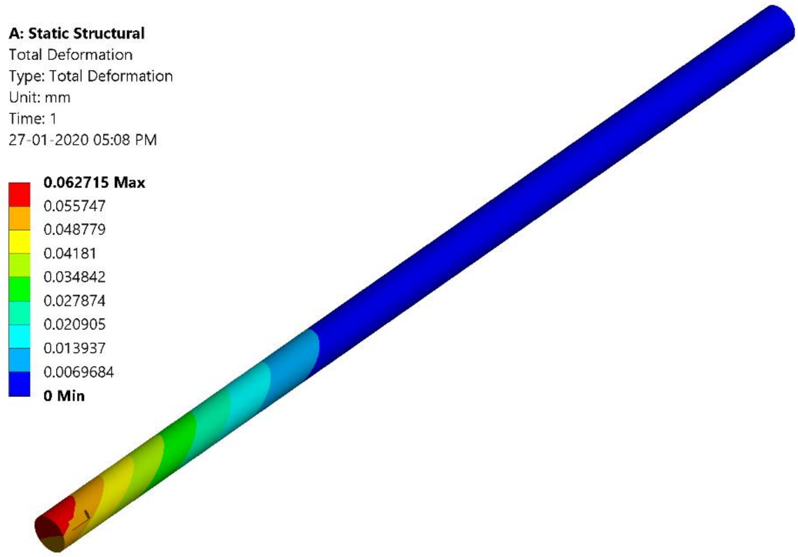

Figure 6: Total deformation of output shaft

- From figure 6 the deformation is observed at one of the free ends only. The value of deformation is 0.0627mm which is negligible.

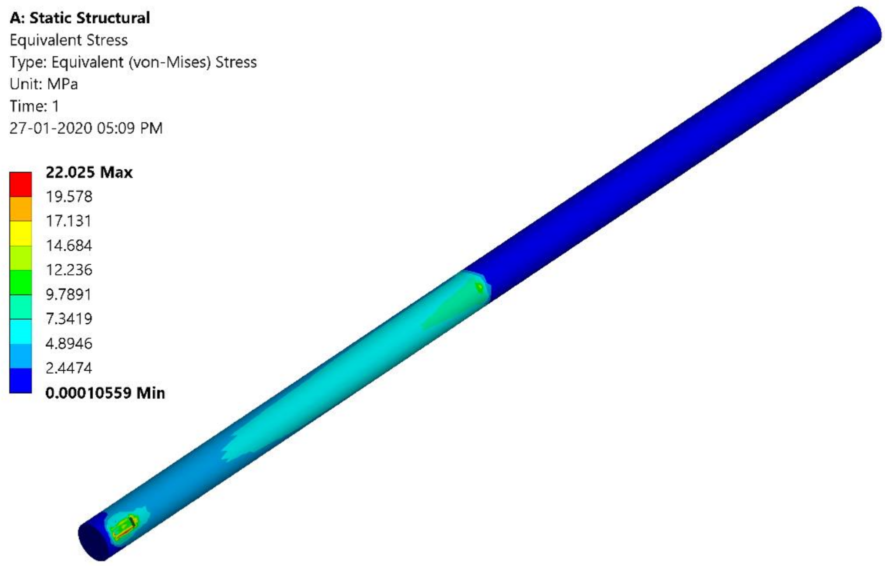

Figure 7: Equivalent Stress distribution on output shaft

- It is observed from figure 7 that the maximum stress is directed over the keyway. The maximum and minimum values of induced stresses are 22.025 N/mm^2 & 0.00010 N/mm^2.
- The output shaft undergoes into minimum loading condition than the input shaft therefore the observed values of stress induced is minimum.

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IV. CONCLUSION

In this paper the study and FEA analysis of shaft is examined. FEA analysis results were used to validate the analytically obtained results. The analysis is done on 16mm diameter shaft which easily withstands all the forces and torque acting on it without any deformation. Therefore, it is concluded that the design is safe.

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