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Research Article

ENERGY HARVESTING FROM RAIL TRACK SYSTEM

Abhay Bendekar[1]*., Pritesh Dixit[2].,Umang Patel[3]., Nikunj Solanki[4] and Amol Patil[5]

[1,2,3,4,5]Mechanical Engineering, Shree L.R. Tiwari College of Engineering, Thane (E), India

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ABSTRACT

An efficient electromagnetic energy harvester featured with mechanical motion rectifier (MMR) is designed to recover energy from the vibration-like railroad track deflections induced by passing trains.Comparing to typical existing vibration energy harvester technologies can only harvest sub-watts or milliwatts power applications, the proposed harvester is designed to power major track-side accessories and possibly make railroad independent from national grid.Trackside electrical infrastructures for safety and monitoring typically require a power supply of 10-100 Watts, such as warning signals, switches, and health monitoring systems. To achieve such a goal we implement the MMR, a patented motion conversion mechanism which transforms pulse-like bidirectional linear vibration into unidirectional rotational motion at a high efficiency. The single-shaft MMR design further improved our previously developed motion mechanism, increased energy harvester efficiency and expanded power harvesting potential. Major advantages of implementing MMR include bidirectional to unidirectional motion conversion and flywheel speed regulation. Bench test of the harvester prototype illustrate the advantages of the MMR based harvester, including up to 71% mechanical efficiency and 50W power output.

INTRODUCTION

Every year, hundreds of fatalities occur at unprotected rail crossings. The most common types of railroad accidents are collisions with passenger vehicles. On average every 90 minutes a collision occurs between trains and other vehicles at railroad crossings in India.

Many vehicle/train crashes occur at grade crossings in remote areas where electrical infrastructure is not available to power automatic signal equipment and track health monitoring sensor networks. It has been determined that deploying warning light systems at grade crossings and utilizing distributed sensor networks that monitor railroad track health can lead to enhancement of railroad safety in addressing these failure modes. However, due to the lack of reliable electrical power and the high cost of providing electrical infrastructure in remote areas, use of distributed sensor networks and installation of lighted warning systems are impractical for a significant fraction of these remote sites.

Although there are several other possible methods to supply electrical power to warning lamps and other safety implements at railroad grade crossings in remote areas, such as solar energy, wind energy and rechargeable batteries, the lack of reliability and robustness associated with each of them are the major drawbacks of deploying them as a source of energy in remote areas. Accordingly, developing a long-term, low-maintenance, low-cost and efficient electrical power generation plan will facilitate the ability to deliver safety benefits to more remote areas. With regard to the fact that grade crossings equipped with high-efficiency LED lights satisfying federal requirements require power on the order of 10 Watts per lamp, an energy harvesting device capable of generating 40 Watts or a series of devices each capable of 7producing energy on the order of 10 Watts is needed to power 4 lights. Also it is required that the power generation device does not interrupt trains or maintenance operations.

Experimental Setup

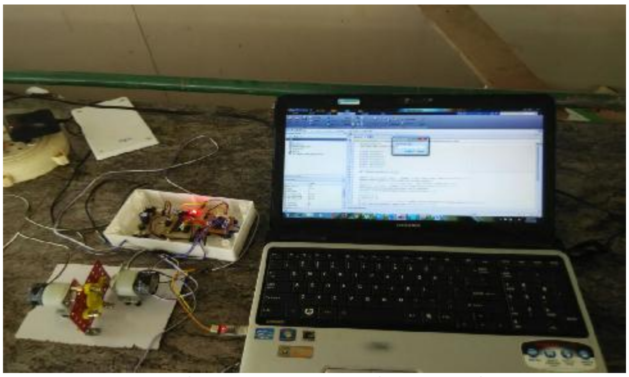

Fig. 1 Actual Setup of Simulation System of Matlab Software with PCD Controller and Motor Driver

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*Corresponding author: ***Abhay Bendekar***
Mechanical Engineering, Shree L.R. Tiwari College of Engineering, Thane (E), India

Working of the Model

Power Requirements

Current railroad crossing warning systems typically consist of eight 12-inch diameter low-power light emitting diode warning lamps. These high efficiency lamps satisfy the federal requirements for illumination and draw power on the order of 10 W per lamp. For remote areas that have the necessary electrical infrastructure for warning lights, the setup is such that there are four lamps per direction of traffic with two sets of two lamps that alternate off and on. With this arrangement, four lights will be illuminated the entire time the crossing is active. According to the American Railway Engineering and Maintenance-of-Way (AREMA) standards, to meet the mandated intensity the nominal power necessary by the lights is approximately 8 W at 9 VDC. The total power required whenever a grade crossing warning lamp system is operational becomes approximately 40 W.

Power Harvesting Device

To achieve these power requirements two power harvesting devices were designed and tested. The devices span across two rail ties and are directly driven by the vertical displacement of the rail and tie(s) due to passing railcar traffic. The devices utilize this displacement and translate the linear motion into rotational motion. This rotational motion is then used to rotate a permanent magnet direct current (PMDC) generator which produces power for our electrical system. To convert the linear motion of the rail deflection into rotational motion that would be used by the PMDC generator, a rack and pinion gear system was used. The rack 10 is mounted in the ground and kept stationary while the pinion gear along with the entire device move up and down with the rail and tie(s). Depending on the design, the rotary motion of the pinion gear was either rectified by a single one-way clutch or a combination of two one-way clutches and a system of gears. Without these clutches, as the rail deflects down and then back up, the pinion gear would oscillate between clockwise and counterclockwise motion. With the generator being designed for one way motion the oscillation between the two would have a cancelling effect on power production. The single one-way clutch prevents this alternating clockwise and counterclockwise rotation of the generator and only allows the rotary motion created from the downward deflection of the rail to be translated through the clutch and into the generator. Because this design only utilizes the downward motion of the track it is only taking advantage of half the power that could be generated. Utilizing a combination of two one-way clutches, both the downward and upward motion of the track can be harnessed, maximizing power production. With the deflection of the rail being minimal, approximately 0.05 to 0.75 inches, amplification of the rotary motion is necessary to rotate the generator with enough speed to produce a sufficient amount of power. To achieve this amplification a planetary gear head was used. The single one-way clutch system utilized a 1:50 planetary gear head whereas the double one-way clutch system used a 1:100 planetary gear head in MATLAB coding. With every rotation of the pinion gear the generator would rotate either 50 or 100 times depending on the design. The amplified rotational motion of the shaft is then transferred into a PMDC generator to produce the required electrical energy.

Physical constraints

Searching for allowable workspace in which the energy harvesting device could be mounted, a 30 inch long space along the track from one tie edge to the next tie edge, a 13-16 inch wide serviceable space from the edge of the tie plate to the end of the rail tie, and a 5-6 inch height, a total space across two railroad ties in between the edge of the ties and the rail, is being considered as the practical space.

The device scavenges electrical energy from the vertical displacement of railroad trackdue to passing railcar traffic. It is mounted to and spans two rail ties such that it directly harnessesthe track’s entire upward and downward displacement and converts the linear motion into rotarymotion and then magnifies the rotary motion to a permanent magnet DC generator (PMDC) generator. current generators allow for easy integration of multiple power harvesting devices together.

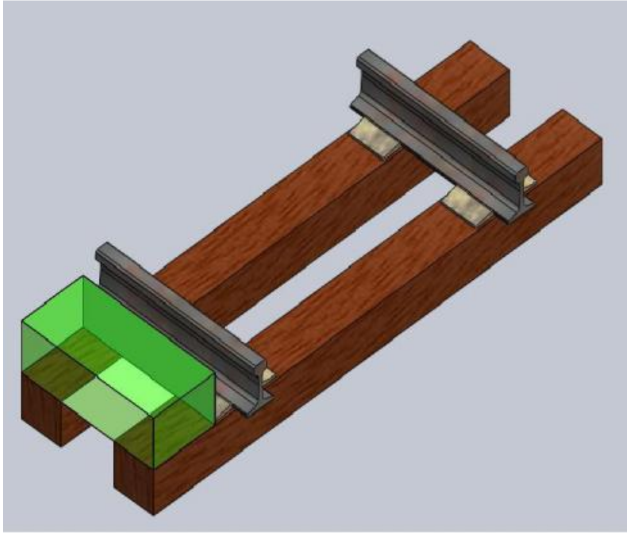


Fig. 2 Allowable workspace for energy harvesting device

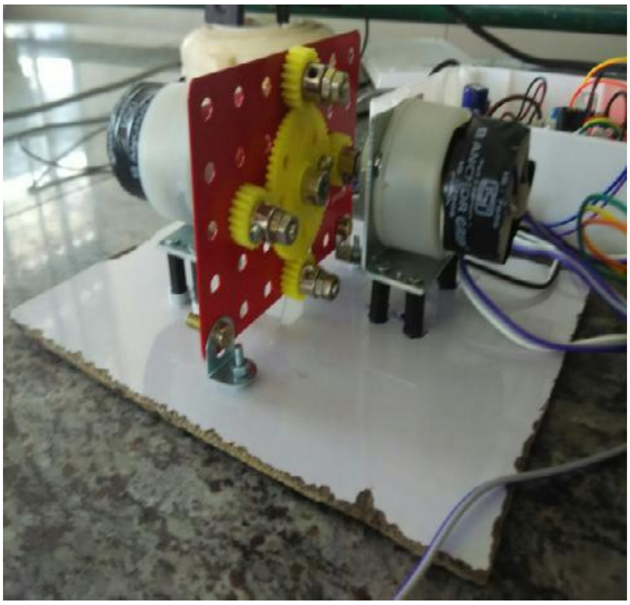


Fig. 3 Sun Planet External Gear

For the first generation single one-way clutch system a generator with smaller power production capacity was used. This generator operates within the range of zero to 5,000 revolutions per minute and produces a current in the range of zero to 2.5 amps. For the second generation double one-way clutch a larger capacity generator was used. This generator operates within the range of zero to 5,000 revolutions per minute and produces a current in the range of zero to 8 amps. The overall design of the first generation sun planet external gear is shown below with flow diagram.

Simulation

To calculate the expected results of different prototypes, MATLA Bcode was used for the simulation. The MATLAB code was split into seven separate files corresponding to specific tasks. Depending on user inputs the code first calculates maximum track deflection. Then, depending on the type of gear ratios, the simulation determines the average power production for the generator. With that the program calculates the minimum number of devices needed to power the warning lights along with the appropriate positioning for the devices along the section of track. Power losses through the wiring are then determined and an adjustable duty cycle is applied to the warning lights. With all these calculations taken into consideration the simulation goes through a pass/fail criterion where it tests to see if the lights have enough power to remain on the entire time it would take the train to pass, while also checking that there is minimal power loss to a rechargeable battery which is used in conjunction with an electrical control system.

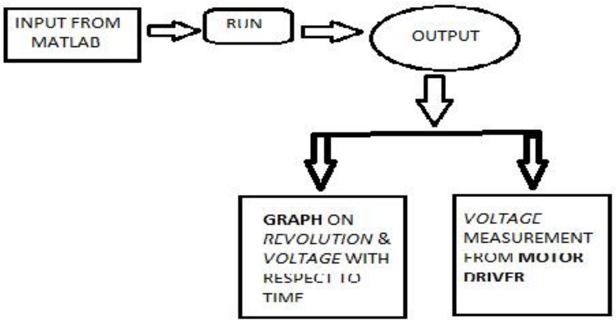
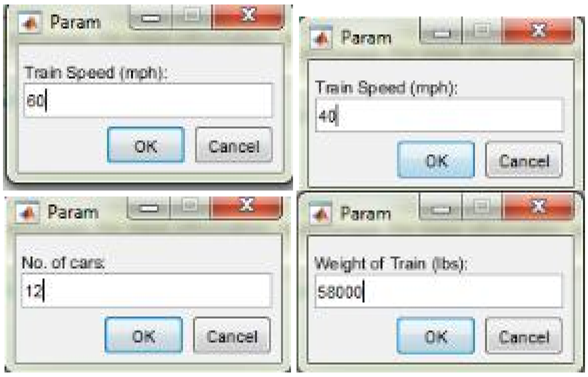


Fig.4 Flow diagram of overall simulation

Graphical User Interface

The first file used in the simulation is for a graphical user interface (GUI), labelledWork1.This file builds the GUI, and is inform how the user will interact with the simulation and input the numerous variables that are available. This GUI allows for quick and easy changes be made to the simulation settings without having to go into the code itself to make changes. For this simulation the user has control over train variables such as speed, changes in acceleration, number of railcars, and the average weight for a single rail car. These variables directly affect power production for the power harvesting device and the overall amount of train device interaction time the simulation will cover. Along with control over train variables, the user can also control variables associated with the build details of the power harvesting device.

These variables include the gear ratio of the planetary gear head with options of1:25, 1:50, 1:75, and 1:100, the option of harvesting only the downward motion of the rail and tie(s) or both the downward and upward motion, how the devices are positioned (i.e., spread out along the track or cantered at the railroad crossing), and the minimum number of devices to start the simulation. Finally the user has the option to control the amount of power the device can produce, alter the time at which the warning lights turn on, and control which figures are displayed at the conclusion of the simulation (e.g., displacement, velocity, acceleration, revolutions per minute, power production, battery life, and duty cycle).



Train Speed (mph): 60

Train Speed (mph): 40

No. of cars: 12

Weight of Train (lbs): 58000

Fig. 5 GUI Data Method

For the simulation, values for the train's velocity can rangeany where between 10 mph and above with a probable maximum train speed being approximately 60 mph, while the railcar weight can range from 58000 lbs for an unloaded railcar up to 280000 lbs for a loaded railcar.

Within the range of a typical train velocity the rail will always experience the same amount of deflection independent of speed. For a fully loaded railcar of 280000 lbs travelling at 60 mph the deflection experienced by the rail at a given point as a function of time is shown in Figure

The maximum vertical track deflection predicated for this setup was 0.25 inches.

The vertical track deflection for an unloaded train of 58000 lbs was also determined by using the Winkler model with the same constant values. For an unloaded railcar of 58000 lbs travelling at 40 mph the deflection experienced by the rail at a given point as a function of time is shown in Figure.

Power production

With the instantaneous revolutions calculated the simulation continues and calculates the average power produced per single device. The program first calculates the period it takes for one car to pass. It then examines the data for the revolutions over the course of this time period directly in the middle of the total available data. This area corresponds to the time from when the middle of the first car passes over the device to when the middle of the second car passes. This area contains the most complete data when analyzing the two cars. With these results the average generator speed, average current, and average power are all calculated by summing the respective functions over a period of one car and dividing by the total number of samples. For the case shown in Figure the average generator speed was 60 rpm and the average current was 4.5V. For the another case shown in Figure the average generator speed was 40 rpm and the average current was 0.35V. These values are then outputted at the conclusion of the simulation.

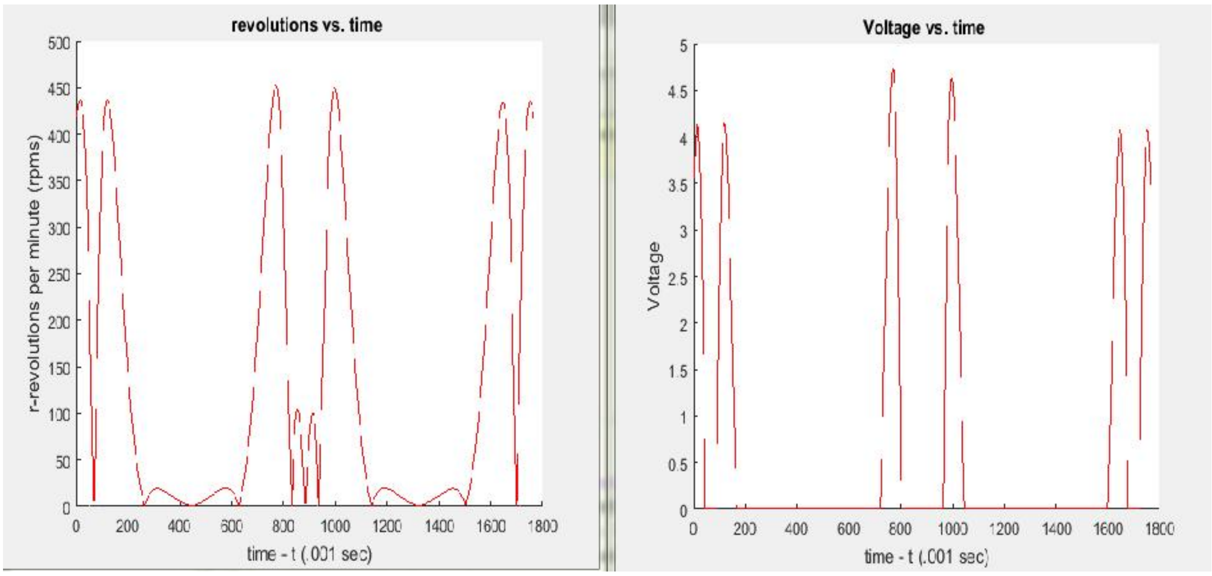


Fig.6 Track deflection profile for a loaded train at 60mph

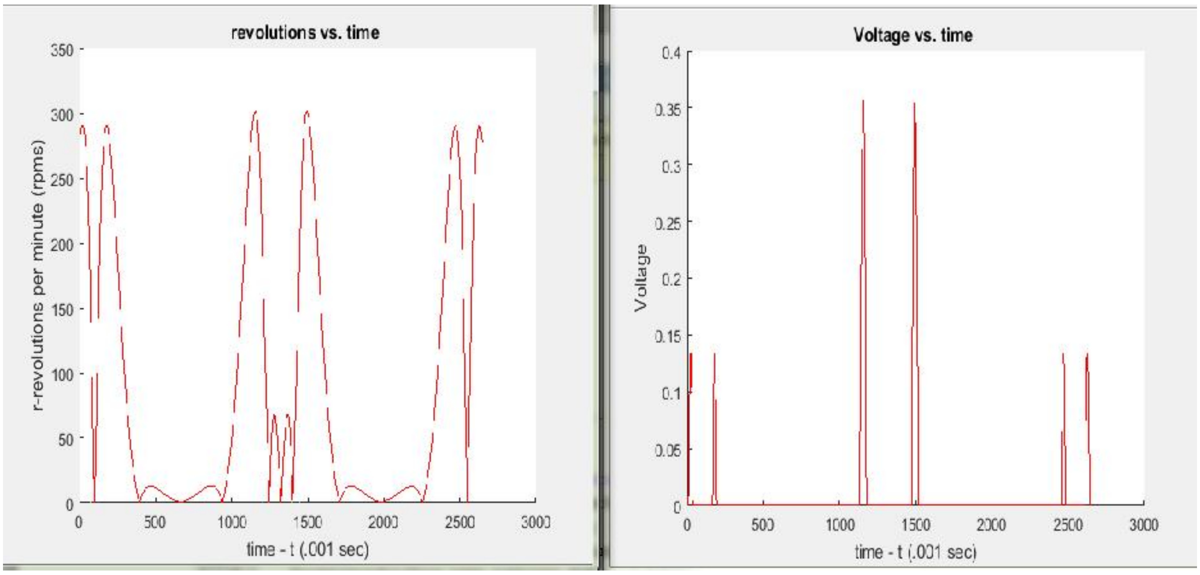


Fig.7 Track deflection for an unloaded train at 40 mph.

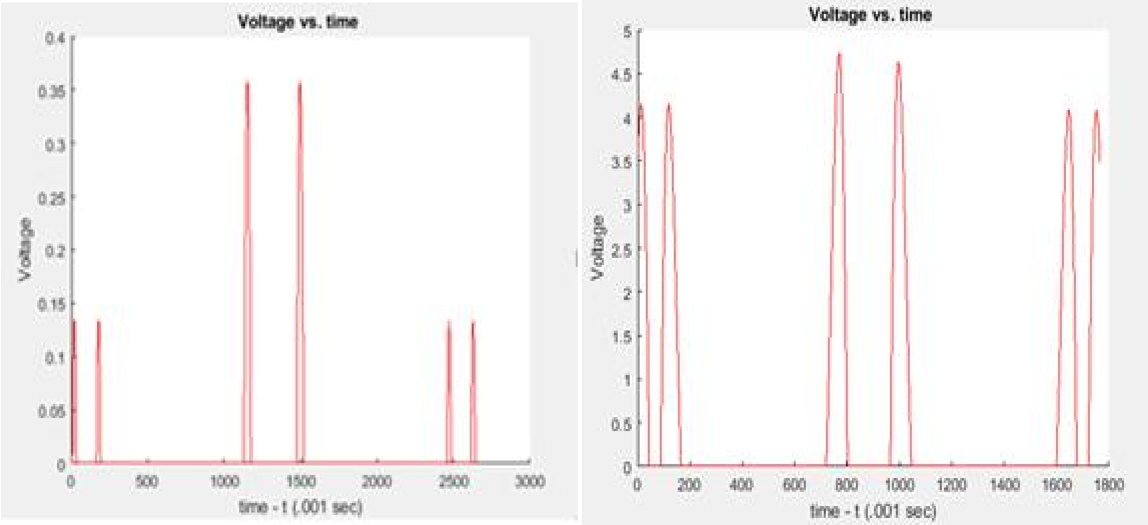


Fig.8 Power production of first generation design with 1:50 gear ratio.

Matlab Programming

```
% clc;clear all
%% % declare global variables
global Speed Value
global Car Value
global Accel Value
global Power Value
global Light Value
global Weight Value
global Device Value
 %% % Enter parameter values
Speed={'TrainSpeed}
(mph):'};name='Param';numlines=1;defaultanswer={'60'};
Speed=inputdlg (Speed, name, numlines, defaultanswer);
Speed Value=str2num (cell2mat (Speed)); %#ok<ST2NM> %
Max up to 60
Cars={'No. of cars:'};name='Param';
numlines=1;defaultanswer1={'2'};
Cars=inputdlg (Cars, name, numlines, defaultanswer1);
Car Value = str2num (cell2mat (Cars));%#ok<ST2NM> %= 2;
Accel Value= 100;
Power Value= 2;
Light Value= 2;
Weight={'Weight of Train (lbs):'};name='Param';
numlines=1;defaultanswer2={'58000'};
Weight=inputdlg(Weight,name,numlines,defaultanswer2);
Weight Value=str2num (cell2mat (Weight)); %#ok<ST2NM>
Max up to 280000
Device Value= 1;
GearRatio = 50;% gear ratio of the planetary gearhead
Fposition (Speed Value, Car Value, Accel Value, Power Value,
Light Value, Weight Value,...

Gear Ratio, Motion, Position, Device Value);
[v_revolution, voltagesec] = fdeflection (Speed Value, Weight
Value);

%% Call interfacing function
interfacing_serial(v_revolution)
```

RESULT GRAPH

Sr. No.	Train Speed (mph)	No. of Cars	Weight of Train(lbs)	Output Voltage from Generator(V)
1	60	12	58000	4.29
2	40	12	58000	0.35

CONCLUSION

Hence, we compare the value from Mathematical Modelling with Output Voltage from motor driver unit with the help of MULTIMETER. Future work will include making improvements and additions to the simulation engine.

A third generation prototype is currently being developed that will be included into the simulation such that power production for the device can be predicted for various train speeds and weights. Another inclusion to the simulation is developing a third option for determining the spacing of the devices. This third option would calculate and test all the possibilities of how the devices can be positioned along the track until the best possible positioning is determined. This third option would greatly increase the time for the simulation to run to completion.

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