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Intermittently Powered, Externally Driven Rail Transit: A Futuristic Approach to Public Transportation System

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Abstract: *Multiple problems being experienced within public transportation such as accident-prone transportation due to driver dependency besides road, environmental issues mainly due to hydrocarbon fuel pollution has highlighted the need for an efficient system of public transport to reduce the load on the infrastructure and the environment. To overcome the issues faced by the public transit systems, an alternative public transportation system which is 'Intermittently powered, externally driven rail transit' was proposed and has been conceptualized at proof of concept level. The vehicle is intermittently powered and driven externally which runs using the principle of inertia. It eliminates the present concept of onboard driving devices and driver dependency. The vehicle is driven by a roller bank which consists of motor driven rollers and many such sets of roller banks are placed at certain intervals along the track. The vehicle is driven by the force imparted by rollers and moves towards the next roller bank where again the force imparted by roller is such that the vehicle travels further with almost constant velocity. This paper highlights the development of experimental set-up and tests performed at varied speed conditions, load conditions and track profiles.*

Keywords:*Externally driven, Intermittently powered, Public transport systems, Rail Transit, Roller bank*

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I. Introduction

Public transport system is a term used to describe both road and rail based modes of transport such as buses, trams, passenger trains, monorails, metros, bullet trains, subways etc. P. Fouracre*etal.*examined the technical and economic advantages of the most widely used Mass Transit Systems(MTS) for developing cities. Road based public transport system has passenger handling capacity of 20000-25000 passengers/hour/direction [1]. But higher flow requires heavy rail based system with higher capacity. Railway is also being used at the peak of its capacity and is still falling short in fulfilling the need for supporting passengers. Hence, there is a direct need for capacity enhancement and contribution to the rail based public transport system [1].

Though railway is the most efficient mode of transportation, railway system still needs to work on emissions. The railways operations have created hazardous effects on the environment. This suggests that railway sector should be modified to zero carbon emissions by using renewable energy sources. Diesel engines should be converted into electric engines [2].

Consequential accidents on Indian railways during 2005-06 to 2009-10, indicate a total of 965 cases. Out of which 832 accidents are recorded on human failure i.e. 86.21% [3], which clearly highlights the need for considering safety of the passengers. The passengers commuting by railways deserve a safe and comfortable travel. Accident prone transportation due to driver dependency can be eliminated with the use of automated vehicles. Lukasz Owczarzakaetal.have developed transportation solutions based on driverless vehicles and compared those solutions with traditional forms of passenger transportation by considering criteria for safety. Automated vehicles in public transport system can be very useful and efficient [4].

As present vehicles have onboard driving devices, weight of vehicles is more due to driving devices and accessories. More is the weight of the vehicle; more energy is required to drive the vehicle.

To overcome the problems in public rail transit systems, new concept called 'Intermittently powered, externally driven rail transit' was proposed and has been conceptualized at proof of concept level for the patented idea [5]. Merits of this system are:

- Autonomous vehicle due to elimination of driver dependency.
- Light weight vehicle due to elimination of on-board driving devices.
- Low energy consumption because of intermittent supply of power.
- Efficient in short and long distance transportation with last mile connectivity.
- Lowest net cost to the society mobility system.
- Reduction in the emissions by eliminating usage of hydrocarbon fuels.

The proposed system does not have on-board driving devices and vehicle is driven with the help of set of roller banks placed at certain intervals along the track. The vehicle is driven by the force imparted by rollers and moves towards the next roller bank where again the force imparted by roller is such that the vehicle travels further with almost constant velocity. There is no active source of power in between two roller banks. The vehicle is driven from one roller bank to another because of inertia. Research work on externally driven rail transit system is done by Y. Suda et al. The principle of potential energy for driving a vehicle (application: roller coasters) is demonstrated by authors in the paper. The present paper discusses use of intermittent supply of energy to drive the vehicle with least possible slope variations and speed variations unlike the concept of “Eco-Ride” as demonstrated by Y. Suda et al. [6].

First section of the present paper describes the concept of intermittently powered, externally driven rail transit system. Second section discusses about the construction of different test tracks and the prototype vehicle to confirm the basic performance of a system. Performance of the prototype vehicle is checked on horizontal, curved, uphill and downhill track. Testing of the vehicle is done at different speed and load conditions. The present paper focuses on determination of the velocity variations along the horizontal track and acceleration for passenger stability. The prototype vehicle used in the experimentation is not made in accordance with the passenger requirements. It is in the very primitive form just to present the proof of concept of the patented idea.

II. Concept Development

Concept of intermittently powered, externally driven rail transit system is proposed to solve multiple problems faced by current public transport systems. Basic concept is as follows:

- The vehicle is externally driven by the set of roller banks placed at certain intervals.
- There is no power supply to the vehicle in between two roller banks (i.e. intermittently powered).
- The vehicle is passive and the rails are active.

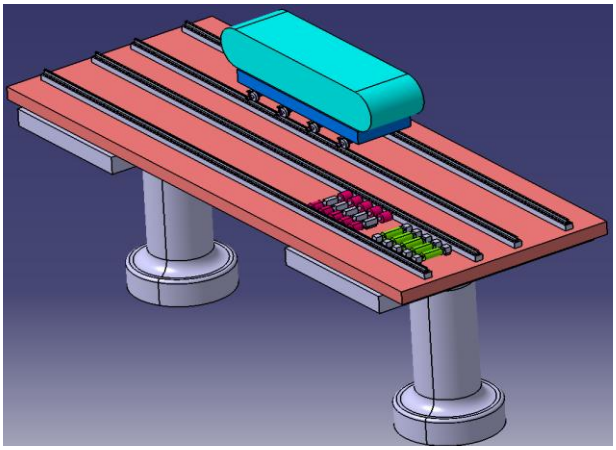


Fig. 1: Conceptual model of intermittently powered, externally driven rail transit system

As shown in fig. 1, set of roller banks are fixed in the rail track at certain intervals. These rollers will push the vehicle from bottom and the vehicle will move ahead. Hence, the basic driving mechanism is a friction drive by using a set of rollers. Once the vehicle is pushed ahead by one roller bank, it will reach to the next roller bank because of inertia. Again next roller bank will push the vehicle ahead. There is no active supply of power in between two consecutive roller banks. This concept of supplying intermittent power to the vehicle is similar to bowling a bicycle rim hoop.

There are different mechanisms of driving the vehicle externally such as pneumatic drive, electromagnetic drive, friction drive etc. Out of these mechanisms, friction drive is selected in which the vehicle is driven by the force imparted by motor driven rollers.

Different positions of roller banks were tried out such as rollers placed at the bottom of the vehicle, rollers placed at the top of the vehicle and rollers placed sideways of the vehicle. The rollers placed at the bottom exert upward force and lead to the uplifting of the vehicle. The rollers placed sideways cause toppling of the vehicle while moving on the curved track. The rollers placed at the top exert force in the downward direction preventing lifting of the vehicle and are also suitable for curved profile of the track. Hence, during experimentation rollers are placed at the top of the vehicle.

III. Prototype Development

III.1 Stage 1: Experimentation on I-section Track

To conduct initial experimentation related to the proof of concept, I-section track of mild steel is used to replicate the design of railways. Track length of 2m is decided for the first testing. Track gauge is 500mm.

Design of the vehicle is done by scaling down the flat railway wagon.Dimensions of the flat railway wagon are scaled down by using ‘G’ scale [7]. For initial proof of concept, a flat plate of mild steel is used as the load carrying vehicle. Wheels with flange on one side are selected for the vehicle body as per the track section. Checkered sheet is attached on the base plate as a friction providing surface. Initially, a single set of roller bank is used with two rollers mounted on a shaft which are driven by the motor. Speed control is achieved by using D.C. drive connected to the motor. A set of rollers impart the force to push the vehicle ahead.Selection of rollers is based on the friction required between the vehicle surface and rollers. Fig. 2 shows the experimental setup on I-section track along with the vehicle [8]. Readings are taken for distance travelled by the vehicle with a single roller bank by varying speeds of the motor.

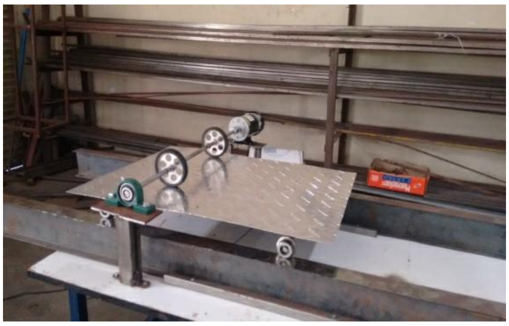


Fig. 2: Experimental setup for stage 1(I-section track)

III.2 Stage 2: Experimentation on Horizontal Track

In the second stage, experimentation is done on the horizontal track [9]. As bending of I-section is costly, various alternative options available for the track like square and rectangular tubes, C-channels, L-channels etc. were searched. Rolling of square bar can be done easily so square bar of 12 mm cross-section is selected for the track. Material used for the track is bright steel which is corrosion resistant. The test track of length 8m is constructed. Track gauge is 300mm.

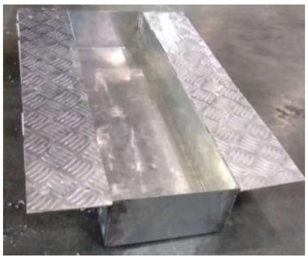


Fig. 3: Modified vehicle body

The vehicle body is redesigned to reduce the weight of the vehicle. Checkered sheet is attached on two flanges of a vehicle for better contact with rollers. The vehicle body is made up of galvanized iron because it is light in weight and welding is easier. The vehicle body is manufactured by sheet bending process. Two flanges are provided for contact with rollers as shown in the fig. 3.Wheels with flanges on both sides are selected which are suitable for square cross-section track. Wheels are having swiveling base as same wheels can be used for experimentation on the oval track. Set of roller banks along with motor and D.C. drive are positioned on the horizontal track at certain intervals. Fig. 4 shows a single set of roller bank.

Fig. 4: Single roller bank

Levelling of the horizontal track is done to avoid interruptions in roller and vehicle contact. Rubber dampers are placed below each motor and bearing to reduce the noise and vibration.

Fig. 5: Experimental setup for stage 2 (Horizontal track)

Experimental set-up for stage 2 is shown in the fig. 5. Testing on the horizontal track includes acceleration, deceleration, eddy current braking, ramp-up and ramp-down. The position of motors is decided on the horizontal track by performing trials with different speed and load conditions. The maximum distance travelled by the vehicle at a particular speed is determined experimentally. Thus from the data obtained, position of next consecutive roller bank is determined which must be placed such that the vehicle travels further with constant velocity.

Fig. 6: Construction of ramp-up track

Horizontal track is ramped up as shown in fig.6 to check feasibility of the system on an uphill track [10]. Track is elevated by angle of 7.62^0. To move the vehicle on uphill track, timing belts and pulleys are used to transmit power from primary motor to rollers. Further rollers impart force on the vehicle surface to move it ahead. Position of roller banks for ramp-up is decided in such a way that at any point, two roller banks should be in contact with the vehicle to avoid reversing of the vehicle.

Eddy current braking is used to stop the vehicle. It is contactless magnetic braking and slows down the vehicle smoothly without any energy consumption. Set-up for eddy current braking is as shown in the fig. 7. It consists of two parts, a stationary permanent magnetic field system and a solid moving plate mounted on the vehicle. During braking, non-ferrous metal (Alumiminium) plate is exposed to a magnetic field from a permanent magnet, generating eddy currents in the plate. The magnetic interaction between the applied field and the eddy currents slow down the moving Aluminium plate. Thus the vehicle also slows down since the plate is directly mounted on the vehicle, thus producing smooth stopping motion.

Fig. 7: Set-up for eddy current braking

Velocity of the vehicle varies along the length of the track. To determine the velocity variations, time measurements are done at different positions along the track with the help of proximity sensors and CRO setup as shown in fig. 9 and fig. 10. From the readings of time measurement, velocity of the vehicle is calculated. Position of sensors is decided on the basis of velocity changes over the track as shown in the fig. 8.As velocity is high when the vehicle is pushed by rollers, position A is located just ahead of motor setup. Velocity goes on decreasing as the vehicle travels and minimum velocity is attained just before the set of next roller bank. Hence, position B is located before the next roller bank. Similarly sensor positions are decided on the entire track. In this way, variation of velocity from maximum value to minimum value is determined.

The maximum admissible acceleration to which a passenger should be exposed seated in a vehicle for transverse (forward- or backward-facing) seats is given as 2.45 m/s^2 and for longitudinal (side-facing) seats is given as 1.4 m/s^2[11].

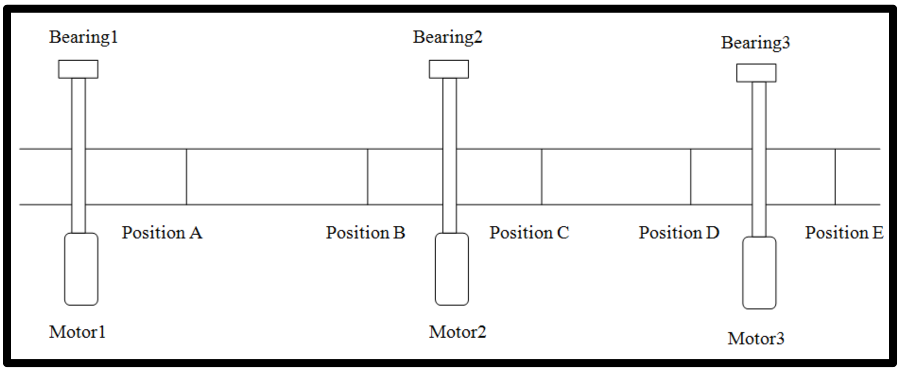


Fig. 8: Schematic diagram of position of sensors on the track for velocity measurement

Fig. 9: Proximity sensor position on the track

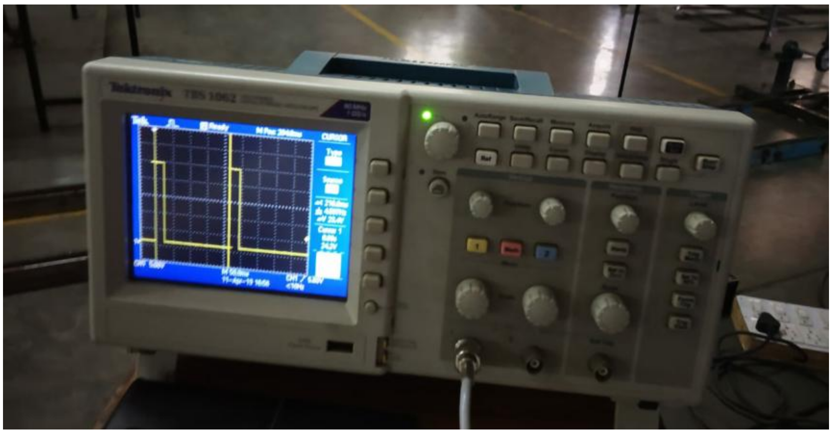


Fig. 10: Time measurement on CRO

III.3 Stage 3: Experimentation on oval Track

In the third stage, the vehicle is tested on the oval track [12] to check the performance on the curved track profile as shown in fig.11. Support structure for the oval track is fabricated on which the oval track is welded.Dimensions of the track are selected as per the availability of space and the vehicle body dimensions. Square bar of 12 mm cross-section is selected for the track. Material used for the oval track is bright steel which is corrosion resistant. Curved surfaces of the oval track are rolled on a rolling mill and are welded together to form the oval track. The track is lubricated to reduce friction between the track and the wheels. Inner diameter of the oval track is 1700mm, outer diameter of the oval track is 2000mm and center to center distance is 1800mm.

Wheels of the vehicle should rotate freely while taking a turn; hence swiveling base wheels with flanges on both sides are selected. Reason for selecting wheels with flanges on both sides is that while taking a turn, vehicle should not topple. Three sets of roller banks are used on the oval track so that the vehicle covers full track length with almost constant velocity. Same prototype vehicle which was designed for experimentation on the horizontal track is used for experimentation on the oval track. Experimentation is done on the oval track by varying the speed and load conditions.

Fig. 11: Experimental setup for stage 3 (Oval track)

IV. Results and Discussion

Tests are performed at different speed and load conditions on the I-section track, the horizontal track and the oval track. Velocity of the vehicle at various locations along the horizontal track is determined. Fig.12 indicates the distance covered by the vehicle on I-section track at different roller speed. It shows that with increase in the speed of the motor, the distance travelled by the vehicle on the I-section track increases. The maximum distance travelled by the vehicle at 555 rpm is 0.58 m which implies the position of next roller bank that has to be placed before 0.58 m to maintain uniform velocity of the vehicle.

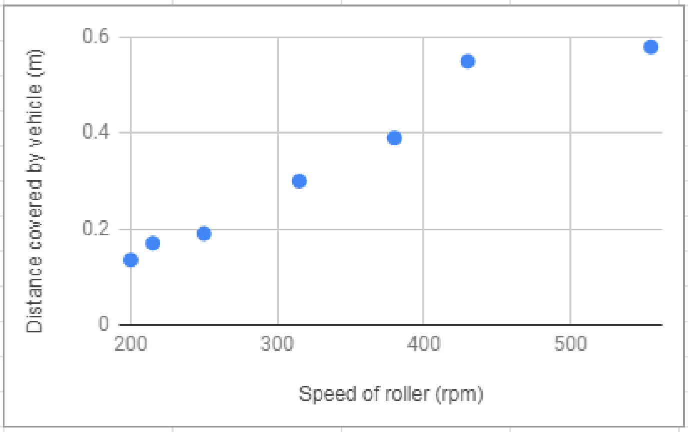


Fig. 12: Distance covered by the vehicle vs. speed of roller on the I-section track

Various sets of readings are taken by varying load conditions and speed of the motor on the horizontal track and the oval track. Self-weight of the vehicle is 8 Kg. When extra load is added to the vehicle, total load is the summation of self-weight of the vehicle and the load placed in the vehicle. Fig.13 is a plot of distance covered by the vehicle on the horizontal track with different load conditions at 1000 rpm, 1500 rpm and 1800 rpm. The maximum distance travelled by the vehicle is at 1800 rpm of all speeds at same load conditions. From this data, position of next roller bank is decided at a particular speed of roller. Velocity variations over the horizontal track at various positions along the track with different load speed and load conditions are shown in the fig.14. It is seen that the vehicle travels with almost constant velocity at particular speed of rollers which are placed at certain intervals along the track. The value of acceleration obtained from experimentation results is 1.9752 m/s^2. Thus value of acceleration obtained from experimentation is less than the admissible value of acceleration and hence velocity variations are within limits [11].

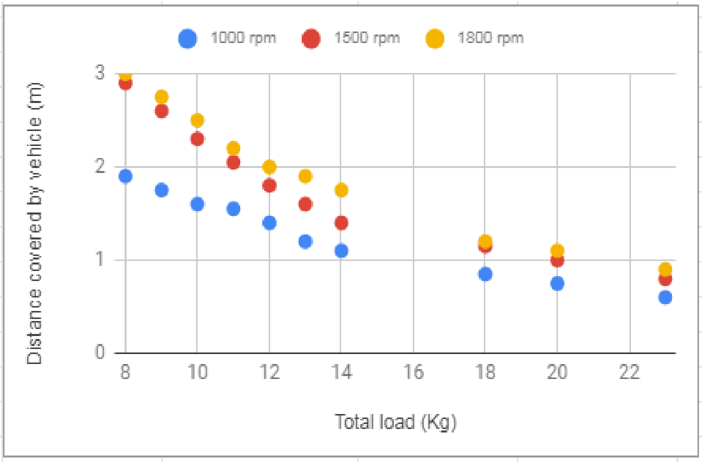
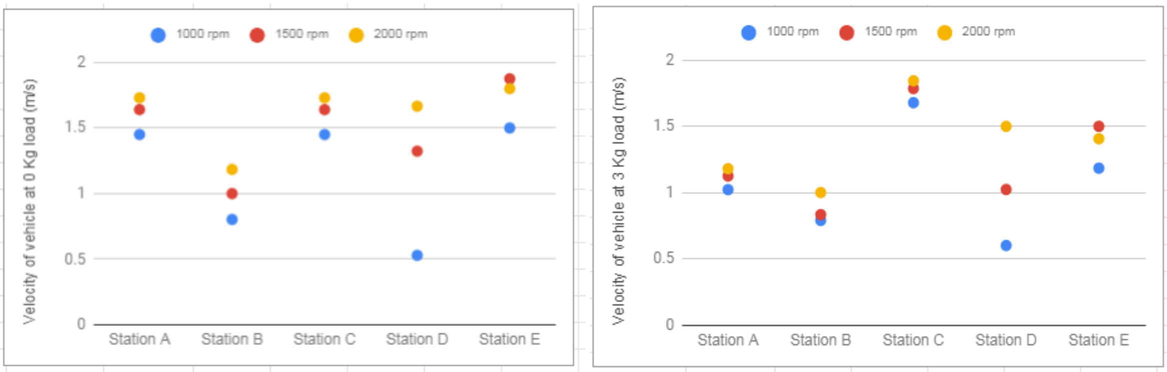


Fig. 13: Distance covered by the vehicle vs. total load at different roller speeds by using only one motor on the horizontal track



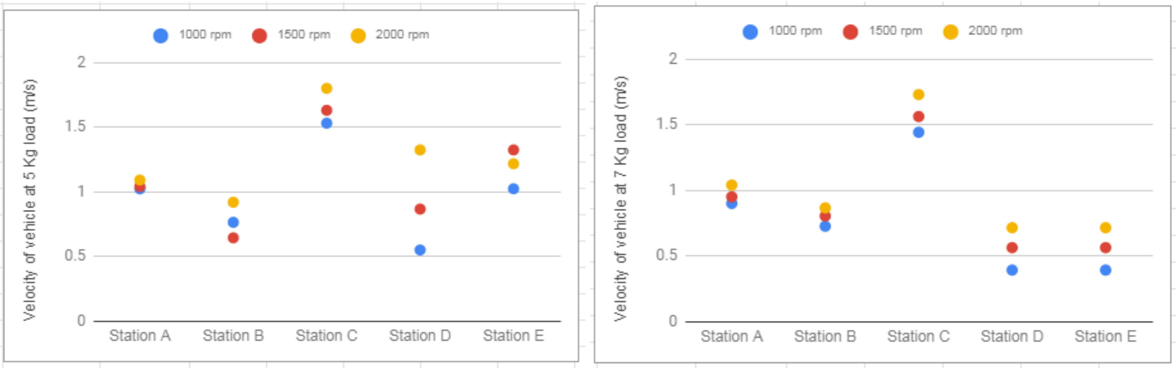


Fig. 14:(a) Velocity of the vehicle vs. distance travelled at different speeds with 0 kg load, (b) Velocity of the vehicle vs. distance travelled at different speeds with 3 kg load, (c) Velocity of the vehicle vs. distance travelled at different speeds with 5 kg load, (d) Velocity of the vehicle vs. distance travelled at different speeds with 7 kg load.

Fig.15 and fig.16 are the plots of the readings taken on the oval track. From fig.15, it is seen that, as total load on the vehicle increases, distance covered by the vehicle decreases. The distance travelled at 2000rpm is more than that of distance travelled at 1000rpm for the same total load with single motor. Fig.16 plotted indicates that when two motors are at the same speed i.e. at 1000rpm, distance travelled decreases with the increase in the load. When two motors are at different speeds i.e. first motor at 2000rpm and second motor at 1000rpm, there is uniform deceleration. Velocities achieved in second case are higher than in the first case. Accordingly the position of third roller bank is decided on the oval track.

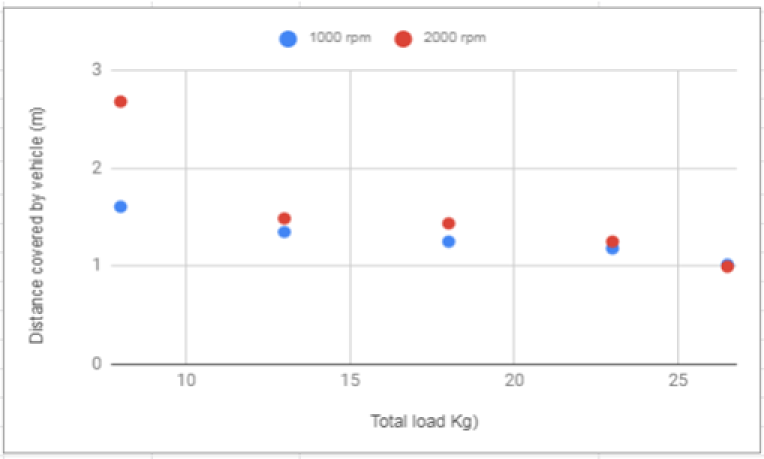


Fig. 15: Distance covered by the vehicle vs. total load using only one motor at 1000rpm and 2000rpm on the oval track

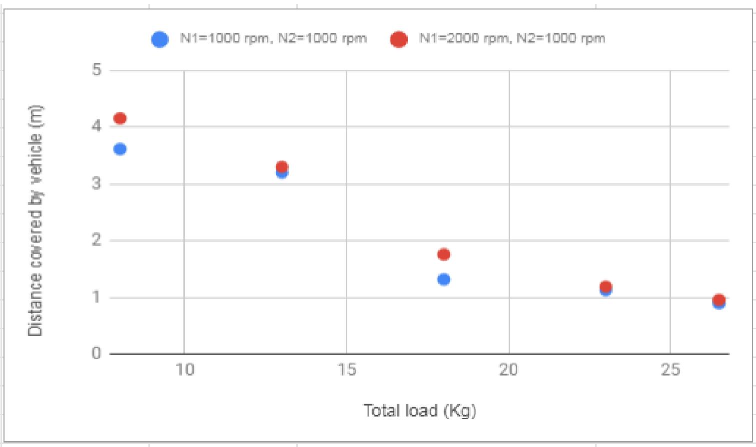


Fig. 16: Distance covered by the vehicle vs. total load at same and different motor speeds on the oval track

V. Conclusions

New concept of public transport system of 'Intermittently powered, externally driven rail transit' was proposed.Different test tracks were constructed and basic performance of the prototype vehicle was checked.The vehicle was successfully driven using an external drive i.e. using sets of roller banks and the proof of concept has been presented. From the experimentation following conclusions are drawn:

- The contact between the vehicle surface and the roller is improved using a checkered sheet and rubber rollers.
- Friction drive is not suitable to externally drive the vehicle because of wear and tear of rubber rollers. Further studies on roller-contacting surface combinations are necessary as it is important consideration in this mechanism.
- As load increases, distance covered and velocity of the vehicle decreases.
- Friction brakes pose several problems; hence eddy current braking is used in the system.
- Maximum distance travelled by the vehicle on the horizontal track at 1800 rpm is 3m experimentally.
- Experimental velocity of the vehicle at 1800 rpm with no load condition is 1.8 m/s. With further improvement in the vehicle design and overcoming friction between rail and wheels, higher velocities can be achieved.
- This system can be initially used as a medium of internal transportation in large campuses and airports. This system can also be employed as a connecting link of feeder service to serve main railway stations and metro stations; thus enabling last mile connectivity.

Open frame motors can be a suitable alternative solution to current friction drive. System monitoring of real-time performance at all levels is required. Sophisticated multi-layer control systems are required to ensure vehicle management, mobility management and Integrated Transport System management – all working in a comprehensive and cohesive manner.

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