Design and Development of Mechanical Regenerative Braking System for Road Vehicles

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Abstract: **An innovative mechanical regenerative braking system for road vehicles, developed by the authors and patented, has been described. This system has been installed on an experimental solar electric vehicle and the energy saving during on road experiments has been studied and test results presented in this article. It has been concluded that by using this system about 70% of the energy, that might have gone waste while applying brakes, can be saved and the driving range can be increased.**

Keywords: ***Regenerative Braking, Energy Conservation, Mechanical Regenerative Braking, Energy Conversion.***

I. INTRODUCTION

In road vehicles much amount of energy is wasted due to frequent braking. A municipal bus absorbs about 59% of the work produced by an engine [1]. In urban areas the IC engine powered vehicles travel with low velocities and frequent stops and idling periods, such vehicles have overall efficiency below 10% [2]. In case of metro-rolling stocks, the inter station distances are smaller, so Metro operation is essentially of start / stop nature. A major part of energy goes waste due to frequent acceleration and de-acceleration, if regenerative braking is not used. This wastage of energy at the time of stopping or slowing down of the vehicle can be reduced up to some extent by using Regenerative Braking.

The Electrical Regenerating Braking System came into existence and was used in Electric Trains for quite some time. In Electrical Regenerative Braking, the kinetic energy of the vehicle is absorbed through spinning rear wheel's axle and converted into electrical energy and then to chemical energy, as batteries are charged before the vehicle is stopped or slowed down. This stored energy is reutilized when the vehicle restarts or accelerates. The concept of Mechanical Regenerative Braking was also applied and it was used in London Railways. In Mechanical Regenerative Braking System employed in London Railways, the stations are situated at certain heights above the level track. The slope of the track while leaving the station maintained at 1 in 30 and while reaching the station the slope of the track is kept at 1 in 60. In this system the kinetic energy of the train is converted to potential energy, while the train approaches the station and this stored energy is reutilized while the train leaves the station [3]. This type of Mechanical Regenerative Braking System is not suitable for road vehicles for obvious reasons.

Further, fossil fuels used in IC engine powered vehicles may get exhausted some time or the other. There is also noise and air pollution due to IC engine powered vehicles. For combating these problems Electric, Solar, Solar-Electric, Hybrid (Electric), and Air Hybrid vehicles have been developed. Different Regenerative Braking Systems are in use for above vehicles for efficient use of energy. IC engine and Electric motor are used for vehicle propulsion in Hybrid Electric Vehicles. In such type of vehicles Electrical Regenerative Braking is used. The braking energy recovered by generator in case of Hybrid City Bus in urban area during braking is converted to electrical energy and then to chemical energy as the batteries are charged. This process entails losses of the order of 25% of energy [4]. The driving range of Electric vehicles could be increased 8-25% by using fuzzy logic control for braking [5]. Regenerative Braking with ultra-capacitor based auxiliary energy system improves km/kwh about 18.2% in case of Electric vehicles [6] Hydraulic Launch Assist (HLA) system is also used for Regenerative Braking for vehicles. The HLA system for use in small road vehicles improves 7-10% in fuel economy [7]. The HLA Regenerative Braking System for large truck improves fuel economy approximately 25-35% during stop and go driving conditions [8]. The design and simulation of a purely mechanical system for energy storing for road vehicles has been reported by Latchezar, Tchobansky, Martin Kozek Gerd Schlager and Hanns P. Jorgl. This proposed system will save up to 0.72 kg fuel per 100 km. [9]. The present system developed by the authors [10, 11] is particularly suited for IC engine powered vehicles, Hybrid and Electric road vehicles as well. Indian patent has been granted for this innovative Mechanical Regenerative Braking System for vehicles [11]. It has been concluded that about 70% of the energy that goes waste during braking is reutilized by using this system. The objectives of this work are:

1. To describe the innovative mechanical regenerative braking system.
2. To study the energy saving by installing the MRBS.
3. To study the increase in driving range by installing the MRBS.

II. MECHANISM OF INNOVATIVE MECHANICAL REGENERATIVE BRAKING SYSTEM

This system comprising:

- A motor (1) driving the shaft of the rear axle of the vehicle through a clutch (4) and transmission system (5).
- An energy storage system / fly wheel (3) is connected between said motor and the clutch (4) on the main shaft (2).
- A clutch (7) and the Regenerative Braking System / compound chain drive (8) is connected to said energy storage system (3) and said rear

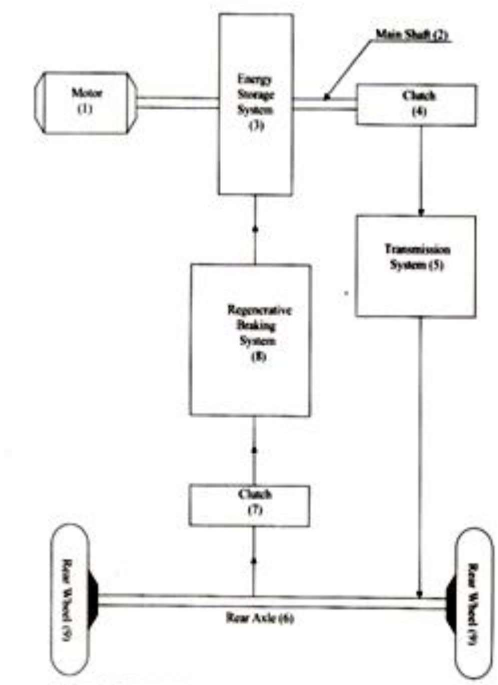

Fig. 1: MECHANICAL REGENERATIVE BRAKING SYSTEM

Axle (6) as shown in Fig. 1, the motor (1) delivers the energy to the rear axle (6) through transmission system (5). Before the vehicle starts, the Regenerative Braking System (8) is disconnected from energy storage system (3) and is kept disconnected during the running of the vehicle until braking is not required. If vehicle is running on the road, it has kinetic energy. If one wants to stop or slow down the vehicle, the connection of energy storage system (3) with a rear axle (6) through power transmission system (5) is cut off and connection through Regenerative Braking System (8) with energy storage system (3) is established through clutch (7). The kinetic energy of the vehicle is transferred from spinning rear wheel's axle (6) through Regenerative Braking System (8) to the energy storage system (3) and this stored energy is reutilized in starting or accelerating the vehicle.

III. EXPERIMENTAL SET UP

The experimental set up for energy studies is shown in Fig. 2. In this set up there is an energy meter to measure the energy consumption under different conditions.

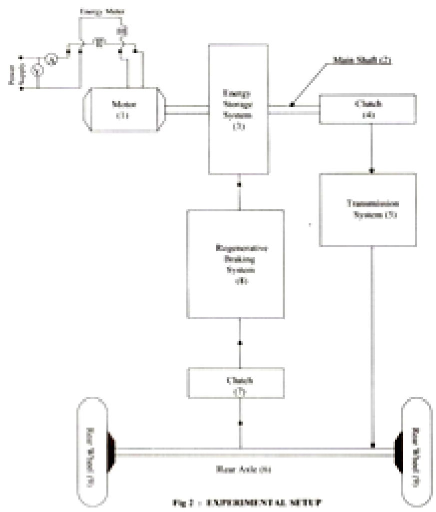

Fig 2 : EXPERIMENTAL SETUP

IV. EXPERIMENTAL CONDITIONS

1. Gross weight of the vehicle is 242 kg (constant)
2. Distance traveled is 120 m (constant)
3. Vehicle speed is kept 8 km / hr (constant)
4. No. of times brakes are applied in 120 m travel
   (i) 4 times after every 25 m in 120 m travel
   (ii) 3 times after every 35 m in 120 m travel
   (iii) 2 times after every 50 m in 120 m travel
   (iv) Without braking in 120 m travel
5. Conditions of vehicle driving:
   (a) Without Regenerative Braking
   (b) With Mechanical Regenerative Braking System (MRBS)
6. Motor is stopped at the time of braking
7. Road conditions and air pressure in tires were kept constant as far as possible.
8. Vehicle is restarted just after the vehicle is stopped by braking without any delay.

V. RESULT AND DISCUSSION

The energy consumed in vehicle propulsion with and without the use of Mechanical Regenerative Braking System has been experimentally determined under different running conditions and results are plotted. From Fig.3 it is evident that the specific energy consumption with the use of MRBS is less than the specific energy consumption of the vehicle when MRBS is not used, for a particular frequency of applying brakes. It can also be observed that the specific energy consumption decreases as the distance after which brakes are applied increases.

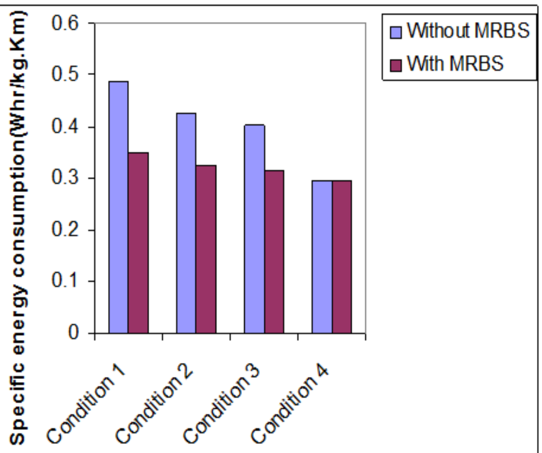

FIG 3: SPECIFIC ENERGY CONSUMPTION UNDER DIFFRENT CONDITIONS

Condition 1: Brake is applied 4 times after every 25m in 120m travel.

Condition 2: Brake is applied 3 times after every 35m in 120m travel.

Condition 3: Brake is applied 2 times after every 50m in 120m travel.

Condition 4: Brake is not applied in 120m travel.

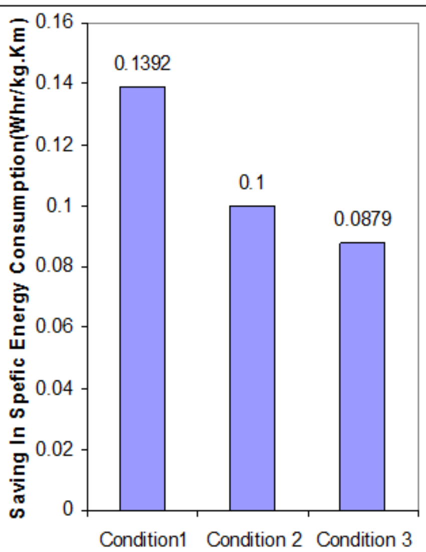

Fig4:Saving in Specific Energy Consumption Under Diffrent Conditions

Condition 1: Brake is applied 4 times after every 25 m in 120m travel.

Condition 2: Brake is applied 3 times after every 35 m in 120 m travel.

Condition 3: Brake is applied 2 times after every 50 m in 120 m travel.

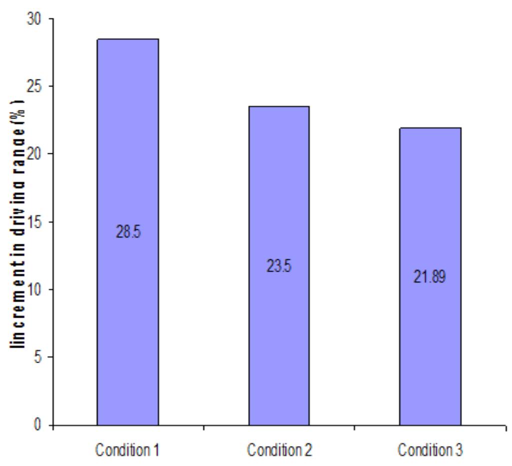

FIG 5: PERCENTAGE INCREMENT IN DRIVING RANGE UNDER DIFFRENT CONDITIONS

Condition 1: Brake is applied 4 times after every 25 m in 120m travel.

Condition 2: Brake is applied 3 times after every 35 m in 120 m travel.

Condition 3: Brake is applied 2 times after every 50 m in 120 m travel.

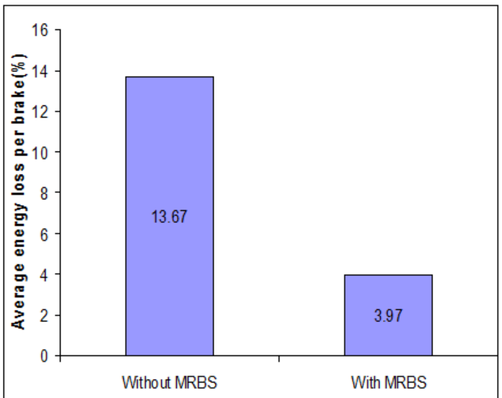

FIG 6: PERCENTAGE AVERAGE ENERGY LOSS PER BRAKE UNDER DIFFRENT CONDITIONS

The higher the frequency of braking for a given travel range, the more will be the saving in specific energy consumption. This is shown in Fig. 4.From Fig. 5 it is observed that the range of distance that can be covered using MRBS increases with frequency of applying brakes under constant power consumption per brake. When brake is applied 4 times after every 25 m in 120 m travel, the travel range increases by about 28%. This is in agreement with the results of Paterson and Ramsay [5].

It is seen from Fig. 6 that the energy loss per brake is 12% when MRBS is not applied. The motor is switched off at the time of stopping or slowing down of the vehicle by applying MRBS. Therefore, the energy loss reduces to 3.67% when MRBS is applied. Thus, the energy loss due to braking reduces to a very low value if MRBS is used, resulting in a saving of about 70% of the energy that goes waste while applying the brakes.

VI. CONCLUSION

The following conclusions can be drawn from this work.

1. By applying the Mechanical Regenerative Braking System developed by the authors, a huge amount of energy which otherwise goes waste during braking, can be reutilized for restarting or accelerating the vehicles.
2. In Solar Electric or Hybrid vehicles, driving range can be increased by applying this system.
3. Specific energy consumption reduces as frequency of braking decreases and vice-versa.
4. With MRBS installed on the vehicle, the energy saving is about 70% of the energy that may have gone waste in braking.

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