Design and Calculations of Kinetic Energy Harvesting System for a Decelerating Train

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Abstract

Every moving object possesses kinetic energy. Whenever it has to stop or reduce speed this kinetic energy has to be dissipated hence energy is lost from the system. This is the case with every mode of transport. With trains due to their mass the amount of energy lost is at a larger scale. Various methods have been developed by train manufacturers and other energy specialists in a bid to recapture this energy from the train. Though these may be successful in some respects they have some significant short comings. One of the most salient of these is that these methods have mechanisms which limit them to electric and electric hybrid trains. This paper is concerned with the development of a system of harvesting kinetic energy from trains which is independent of the source of traction energy. The system is based on the concept of flywheel energy storage.

Keywords
Design, Kinetic energy, Harvesting, decelerating train.

1. Introduction

One of the most essential things required by human beings for easy sustenance of life is transportation. Increased geographic mobility has been a major characteristic of the past century and this has seen a rise in capacity and efficiency in the various contemporary transportation systems. Ever since its introduction in the mid-19th century railway (Lambert, 2014) transportation system has also had its share of improvements and advancements for example the introduction of high speed trains and even more contemporary, the magnetic levitation trains.

The power consumption by transportation systems is constantly increasing and also at the same time so are power demands in other industries. Therefore reducing power consumption and increasing energy efficiency is of greater importance in this age. On top of that there is greater need for a broad range of environmentally friendly sustainable alternative energy sources (Omi, 2013). Together with speed safety and economy, environmental friendliness has been one of the factors which have motivated the development and advancement of train technology. Even modern companies such General Electric have taken huge steps in this area, through the introduction of highly efficient hybrid trains which have significantly reduced carbon foot print.

There are various methods which are used to obtain energy from renewable and environmentally friendly sources such as solar and wind energy. The good news for mankind is that there is another source of clean energy which can be harnessed from a decelerating train. This is the kinetic energy of the train during deceleration. Just like any other moving object a train possesses kinetic energy and whenever it has to stop that kinetic energy has to be changed to some other forms of energy. There are various mechanisms of braking which are used by different transport modes. The most conventional and common of these methods is the use friction brakes to reduce speed or bring it to a complete stop. In friction braking the kinetic energy of the train is dissipated as heat energy via friction (Pendrill, et al., 2012).

1.1 Background

During deceleration a train dissipates a large amount of valuable energy as waste which can otherwise be harnessed for other uses.

1.2 Justification

According to the law of conservation of energy, energy can neither be destroyed nor created but is changed from one form to another. When a train is in motion it possesses a large amount of kinetic energy which has to be dissipated before it can come to a halt. As stated above in conventional braking system this energy is dissipated away as unwanted energy via friction heating in the braking system (McGonigal, 2006). Most trains, especially passenger trains, undergo numerous start-stop cycles as they approach stations and signals and then move on again. With the current demand for energy simply dissipating energy without an effort to tap some of it for other uses is not the best option. Especially with high speed trains which possess relatively high kinetic energy a considerably useful amount of kinetic energy can be obtained.

The convention friction braking of trains not only dissipates most of the energy as waste but also presents certain draw backs which need to be eliminated or minimised by as much as is possible. One of these is the wearing of brake linings due to the extremely high temperatures generated when bringing the train to a stop. The heat is so great because a large amount of energy is being dissipated via friction which if some of it was dissipated by some other means the temperatures generated will not be as high as they get with friction braking alone. Friction braking also leads to high rates of mechanical wearing in braking system elements. Thus increasing the maintenance costs. Harnessing the kinetic energy of the train using some other means so as to lessen the burden on the friction brake is a viable solution for reducing these negative effects and hence reduce maintenance costs.

Recycling the energy will result in an increase in energy efficiency and also reduce CO_2 emissions (ClimateTechWiki, 2006) thereby making the train system more environmentally friendly. Some methods have been suggested and developed in recent years for tapping kinetic energy from various transport modes such as the harvesting of kinetic energy from landing aeroplanes (Adler et al., 2014) and recovery of energy by regenerative braking in electric trains, which has been reported to lead to 8 to 17% recovery of electricity (ClimateTechWiki, 2006).. The disadvantage of the above mentioned method of recycling braking energy by regenerative braking is that it depends on reversing the current in the motors hence it cannot be used on non-electric trains such as diesel powered trains. There is therefore a need to develop more methods which are compatible with trains which have a non-electric traction system.

The energy that can be harnessed from a train during its deceleration can be used as hotel electric power or used for the next acceleration thus larger efficiency as compared a train without any energy recovery system. There is great potential in kinetic energy harvesting from decelerating trains as has been outlined so as to increase energy efficiency and also there is need for zero pollution energy production systems for the environmental friendliness. To approach such high goals development of new technology has to be attempted and all possible engineering principles have to be applied. The goal of this project would be to tackle the problems presented and also reach the set goals.

2. Literature review

According to the principle of conservation of energy, energy can neither be destroyed nor created but is changed from one form to another. Kinetic energy is defined as the energy possessed by an object by virtue of its motion. In other words any object which possesses kinetic energy will be in motion. This therefore means that in order to reduce the speed of a moving object or bring it to a halt the part or all of the kinetic energy which it has must be converted to another form of energy (PrincipleConvEnergy). The process by which this occurs is called braking. For objects which travel on wheels such as locomotives and automobiles the total kinetic energy of the body is the sum of the kinetic energy of translation and the kinetic energy of rotation of the wheels. This means that the braking system has to convert these forms of kinetic energy to other forms (Khurmi & Gupta, 2005).

3. Materials and Methods

In this section the structure of how the solution is going to be obtained together with the stages and various aspects that need to be considered in this design. For mechanical drawings Solid Works 2014 and AutoCAD 2014 was used. For purposes of typical design calculation, modeling and simulations a train of specific character has to be considered. For this design a train with the following characteristics will used:

- 2 InterCity power cars (diesel-electric locomotives)
- 10 Mark 3 locomotive hauled coaches

Intercity 125 locomotives are high speed diesel electric hybrid power cars. The technical specifications are shown below.

Table 1. Locomotive specifications

Component	Quantity
Service speed	201km/h
Power output	1678kW
Tractive force	Maximum – 80kN
	Continuous – 46kN
Gauge	1435mm
Bogies	B10
Length	17.79m
Width	2.74m
Weight	70.25 tonnes
Fuel capacity	4500*l*
Brake force	349 kN

Mark 3 coaches where specifically designed for InterCity 125. They are not self-powered. There are used mainly for passenger trains. The technical specification are given in the table below.

Table 2. Coach Specifications

Specification	Amount
Gauge	1435
Width	2.74m
Floor height above rail	1180mm
Tare weight	34.3 – 39.8 tonnes
Bogie centres	16000mm
Bogie wheel base	2600mm
Wheel diameter	914mm
Bogie type	BT 10
Maximum design speed	200km/h
No of seats	70 (standard class)

4. Results and Discussions

This concept works in the principle that the energy is transferred from the wheels using a gearing system. In this case the energy is used to accelerate a high speed flywheel which acts as the energy store. By decelerating the flywheel the energy is released from the flywheel. In this concept the flywheel system is placed in each car of the train. Energy is recovered from each car and stored there and then when required it is fed back into the wheel set(s) of the same car.

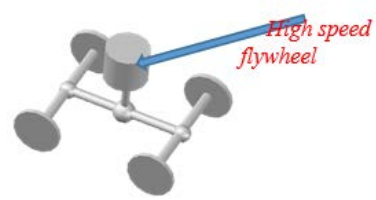

Figure 1. Flywheel based concept

The energy harvesting system has to be isolated during normal motion of the train and engaged only during braking or whenever desirable. A mechanism is here presented on how this can be done. The mechanism consists of a system of gears which provides mechanical connection between the axle of the train and the kinetic energy recovery system. There is an arm carrying a bevel gear on one end and a helical gear on the other. This arm can move in the direction shown being controlled by the locomotive operator such that it can engage the energy recovery system and also disengage. The epicyclic gear train provides speed reduction so that proper meshing of the teeth can be achieved at the engaging gears with reduced wear of teeth.

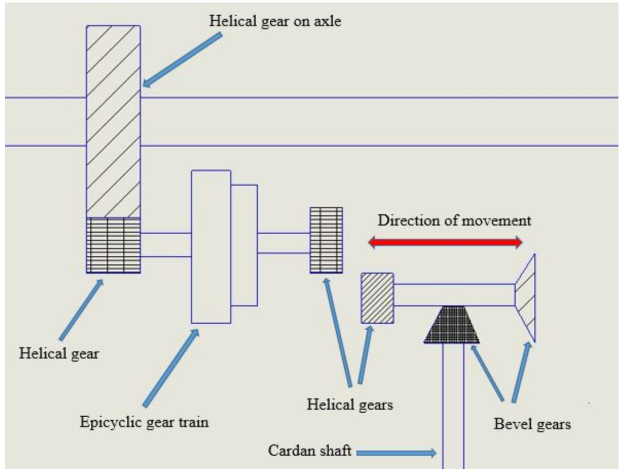

Figure 2. Energy harvesting system disengaged

In this section the design procedure of the energy storage component is done using as a design specimen a locomotive hauled train whose characteristics will be outlined. The parameters which will be determined are the dimensions of the flywheel which will be required to store the specified energy for this train. For design purposes a model locomotive hauled train of following characteristics is going to be used

No. of locomotive (InterCity125) = 2 (one at each end of train)

No. of coaches (standard class Mark 3) = 10

The design will be based on bounding case deceleration i.e. deceleration from the maximum speed (200km/h) and the train will be assumed to be filled to capacity with passengers. The average mass of a passenger was taken as 65kg

Mass of train at full capacity = Mass of locomotives + Mass of coaches + Mass of passengers

= 2 (70250) + 10 (35000) +700 (65)

=**535.5 tonnes**

Total kinetic energy of train at full speed.

$$E_K = \frac{1}{2} MV^2$$

$$E_K = \frac{1}{2} \times 535.5 \times 10^3 \times \left(\frac{200}{3.6}\right)^2$$

$$= \mathbf{826.5\ MJ}$$

This is the amount of kinetic energy which the train has to dissipate in order for it to come to a complete stop. This is the amount of energy available for harvesting but the energy which can actually be recovered is less than this because of losses (Hansen & O'Kain, 2011) If 100% energy recovery is assumed the resultant flywheel will have extra weight which will not be used in any recovery event. This will therefore lower the fuel efficiency of the train. Therefore to increase the fuel efficiency the mass of the flywheel has to be optimised. In the design of flywheel based energy recovery systems for automobiles designers choose an efficiency typically between 70% and 80% (Hansen & O'Kain, 2011). The mechanism employed in this design is a redesign of the system used in automobiles therefore it can be approximated as an amplification of that system. On the other hand taking into consideration that the increase in size may lead to more loses from the system therefore the design bounding case for energy recover will be taken as 65%.

$$E_K = 0.65 \times 826.5\, MJ$$

$$= \mathbf{537.225}\ \boldsymbol{MJ}$$

As described above the design in a multiple unit recovery system with the recovery units being the coaches only. Therefore it has been assumed that the energy recovery will be evenly distributed among the 10 coaches. Since system is uniform for all the coaches calculations will be based on only one coach. The most important parameter in the energy. The energy available per coach,

$$E_{K_{coach}} = \frac{537.225}{10}\, MJ$$

$$= \mathbf{53,723}\ \boldsymbol{MJ}$$

For the calculation of the power transmission at each coach the average braking distance of the Intercity 125 from a speed of 200km to a dead stop will be assumed.

Braking distance = 1750 metres

Assuming the deceleration is constant time taken to bring the train to a complete stop will be calculated from the equations of motion,

$v^2 = u^2 + 2as$……(1) $a = \frac{v-u}{t}$……..(2)

Substituting 2 into 1, with s = 1750m, v = 0 and making t the subject

$$t = \frac{2s}{u}$$

$t = \frac{2(1750)}{55.56}$ = **63 seconds**

Average energy conversion rate during braking = 826.5MJ / 63 sec **= 13.12 MW**

Assuming all this power is absorbed by the kinetic recovery system without any loses, Average Power per flywheel

= 13.12MW / 10

= 1.312 MW

5. Recommendations and Conclusion

The flywheel energy recovery system discussed and developed consists of many components which are every pivotal in the transfer of energy. More attention has been turned on developing the flywheels hence energy transfer mechanisms are lagging behind in development. Different arrangements of the already existing kinetic energy recovery systems have to be explored, as this may lead to better compatibility and wide application.

In the design here presented there is much development need to meet the required performance of the system. Further research has to be done in the following lines

- Acceleration of the flywheel

Due to the high amounts of energy to be harvested from trains the flywheels used have a relatively large mass and therefore have high inertia. This calls for the development of mechanisms to enable quick take off for flywheel.

- Safety

High speed flywheels are always a risk. Any failure should be averted by all means. This can be done by the improvement containments by increasing their robustness. Shock absorbing systems should also be developed so as to reduce the extent of damage in the case of any failures.
Further consideration has to be done in how energy can be obtained through the kinetic energy harvesting system besides in braking. An example is when moving downhill. The train will be transforming gravitational potential energy into kinetic energy. This kinetic energy can also be harvested.
Environmental friendliness is the rising to supremacy in design considerations of 21st engineering. Governments, councils and other such like organizations should develop and adopt policies on environmental friendliness so as to invoke innovation and development towards a greener world.

Rail way transport is regarded as the most energy efficient mode of transport and increasing their energy efficiency has proven to be one of the most effective ways of reducing overall CO_2 emissions. It should now be the goal of every railway manufacturer or operator to meet high standards of environmental friendliness through innovative design, manufacture and operation of rolling stock.

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I would like to thank the company that I worked with for data gathering.

Biography

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