Mechanical Interface of Flywheel Kinetic Energy Recovery System on Motorized Tricycles

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Abstract. In the Philippines, motorized tricycle was subjected to repetitive utilization of brakes due to traffic and road condition. To address the problem regarding the energy loss due to the application of brakes, Kinetic Energy Recovery System or KERS was introduced. KERS serves as the medium to recover and store the momentum of the vehicle. The study was aimed to design a mechanical interface of the kinetic energy recovery system applicable on motorized tricycles. This also aimed to determine the optimal dimensions and material of the flywheel that can maximize the recovery and storage of the lost kinetic energy of tricycles during braking. The triggering mechanism used was a combination of an actuator mechanism and a hand brake lever. The study was able to accomplish and design the appropriate triggering mechanism in order to utilize KERS. The group was able to prove the prototype’s cost-effectiveness of the system with the percent of fuel saved with the application of KERS. It is determined in the study that by utilizing the Flywheel KERS on the motorized tricycle, fuel savings of 2.93%, 4.28% and 5.93% were obtained for uniform velocities of 30 kph, 40 kph and 50 kph, respectively. In this study the group was able to design and fabricate a functional Flywheel Kinetic Energy Recovery system on a Motorized Tricycle.

1. Introduction
In the Philippines, the motorized tricycle is one of the most common means of public transportation. Motorized tricycles are exposed to a repetitive stop and go motion especially on the tricycle since the road scenario in most areas is characterized with moderate to heavy traffic most of the time. This states that the tricycle utilizes the braking system often, thus wasting energy due to braking. Heat energy loss is always present in the braking system of a vehicle; due to this phenomenon a method was developed to recover and store the energy loss due to the friction in the brakes. With the use of the regenerative braking, the energy loss due to braking could be stored for another use. Regenerative Braking is a type of braking system that can recover and store the kinetic energy produced by the car and convert the recovered energy into either mechanical or electrical energy [1]. In order to store the kinetic energy recovered by the braking system, a mechanical component called flywheel is used. The amount of the kinetic energy that may be gathered depends on the inertia and the speed of the rotating mass or flywheel; this energy is stored as a rotational energy [2, 3]. Stored energy in flywheels may be used for generating electricity by combining the flywheel to the electrical equipment such as generators or motors or may be used as a prime mover for mechanical purposes [4]. With the concept of the flywheel and the regenerative brakes, the mechanical kinetic energy recovery system (KERS) is utilized. KERS is a system that recovers and stores the kinetic energy that would be otherwise converted to heat energy during braking and use it for other applications in the vehicle [5].
The braking process with the use of KERS will not be able to completely stop the vehicle but rather, will only slow down the vehicle to a certain amount of reduced speed [6]. The researchers will conduct a mechanical approach that can mitigate the conversion losses of the usual KERS. Three-wheeled vehicles are often overlooked when it comes to implementing technological advancements in decreasing the fuel consumption, since most application of KERS is focused in two wheeled and four wheeled vehicles [7]. Also, three-wheeled vehicles or motorized tricycles play a vital role in the Philippines as they are used as a mode of public transportation in various provinces, cities, and municipalities all throughout the country [8].

2. Materials and methods

The regenerative braking concept is used for the flywheel kinetic energy recovery system. A pulley is connected through a drive belt, where the drive belt gathers and transfers kinetic energy to the flywheel, from the larger pulley which is coupled to the rear wheels. The flywheel is engaged and disengaged through a mechanical clutch controlled by a modified hand break lever using an actuator. An actuator has an up and down movement. Whenever the driver switches on the flywheel KERS, the actuator pulls up the steel lever that engages the flywheel. While the flywheel is engaged, it serves as an engine brake that decelerates the vehicle and harnesses the kinetic energy from the rear wheels and transfers to the flywheel in the form of stored kinetic energy. To store the energy, the driver disengages the clutch system again, whenever it disengages, the momentum and kinetic energy transfers continuously, which makes the flywheel rotate at a certain period at a constant decreasing speed until the flywheel stops. When the flywheel has stored kinetic energy, it is used to aid in the acceleration of the motorized tricycle by transferring the energy back again to the larger pulley that makes the motorcycle to move forward. Flywheel kinetic energy recovery system is integrated into the motorized tricycle to become helpful in aiding the acceleration and help in decreasing the fuel consumption, therefore improves the fuel economy of the vehicle since the system harnesses the kinetic energy repeatedly.

The system operation of the motorized tricycle will still be the same; the only change that occurred was the mode of transmitting the power back and forth the flywheel mechanism. Unlike the sprocket system the where the speed was restricted by the ratio between the introduced bigger and smaller sprocket, the pulley system had a wider range of speed that it can sustain which made it more appropriate for the system. The sprocket may be better in terms of power transmission but because of the limited space for the flywheel it became a hindrance to make the sprocket advantageous over the pulley. Figure 1 shows the schematic flow diagram of the complete flywheel based KERS.

2.1. Flywheel

In deciding the material for the flywheel, the researchers considered the rotational speed limit of the material. This characteristic of the material selected is dependent on the strength of the material, since the centrifugal force experienced by the flywheel can break it apart. The material chosen should be able to withstand this centrifugal force to prevent yielding and shattering of the flywheel. Subsequently, the specific energy of the material was considered, since it is considered as the efficiency of the material used on the flywheel. Greater energy stored per unit of mass is preferred to maximize the amount of energy stored while minimizing the mass of the flywheel. This parameter primarily depends on the geometry and properties of the material. A disc-shaped flywheel will be the best geometry since it has the highest shape factor which is proportional to the energy storage capability [9]. Another consideration was the mass of the material to be used for the flywheel. Excessive mass of the flywheel was not suitable for applications in smaller vehicles like the tricycle, since the excessive addition of the weight on the tricycle can increase its fuel consumption and will invalidate the objective of this study. The mass and energy stored by the flywheel was balanced to provide the optimum operation of the flywheel. It was ideal to use the carbon fiber reinforced polymer [10]. However, this material also had the largest diameter of all the materials, given the same amount of energy that can be stored. The diameter was a great factor since the space in the tricycle is
constrained by its size. If the two alloys, titanium and beryllium, were used, it would be not feasible for tricycle applications since these metals are known to be expensive and not locally available. The right balance of the parameters gave the group the decision of choosing cast iron. Cast iron did not contribute that much to the weight of the whole system, but at the same time it could store energy just like other material. Another consideration was its diameter. Its diameter had the smallest of all the mentioned materials; thus, it made a good selection for small applications like the tricycle.

Figure 1. Flowchart diagram of the flywheel kinetic energy recovery system

2.2. Bearing

Two types of bearing were available in the market that can be utilized for the flywheel based KERS. One was the ball bearing and other was the roller bearing. The ball bearing was suitable for applications where there are both axial loads and thrust loads occurring. Having spherical-shaped rolling elements reduces the contact area, allowing lesser friction between the outer ring, balls, and inner ring. However, due to its spherical shape, it has lesser contact area which increases the stress experienced and negatively affects its durability, which made it unfavorable for larger loads. The roller bearing used cylindrical-shaped rolling elements which had greater contact area and is more advantageous when larger load is applied. The friction is greater in cylindrical roller bearing since it is greater contact area compared to the ball bearing.

In this study, the bearing that was used was a high-grade ball bearing. Although the cylindrical bearing was more advantageous compared to the common ball bearing, the load that was considered in the Flywheel KERS can already withstand by a typical ball bearing which was lesser in priced compared to a cylindrical bearing. Cylindrical bearing is more complicated to be manufactured, which makes it pricier than a ball bearing.
2.3. Clutch
Possible types of clutch to be used for the flywheel based KERS were the jaw clutch, disc clutch, and the cone clutch. Jaw clutch was the best choice for eliminating slip during engaging and disengaging [11]. Mitigation of the slip during engaging and disengaging removed the likelihood of generating heat. Conversely, it was not suitable for engaging at high speeds as there was no slip between the mating parts and may lead to damage due to the shock during sudden engagement making it require a synchronizer. Another type was the disc clutch. It has a slip during engagement, which may reduce the shock. It does not require a synchronizer, allowing engagement and disengagement while the system was running. One drawback of the disc clutch was that it is subjected to wear. Lastly the cone clutch was also considered in the selection of clutch. Due to the cone angle, cone clutch had greater normal force acting on the friction in comparison with the axial force resulting to greater grip. However, when the angle of the cone is made smaller than a certain angle, the mating cones tend to bind together, and disengaging becomes difficult.

2.4. Design
The researchers selected a site that helped in showing the application of the flywheel kinetic recovery system installed in a motorized tricycle. Flywheel KERS was a product of regenerative braking system which means that the road condition of the selected site was exposed to frequent vehicle braking. Frequent vehicle braking helped to store energy for every braking action.

2.4.1 Site assessment
The researchers chose the tricycle operation with a route from Paseo to Sta. Rosa Complex and vice versa. The route is moderate to heavy traffic most of the time since it is a national road and is a prime location because of the business establishments in the vicinity. Moderate to heavy traffic repercussions to a necessary stop and go motion of the vehicles and this is a valuable thing in regenerative braking. Along the road route, the Santa Rosa expressway toll plaza is also located, resulting to an increase in the volume of the cars passing through.

2.4.2 Design formulas
Below are the major formulas used in designing the mechanical interface of the KERS system used for motorized tricycle. Determination of kinetic energy stored in the flywheel is described the formula

\[ E_k = \frac{1}{2} I \omega^2 \]  

(1)

In the operation of brakes, when the brakes are utilized, the kinetic energy of the tricycle will be stored in the tricycle. It is where the concept of the regenerative braking will be utilized. The calculations involved in the brakes were based from [12] as follows

Braking Energy, during braking

\[ E_b = \frac{m}{2} (V_1^2 - V_2^2) + \left(\frac{1}{2}\right) (\omega_1^2 - \omega_2^2) \]  

(2)

Braking Energy, when stopped

\[ E_b = \frac{m}{2} V_1^2 + \left(\frac{1}{2}\right) \omega_1^2 = \frac{K m V_1^2}{2} \]  

(3)

Braking Power:

\[ P_b = Kma (V_1 - at) \]  

(4)

Average Braking Power:

\[ P_{bavg} = \frac{KmaV_1}{2} \]  

(5)
Where \( m \) is the total mass of the system, \( V_1 \) and \( V_2 \) are initial and final velocities of the tricycle, respectively, \( \omega_1 \) and \( \omega_2 \) are the initial and angular velocities, respectively, \( t \) is the time of travel, \( a \) is the acceleration of the tricycle and values of \( K \) for passenger cars ranges from 1.05 to 1.15 at high gear and 1.3 to 1.5 in low gear while for trucks ranges from 1.03 to 1.06 at high gear and 1.25 for low gear.

2.4.3 Design of mechanical interface
The dimensions of the Flywheel KERS depend on the parameter constraints and the limited size of the chosen tricycle as seen in Figure 2 for both theoretical and actual design.

![Figure 2. Design of mechanical interface of KERS system](image)

(a) (b)

3. Testing
The testing of the modified flywheel based KERS on the tricycle was done following two various methods. The first one was done through the most ideal or theoretical conditions, where the rear wheel of the tricycle was isolated from the ground, negating the drag force and the rolling friction force on the tricycle when it was moving. The group was able to measure the amount of energy that the flywheel could store after harnessing the momentum supplied by the motor to the tricycle, after reaching a constant speed at specific amount of time for about ten (10) trials. The tricycle was subjected to a constant speed of thirty kilometers per hour (30kph) for about 30 seconds before finally using the KERS. The group was able to compute for energy the flywheel can recover by measuring the angular speed of the flywheel itself.

The second part of the testing was done by measuring the amount of fuel that can be saved using the KERS. The tricycle was tested as it was, applying a load inside the sandbags, simulating the load of the possible passengers. The researchers subjected the tricycle to a constant speed of 30kph, 40kph and 50kph before applying the brakes, repeating this step for about ten (10) consecutive repetitions for each of the speed variation. Ten (10) seconds was the allotted time to stabilize the speed during testing. This was done for ten (10) trials for each speed variation while measuring the initial amount of fuel and the final amount of fuel for each trial. The amount of fuel saved by the system was measured by using the KERS instead of the normal braking and accelerating action of the tricycle. The KERS was able to recover some of the momentum of the tricycle during deceleration and aiding the acceleration of the tricycle using the energy stored in the flywheel.
The third part of the testing was determining the amount of fuel savings made with the use of the Flywheel KERS on the tricycle when subjected to the actual run on the exact Paseo to Complex route on a back and forth round trip basis for about five (5) trials. The fuel savings was measured by subtracting the average fuel consumption given by the beneficiary from the actual fuel consumption while using the KERS. The speed requirement before using the KERS was always varying since the road condition and scenario during the testing was not constant therefore the researchers measured the time it took to complete a back and forth travel and measured the average speed of the tricycle. The fuel savings in the tricycle was measured by the difference in the final height of the fuel inside a container after measuring the fuel consumption with and without the use of Flywheel KERS.

4. Results and discussion
The data was obtained by isolating the rear wheel of the tricycle from the ground. The theoretical amount of kinetic energy absorbed and stored by the flywheel during the braking of the tricycle was determined. The obtained kinetic energy of the flywheel implied that it can be used as energy storage for later use in acceleration of tricycle. The fuel consumptions of the tricycle with and without KERS were monitored at speed of 30kph, 40kph and 50kph, respectively as shown in Figures 3, 4 and 5.

**Figure 3.** Fuel consumption of the tricycle at 30 kph

**Figure 4.** Fuel consumption of the tricycle at 40 kph
It can be determined that the average percent of fuel saved for a ten second trial uniform speed of 30 kph is about 2.93%, while 4.28% for 40 kph and 5.93% for 50 kph. At 5.93% fuel savings, it can be calculated that at most 1 liter of fuel can be saved from a Paseo to Sta. Rosa Complex and vice versa 42-minute round trip.

5. Conclusion
This study has achieved the preferred overall assembly of the flywheel KERS installed in motorized tricycle. This has shown that flywheel KERS is functional and feasible for motorized tricycle. It can be observed that with KERS, fuel savings can be achieved. It is determined that the percent of fuel savings is proportional to the speed of the motorized tricycle. The installed flywheel based KERS provided an average fuel savings of 2.93%, 4.28% and 5.93% for uniform velocities of 30 kph, 40 kph and 50 kph, respectively. The fuel savings allowed the tricycle owner to have a decrease in his annual fuel consumption cost. In order to provide further increase in the fuel savings, the following recommendations can be done for future works such as the material used in the fabrication of the flywheel, installation of a better power transmission mechanism and carbon footprint reduction. A flywheel material that has a lower density is more favorable. A larger flywheel can be manufactured and still have the same mass as the previously installed flywheel. Meanwhile, a better power transmission can be achieved using chains and sprocket instead of belt and pulley, but this was not implemented in this study due to the speed constraint during the testing of the fabricated sprocket. But still, if the flywheel design is optimized, it can be said that a sprocket and chain can be convenient to use since the size and the sprocket ratio can be decreased. For environmental considerations, study of the carbon footprint reduction brought by the fuel savings can be conducted to extend the research on the advantage having this mechanical interface in motorized tricycles.

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