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REVIEW ARTICLE

Bicycle kinetic energy recovery system by using flywheel- a review

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Abstract

The Kinetic Energy Recovery System (KERS) is a system for the recovery of braking power energy from the moving vehicles, which is present in the form of residual heat generated during braking. It stores energy and converts it into power, providing power boosts to the vehicle. The KERS system used by the vehicle serves the purpose of saving some of the energy lost during braking, and is more efficient to operate at high temperatures than conventional braking systems. While riding a bike, a lot of kinetic energy is lost during braking. KERS are used to store energy lost during braking using flywheel. Flywheel is used to store and release energy as kinetic energy. Riders can charge the flywheel when they slow down or slope down the mountain and lift the bike as they accelerate or climb the mountain. The proposed design is to simply implement the same concept of using the flywheel as an energy reservoir or energy storage device. However, there are some areas that need to be studied and better results can be achieved by better weight optimization in reducing pedal power. Continuous variable transmission can also be an option to improve transmission efficiency.

1. Introduction

KERS is a collection of parts that slow down a part of the vehicle's kinetic energy, store it, and, when released, release it again into the vehicle's drive train to power the vehicle. KERS stores energy on the application of brake and returns energy at acceleration. During braking, energy is wasted because kinetic energy is mostly converted into heat emitted into the environment. Vehicles using KERS can take advantage of some kinetic energy, which will help with braking. Through the appropriate mechanism, this stored energy is converted back into kinetic energy, which increases the vehicle's additional power [1]. In KERS bikes, flywheel is used to store and release energy. The flywheel is mounted between the frames of the bicycle and has aesthetic and ergonomic considerations. The flywheel is mounted on the shaft, which is supported by a frame. The flywheel can be engaged with the rear wheels and has a clutch mechanism. The mechanism consists of a clutch, free wheel and sprocket with an appropriate transmission gear ratio. When the bike goes down or the traffic jam clutch is slow, it can be connected with the flywheel to store energy, which can be restored when needed. Now, when the need to decelerate the clutch and flywheel starts to rotate to store energy, although this pedal power can be reduced, the system efficiency can be improved.
Menon, S. S et al. [2] found that flywheel and transmissions increased the weight of bicycles. The increased weight will increase the energy required to accelerate the bike and ride uphill. However, once the rider provides energy to reach cruising speed, the flywheel reduces the energy cost of decelerating from this speed because it contributes to subsequent acceleration. The road is the best environment for flywheel because it is flat and cyclists have many reasons to slow down. Considering the weight standard, the authors found

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that the best weight to improve efficiency is 5 kg of normal cycling. Ludlum, K. [3] stated that flywheel technology is emerging in a variety of technologies. It is a pollution-free method for storing energy with many currents and potential applications. In the case of road vehicles, there is much to be improved in terms of energy efficiency, particularly when considering unit energy pollution. Any braking regeneration system can help, but flywheel have the potential to improve the efficiency of road vehicles without having a direct or indirect negative impact on the environment. The batteries used in hybrid vehicles do not last the life of the car and can have an expensive impact on the environment. Flywheel only have an impact on the environment at the time of production and are likely to significantly exceed these costs by using them. Bicycles do not have pollution problems with cars and other modes of transportation, but they can be used as a good analogy for how kinetic energy recovery systems can improve vehicle efficiency. Mugunthan, U., & Nijanthan, U. [4] conducted speed tests to find out the efficiency of the Flywheel based KERS bikes they installed. It has been found that flywheels provide energy so that the cycle can advance 10% of a given input. Depending on the input given, the efficiency will vary. However, only 10 per cent can be obtained through this principle.

Kumar, D. N. et al. [5] stated that a flywheel bicycle with a mobile charger was designed and manufactured to capture the kinetic energy generated by pedal power. When pedaling a bike, the flywheel also rotates in chain arrangement, which in turn slightly increases the speed of the bike. This setting is more suitable for cycling on highways. By rotating the wheels, the generator's drive wheels also rotate, which in turn generates 5V of alternate current and converts it to DC. As a result, the rear wheel rotates while pedaling the bike, and the generated kinetic energy is restored by the rotation of the flywheel as an additional movement of the rear wheel of the bike. The authors note that the system has the potential to become an alternative energy source in the near future. Sachin R sangle et al. [6] concluded in his work that Kers is a very effective system for racing cars as energy recovery equipment. Similar concepts can be used for small commuter vehicles, such as bicycles, to reduce manpower. However, there are some things to consider, such as losing weight and the ability to sell. Continuous variable transmissions can also be considered for increased transmission efficiency. Using ergonomics, such as dual centrifugal clutches, will result in better power transmission for automatic transmissions. Chicurel, R. [7] conducted an experiment in which the regeneration components included a fixed displacement hydraulic pump/motor that discharged or received high-pressure fluid from the scuba accumulator. The brake power provided by the pump is determined by the pressure in the accumulator. It is only put into service when greater total braking power is required, in which case the traditional dissipated brakes provide a difference. Based on a preliminary analysis of acceleration using probability data, it is estimated that approximately 45% of the total kinetic energy wasted in braking can be transported through hydrodynamic components. The system is considered a practical alternative to the use of variable displacement pumps in more expensive fully regenerative systems.

The above literature explains the design, manufacture and analysis of bicycle kinetic energy recovery systems. This paper also focused on kinetic energy recovery system in bicycle by using flywheel.

2. Kinetic energy recovery system overview

The designed work carried out was based upon a Mitsubishi "Galant," which would represent the average family sized saloon car, and based upon the driving cycle and calculated gains would reduce the energy levels required for commuting. A Microsoft Excel visual basic for applications (VBA) program was presently developed to calculate the potential gains of using a kinetic energy recovery system. The VBA program was then used to investigate the potential for fuel saving by replacing the bigger Mitsubishi automobile with other more lightweight models with reduced emissions [8].

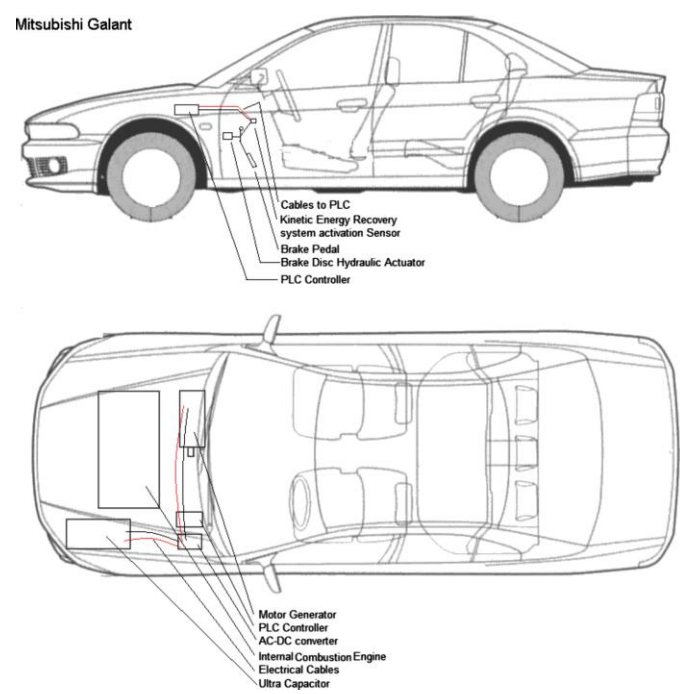

Figure 1: Kinetic energy recovery system overview [8]

Table 1 demonstrates the potential overall gains to be made with the installation of a kinetic energy recovery system, calculated for both the Mitsubishi Galant and six other models which represent the bulk of the car fleet to be found in Edinburgh City. The calculations assumed that the cargo weight would be the same for all vehicles. The average potential reduction in energy with the use of the kinetic energy recovery system installed in the vehicle is 35%, but this is the optimum potential reduction in energy used as the operation of the brake pedal and accelerator by the driver and the driver's style can have an effect on the overall performance. The research community would significantly benefit from information on the impact of effect driver's style has on regenerative braking effectiveness. It is recommended that such research be undertaken in future studies. The design of the kinetic energy recovery system is illustrated in Fig. 1, which consists of a motor generator, ultra-capacitor, ac-dc converter, programmable logic controller, and sensors. Other forms of energy storage were considered but it was concluded that ultra-capacitors have the best potential [8].

Table 1: Kinetic energy recovery model results based on route 1. (Note: The kinetic energy recovery system weight has been estimated to be equal to 110 kg.) [8]

Car Model	Reduction in energy (%)	Vehicle curb weight (Kg)	CO_2 emission (g/km)
Mitsubhishi Galant	37.5	1260	203
Citroen C1	35.2	790	106
Ford Focus	34.5	1493	225
Vauxhall Astra	34.4	1402	164
Vauxhall Corsa	37.7	1402	189
Ford Mondeo	34.6	980	189.6
Audi A4 Estate	32.7	1550	179

2.1 Working of KERS

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. Fig. 1 shows the schematic flow diagram of the complete flywheel based KERS [9].

The crank wheels connected to the rear wheels always rotate the clutch plate and are connected in the flywheel axle. This is by using the chain transmission in the specified gear ratio, the crank clutch sprocket helps us to improve the overall speed of the flywheel. To slow down the speed of cycle, use of contact is required between the clutch and the flywheel. Then the flywheel starts to spin, charges and the speed of the bike decreases. As a result, the regenerative braking system is implemented. Of course, energy is stored during the flywheel. If the brakes are applied completely, after the flywheel rotary clutch is disengaged. Now, when the bike is started again, during this time, it is required to apply the clutch at this time, because the rear wheel rotation is smaller flywheel energy transmitted from the flywheel to the wheel. Now it can also reduce the overall pedal power required during coverage by fully engaged clutching [10].

During charging, it is best to use a higher gear ratio (rear: front) so that the flywheel can be charged in a shorter time. But this will lead to a higher initial lift while engaging. Therefore, it is best to engage the clutch with the lowest gear ratio and then increase the gear ratio to the maximum. There is another advantage. As the gear ratio increases, the relative speed of the flywheel to the rear wheel decreases. As a result, the extra torque acts on the flywheel and accelerates to a higher speed. In this way, the flywheel can successfully reach the maximum rpm it needs. Now, the wind has the greatest potential energy. Therefore, if the driver wants to brake, he simply applies the brakes, which automatically disengage when the string that drives the flywheel is connected to the other end of the left-hand brake.

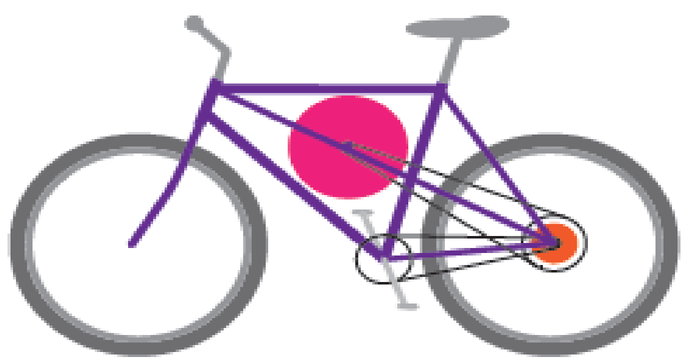

Fig. 1: (Model of KERS bicycle) [1]

Now come to the flywheel offload, discharge can be done for a long time by keeping the sprocket lower than (after: front). However, if the gear ratio is more torque will be more. When discharge begins, higher torque is required, and when the cycle reaches a certain speed, there is a requirement of low but continuous discharge. However, at the end of the charging cycle, the gear ratio is maximum. Therefore, when the discharge starts, then the gear ratio at continuous intervals is to be reduce. There is another advantage. When the gear ratio is lowered, the flywheel is faster than the rear wheels. As a result, the power rotates from flywheel to rear wheels, and the cycle accelerates. The shifter for the KERS system will also be on the left. Therefore, the driver only needs to focus on manually operating the system. When he needs to brake (suddenly), he can only brake. The loop will stop. Start-up efforts will be a little more, but not more, because although the start gear ratio is the lowest. Or, if the driver is a little smart, he can apply the brake lever a little and speed up the bike easily. In this case, KERS will disengage and will not apply the brakes. The amount of power released from the KERS system is the most important and completely controllable. The rider can release the exact power he needs and get the desired acceleration.

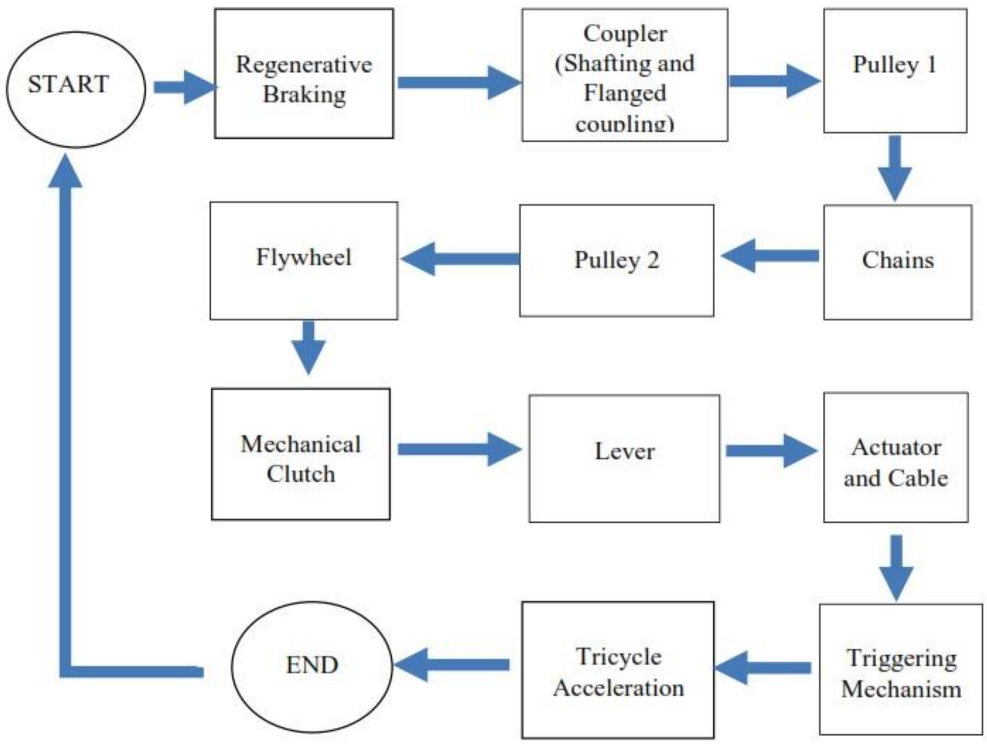

Figure 1: Flowchart diagram of the flywheel kinetic energy recovery system [9]

2.2 Design consideration

Several parameters need to be considered when designing the system for feasible and better results. These can be specified as [11]:

- Store energy when braking
- Must be suitable for cycling
- Return energy start-up
- Light weight
- Good stop force
- Good stop range
- Safe users and environmental protection
- Manufacturing
- Economy
- Cheap and affordable
- Reliable

2.3 Fabrication of KERS

2.3.1 Frame Modification

This is the first step in manufacturing. This must be done to install the aforementioned shaft. It is done by using an M.S tube. The frame is to be modified by adding steel pipes. One end will be welded to the handle end and the other end will be welded to the center of the rear wheels. The frame should have enough strength to carry the flywheel and extra power to play. Modifications should not interfere with normal riding.

2.3.2 Flywheel

It is designed in a dynamic way to avoid swinging. Its weight distribution should produce good inertia. It is the most important component of the system and should therefore be chosen appropriately. The performance of KERS systems depends largely on the choice of flywheel. For clutch accessories, there should be a clause in the flywheel for the transport and release of energy from the flywheel.

2.3.3 Clutch

It is used to engage the rear wheels with the flywheel during energy storage and recovery. It basically provides a small thickness disc with friction lining. It is welded directly to the sprocket mounted on the axle. In contrast to normal clutches, this is usually in a detached state. A spring is inserted between the clutch and the flywheel to leave it out of the state. The larger clutch size used increases torque transmission and heat dissipation.

2.3.4 Axle

Bridges are being built in order to carry flywheel and clutch units. After the bearing is added, the flywheel can be inserted, and if a variable diameter is provided on the shaft at the midpoint, the flywheel can be inserted from one end and automatically locked in the middle of the rotating shaft. The size of the shaft is determined by taking into account the interference between the bearing and the flywheel bearing, and there is an accurate operating fit between the bridge and the sprocket. In addition, threads are provided at both ends of the axis to mount them on slots provided by side members.

2.3.5 Sprocket

Two sprockets are to be used. Gear ratios should be considered here. One sprocket with a larger number of teeth must be selected, while the other sprocket with fewer teeth is to be selected. The larger sprocket is placed at the rear wheel end and the smaller sprocket is located at the end of the axle. This is to ensure that we can provide greater flywheel rotation, increasing energy storage.

2.3.6 Design formulae

Below are the major formulae 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

$$E_k = I\omega^2$$

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.

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

Braking energy, when stopped

$$E_b = \frac{m}{2}\left(V_1^2\right) + \frac{1}{2}\left(\omega_1^2\right) = \frac{km\,V_1^2}{2}$$

Braking power

$$P_b = Kma\,(V_1 - at)$$

Average braking power

$$P_{bavg} = \frac{kmaV_1}{2}$$

Where

E_k	=	Kinetic Energy stored in flywheel
I	=	Mass Moment of Inertia
ω_1, ω_2	=	Initial and final angular velocities (rpm).
E_b	=	Braking Energy
M	=	Total mass of the system,
V_1, V_2	=	Initial and final velocities of bicycle
t	=	Time of travel
a	=	Acceleration of the tricycle
K	=	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

Flywheel and transmissions increase the weight of the bike. The increased weight will increase the energy required to accelerate the bike and ride uphill. However, once the rider provides energy to reach cruising speed, the flywheel reduces the energy cost of decelerating from this speed because it contributes to subsequent acceleration. Moreover, increased weight due to KERS setup rider can now experience better braking as when brakes are applied it stops the vehicle whose speed is already reduced due to charging of the flywheel. The road is the best environment for flywheel because it is flat and cyclists have many reasons to slow down. Additionally, the rider will also have better experience during uphill or downhill.

3. Conclusion and future scope

KERS (Kinetic Energy Recovery System) is a very effective system for racing as an energy recovery device or regenerative braking concept. Similar concepts can be used for non-polluting, small commuting vehicles, such as bicycles, with the aim of reducing the amount of energy lost during braking by human efforts to be met by the bicycle KERS system used in vehicles. The proposed design is to simply implement the same concept of using the flywheel as an energy reservoir or energy storage device. However, there are some areas that need to be studied and better results can be achieved by better weight optimization in reducing pedal power. Continuous variable transmission can also be an option to improve transmission efficiency. Due to the large friction loss of many mating components, it is found in this system that can be improved. As a result of reduced friction, lifting is reduced. Continuous variable transmission can be implemented into this system, which will prove a sharp improvement in energy transmission. Moreover, the materials used for designing of flywheel and shafts is also a matter of research. In our case aluminium was used as flywheel material and shafts were made of M.S. (mild steel). If some better materials can be found, it will add to more strength to our KERS system and importantly reduce weight which will add to the better efficiency. But economy must be kept in mind before choosing materials. KERS powered vehicles are of immense need of future because we are moving towards the time where nonrenewable and conventional form of energy are on the verge of extent and our world is finding new scope towards renewable sources of energy which are non-polluting and reliable. KERS powered Bikes will reduce up to some extent of energy which is wasted during braking and energy used to lift or accelerate the bike again.

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