REGENERATIVE BRAKING PRINCIPLE BY USING KINETIC ENERGY RECOVERY SYSTEM –A REVIEW

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Abstract- **Natural resources conservation has become a requirement in today's world, mainly in the new technology. In many of the rolling applications maximum energy is lost during deceleration or braking. This problem has been fixed with the introduction of regenerative braking. Kinetic Energy Recovery Systems (K.E.R.S.) is a type of regenerative braking system which has different approaches to store and reuse the lost energy. This paper gives an idea about a flywheel based mechanical regenerative braking system (R.B.S.) concept by showing the application of the same on a bicycle to improve the performance and/or efficiency of the bicycle. Thus taking this point of view of such K.E.R.S. application based on the principle of R.B.S. on a bicycle can be seen as a human power generator. By keeping this point, the electricity generated can be used in day to day life like charging your smart phone. The ever increasing energy demand and increased alertness of people towards the healthiness in developing countries like India, are some of the driving forces for the development of such humanly powered machines. Flywheel rotor design is the key of researching and developing flywheel energy storage system. Thus this paper presents a literature report reviewing the human power flywheel motor as well as the flywheel design.**

Keywords- Bicycle, Flywheel, KERS, Regenerative braking.

I. INTRODUCTION

Since ever increasing fuel crises, energy crises, busy schedules of load shedding, unemployment justify the need of human powered machines, the constants efforts are being continuously made to optimize the various parameters of these machines so as to provide the ease for the operator and consequently make efficient use of human energy [1].

In the human power generator, it works on the principle to convert muscular or physical energy of human being into the electrical energy by means of applying pulley arrangement. The pulley arrangement converts the efforts which is applied by human being into the rotating motion which is used to generate electricity and this electricity will be used as a preliminary requirement of electricity. A dynamo machine replicating alternator consists of a stationary structure, called the stator, which provides a constant magnetic field, and a set of rotating windings called the armature which turn within that field. The motion of the wire within the magnetic field causes the field to push on the electrons in the metal, creating an electric current in the wire. On small machines the constant magnetic field may be provided by one or more permanent magnets; larger machines have the constant magnetic field provided by one or more electromagnets, which are usually called field coils. Thus by the above mechanism alternator charges the battery [2].

In actual bicycle the kinetic energy obtained from the pedalling power is utilized and is not recovered. By designing and fabricating the flywheel bicycle, recovery of the kinetic energy produced from the pedalling power is possible. It can recover and store frictional energy produced by braking and releasing of this stored energy in the flywheel which can be converted to electricity by the help of an alternator. Now-a-days, our country and human life is mostly affected by load shedding. It has badly affected the daily human life.

Once we make this cycle which is enough capable of generating electricity which can charge a mobile with help of a mechanical system. All we have to do is spread words about this innovation and market it in a right direction, for example, if a student in pune starts using this bicycle he will be able to charge his own phone every day without using the conventional electrical source instead he'll be using all his energy with help of which he pedalled and at the same time he can be able to charge his parents phone in home. A phone charging uses at least 4-5 units of electricity per day per phone. So by saving this electricity per day we'll be ultimately saving the electricity by reducing its usage in conventional way and thus reducing the carbon footprints. So we just need to do the marketing of such product on a large scale.

A. Regenerative braking system

In order to understand the concept of R.B.S. and its impact on vehicle energy performance, a simple example is presented:
Consider a 300 kg (~ 661lbs) vehicle moving at an initial speed of 72 km/h(~ 45mph).Now, on braking the vehicle to a speed of 32 km/h(~ 20 mph) the amount of energy spent is around 47.8 kJ using the equation given below,

$$E_K = \frac{1}{2}mv^2 \quad (1)$$

Where, E_K: Kinetic Energy of the vehicle; m: Mass of the vehicle and v: Velocity of the vehicle. Ideally, this is the amount of energy available for capturing at each instance of braking. If regenerative braking was used on such a vehicle it would be able to capture this amount of energy and reuse this same energy which would otherwise have been lost in the form of heat, sound etc. Now, even if we suppose that the efficiency of the brake is 25% of this, there would still be an amount of 11.85 kJ (25% of 47.8kJ) of energy available at each braking instance, which shows the amount of energy that can be utilized for beneficial causes. This energy is roughly, neglecting all losses, enough to accelerate a car from 0 km/h to around 32 km/h). This stored energy using R.B.S. can be reutilized for different purposes, either to help improve performance or fuel efficiency, in either case assisting in 'Load Sharing' [3].

In this whole process, R.B.S. also essentially functions as a brake system. But due to heavy torque demands at emergency braking situations R.B.S. alone would not be sufficient; hence it needs to be a system supplemental to existing proven friction braking [4].

II. COMPONENTS

A. Electrical components of flywheel bicycle

1. Alternator

It is the device by which mechanical energy is converted into electrical energy. It is D.C. generator for generating D.C. voltage at output.

2. Rectifier circuit

It is a device which converts A.C. voltage into D.C. voltage. Some A.C. harmonics produced by D.C. generator with pulsating modulation of waves which is not in regular modulation, so for getting regular modulation of waves, rectifier circuit is used.

3. Filter circuit

At the output of rectifier, D.C. voltage is not in pure form some A.C. components are in there so for purification of it, Shunt capacitor filter circuit is used. Filter is a circuit which minimizes of removed the undesirable A.C. component of the rectifier output & allows only the D.C. component to reach at output.

4. Charging circuit

It is the circuit which is used for charging the discharged battery.

5. Battery

It is the source of D.C. voltage. It is the device where we want to store the D.C. voltage or it gives the D.C. source whenever we want.

6. Inverter

This project requires electronic inverter. The function of electronic inverter is to convert D.C. to A.C. [6]

B. Flywheel- Mechanical component

The first class of flywheels uses steel as the main structural material. The second class of flywheels uses a metallic hub and composite rim made up of an advanced composite material such as carbon-fibre or graphite. The metal hub of composite flywheels had the same geometrical shape and work condition with the steel flywheels. This section mainly determines their maximum outer radius. The design method is similar in composite rim [7].

1. Flywheel as mechanical energy storage device

A flywheel such as the one illustrated in Figure is a mechanical device that is commonly used to store kinetic energy associated with its rotation at high speed. The stored energy is then released to the intended application such as described in Section II after the supplied energy is either discontinued or reduced in the magnitudes.

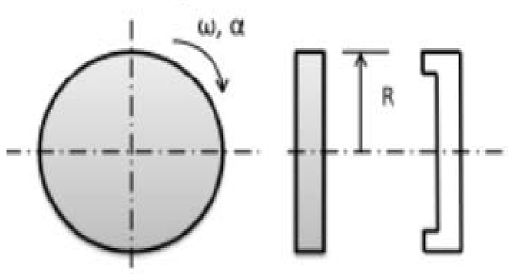


Fig. 1 Flywheel

Fig. 1 shows two popular geometry of flywheels: the uniform cross-section wheels in the middle and the thick-rim flywheels to the right. The kinetic energy that can be stored in a flywheel spinning at an angular velocity ω may be computed by the following expression:

$$KE = \frac{1}{2} I\omega^2 \qquad (2)$$

Where, I is the mass moment of inertia of the spinning wheel. Below Equation is used to compute the mass moment of inertia for flywheel with uniform thickness:

$$I = \frac{1}{2} MR^2 \qquad (3)$$

With M and R being the mass and the radius of the wheel respectively.

The angular velocity of the spinning flywheel ω is maintained by applying torques that is equal to $T = I\alpha,$ in which α is the angular acceleration of the spinning wheel [8].

The flywheel is where the energy is stored from the brake regeneration. A 20 inch diameter bike wheel rim will be used as the flywheel since it will be smaller than the 26 inch wheels on the bike, is an off the shelf part that is easy to get, has most of its mass on the outer edge, would be easy to add weight to if necessary, and has a hub that will be easy to attach to the axle [9].

Instability in voltage can lead to quick wear and tear of the energy storage device. Fig. 2 shows that in comparison with other storage systems, flywheels offer maximum steady voltage and power level, which is independent of load, temperature and state of charge. Second being Lithium ion (Li-ion) battery followed by Nickle metal hydride NiMH and Lead-acid batteries. Super-capacitors / ultra-capacitors being the lowest with 30% stability. Reason being that super-capacitors have self-discharge properties [10].

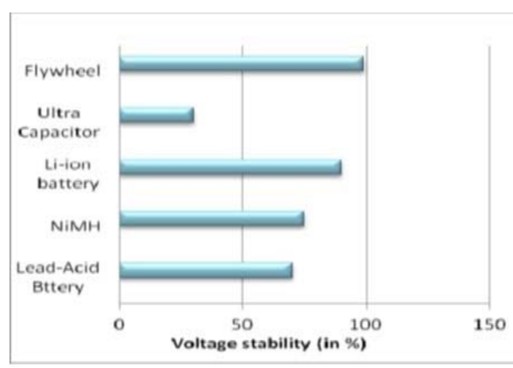


Fig.2 Energy comparison

Cost is the main drawback of every Hybrid vehicle. Causes of high cost are the materials used in making these vehicles and their storage technologies. Fig. 3 shows that flywheel- system is the cheapest after batteries with 15% and 6%. However, flywheels are currently use because of the efficiency they give in this low cost. Batteries cannot store enough energy and hence charge and discharge quickly. Hydraulic systems are the most expensive of them all followed by super-capacitors with 47% and 32% respectively [10].

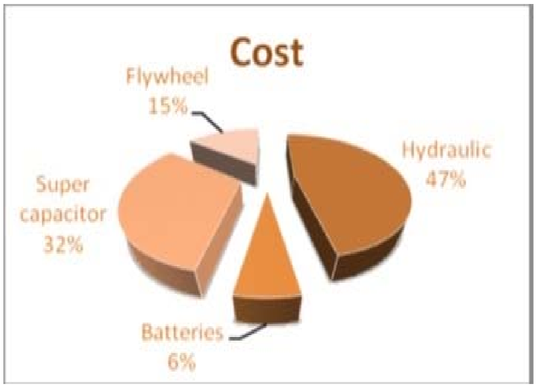


Fig.3 Cost comparison

III. WORKING

Any machine, to power it by human energy, the maximum power requirement should be 75 Watts. Any machine or process requiring more than 75 Watts and if process is intermittent without affecting and product, can also be operated by human energy. This is possible with the provision of intermediate energy storing unit which stores the energy of human and supply periodically at re-quire rate to process unit, this is called as “human powered flywheel motor.”[1]

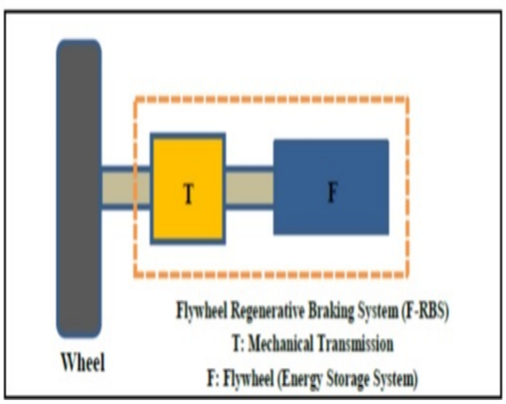


Fig. 4 F-R.B.S.

The electrical Energy Supply System (E.S.S.) has been extensively researched and is an excellent choice due to its high specific energy, compactness and operational/implementation simplicity. But it was found lacking in storage/recharging efficiency and the transmission losses associated with energy conversion from mechanical energy to electrical energy. So, on an exploratory basis, a flywheel with a mechanical transmission was selected with the aim of overcoming these particular shortcomings of an Electrical R.B.S. system. With a flywheel E.S.S., high specific power can be achieved and depending on the design, high specific energy can be obtained as well. Additionally, flywheels have excellent recharge efficiencies and very long cycle lives. On coupling this with a mechanical transmission the conversion losses are eliminated as the mechanical braking energy is transmitted and stored in the same form. The other advantages being the system can be cost effective (depending on the design) and simple to recreate. The problems associated with flywheel systems are high weight addition and safety issues. Therefore most of the design goals are met with a Flywheel based Mechanical System [3].

While pedalling the bicycle, the flywheel also rotates by the mode of chain arrangement which in turn slightly increases the speed of the bicycle. This setup is more applicable while riding bicycle on the highways. Hence the back wheel rotates while pedalling the bicycle and the kinetic energy produced is recovered as the extra movement of the back wheel of the bicycle by the rotation of the flywheel [9].

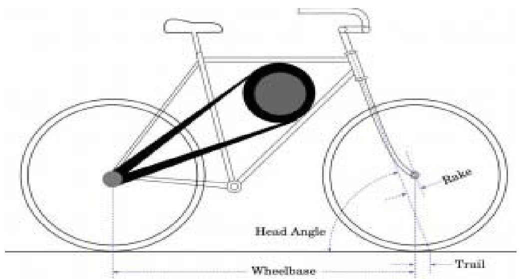
A. Gear Ratio used in transmission with clutch

The gear ratio will determine the speed and torque power of the mechanical bicycle. Gear Ratios are a ratio between the numbers of teeth found on the gear. Using a smaller gear in front, by the pedals, and a larger gear placed in the back of the bike that is connected to the wheel, will allow for a power ratio, and will increase the amount of cycles needed per full rotation of the wheel, which increases the torque. Which could be thought of as peddling up a hill. By placing the larger gear in front and the smaller gear in the back, a speed ratio is enacted. This means that the peddler will be put under a stronger force and will require more energy input to turn the wheel powering the mechanical appliance [8].

B. Efficiency of the whole mechanism

Using (2),

$$E=\frac{1}{2}cmr^2\omega^2 \quad (4)$$



The gain you get from a flywheel must be measured against the extra power required to move the bicycle from the extra weight of the flywheel. Extra work is needed to accelerate the bike because of the flywheel. Therefore the efficiency gained from the flywheel can be shown as:

$$\varepsilon_{TOTAL} = \varepsilon_{GAINED} + \varepsilon_{LOST} \quad (5)$$

The efficiency gained can be expressed as the energy stored in the flywheel (from the above section) over the total energy in the bike. The efficiency lost can be expressed as the energy required to push the extra weight of the bike over the total energy in the bike.

$$\varepsilon_{TOTAL} = \frac{\varepsilon_{FLYWHEEL}}{\varepsilon_{TOTAL}} - \frac{\varepsilon_{FLYWHEEL\ ACCELERATION}}{\varepsilon_{TOTAL}}$$

(6)

After plugging in (4), we get,

$$\varepsilon_{TOTAL} = \frac{\frac{1}{2}\eta c m_f \omega^2 r^2}{\frac{1}{2}m_{total}v^2} - \frac{\frac{1}{2}m_f v^2}{\frac{1}{2}m_{total}v^2}$$

(7)

Where ε_{TOTAL} is the efficiency, η is the efficiency of the transmission, m_f is the mass of the flywheel, and v is the velocity of the bike. Cancelling like terms we get,

$$\varepsilon_{TOTAL} = \frac{\eta c m_f \omega^2 r^2}{m_{total}v^2} - \frac{m_f}{m_{total}}$$

(8)

With this in mind the flywheel design should minimize the mass of the flywheel in favour of a larger radius or faster speed, since the total efficiency will be much higher [13].

C. Critical stress in flywheel

Another design consideration to take into account is the stress experienced by the flywheel. This is given by

$$\sigma = \frac{1}{2}\rho r^2\omega^2$$

(9)

Where, ρ is the density of the material. Usually the key for material selection of a flywheel is the highest possible tensile strength over density. The maximum stress a bike can handle is the tensile strength, so

$$\sigma_{max} > \frac{1}{2}\rho r^2\omega^2$$

(10)

For a bike flywheel, the size and speed are not likely to even approach a higher enough value to create a stress above the tensile strength of a material, so this consideration is not so important. The tensile strength of standard steel is 250 MPa.Since the bike radius will be less than one, and the angular velocity will be less than 100, the tensile strength will not be reached. Since bikes are light, it is much more important to the overall efficiency to minimize the mass of the flywheel. With this in mind the flywheel should have as large of a radius as possible, and spin as fast as possible. The limit to the radius is the physical limitations of the size of the bike and the practicality of fixing the flywheel to the bike. The issue with a high radial speed is the friction losses over time [13].

IV. CONCLUSION

Flywheel technology is on the rise across many kinds of technology and rightly so. It is a pollution free method of storing energy that has many current and potential applications. In the case of road vehicles there is much to be desired in terms of energy efficiency, especially when considering pollution per unit of energy. Any system of brake regeneration can help that, but flywheels have the potential to increase the efficiency of road vehicles without direct or indirect negative effects on the environment. The batteries used in hybrids do not last the cars lifetime and can have costly environmental effects. A flywheel has environmental impact only at its time of production, and has the potential to heavily outweigh those costs through its use. Bikes do not have the pollution problems cars and other modes of transportation have, but they can serve as a good analogy for how a kinetic energy recovery system can increase the efficiency of a vehicle.

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