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Kinetic Energy Recovery System Using Spring

Mayuresh Thombre, Prajyot Borkar, Mangirish Bhobe

***Abstract*—**New advancement of technology and never satisfying demands of the civilization are putting huge pressure on the natural fuel resources and these resources are at a constant threat to its sustainability. To get the best out of the automobile, the optimum balance between performance and fuel economy is important. In the present state of art, either of the above two aspects are taken into mind while designing and development process which puts the other in the loss as increase in fuel economy leads to decrement in performance and vice-versa. In-depth observation of the vehicle dynamics apparently shows that large amount of energy is lost during braking and likewise large amount of fuel is consumed to reclaim the initial state, this leads to lower fuel efficiency to gain the same performance. Current use of Kinetic Energy Recovery System is only limited to sports vehicles only because of the higher cost of this system. They are also temporary in nature as power can be squeezed only during a small time duration and use of superior parts leads to high cost, which results on concentration on performance only and neglecting the fuel economy. In this paper Kinetic Energy Recovery System for storing the power and then using the same while accelerating has been discussed. The major storing element in this system is a Flat Spiral Spring that will store energy by compression and torsion.

The use of spring ensure the permanent storage of energy until used by the driver unlike present mechanical regeneration system in which the energy stored decreases with time and is eventually lost. A combination of internal gears and spur gears will be used in order to make the energy release uniform which will lead to safe usage. The system can be used to improve the fuel efficiency by assisting in overcoming the vehicle's inertia after braking or to provide instant acceleration whenever required by the driver. The performance characteristics of the system including response time, mechanical efficiency and overall increase in efficiency are demonstrated. This technology makes the KERS (Kinetic Energy Recovery System) more flexible and economical allowing specific application while at the same time increasing the time frame and ease of usage.

***Keywords*—**Electric control unit, Energy, Mechanical KERS, Planetary Gear system, Power, Smart braking, Spiral Spring.

I. Introduction

BOTH fuel economy and high performance are the two most important demands for the modern automobile buyers and manufacturers. [1] The awareness of air quality has been increasingly on the emission from vehicle which has critically affected the performance of vehicles as in order to increase the fuel efficiency, performance is reduced. To harness the maximum energy lost during braking a vehicle, a lot of Research and Development has been done. Alternative to increasing the fuel economy is the use of Regenerative braking system. [2], [3]

Mechanical KERS is the assembly of parts which stores some of the kinetic energy of a vehicle under deceleration, deposit this energy in storing element and then discharge this deposited energy back into the drive train of the vehicle, adding a power boost to that vehicle. For the motorist, it is like having two power sources at his disposal, one of which is the power directly coming from the engine while another is the stored kinetic energy. Kinetic Energy Recovery System (KERS) stores energy only when the vehicle is under braking and returns it during vehicle accelerates. During braking, most of the kinetic energy of the vehicle is wasted by converting into heat energy or sometimes sound energy that is released into the environment. Vehicles equipped with KERS are able to harness some this otherwise wasted kinetic energy and also assist vehicle in braking. By using a fitting mechanism, this stored energy is converted back into kinetic energy giving extra boost of power to the vehicle. The two basic type of KERS system are Electrical and Mechanical. The distinguishing factor between them is the way they convert and store the energy within the vehicle. Electric KERS system use battery as storing element and require a number of energy conversion which results in energy losses. [5], [6] On reapplication of this stored energy to the drive train, the overall energy conversion efficiency is 31-34%. [4] The mechanical KERS system stores energy in a spiral spring eliminating the various energy conversions and provides overall conversion efficiency exceeding 90%, approximately thrice the efficiency of electric system.

This design of spring based KERS was inspired by a desire to build a economical energy storage unit as a proof of concept. The energy that is lost during braking is stored in a spring which stores the energy by virtue of torsion force which is developed in the spring. By using spring it was ensured that the energy stored is permanent until used by the driver. The energy storing and releasing operations will be done gradually by the use of sprag clutch to make sure the use of system safe and user friendly. In this research paper, the major components used in the system, detailed working and the problems encountered have been discussed.

II. Brief Description

A. Kinetic Energy Recovery System

Kinetic Energy Recovery System is related to the flywheel energy system that is generally used in sports vehicle. The concept of this system is to store the energy that is lost in any

Mayuresh S. Thombre is currently pursuing undergraduate program in Mechanical Engineering in Jawaharlal Darda Institute of Engineering and Technology, Yavatmal, India (phone: 7588590810 e-mail: mayureshth@gmail.com).

Prajyot P. Borkar is currently pursuing undergraduate program in Mechanical Engineering in Jawaharlal Darda Institute of Engineering and Technology, Yavatmal, India (phone: 9623361656 e-mail: prajyotb31@gmail.com).

Mangirish S. Bhobe is currently pursuing undergraduate program in Mechanical Engineering in Jawaharlal Darda Institute of Engineering and Technology, Yavatmal, India (phone: e-mail: msbhobe@gmail.com).

other form and then again use this stored energy whenever required. Various Kinetic Energy Recovery Systems differ from each other as result of different storing element used. The below discussed KERS system makes use of Flat Spiral Spring as energy storing element and planetary gear system for transmission of power to and from the spring to the shaft. [16] Some of the basic requirements necessary for implementing KERS in automobiles are-

1. Compact shape enabling easy mounting
2. Lightweight
3. Permanent and continuous energy storage so that energy is available whenever required to add to performance

The power addition of the KERS to the power train will be controlled by Electronic Control Unit (ECU) so as to ensure safe usage wherever possible. Instant power boost can also be given on the responsibility of the driver.

B. Energy Storing Element (Spiral Spring)

In this case of mechanical KERS, the energy storing element that has been used is a Flat Spiral Spring. The energy that has been secured from the braking action of the vehicle is converted into the torsional energy of the spring. The use of spiral spring ensures that the mechanical energy is stored when it is wound. When the inner end of the spring is wound in such a way that the there is a tendency in the increase of number of spirals in the spring, the strain energy developed during braking the vehicle is stored into its spirals. This energy is utilized in accelerating the vehicle while the spring opens out and tries to regain its former shape or position. The inner end of the spring is clamped to the drum inside which the gear assembly is mounted, while the other end is clamped to the cover of the whole assembly.

Since the radius of curvature of every spiral decreases when the spring is wound up, therefore the spring is in a state of pure bending. [7]-[9]

The strain energy stored in the spring =

$$\frac{\sigma_b^2}{24E} \times btl = \frac{\sigma_b^2}{24E} \times Volume\ of\ Spring \text{ [17], [18]}$$

where,

- σ_b = *Maximum bending stress induced in spring material*
- b = *Width of strip*
- t = *Thickness of strip*
- l = *Length of strip forming the spring*
- E = *Modulus of elasticity*

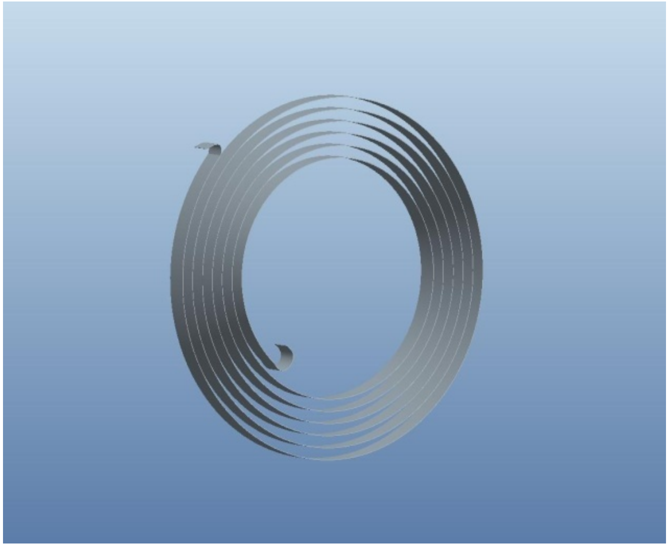

Fig. 1 CAD drawing of spiral spring

Fig. 1 shows the CAD model of the spring used for manufacturing the spring. The design of spring is prone to change for different vehicles and different materials. It also depends upon the energy which is stored within the spring. The major stresses produced in the spring are tensile and compressive because of bending.

Fig. 2 Manufactured spring

The dimensions of the spring are taken as:-

- Internal diameter = 185mm
- External diameter = 300mm
- Length of strip = 4850mm
- Width of strip = 40mm
- Thickness of strip = 1mm

The specific advantages using a spiral spring are-

1. In comparison to other methods to store energy, the size is small and the weight is less
2. Large amount of energy can be stored.
3. The energy stored is permanent, as there are no rotating or reciprocating elements.
4. In case of mechanical damage, the parts can be re-placed easily.

C. Planetary Gear System (Transmission Assembly)

The energy stored in the spiral spring is directly proportional to the extent of compression of spring. [10], [11] As the spring unwound the energy released by it also decreases. [12], [13] In order to transfer energy to and from the shaft the planetary gear system is used which contains three types of gears which are as follows –

1. Sun gear
2. Planetary gear
3. Ring gear

Some of the advantages of using gear assembly,

1. Higher reliability therefore requiring less maintenance and provide longer service
2. High efficiency
3. Compact size and lower weight
4. Infinite gear ratios for different vehicles

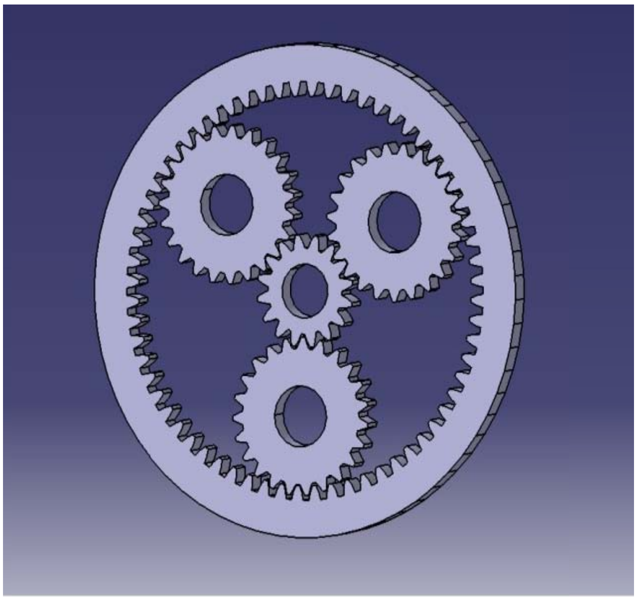

Fig. 3 CAD drawing of gear assembly

Fig. 3 is the CAD model which was drawn to ensure proper meshing of all the gears and avoid any misalignment of the gears are considered because they effect on the performance of the gears. While designing all the gears module (*m)* for all the gears was kept same. The whole planetary gear assembly consists of one Sun gear, three planetary gears and one annular gear (Ring gear). The sun gear is centrally located and mounted on the shaft. While all the other gears are mounted around the sun gear. Three planetary gears are mounted in between the sun gear and annular gear. The number of planetary gears used is dependent on the balancing of whole assembly and the power to be transmitted. [15] Minimum two planetary gears must be used to achieve proper balancing. In our case we have used three planetary gears which are placed 120^0 apart from each other to ensure balancing. The annular gear is placed over the three planetary gears.

Fig. 4 Actual Manufactured Gears with bearings

Precisely manufactured gears are as shown in Fig. 4. The planetary gears are bored with the diameter equal to that of the bearings which are to be placed inside the bored gears. Material used for manufacturing the gear assembly is 16MnCr5 which is heat treated. It is an alloy special steel allowing tensile strength of 550MPa and Brinell hardness (BHN) in range of 156-207. It is easily hot machinable and weldable. It has low hardenability and therefore it can show good core features till thickness of about 20mm. [14]

Therefore the thickness for all the gears is kept constant i.e. 20mm.

The gear ratios between gears are as follows:

- Between sun and planetary gear = 1.43
- Between planetary and ring gear = 2.78
- Overall gear ratio = 2.78×1.43 = 3.97

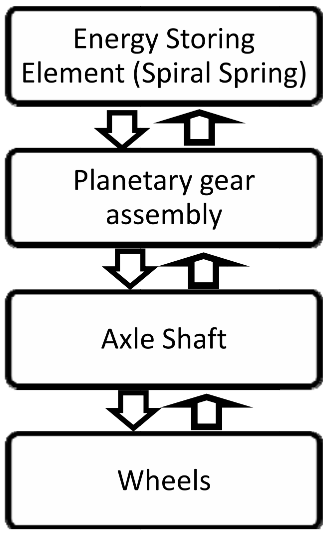

Fig. 5 Storage and release sequence

III. Assembly and Working

In this mechanism the planetary gears are attached to the planet carrier by using studs and bolts. During normal motion of vehicle, both the planet gear and carrier rotates about the same axis i.e. axis of shaft. Thus no motion is transmitted to the ring gear and is at a standstill position which thereby results in no energy is being transmitted and stored into the spring.

However when the brake is applied to stop the vehicle, the planet carrier stops rotating about the axis of shaft and as a result the gears start rotating about its own axis with the help of bearing which are previously bored into the planetary gears. Now the motion is transmitted to the ring gear and ring gear starts rotating in opposite direction as that of the wheel. As the drum and ring gear are coupled together, as soon as the ring gear starts rotating; the drum also starts rotating in the same direction as that of the ring gear. Since the internal end of the spring is brazed with the drum, as the drum rotates spring also starts winding. The winding of spring results in compression of spring and in this way the energy is stored into the spiral spring. In this way the spiral spring plays a vital role in Kinetic Energy Recovery System as main energy storing element. The sprag clutch restricts reverse motion of spring (i.e. involuntary unwinding of spring) and only allows spring to be winded.

Restoring this stored energy is exact opposite of the storing method. When the brake is released and accelerator pedal is pressed, clutch will also open. Due to this the spring is release and starts rotating in the same direction as that of the wheel. This rotation of the spring is transferred to the axle shaft through the planetary gear assembly. Vehicle is accelerated by using the energy stored in the spring in form of compression of spring.

In this way KERS utilizes the energy which is otherwise lost during braking in the form of heat energy and increases the fuel efficiency of the vehicle. It does so without affecting the performance or fuel economy of the vehicle.

IV. Advantages

Some advantages of using this system are as mentioned below:-

1. The energy stored is permanent. Therefore the energy can be released whenever required.
2. Use of ECU ensures safe usage and longer life of mechanical components.
3. Use of planetary gear system allows energy to be transmitted in the same sense of rotation as that of the axle.
4. The system is robust, compact and can be mounted easily inside wheel rim.
5. Unlike flywheel based KERS, this system is inexpensive.
6. Compared to Regenerative Braking System this mechanical KERS is more efficient due to fewer conversions.

V. Choice of platform

In this case of designing this system, we have selected four wheelers particularly due to:-

1. The Kinetic Energy Restoration System can be mounted easily inside four wheeler's rim.
2. Latest environmental norms for pollution control require better fuel efficiency of four wheel vehicles.
3. Four wheelers are most widely used means of transport and employing this system will result in a huge impact.

VI. Conclusion

The aim of this system is to improve the fuel efficiency of the vehicle without compromising the vehicle performance by storing the energy which would otherwise be lost during braking in the spiral spring and using it during acceleration. Deep study in this field will result in cost and size reduction of the components.

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Mayuresh S. Thombre (M′21) lives in Yavatmal, India. Born on 2nd November 1992. He has previously completed Diploma in Mechanical Engineering at Government Polytechnic, Yavatmal. Currently, he is the undergraduate student in Mechanical Engineering in Jawaharlal Darda Institute of Engineering and Technology. He has published many papers in Malaysia, India and now in Dubai. He is looking forward for new innovations and guidelines provided by such conferences will help him in big innovations in near future.