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An Innovative Design of Regenerative Brake System for Bicycle

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Abstract

In a bicycle, great amount of energy is lost when braking. In this paper a new design of regenerative brake system is discussed in which kinetic energy of the bicycle is captured during braking and this stored energy is released either just after braking or later as desired by the rider to move the bicycle forward and thus it will be possible to eliminate the loss of muscle energy for braking.

1. Introduction

Regenerative brake system is generally implemented in electric bikes, electric and hybrid cars. These all are completely electrical regenerative brake systems in which driving motor of the bike/car acts as generator during braking and the captured energy is redirected to the battery for charging.

Provision for electrical regenerative brake is naturally, not possible in man powered typical bicycle. Few initiatives however, taken by some other peoples to arrange the mechanical regenerative brake system for bicycle but all these are complicated and not accepted in practical field.

The proposed brake system is designed for rear wheel only. Front wheel is to be equipped with conventional brake as usual. Regenerative brake mechanism is not appropriate for front brake application.

2. Constructional Details

The mechanism is shown in Fig.1. A wheel gear (1) is fitted inside of stepped wheel hub (2) through tap bolts (3) and rotated with the hub. While rotates, it drives drive gear (4) through pinion (5). All these gears are bevel gear type. Pinion is fitted inside of stationery gear housing (6). On the outside circumference of a freewheeling device (7), drive gear hub is press fitted and this freewheeling device is mounted on the driveshaft (8) through threaded joint. The hollow drive shaft loosely enclosed the axle (9) and freely passed through the large bore of the wheel gear. One end of the driveshaft is splined and a brake disc (10) is splined over the driveshaft. Splined brake disc hub(11) is passed through the bore of the narrowed diameter portion of stepped brake housing(12) and extended up to the larger diameter portion of brake housing where brake disc operating mechanism(13), like toggle lever etc are provided. A pulley(14) is mounted on the other end of driveshaft and a set of three compression springs(15) are compressed or decompressed through a wire(16) during driveshaft forward or backward rotation for winding or unwinding of wire on the pulley. Springs are kept inside of a corrugated shape common spring cage (17) as shown in Fig.2 which is secured diagonally by clamps with the bicycle mainframe (18) in left side as shown in Fig.3 and supported at its bottom on stepped lower diameter portion of gear housing on a support block (19). The cage has a clearance with mainframe pipes to keeps align the pulley with drive wire in the same plain. The spring actuating wire is fastened at its one end with the driveshaft pulley and after two or three turns it passes through the axis of the middle spring of the spring set and attached with common spring actuating plate (20). Set of three springs are used to reduce the diameter of springs to avoid obstruction during pedaling of the bicycle. A ratchet wheel (21) is mounted on the drive shaft and a spring loaded pawl (22) pivoted in gear housing unlatched the ratchet tooth when it is pulled by the release wire through a thumb operated release lever located in bicycle handle. A locking slot is provided in bicycle handle to keep the release lever in pulled position when desired. Gear housing and brake housing are fitted with the chain stay pipe fork end

(23) through axle, i.e. position of these housings is in between rear wheel forks (24) also. Stoppers (25) located at rear wheel fork legs prevent any undesirable rotation of these housings. Wheel hub is mounted over these end housings through ball bearing (26). Bore of the ratchet pinion (27) for normal chain drive is to be fitted on the stepped smaller diameter portion of wheel hub. Rim spokes (28) are attached with the wheel hub at larger diameter portion. To provide the whole mechanism in between chain stay pipes and in between rear wheel fork legs, the distance in between the fork end of chain stay pipes and in between rear wheel fork legs will be more than conventional type. Chain stay pipes will be made L-shaped at its fork end after spring cage, adjacent to gear housing. Diameter of sprocket and pinion of chain drive are to be made larger than the sprocket and pinion of the typical bicycle. Bicycle mainframe will also to be built robust to bear the load safely during spring actuation.

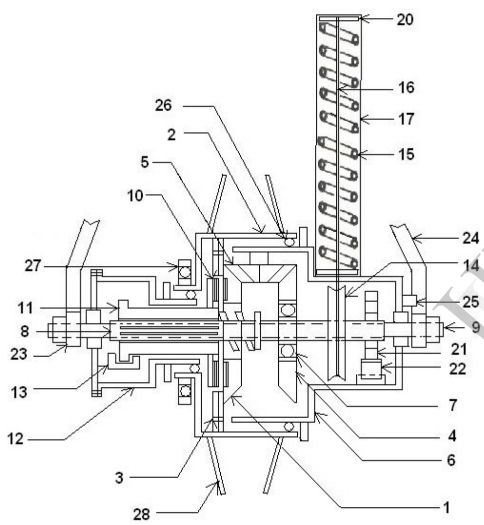

Fig.1: Regenerative Brake Mechanism

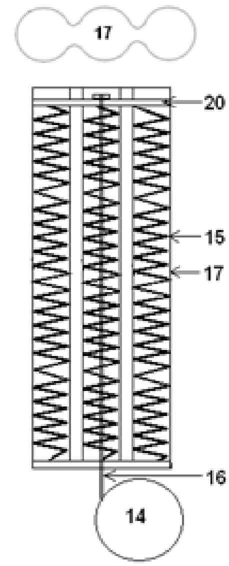

Fig.2: Corrugated Spring Cage with Springs in Spring Chambers

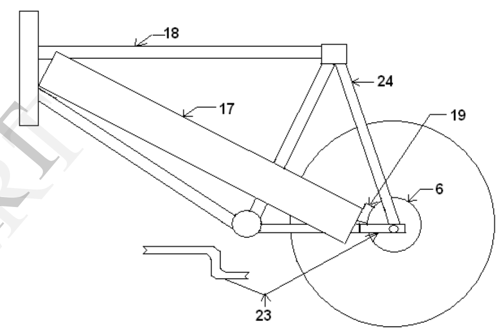

Fig.3: Spring Cage in Bicycle Mainframe

2.1. Operation

While wheel gear is rotated with wheel hub it drives drive gear in opposite direction through pinion. As drive gear assembled with drive shaft through freewheeling device so the gear freely rotated on the shaft. When brake lever is pulled, the splined brake disc hub slides over the splined portion of drive shaft and pressed against the wall of the wheel gear disc, which acts as driving plate of the brake disc. As a result, drive shaft rotated along with wheel gear and springs are compressed for winding of spring actuating wire on driveshaft pulley which resists the motion of wheel gear, i.e. motion of wheel hub. Thus, brake is applied and kinetic energy of the bicycle is stored in the springs. During this time, rotary motion of the drive shaft does not impose any effect on drive gear for freewheeling device and this gear freely rotated in backward direction as before until bicycle comes to rest. After braking when brake lever is released, strain energy of the springs is released to impart forward motion to the bicycle because during decompression of springs, drive shaft rotated in backward direction and as freewheeling device is jammed in this direction of drive shaft motion, so this time drive gear is rotated by the drive shaft which in turn, impart rotary motion to wheel gear, i.e. to wheel hub in forward direction.

A ratchet mechanism is provided in the system for convenient use of stored energy. When release of stored energy immediate after release of brake lever is not desirable then before releasing of brake lever, rider should release the thumb operated release lever located at bicycle handle to prevent the rotation of drive shaft in reverse direction by locking of ratchet wheel through engaged pawl. When again to move, rider can pull the release lever to pull the spring loaded pawl to unlatch the ratchet tooth for releasing stored energy. If desire, this release lever can also be remained always in pulled position for which locking slot is provided in bicycle handle.

Normally brake disc will work as like as clutch but when total kinetic energy of the bicycle exceeds the design value then after compression of springs up to the limit, frictional force in between the brake disk and driving plate will be less than the force required for further compression of springs and brake disc will be slipped over the driving plate during remaining part of brake application and proposed brake will work as like as conventional disc brake during this period.

3. Merits of Proposed Mechanism over other Designs

1. The main problem associated with all the existing designs is that, these are inconvenient for actual implementation in a bicycle for the lack of compactness. In all other existing designs, a set of pulleys or gear train is implemented to transfer the energy of wheel to the spring. So, these mechanisms consist of numbers of rotating parts with high rate of transmission loss. For the same reason, all these mechanisms occupied an extended space also. Proposed mechanism is most compact with fewer components. In this design, energy transmission is made possible without the use of intermediate drive and unique feature of the system is that, except compression springs, the whole mechanism is conveniently arranged in between the space of chain stay pipes. Springs are kept inside of a cage which is conveniently secured with the frame of the bicycle and supported on the housing of the mechanism.

2. In other designs, only one compression spring is implemented to store the energy but in that case, to store the same amount of energy as designed to store in the proposed brake mechanism either length of the spring will be so long or the diameter of the spring will be so large that it cannot be conveniently arranged in the limited space within the bicycle frame.

3. In the proposed mechanism, a ratchet and pawl mechanism is applied in addition for which it is possible to retain the stored energy in springs even after release of brake when rider wants to keep the bicycle in rest position after braking. Later he can use this stored energy when he again wants to start cycling. This necessary provision is not provided in other systems for which the rider cannot be able to release the brake lever even he does not want to move just after braking and it is very inconvenient during actual riding of the bicycle.

4. In regenerative brake arrangement described by Michael Rescinity and others [1], a set of pulleys are used in drive which is complicated, affected by high transmission loss and also occupied an extended space. Flywheel energy storage system is implemented by Sreevalsan S Menon and others [2], though the arrangement is simple but the mechanism is able to store a part of kinetic energy during braking phase and when the brake is to be applied fully then after flywheel rotations, the conventional brake also to be applied. Spiral spring is used in regenerative brake system invented by Dunkley, Jason [3], Spiral spring is not at all suitable for sufficient energy storage. Weight of the spiral spring will be 14.8kg if to store the equivalent amount of energy as designed to store in compression springs of the proposed brake system.

4. Engineering Design

Design is based on 20inch. Hero Jet Master bicycle of Hero Cycle Ltd of India. Total weight of the bike including rider is considered 90kg and braking distance selected 2.5mt at a speed of 12kmph by the application of rear brake only.

Nomenclature of the bicycle:

Self weight-18kg.
Load with rider-90kg.
Wheel diameter-65cm.

Wheel base-108.5cm.
Height of the seat-84cm.
C.G. point taken-95cm from the ground.

Static Load Distribution:

Static load distribution was measured by the help of portable weigh machine keeping both wheels in the same level. It has been observed that 58kg load is distributed to rear wheel and rest 32kg load distributed to front wheel i.e. nearly 65% of load is taken by rear wheel and rest 35% load is taken by front wheel. During test, 170cm tall rider of 72kg weight was chosen to select total weight of 90kg of the bicycle. Same test was also performed with other riders. Test also performed in a typical 22inch BSA bicycle but percentage of static load distribution in all the cases found almost same. Actually, the percentage of weight distribution on rear wheel will be more than 65% when the proposed brake implemented because, the mechanism will be arranged at the location of rear wheel hub of present day bicycle. Self weight of the bicycle will also be increased with this brake system.

During Checking for suitability of 2.5mt braking distance by the application of rear brake for a bike of 90kg weight running at the speed of 12kmph (3.33mt/sec) the following measurements are found from design calculations:

Braking force-20.34kg.
Due to inertia, weight transferred to front wheel during braking-17.8kg.
Dynamic load on front wheel during braking-49.8kg.
Dynamic load on rear wheel during braking-40.2kg.

In order to avoid skidding during braking phase, the maximum braking force must not exceed the product of dynamic load and of coefficient of friction in between wheel tyre and road.

Taking the lower value of coefficient of friction 0.6 (μ ranges from 0.5-0.8 between rubber tyre and asphalt road), product of dynamic load on rear wheel during braking and coefficient of friction is found 24.12kg, which is higher than braking force and so rear wheel will not skid during braking.

Regenerative brake mechanism will be less complicated if implemented in front wheel for the absence of sprocket pinion for chain drive in front wheel hub. But, unless braking force is fairly low (2.5mt braking distance at 9kmph speed), stored energy when released to accelerate the bike, front wheel will spin freely for loss of gripping on road surface as product of dynamic load on front wheel during acceleration and coefficient of friction will be less than acceleration force. Arrangement of low brake power in front wheel is not desirable because front brake should be strong enough to stop the bicycle within a short distance in case of emergency.

4.1. Component of Materials and analytically derived Specifications

Axle Rod:

Material-Carbon steel, hardened and tempered.

Diameter of axle-1.3cm.

Drive Shaft:

Material-Carbon steel, case hardened.

Inside diameter-1.4cm.
Outside diameter-2.1cm.
No. of splines-4.
Distance in between two opposite splines-2.6cm.
Height of spline-0.25cm.
Width of spline-0.65cm.
Designed length of the spline-5.5cm, ultimate length of the spline is approximately 7cm as splined portion of the driveshaft is extended through the narrowed bore of the brake housing up to the larger bore.

Brake Disc:

Lining material-Asbestos in rubber compound, compressed, on metal. Both brake disc and wheel gear disc facing brake disc provided with friction lining. Brake disc is be made of carbon steel and thickness of the plate will be 3mm. Brake disc operating toggle lever is made of carbon steel.

Outer radius of friction lining-5.3cm.
Inner radius of friction lining-4.1cm.
Face width of lining-1.2cm.
Diameter of the brake disc hub-3.9cm.
Length of the hub extended from brake disc-6.5cm.
Brake operating lever provided in bicycle handle is to be pulled by 11kgforce.

Toggle Lever:

Length of the power arm of lever from pivot-10cm.

Width of lever-1cm.
Depth of lever-2cm.

Freewheeling Device:

Type-Over running clutch type.

Material-Forged steel hardened steel ball in recess.

Diameter of balls-0.48cm.
No. of balls-8Nos.
Angle between tangents to the cam contour and to the ball surface at the point of contact-30degree.
Outside diameter of driving member-5.5cm.
Diameter of driven member shell-6.9cm.
Width of freewheeling device-1.7cm.

Bevel Gear and Pinion:

Material-0.4% carbon steel hardened and tempered.

Pressure angle-20 degree.
Circular pitch- 0.63
No. of teeth in pinion-17
P.C.D of bevel pinion at the large end-3.4cm.
No. of teeth in bevel gearwheel-60
P.C diameter of gear at large end-12cm.
Pinion semi pitch cone angle-$16^{o}12^{/}$
Wheel semi pitch cone angle-$73^{o}48^{/}$
Face width-2cm.
Pitch cone distance-6cm.
Check for Gear Wheel:
Wheel semi pitch cone angle-$73^{o}48^{/}$
Wheel pitch cone distance-6cm.

Information required for gear cutting and tooth proportions:

a. Tooth proportions at large end:

Addendum-2mm.
Clearance-0.3mm.
Dedendum-2.3mm.
Whole Depth of Tooth-4.3mm.

b. Information for pinion:
Blank diameter-37.8mm.
Pinion addendum angle-$1^{o}54^{/}$
Semi face angle-$18^{o}6^{/}$

c. Information for wheel:

Blank diameter D-12cm.
Semi face angle-$75^{o}42^{/}$

d. Dedendum angle for both pinion and wheel-$2^{o}12^{/}$

e. Face width-2cm.

f. Exact gearing ratio-3.529:1

Compression Springs:

Material- Manganese steel.

Corrugated shape Spring Cage is made from 2mm thick aluminium sheet. To avoid the wear of aluminium cage due to friction, another cage made from 0.5mm thick stainless steel sheet is push fitted inside of aluminium cage.

Number of springs in spring cage-3Nos.
Mean diameter of each spring coil-2.5cm.
Diameter of the wire SWG-7.
Driveshaft pulley diameter-7cm.
Total deflection of springs-26.83cm.
Stiffness of the spring-2.34kg/cm.
Spring index-5.59
Number of active turns-116.83, squared and ground ends.
Solid length of the spring-52.22cm.
Free length of the spring-83cm.
Weight of each spring-1.12kg.

In conventional bicycle, distance of bicycle mainframe from right side and left side food pedal cranks are 5cm and 4cm respectively. The spring cage is to be arranged in left side of the bicycle frame and so left side crank gap from mainframe of the bicycle with the proposed brake system will be 5cm to avoid any obstruction during pedaling of the bicycle.

Steel Wire Rope:

Diameter of wire-3.175mm.

Driveshaft Pulley:

Material-Carbon steel.

Diameter of the pulley-7cm.

Ratchet and Pawl Mechanism:

Material-Carbon steel, hardened and tempered

Diameter of root circle of ratchet wheel-4.2cm.
Addendum circle diameter of the wheel-6.3cm.
Height of the high end of each tooth-1.05cm.
Mean radius-2.6cm.
Length of the tooth-2.4cm.
Base width of the tooth-1.57cm.

Wheel Hub and Stationary Housings:

Wheel hub and other two stationary housings are made of die cast aluminium alloy.
Diameter of wheel hub at larger portion-16cm.
Diameter of stepped smaller portion-6.5cm.
Thickness of the hub shell-3mm.
Thickness of stationery housings-3mm.

Sprocket and Ratchet Pinion:

Ratchet pinion of chain drive-1.5times of conventional bicycle pinion.
Diameter of the sprocket-1.5times of conventional bicycle sprocket.
Teeth dimensions of sprocket and pinion is same as conventional bicycle chain drive but number of teeth will be increased.

Rear Wheel Fork and Chain Stay Pipes:

Material-Carbon steel.

Spacing in between legs of rear wheel fork and chain stay pipes of the mainframe-19cm.

Conclusion

Prototype formation is presently required for detailed tests to promote this conceptualized innovation into actual implementation in bicycles to avoid loss of muscle energy during braking.

Reference

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[2] Sreevalsan S Menon, Sooraj M S, Sanjay Mohan, Rino Disney, Suneeth Sukumaran. Design and Analysis of Kinetic Energy Recovery System in Bicycles, International Journal of Innovative Research in Science, Engineering and Technology- Vol. 2, Issue 8, August 2013.

[3] Dunkley, Jason. Regenerative Braking and Driving Apparatus, United States Patent 6557877