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Design Analysis Of Flywheel Based Kinetic Energy Conversion System In A Bicycle.

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***ABSTRACT* -** In many conventional consumer and industrial tools such as blenders, grinders, drills, and even transportation devices like bicycles, significant energy wastage occurs due to inefficient energy transfer and storage systems. This research proposes a novel design improvement for industrial drills by integrating a flywheel-based energy transfer system. A flywheel acts as an energy reservoir, smoothing power delivery and improving efficiency by storing rotational energy from a motor and releasing it as needed. The system comprises a motor connected to a flywheel via gear or belt mechanism chosen based on traction and application requirements. The stored energy is then transmitted through a gearbox or transmission system to achieve the desired torque-speed output ratio, crucial for drilling operations. This method not only enhances energy efficiency but also reduces mechanical stress and power fluctuations, potentially increasing the lifespan and reliability of industrial drills. This paper presents a theoretical model and design framework to implement flywheel-assisted energy transfer in systems.

Keywords : Kinetic Energy, Bicycle, Drills Dog Clutch, Fly Wheel

INTRODUCTION

basically the flywheel takes in rotational energy and outputs rotational energy in a highly efficient and amplified way, and thus the above concept can be applied to any machine that employs the use of rotational mechanisms for its functioning, here we present the concept in more detailed ways for the inspection at a micro level while taking into account all the necessary elements , supported by diagrams , pre-existing concepts and put them together efficiently for practical use .

We selected the above topic to see if an efficient system using flywheels would be applicable in the automobile engineering sector as a means of direct source for transportation application. With the pollution levels rising, and the push for green and renewable energy, we are to adapt the existing systems to be more efficient, we have tried to adapt the overall design process to various other consumer products using rotatory motion, while adapting our calculations and system to them respectively.

Systems are widely used, where efficient energy utilization and consistent performance are critical. Despite technological advancements, most traditional industrial designs suffer from inefficiencies in energy transfer, frequent power fluctuations, and high mechanical stress during operation. These challenges not only reduce the operational lifespan of the equipment but also increase energy consumption and maintenance costs.

One promising yet underutilized solution to these issues is the integration of flywheel-based energy storage systems. Flywheels, which store rotational kinetic energy, have long been used in mechanical systems for balancing and stabilizing power output. In the context of industrial systems, a flywheel can absorb excess energy from a motor and release it steadily as needed, providing a smoother and more controlled drilling operation. This also enables better torque-speed management and can significantly reduce energy losses that occur during startup or under variable loads. This paper explores the application of flywheels in system, focusing on improving energy efficiency, reducing mechanical wear, and enhancing overall performance. It also discusses the theoretical design of a transmission system connecting the motor, flywheel, and mechanism, along with potential benefits and limitations of such an integration

Parts of the project:

► The proposed system consists of 3 main segments:

1. Flywheel assembly
2. Transmission assembly
3. Output assembly
4. Battery build (optional)

Flywheel and motor assembly:

The smaller gear mounted on the motor shaft is in mesh with the bigger gear integrated on the edge of the flywheel, it transmits rotational energy to be stored and amplified to be transferred to the transmission box, delivered by the motor, stored and amplified by the flywheel,

The motor selected is a BLDC motor as there are no contact brushes, the motor upon being loaded does not draw additional current, and its rpm is not affected by the heated coils, its RPM can be regulated using a microcontroller or a potentiometer to deliver a PWM signal to the ESC, electronic circuit control

At the Centre of the flywheel is the input shaft of the transmission which is responsible of delivering the power in the flywheel to the transmission

All the numerical and design aspects of the components are provided in the later sections

Transmission assembly:

► the transmission assembly consists of 3 shafts and 11 gears; The first shaft is the extended flywheel shaft which is held up in its bearings (of the machine), on the flywheel shaft are mounted the 1st five gears in a decreasing order of size, each consecutive gear having rounded edges, and fewer teeth than the previous ones, the gears vary in size, following the gear ratios of (x): (x+0.5), or (x+0.5): (x), which is dependent on whether the gearing is increasing or decreasing. The second shaft consists of the output shaft which holds the other five gears required for varying the output speed to torque ratio and is again held up in the bearings (of the machine). The gears mounted on the output shaft are of same dimensions as that of the flywheel shaft but in reverse order. The 3rd and the final shaft of the transmission assembly is the shifter shaft, which is responsible for holding the shifting gear which is mounted as such in between the flywheel and the output shafts that its ends are always in contact between the gears mounted on the other two shafts; the sliding gear is also equipped with the curved edges. This basic transmission is able to output 5 different speeds , and can shift in between gears without the use of a clutch at low to moderate load conditions ; its ability to do so is given by the rounded edges of the gears on both the shafts that is the input /flywheel shaft and the output shaft , while the rounded edge sliding gear on the shifter shaft moves in between the shafts; if noticed carefully , the pitch circle diameters of all the gears is so selected that the common line between the points of contact with each step gear in the shafts is a straight line , thus while shifting in between gears, while the flywheel maintains constant to near constant speeds , the rounded edges of the gear provide it the ability to switch gears in between operations without the use of a clutch , since the point of contacts in each step gear are straight , the teeth of gear per step are aligned and thus while shifting the wear and tear of the gears is less due to lack of hard or sharp corners in the gears. The movement of the gears can be controlled by a rack and pinion setup which is fixated at the axis of the sliding gear, thus upon turning the pinion of the rack the position of the shifting gear can be adjusted to switch between the gears to get the desired output of speed tot torque ratios on the output shaft. In case of heavy loading conditions, we can use a dog clutch mechanism fitted in the flywheel and output shafts simultaneously where the whole transmission can be disengaged from the main system, change the gear, and then engage it into the system, thus resulting in smooth operations

The output assembly:

► the output assembly is very basic and is equipped with mounts which can house various tools or joints according to the need of application . It could be a gear , a drill holder, drill chuck, a Universal coupling ,a sprocket for chains etc. The selection on type of mount/ coupling to be used on the output shaft depends on the need of application and thus is very versatile, this makes the project to be widely applicable on machines that use a rotational motion as the base to do work/ function . The machine finds applications in many consumer products such as mixers, grinders blenders, drills, etc., with an appropriate size of fly wheel we can even apply this concept to bicycles

Additional components: battery:

► the battery build is an optional part of the project, where if the designer decides to apply the system to a movable machine, then there should be a source of energy to power the motor, in that case the following battery build is intended to be used:

► we aim to use li-ion cells, which have the capacity of 2600mAh with a peak charge voltage of 4.2 volts, and minimum charge voltage to be usable is 3 volts (even though li-ion cells can sustain up to 2.2 volts of charge, we limit our discharge of cells to 3 volts in order to increase the life span of the battery). The battery would be consisting of multiple cells hence a battery balancing circuit is required, here we use a 6s battery BMS which helps us regulate the charge of the cell within desired constraints, thus having an average output of 24 volts in a 6 series arrangement, with multiple cells connected in parallel usually 3p or 4p i.e., 3 cells in parallel or 4 cells in parallel. There after we use a Buck-Boost converter to regulate the battery voltage and current output which is to be supplied to the ESC circuit of the BLDC motor, since the RPM of the BLDC motor is supposed to be varied upon the voltage supplied, we can obtain different levels of rpm of the motor by varying the input voltage, other than having the control of the potentiometer, or PWM signal as well, thus this increases our versatility of the project

Additional components: dog clutch:

► The dog clutch is supposed to be used in only heavy-duty applications, where the load is so much that, upon shifting the intended transmission of gears with curved edges will cause withering or locking of gears, since heavy loads directly mean more mass of the fly wheel, which will translate to higher rpms to keep the systems sustained, thus very high speeds among the gears may cause locking while shifting

► The dog clutch can be applied at points of load like the segment of input shaft just after fly wheel, of the segment of output shaft just before the load.

Materials used in components:

Materials: we use the commonly suggested materials for the following model to conduct our experiments on, and to check the theoretical aspects of the discussed concept, the following table summarizes the materials used for the components:

Component	**Material used**
Flywheel	Steel
Shafts	Mild Steel
Gears	Hard Abs Plastic
Bearings	Chrome Steel, Mild Steel
Clutch	Steel

Experimental design of components:

- flywheel: mass ‘m’, width/thickness ‘b’, diameter ‘m’
- shafts: length ‘a’, ’b’, ’c’, diameter ‘d_2’ ‘d_3’
- power adapter: 19 volts, 7 amperes
- BLDC motor: of ‘x’ Kev
- ESC: ‘I’ ampere
- bearing: of size as per shaft: same as that of shaft diameters

Gears 1,6	**Teeth: 8**	**Diameter: 2 cm**
Gears 2,7	Teeth: 12	Diameter: 3 cm
Gears 3,8	Teeth: 18	Diameter: 4.5 cm
Gears 5,10	Teeth: 40	Diameter:10 cm

The Design procedure:

If we were to design a bicycle, then we need to gather information regarding

• Average speed of cycling

• Average calorie burns per person

• Average amount of calories consumed per person

After the gathering of the above information we can easily obtain the average per kilometer energy spent by our bodies , that energy must be the equivalent of the kinetic energy stored in the flywheel, with which we should be able to obtain the amount of RPM that is required for the fly wheel to keep the system sustained , and hence , we can decide the BLDC motor with the lowest power consumption , which is able to keep the rpm of the flywheel just above the threshold RPM for the system to be continually stable .

The next section discusses the above examples in detail

Formula Used:

RPM of BLDC Motor	**Kv * volts**
Ohms law	V =IR
Area of rectangle	Length * width
Volume of cylinder	$\Pi r^2 h$
Density	Mass/volume
Torsion	$T/J = \tau/(D/2) = G\theta/l$
Stress	F/A
Strain	dl/l
Maximum shear stress theory	f.s=Ssy/σ max
Moment of inertia of flywheel	$0.5 M*r^2$
K.E stored in a flywheel	$0.5*I*w^2$
Power	P=VI (W), Joules Per second, Watts
Centrifugal force	$M*w^2*r$
Relation of RPM to angular velocity	2ΠN/60
Relations between 2 gears	(Speed A * Number of teeth A) = (Speed B * Number of teeth B)
Relation between gear diameter and teeth	D=pitch*z/Π
Accepted efficiency of fly wheel	85%

Design of KERS Bicycle:

The collected prerequisite information for the energy spent per person on cycling is portrayed in the following table:

Average cycling speed per person	**16km/h = 4.445 m/s**
Average calories spent per person for 8 kilometres	318 Kcal = 1330512 joules
Average calories spent per person for 16 kilometres	635 Kcal = 2656840 joules
Average calories spent per person for 24.2 kilometre	953 Kcal = 3987352 joules
Average calories spent per person for 32.2 kilometres	1270 Kcal = 5313680
1 kilo Calories	4184 joules
Density of steel	7750 kg/m^3
Efficiency of the flywheel	85.

Calculation For Flywheel:

Average energy consumed per kilometer = 165278 joules/km = 16.5278 joules per meter (given by summation of all energy divided by summation of all distance)

Now this energy is supposed to be spent by the human body while cycling 1 kilometer at an average speed of 16 km per hour, therefore this must be equal to the kinetic energy the flywheel must hold and continuously supply as the cycle passes per meter of the ground

Now the average cycling speed of the person is 4.445 m/s this implies that the amount of energy consumed per second is given by

16.5278 x 4.445 = 73.466071 ~ 73.46 joules/sec

Let us say that we want to operate our cycle for

2 hours = 7200 seconds, which means that about 528912 joules are consumed in a time span of 2 hours

Now for the kinetic energy of the flywheel is given by

K. E= 0.5 x I x w2, where I = 0.5 MR^2.

Now taking into account the efficiency of the flywheel that is 85 % we get the total energy required would be

528912 + (0.85x528912) = 978487.2 joules for 2 hours

~978.5 kJ for 2 hours

Let us assume a flywheel of radius 20 cm, thickness 3 cm therefore its volume in m3 is given by 3.14xRxRxH=3.77/1000 m3 , and density x volume = mass, where density of steel is 7750kg/m3

Therefore, flywheel's mass is 29 .21 kg

Now kinetic energy of flywheel is given by

0.5xx0.5x29.21x0.22 x (2x3.14N/60)2

=978.5x103 J

Here N2 =30547244.22

Where N = 5526.9561 rpm

~ 5550 rpm is needed for the flywheel to remain constant so that the bicycle with the applied flywheel system can work continuously (as long as the speed of fly wheel remains upward of 5550 rpm)

Finally, we need to find a motor which can sustain the flywheel speed of 5550 rpm at minimum consumption for a particular gear ratio

Design calculation for gears:

We know the average speed of the person for riding a bike is 16 km/h, which when converted to m/s gives 4.445m/s

4.445m/s is the speed of the wheel in forward direction in linear motion, angular velocity of the wheel is given by

2(pi)N/60 where N is no of rotations per minute, relation of angular velocity and linear velocity is given by v=wr

Average diameter of a cycle tyre is 70cm

• Here v=2(pi)Nr/60 where N=4.445*60/[2(pi)0.35] where N=121 .2 RPM υ ~ 122RPM

Now let us assume that the sprocket on the bike axel and sprocket on the output shaft of the transmission has the same no of teeth for power delivery, therefore the output shaft at its 3rd gear arrangement should be rotating at 122 RPM, considering that, in the transmission box, when the gearing is at the arrangement no 3 gears no 3 and 8 should have same pitch diameters and should have the same no of teeth yielding out a gear ratio of 1:1

Therefore, all the other gears can be designed on the basis of the wry diameters of the 3rd and 8th gears, let us assume that the 3rd gear has a diameter of 4.5cm then the diameters of 1st and 6th , 2 nd and 7 th , 4 th and 9 th , and 5th and 10th gears should be 2cm, 3cm, 6.75cm and 10cm respectively

The above values have been in GP since the ratios of diameters of two consequent pitch circles is supposed to be same for the sliding gear to be able to slide in between the gears on the input and output shafts while in operation

The diameter of the sliding gear can be taken anywhere between 3 to 7 cm, as there is not much use of gear ratios here since the work of sliding gear is only to transmit power, but keeping in mind, the space utilization should not be too much, so we settle at a measurement of 5 cm diameter for the sliding gear

Now, with the above we have defined the pitch diameters of the said gears in the gear assembly, additional reduction or increasing gears can be employed before or after the transmission as per application

Note: all the diameters are pitch circle diameters

<u>Design Calculation of BLDC Motor:</u>

It had been shown that flywheel needs to attain a speed of 5550 RPM at minimum to keep the Bicycle in motion, regarding that the gearing between the flywheel and the motor can be arranged υ Let us say we select a 3000 Kv BLDC motor with a generic 30 Ampere capacity ESC, then to sustain a flywheel of diameter 40 cm (we had assumed radius to be 20 cm, at a speed of 5550 or above the required gearing can be given by the formula of:

(Speed A * Number of teeth A) = (Speed B * Number of teeth B)

= n1*z1 = n2*z2

Therefore, speed of flywheel 5550, no of teeth on flywheel 160, no of teeth on gear let us say 20 (because smaller the gear of the motor, larger is the efficiency while transferring torque to the large flywheel.

A gear of pitch diameter 5 cm will have 20 teeth)

The above numbers will give us the rotational speed of the motor shaft to be 44400 RPM at the minimum

Now the motor is of 3000 KV, we plan to operate the motor at 18 volts (stepped down from 24-volt 6S Li-ion battery) therefore the rpm of motor that it can achieve comfortably is about 54000 RPM, thus we have the capability to push the system further

It is not necessary to use a motor of 3000 RPM, we can use less, for less heavy-duty applications

The underload current draw from the motor is about 7 amperes and when operated at 18 volts for 2 hours it will consume an energy of

18*7*120*60 = 907200 joules

=907.2 KJ

<u>Design Calculation for Gears:</u>

We know the average speed of the person for riding a bike is 16 km/h, which when converted to m/s gives 4.445m/s is the speed of the wheel in forward direction in linear motion, angular velocity of the wheel is given by ▪ 2(pi)N/60 where N is no of rotations per minute, relation of angular velocity and linear velocity is given by v=wr

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Note: all the diameters are pitch circle diameters

Comparison:

Let us compare the results we have obtained to the results with the kits available on the market.

The standard electric bike conversion kit consists of a motor of 1.2 kW =1.2kJ/sec.

The operation for 2 hours will consume 1.2*120*60 = 8640 kJ of energy

Thus, our system is very efficient by far with a power consumption of only 907.2 kJ.

Even if the major losses are considered into calculations, the result will not exceed the energy consumption of the BLDC motors available in the market

Conclusion:

The above analysis thoroughly deals with the concept of flywheels to be used in daily consumer products for both light duty or heavy duty products in day to day life , we aimed to design a flywheel based power delivery system capable of powering elements of machine which rely on rotational motion for their operation , and tried to synthesize the components of the machine such as flywheel , gears , BLDC motors , and batteries etc, from bit mechanical and electrical aspects , we did a comparison between human input to operate a cycle for 2 hours , with a market available motor , and again of both with our system.

It was observed that for human body to be able to cycle 2 hours with an average speed of 16 km/h, we require 978.5 kJ of energy, and that the market available electric conversion system consumes about 8640 kJ of energy, and that our system consumes 907.2 kJ of energy

Each of the above values has been derived with a detailed procedure in the results and discussion section.

The results have proven that our theorized system is applicable to wide array of systems, and is very efficient, and can be modified very easily to be applicable.

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