Design, Fabrication and Testing of Regenerative Braking Test Rig for BLDC Motor

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Abstract - *In this project work a test bench for testing of regenerative braking capability of a Brushless DC Motor is design and then fabricated. The thesis discusses in detail about the steps carried out in designing the test rig and its fabrication. The BLDC Motor used in the project for the test rig is an industrial grade BLDC Motor imported from China. The BLDC Motors are found to be more efficient at higher speeds and the regenerative braking is more effectively applied only at higher speeds. It can concluded from this intensive project that the regenerative braking cannot be used are the sole way of braking in electric and hybrid vehicles and only small part of a vehicles kinetic energy can be recovered.*

Key Words*: *BLDC; Regenerative braking; Hybrid vehicle; Electric vehicle; Test Rig.

1. INTRODUCTION TO REGENERATIVE BRAKING

A regenerative brake is a mechanism that reduces vehicle speed by converting some of its kinetic energy into another useful form of energy - electric current, compressed air, etc. This captured energy is then stored for future use or fed back into a power system for use by other vehicles. For example, electrical regenerative brakes in electric railway vehicles feed the generated electricity back into the supply system. In battery electric and hybrid electric vehicles, the energy is stored in a battery or bank of twin layer capacitors for later use. Other forms of energy storage which may be used include compressed air and flywheels. Regenerative braking utilizes the fact that an electric motor can also act as a generator.

When a conventional vehicle applies its brakes, kinetic energy is converted to heat as friction between the brake pads and wheels. This heat is carries away in the airstream and the energy is effectively wasted. The total amount of energy lost in this way depends on how often, how hard and for how long the brakes are applied. Regenerative braking refers to a process in which a portion of the kinetic energy of the vehicle is stored by a short term storage system. Energy normally dissipated in the brakes is directed by a power transmission system to the energy store during deceleration. That energy is held until required again by the vehicle, whereby it is converted back into kinetic energy and used to accelerate the vehicle.

2. COMPONENTS OF REGENERATIVE BRAKING TEST RIG

The test rig is designed to check the regenerative braking capability of BLDC Motor. The energy storage system used for is Flywheel. The regenerative braking test rig consist of following components:

1. Flywheel
2. Motor/Generator Unit
3. Power Electronics
4. Control Electronics

The recoverable power for which the test rig is design is selected as under:

We are designing this test rig considering the generally available vehicles like a car. The average weight of a car is assumed to be about 1.5 tons. This new segments of car consisting of regenerative braking to improve their efficiency and reducing the power losses are called as Hybrid's.

Let us consider that the car is moving with a velocity 40 km/hr and by applying brakes we need the car to come to rest in 10s. The kinetic energy possessed by the car and the power that can be recovered can be given as

Velocity of the car (V) = 40 km/hr or 11.11 m/s.

The Kinetic Energy of the car at this velocity is given by

$$K.E. = \frac{1}{2} mv^2$$

$$= 0.5 \times 1500 \times (11.11)^2$$

$$K.E. = 92574.075 \text{ J}$$

Now if the brakes are applied and the car is assumed to stop within 10s, then the average power during braking is,

$$P = \frac{92574.075}{10}$$

P = 9,257.40 W

Or

P = 10,000 W

Hence the Motor Generator Unit (MGU) is required to be 10 KW for this Hybrid car.

For preparing this test rig, we scaled this system to a scale of 1: 100, thus requiring our MGU to be of 100W power rating.

2.1. DESIGN OF FLYWHEEL

A Flywheel is a rotating mechanical device that is used to store rotational energy. Flywheels have an inertia called the moment of inertia and thus resist changes in rotational speed.

$$E = \frac{1}{2} I\omega^2$$

The upper equation can be further expanded as,

$$E = K\, r^4 \omega^2 t$$

Where, $K = \frac{1}{4}\rho\pi$ is constant.

ρ = density of the material.

t = thickness of the plate.

Considering the thickness of the flywheel to be t = 10 mm.

Thus, substituting all the values in the equation, we get,

r = 0.11322 m or 113.22 mm

Thus, the diameter of flywheel (d) that is to be taken is 226 mm.

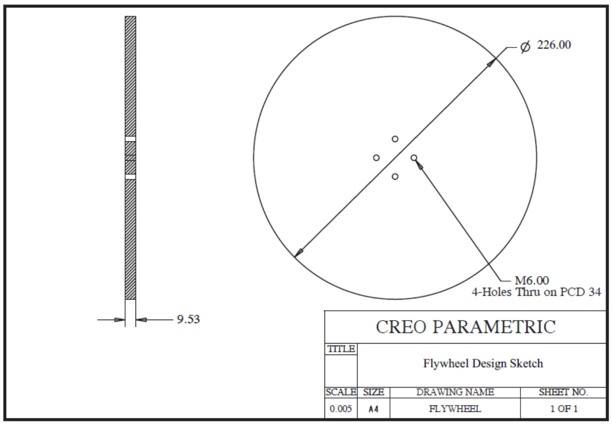


Fig.1. CAD model drawing of Flywheel

2.2. SELECTION OF MOTOR

According to the basic design needs of the test rig, a motor/generator unit of 100W rating is needed with a regenerative braking capability.

Thus a BLDC Motor with regenerative capability is selected. The specifications of the motor are as follows:

100 W BLDC Motor

Voltage rating – 24 V

Speed rating (N) – 3000 rpm

Maximum Current rating – 6A

Fig.2. BLDC Motor

2.3. POWER ELECTRONICS

The Power Electronics consists of the electronic circuit that deals with the actual electrical power flow of the BLDC Motor. Power electronics deals with the voltage considerably higher than that of the control electronics.

The Arduino Uno R3 Programmable Control Board and the Hall Effect sensors used in the Control Electronics work on 5V logic level and are not designed to sustain any voltage above 12V whereas the power electronics mainly consists of 6 Power MOSFETs that are capable of working at 100V as in case of Low side MOSFETS and 220V as in case of High Side MOSFETs.

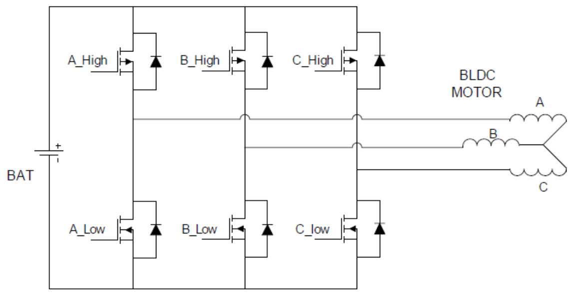


Fig.3. Schematic of Power Inverter

The Power Electronics circuit in as Triple Half-H Bridge circuit made up of 6 Power MOSFETs. The MOSFETs connected between the load and the ground are called Low Side MOSFETs or Low Side Switches and the ones that are connected between the Load and the +VCC i.e., 24V are called the High Side MOSFETs or High Side Switches.

2.4. CONTROL ELECTRONICS

A microcontroller is required to read the Hall Effect sensor feedback and decide the required combination of the switching as per the bellow mentioned switching algorithm-

Table-1: Motoring Control Algorithm

Forward/Clockwise Motoring Commutation Sequence						
Step	Hall A	Hall B	Hall C	Phase A	Phase B	Phase C
1	1	0	0	-V	+V	NC
2	1	0	1	NC	+V	-V
3	0	0	1	+V	NC	-V
4	0	1	1	+V	-V	NC
5	0	1	0	NC	-V	+V
6	1	1	0	-V	NC	+V

It is worth noting that the high side switches where (+V) is applied, is applied as PWM whereas the corresponding lower side switches of the step, where (-V) is applied, is applied by keeping the switch ON for the complete step.

Table-2: Regenerative Control Sequence Algorithm

Forward/Clockwise Regenerative Inverter Operation			
Step	PWM Switch	ON Switch	OFF Switch
1	A_Low	Nil	Remaining
2	C_Low	Nil	Remaining
3	C_Low	Nil	Remaining
4	B_Low	Nil	Remaining
5	B_Low	Nil	Remaining
6	A_Low	Nil	Remaining

3. EXPERIMENTATION ON THE TEST RIG

The experimentation setup consist of a DSO (Digital Storage Oscilloscope), a Digital Tachometer, a stop watch and the test rig. The motor driving the flywheel is mounted on the block of wood. DSO is used to get the peak to peak value of the back emf that we get from the motor. The DSO that we used consisted of two channels. The setup was arranged are shown below:

Fig.4. Setup of the Test Rig

The observations to be taken where the RPM of rotation, back emf (V_{pp}), free rotation of time of flywheel without load, braking time of the setup.

Procedure for the experimentation:

1. The Universal Motor is started, it will rotate the Flywheel connected to the BLDC Motor.
2. Using the Tachometer the RPM of rotation of the Flywheel is calculated. As the Tachometer is a Contact Type Digital Tachometer, the tip of the shaft of tachometer is connected to the center of the Flywheel, so that the tachometer shaft will rotate at the same speed as the Flywheel.
3. Once the required RPM is reached the back emf corresponding to that RPM is taken as displayed in the DSO.
4. The Free Rotation Time of Flywheel without application of load is calculated by running the Flywheel at the required RPM and then calculating the time required for the Flywheel to come to rest.
5. The Braking Time of the Motor is calculated by adding a load in the circuit, this gives the braking time with the regenerative braking. In this case a 12V battery is used as a load which is charged by back emf.
6. A buck/boost converter is used to stabilize the back emf at 14V for charging the battery.
7. The above steps were carried out for several speeds of flywheel.

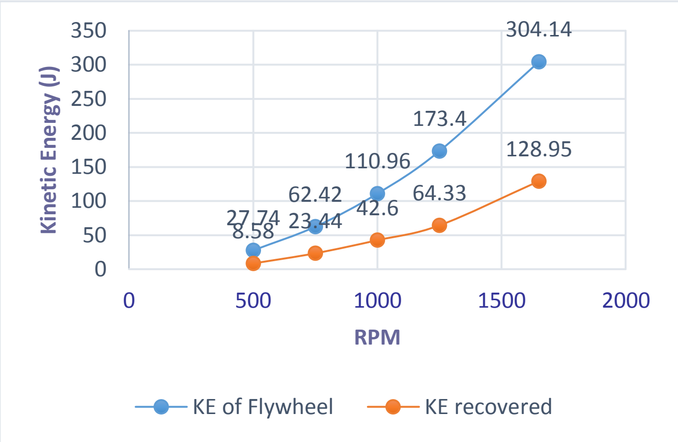
4. RESULT AND DISCUSSION

Table-3. Result Table

RPM	Back Emf(V_{pp}) (Volts)	Free Rotation time of Flywheel(s)	Braking Time(s)	K.E of Flywheel (J)	K.E Recovered (J)
500	8.2	18.63	7.22	27.74	8.58
750	10.73	22.73	8.49	62.42	23.44
1000	12.26	24.05	9.45	110.96	42.6
1250	14.2	25.1	13.0	173.4	64.33
1650	15.24	28.8	14.1	304.14	128.95

It can be seen from the result tables that the efficiency of the regenerative braking systems using BLDC Motors increases as the angular velocity of the motor increases and hence the regenerative braking systems are more efficient as higher angular velocities and the recoverable energy increases with increase in the motor speed.

The losses are higher at lower speed as we already know that the motors are inefficient at lower speeds, whereas the losses at higher speeds are mainly mechanical losses like friction losses and air drag.



Graph1: Kinetic Energy vs RPM

The graph gives a comparison of the kinetic energy available and the kinetic energy that is recovered.

5. CONCLUSION

Depletion of fossil fuels and awareness of environmental impacts of the human factors are the driving factors for the advancements in the field of technology and a race towards energy efficiency and lesser carbon footprints from our day to day commutation. This project deals with the study and experimentation and testing of BLDC Motors that makes the heart of the Hybrid vehicles and Electric Vehicles that will definitely be the future of road transport. The project creates awareness to engineers towards energy efficiency and energy conservation. The definite use of this technology described is in the future automobiles that prepared us to a certain level towards sustainable and bright future of energy efficient world.

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