Flywheel Energy

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Chapter 1
Introduction to Concept

Introduction:

FLYWHEEL ENERGY STORAGE:

Flywheel energy storage uses electric motors to drive the flywheel to rotate at a high speed so that the electrical power is transformed into mechanical power and stored, and when necessary, flywheels drive generators to generate power. The flywheel system operates in the high vacuum environment. Characterized by no friction loss, small wind resistance, long life, no impact on the environment, and needing no maintenance, this flywheel system is applicable to power grid frequency modulation and power quality guarantee. However, it also has some shortcomings such as low energy density and the high cost of ensuring the system's security. Its advantages cannot be manifested on a small scale. At present it is mainly used to supplement the battery system.

FLYWHEEL:

Flywheel energy storage is a smart method for storing electricity in the form of kinetic energy. The idea behind this technology is that the surplus electricity to be stored drives a motor that spins a flywheel thousands of rounds per minute to store kinetic energy. The flywheel moves easily because of being levitated in an evacuated chamber with magnets and highly efficient bearings. The stored kinetic energy is the momentum of the flywheel and can actuate an electricity generator as another part of the system to produce power. Low maintenance costs, a long expected lifetime, fast response, and roundtrip efficiency of about 90% are of the main advantages of flywheel systems. The main disadvantages are high cost, self-discharge risk, and appropriateness for smaller capacities only (from 3 kWh to 130 kWh) [18].

KEY TECHNOLOGIES:

Flywheel energy storage is now at the experimental stage, and there are still five main technical problems: the flywheel rotor, bearing, energy conversion system, motor/generator, and vacuum chamber.

1. Flywheel rotor:

The flywheel rotor is the most important part of the flywheel energy storage system. The transformation of energy of the whole system depends on the rotation of the flywheel. It is necessary to develop the flywheel with high strength and suitable structure based on rotor dynamics design.

2. Support bearing

Bearing technology supporting a high-speed flywheel is one of the key factors restricting the efficiency and service life of the flywheel.

3. Energy conversion system

The core of the flywheel energy storage system is the conversion between power and mechanical energy, which adjusts energy input and output of the conversion process to coordinate the frequency and phase. The energy conversion unit determines the efficiency of the system and governs the operation of the flywheel system.

4. Generator/motor

The high speed of the flywheel energy storage rotor leads to the high speed of the flywheel motor, which requires high efficiency, low power consumption, and high reliability of the flywheel motor system. The current research on permanent magnet motors focuses on reducing loss and resolving the temperature sensitivity of a permanent magnet.

5. Vacuum chamber

The vacuum chamber is the auxiliary system of the flywheel energy storage system that makes the system independent from the outside environment.
Advance Concepts:
Flywheels are devices that store energy in rotational kinetic form. Two major applications for energy storage flywheels include the transportation industry (both automotive and rail) as an alternative to the use of batteries in hybrid vehicles, and in the power industry for applications such as an Uninterrupted Power Supply (UPS), power grid stabilization, and as an immediate, though limited, response to peak demand. This summary concentrates on current flywheel research for power generation applications.

Flywheel energy storage (FES) systems are well suited for short-duration applications. In particular, the systems have been used as UPSs for over 30 years. More recently, FES systems have been used to improve power quality in solar and wind energy projects, maintaining frequency and voltage, and providing steady power during electrical disturbances. This recent usage, along with the development of applicable renewable energy sources, has sparked renewed interest in FES technology.

Introduction to our Concept:
The present production and use of energy pose a serious threat to the global environment and consequent climate change. As non-renewable energy sources are becoming scarce, there is a need to make major changes in energy supply and utilization systems. At this juncture flywheel energy storage technology is a significant and attractive manner for energy futures sustainable. In addition to the advantages like short charge and discharge time, they are also very competitive economically in terms of price per unit power and energy. Flywheel energy storage system is an electromechanical battery having a great deal of advantages like high energy density, long life and environmental affinity. Flywheel energy storage can have energy fed in the rotational mass of a flywheel, store it as kinetic energy and release out upon demand. The FES system mainly consists of non contacting magnetic bearings that provide very low frictional loss, a composite flywheel of high energy density and high mechanical strength, a motor/generator that transfers electrical energy into mechanical form and vice-versa and a vacuum chamber that minimizes wind age losses.

High temperature superconductor magnetic bearing offers dynamic stability without active control. The rotors made up of an advanced composite material such as carbon fibres have very high strength to weight ratios, which give flywheels the potential of having high specific energy.

The geometry of an energy storage flywheel is generally chosen in such a way as to maximize the energy density and specific energy. The spinning rotor must be supported on bearings. Magnetic bearings can accommodate very high spin speeds. High temperature superconducting bearings have the potential to reduce rotor idling losses and make flywheel energy storage economical. But super-conducting bearing technology is not mature enough for use in FESS.

Chapter 2
Design

Design of a Flywheel
A flywheel acts as an energy reservoir, which stores energy during the period when the supply of energy is more than the requirement and releases energy during the period when the requirement is more than the supply.

1) Selection of the engine
Data tables will be provided and select the problem based on the serial number

2) Calculation of Turning Moment
- calculation of torque due to inertia forces
- calculation of torque due to pressure forces
- the indicator diagram of the engine will be provided

3) Obtain the turning moment and hence find the mean torque

4) Calculation of the Moment of Inertia of the Flywheel to limit the speed fluctuation to given value

5) Design of the flywheel with the required Moment of Inertia

For Flywheel:

Flywheel rotor design is the key of researching and developing flywheel energy storage system. The geometric parameters of flywheel rotor were affected by much restricted condition. This paper discussed the general design methodology of flywheel rotor base on analyzing these influence, and given a practical method of deterring the geometric parameters. The foundation was laid for optimal design and analysis of flywheel rotor in the future.

Flywheel energy storage system (FESS) mainly consists of a flywheel rotor, magnetic bearings, a motor/generator, a vacuum chamber, and power conversion system. The flywheel rotor was supported by non-contacting magnetic bearings that provide very low frictional losses. It stores energy in a kinetic form, the motor/generator converts mechanical energy to electric form, and vice versa. The flywheel rotor work in a high speed, must be high energy density, high mechanical strength, and dynamics properties. Therefore the flywheel rotor was the key of FESS research and develop.

Flywheel rotor design process:

Fig. 2.1 illustrates flywheel rotor design process and its influence factor. The process included requirements analysis, rotor type option, general design, optimum design, and performance evaluation. Goals of general design is to determinate geometric parameters of flywheel depending upon the limiting factor, a very large number of conditions and factors must be considered, such
as general configuration of flywheel energy storage device, the stored energy, operation speed, material behaviour, moment of inertia, rotor dynamics, flywheel rotor mass, structural manufacturability.

Maximum outer radius:-
The primary components of a flywheel rotor are shown on Fig.2 and consist of metal shaft, flywheel, magnetic bearings rotor and thrust disk, motor/generator rotor. There are two basic classes of flywheels based on the material used in the rotor. 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-fiber or graphite. The metal hub of composite flywheels had the same geometrical shape and work condition with the steel flywheels. This section mainly determine their maximum outer radius. The design method is similar in composite rim.

Stress analysis :-
Fig. 2.2 and 2.3 shows that the metallic hub (or steel flywheel) can be divided into spoke and metal rim. They become of uniform thickness rotating disk. The stress at a point in the disk is three stress states: the radial stress $\sigma_r$, tangential stress $\sigma_\theta$, and axial stress $\sigma_z$. Because the surface of the disk is a free surface in the $z$ direction, $\sigma_z = 0$. For an isotropic material the radial and tangential stress are expressed by

$$\sigma_r = \frac{3+\mu}{8} p w^2 \left( R^2 + r^2 - \frac{R^2 r^2}{r_1^2} - \frac{r^2}{r_1^2} \right)$$

**Failure criteria:-**

Selection Failure criteria of composite rim are Tsai-Hill, Tsai-Wu, Maximum Failure and Hoffman [3]. Failure Criteria of isotropic materials are Tresca, Tresca Stress and Von Mises. Teresa criteria is more conservative than Von Mises, it is also valid for isotropic & ductile materials. The disk is generally made of plastic metal, the tresca stress criterion is used as failure criterion. This states that failure occurs when the maximum shear stress in the component being designed equals the maximum shear stress in a uniaxial tensile test at the yield stress.

**Select materials and calculate maximum outer radius**

The material for the flywheel rotor shaft is 40Cr which is relatively cheap and easy to manufacture. The inner diameter respectively is 300 mm, 200 mm, and 50 mm, the material respectively is aluminium 7050, carbon steel 45, and alloy steel AISI 4340, the maximum outer diameter can be calculated from Eq.(8), the results are listed in Table 1. The maximum outer diameter decrease as inner diameter are increased, there are the larger outer diameter with better strength and low density materials. So we select that the metallic hub of composite flywheel is made of aluminium 7050, and the steel flywheel is made of alloy steel AISI 4340.

**Calculation of torque due to inertia forces**

Calculation of torque due to inertia forces

$$Q = M x$$

$$x = l + r - [r \cos \theta - l \cos \alpha]$$

$$x = (n+1)r - [r \cos \theta - nr \cos \alpha]$$

$$nr \sin \alpha = r \sin \theta$$

$$x = (n+1)r - r \cos \theta - r(n - \sin \theta)$$

$$Q = M x$$

$M$ is the mass of reciprocating parts

But we don’t need the consideration of reciprocating part.

**Design of a Flywheel: Mass**

Find the equivalent mass system

Mass is variable each time because of manual operation

**Calculation of torque due to pressure force**

$$P = S \cos \alpha$$

$$T = Sh \cos \alpha$$

$$T = Ph$$

**Calculation of resultant torque**

$$T = (P - Q) h Q$$

$$T = Ph - Qh$$

**For Solid Shaft:-**

The term shaft usually refers to a component of circular cross section that rotates and transmits power from a driving device, such as a motor or engine, through a machine. Shafts can carry gears, pulleys, and sprockets to transmit rotary motion and power via mating gears, belts, and chains. Alternatively, a shaft may simply connect to another via a mechanical or magnetic flux coupling. A shaft can be stationary and support a rotating member such as the short shafts that support the nondriven wheels of automobiles often referred to as spindles. A selection of common shaft arrangements is illustrated.
Design of a Flywheel: Shaft

The diameter of the shaft should be large enough to prevent from failure due to the torque on it.

\[ \frac{T}{J} + \frac{t}{r} \]

- \( r \) = distance from the centre
- \( D \) = diameter of the shaft
- \( \tau \) = shear stress on the shaft at radius \( r \)
- \( T \) = torque on the shaft
- \( J \) = Polar second moment of area

\[ J = \frac{3.149 \times d \times d}{32} \]

Shaft design considerations include:

1. Size and spacing of components (as on a general assembly drawing), tolerances,
2. Material selection, material treatments,
3. Deflection and rigidity,
   a. Bending deflection,
   b. Torsion deflection,
   c. Slope at bearings,
   d. Shear deflection,
4. Stress and strength,
   a. Static strength,
   b. Fatigue,
   c. Reliability,
5. Frequency response,

Shafts typically consist of a series of stepped diameters accommodating bearing mounts and providing shoulders for locating devices such as gears, sprockets, and pulleys to butt up against and keys often used to prevent rotation, relative to the shaft, of these “added” components. A typical arrangement for a transmission shaft supporting a gear and pulley wheel illustrating the use of constant diameter sections and shoulders is shown in Figure 2.5 and 2.6.
Foundation Design :-
Many a good weld design is ruined by mistakes made in fabrication. This chapter will help you avoid the most common mistakes, and also a few uncommon mistakes. Though not all of the following steps are used on all projects, the typical weld fabrication steps are:

- Get or make a fabrication sketch or drawing.
- Develop a well thought out step-by-step procedure.
- Gather tools and materials.
- Make patterns, jigs, templates and fixtures, if needed.
- Put together a cut list.
- Lay out and cut the materials.
- Make edge preparations and clean the metal areas to be welded.
- Position and clamp materials prior to welding.
- Tack weld assemblies, check dimensions, setup and sureness.
- Place the final welds and assemble the final fabrication.
- Grind welds smooth only if necessary.
- Paint the fabrication, if needed.

Both methods work, but with notching it is easier to get good results and this technique is more dimensionally tolerant because the joint gaps between the angle irons’ length can be adjusted to bring the frame square and the side lengths equal. After welding and grinding, both methods will look equally good and be equally strong. In general, use mitered corners when you have a bandsaw or a notching tool to cut perfectly matching corners.

The third approach for making square and rectangular frames from angle iron lends itself to production work because it requires notching and bending, which is best done on a machine like an Ironworker. These versatile machines can perform the functions of a press brake and a bending fixture, such as bending and notching angle iron. As shown in Figure 14-2, getting the correct bend-allowance gap is critical because this gap provides the extra material needed to go around the outside corner when the bend is made.
To make these mitered and bent corners, begin by setting the bend-allowance gap to slightly less than the thickness of the angle iron and go from there. *This method only works if corners are bent by machine.* Heating the corners and manually freehand bending them will produce rounded corners—and scrap.

When welding a very large L-shape, where a square is too small and there are no diagonals to measure, use a 3-4-5 triangle. Here’s how it’s done:

- Measure off four units on one leg, or member, of the frame.
- Measure off three units on the other leg.
- Adjust the hypotenuse by moving either leg of the L-shape until the hypotenuse measures exactly 5 units. Following this procedure makes a perfect right triangle.
Check for equal diagonals between opposite frame corners using a steel measuring tape. This method is used in Figure 1.4.7.

On large frames, check the squareness using a carpenter’s square, and on smaller frames, check squareness using a machinist’s square.

If the sides of the frame are to be plumb and level, a large level can be used.

**Multiple key Elements :-**
1) Flywheel :-
2) Bearing Support Structure :-
3) Bearing :-
4) Shaft :-
5) Coil And Magnet :-
6) Output :-
7) Multi meter :-
Chapter 3
Construction And Manufacturing

Construction :-
It consists of wooden frame and two movable links on which circular magnets are mounted, wooden shaft with two circular magnets at the end and two NdFeB magnets, flymass mounted at the centre of the shaft. The shaft is supported by a single point contact at one end. The copper coil is winded in a circular pattern over the shaft acting as the armature which is connected to the supply end through brushes and placed within the north south poles of a permanent circular magnet. The CATIA model of flywheel with shaft and magnetic bearings is shown in figure 1. The model of the assembly of FESS is shown in figure 2.

In the Construction Of this Project Include Multiple Steps Required for the Manufacturing As Fallows :-
1) Casting of aluminum
2) Material Selection
3) Shaft Machining
4) Flywheel Machining
5) Foundation Fabrication
6) Electrical Work
7) Assembly Etc.

NOTE :- Elaboration of the particular project is short of want because it toll held on trial and error.

Figure 3.1 Final Assembly

As per shown in picture above the final built is looks like this and for reaching in this point we have to cross many major steps les us study one by one

1) Casting Aluminum :-

Aluminium is heated to its liquid form in the aluminium casting process and then poured into a mould. The mould must be made with precision because it’s quality will have a direct impact on the shape and surface finish of the finished aluminium casting.

The mould can be made from many different materials, including tool steel, because aluminium has a lower melting point than steel. Another material that a mould can be made out of for aluminium casting is sand. For this, the sand is pressed to take the form of the desired finished part. Once the sand is formed, the liquid aluminium is poured into it and allowed to cool. Aluminium castings have properties similar to other aluminium components. Once the casting process is complete the aluminium castings quickly form an exterior layer of aluminium oxide that helps protect against corrosion.
Sand Casting:
In sand casting, re-usable, permanent patterns are used to make the sand moulds. The preparation and the bonding of this sand mould are the critical step and very often are the rate-controlling step of this process. Two main routes are used for bonding the sand moulds:

- The "green sand" consists of mixtures of sand, clay and moisture.
- The "dry sand" consists of sand and synthetic binders cured thermally or chemically.

The sand cores used for forming the inside shape of hollow parts of the casting are made using dry sand components. This versatile technique is generally used for high-volume production. An example of half sand mould is given in Figure 3.3.

2) Material Selection:
- Aluminium for fly Wheel
- Mild Steel for Shaft
- Coil plate and Magnet Barrowed from motorcycle Engine
- 6001 sized Bearing for simply support of shaft
- Angle iron (mild steel) for frame of foundation
- Multi-meter for checking electrical output
- Techno-meter for rpm check

Figure 3.2 Final Assembly

Figure 3.3 Sand Casting
The material for the flywheel rotor shaft is 40Cr which is relatively cheap and easy to manufacture. The inner diameter respectively is 300mm, 200 mm, and 50 mm, the material respectively is aluminium 7050, carbon steel 45, and alloy steel AISI 4340, the maximum outer diameter can be calculated from Eq.(8), the results are listed in Table 1. The maximum outer diameter decrease as inner diameter are increased, there are the larger outer diameter with better strength and low density materials. So we select that the metallic hub of composite flywheel is made of aluminium 7050, and the steel flywheel is made of alloy steel AISI 4340.

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3) Shaft And Fly Wheel Machining :-

**Machining** is a process in which a material (often metal) is cut to a desired final shape and size by a controlled material-removal process. The processes that have this common theme are collectively called **subtractive manufacturing**, in contrast to additive manufacturing, which uses controlled addition of material. Subtractive manufacturing utilizes machine tools, while additive manufacturing utilizes 3D printing.

Machining is a part of the manufacture of many metal products, but it can also be used on other materials such as wood, plastic, ceramic, and composite material. A person who specializes in machining is called a machinist.

A room, building, or company where machining is done is called a machine shop. Much of modern-day machining is carried out by computer numerical control (CNC), in which computers are used to control the movement and operation of the mills, lathes, and other cutting machines. This increases efficiency, as the CNC machine runs unmanned therefore reducing labour costs for machine shops.
The three principal machining processes are classified as turning, drilling and milling. Other operations falling into miscellaneous categories include shaping, planning, boring, broaching and sawing.

- Turning operations are operations that rotate the work piece as the primary method of moving metal against the cutting tool. Lathes are the principal machine tool used in turning.
- Milling operations are operations in which the cutting tool rotates to bring cutting edges to bear against the work piece. Milling machines are the principal machine tool used in milling.
- Drilling operations are operations in which holes are produced or refined by bringing a rotating cutter with cutting edges at the lower extremity into contact with the work piece. Drilling operations are done primarily in drill presses but sometimes on lathes or mills.
- Miscellaneous operations are operations that strictly speaking may not be machining operations in that they may not be scarf producing operations but these operations are performed at a typical machine tool. Burnishing is an example of a miscellaneous operation. Burnishing produces no scarf but can be performed at a lathe, mill, or drill press.
An unfinished work piece requiring machining will need to have some material cut away to create a finished product. A finished product would be a work piece that meets the specifications set out for that work piece by engineering drawings or blueprints. For example, a work piece may be required to have a specific outside diameter. A lathe is a machine tool that can be used to create that diameter by rotating a metal work piece, so that a cutting tool can cut metal away, creating a smooth, round surface matching the required diameter and surface finish. A drill can be used to remove metal in the shape of a cylindrical hole. Other tools that may be used for various types of metal removal are milling machines, saws, and grinding machines. Many of these same techniques are used in woodworking.
4) **Foundation Fabrication**: 
Metal fabrication is a somewhat broad term for several types of fabrication processes. Cutting, punching, forming, shearing, stamping, welding are common fabrication techniques used to shape, cut, or mould raw metal material into a final product. Fabrication is distinct from other manufacturing processes. For example, unlike material that is assembled from ready-made components or parts, fabrication can either produce end products or can produce parts for use in completing those products.

Fabrication manufacturing processes differ depending on the material and the desired end product. The process can be used in making mass-produced products or custom designs. Whether mass-produced or custom designed, the end products are made with a wide range of metals and their alloys—stainless steel, carbon steel, aluminium, copper, brass to name a few. In industrial fabrication processes, chances are one or more of the following methods will be used to finish or produce a part or end product:

**Figure 3.8 Basic Foundation**

**Common Methods or Types of Fabrication We Used**

- **Cutting**
  The cutting of a metal work piece is a common fabrication technique in which the material is split or cut into smaller sections. Cutting can be used as a first step in a much larger fabrication process or the only step necessary in the process. The old days of sawing have been superseded by modern forms of cutting that utilize state-of-the-art machinery. From power tools to computer numerical computer (CNC) cutters, today’s methods include laser cutting, water jet cutting, power scissors, and plasma arc cutting.
In manufacturing, forming is a fabrication process that bends or distorts metal to produce parts and components. Metal can also be formed via rolling, a compressive method utilizing CNC press brakes able to produce up to 400 tons of pressure. Strips or sheets of metal are continuously fed through parallel rollers that shape the workpiece into the desired form. During the process of forming, the metal material does not lose its mass, only its form.
Punching
Punch presses are mechanical devices or machines used to punch or create holes in metals. Punching, as a fabrication process, has a two-fold purpose. A punch press houses turrets that strike metal through or into a die. The result “punches” or creates uniquely designed holes in the metal. The finished product can either be the removed uniquely shaped pieces that were punched out from the metal, known as blanks, or the holes can be used for fastening purposes. Traditionally, in smaller fabrication shops punch presses are mechanical, but smaller and can be hand-powered. In large-scale fabrication operations, industrial CNC programmed presses are used to produce complex designs at greater output to meet both heavy and light metalwork.

Shearing
Used to trim or remove unwanted material from metal material, shearing is achieved by mounting two blades above and beneath the metal to produce one long, straight cut. The process is primarily used to cut smaller lengths and differently shaped materials, the blades can be mounted at angles to reduce the necessary shearing force required. Straight cuts are achieved by combining two tools, essentially blades, with one of the tools above the metal and the other one located below for applying pressure. The upper blade forces the metal down onto the fixed or stationary lower blade to fracture the piece and complete the separation.

Figure 3.11 finalizing the frame

Stamping
Similar to punching, stamping creates an indentation rather than a hole during fabrication. The turret presses against the metal forcing the die to stamp shapes, letters, or images into the metal workpiece. Accomplished through mechanical or hydraulic means, metal sheets up to 6mm (1/4 inch) thickness can be formed into specific shapes and sizes. Stamping machines can also cast, punch, cut, and shape metal sheets to create a wide range of products. Operations such as metal coining, blanking, and four slide forming are all performed with stamping machines.

Welding
One of the more common fabrication processes, welding is the art of joining two or more pieces of metal together utilizing a combination of heat and pressure. Metals can vary in shape or size. The three main types of welding procedures are Stick or Arc Welding, MIG Welding, and TIG Welding. Spot welding and stud welding are two other versatile welding applications used in industrial metal fabrication shops.
5) **Assembly**

a) **Bearing Assembly On the Foundation :-**

![Figure 3.12 finalizing welded joints](image1)

On the two simply supported beam on the foundation the plate is welded with two drilled holes in it. The center of both the drilled holes parallel to each other in this way the both the bearing stay on the equal position as per determine.

This drilled plate is placed on both the pillars at the equal height in this way the shaft rest on the bearing at the equivalence. We used 6001 sized automotive bearing at the count of 4, 2 bearing per pillar and we used 12 mm of nut and bolt with washers this fasteners are automotive graded by which it can handle variable rpm as well as multiple vibration.

We torque the all 4 fasteners at least 12 nm of torque by which it doesn’t move from its place.

b) **Shaft Assembly :-**

The machined shaft is already assembled with the fly wheel already mounted on it. And the we have to assemble the magnet plate on the shaft at approximately 5 inch from fly wheel on RHS side by which we can place our coil plate in it. As per shown in the figure 3.14

![Figure 3.13 bearing assembly](image2)
As per you can see we builted the another frame for mounting of coil plate with using ½ inch square bar mild steel and designed the stainless steel plate for fitment of the coil plate which is responsible to generate electricity from our whole system. The bolted the coil plate on the separate foundation because it doesn’t interact with the rotation of the shaft so whole the shaft is rotating the coil plate doesn’t move it work as stator and whole shaft works as rotor.
Procedure of the whole project is as follows:-
1. How to set up.
2. System check.
3. Tools for measurement.
4. Setting up tools.

1) How to set up :-

[STEP 1]

I. Find a stable ground, or a flat surface by which we can up strain the whole foundation on it.
II. By following up this procedure we can make sure that our whole setup doesn’t move around.
III. Make sure that the whole foundation is placed on even ground and there is no gap around the whole platform.
IV. Now take a look back on your whole setup grab it and wiggle it for more security that it doesn’t move around as it has a rotational mass of shaft as well as flywheel that can generate vibrations during the procedure.
V. If you find any kind of wiggling or vibration place a foam or rubber padding underneath the foundation. As shown in Figure 4.1.

![Figure 4.1 FOUNDATION SETUP](image)

[STEP 2]

I. Make sure all the bearings are lubed up and free to move in there constraint motion.
II. Look back and make sure that all the bearings contact points with the shaft is in contact and wiggle shaft for checking the movement of shaft is aligned with all the bearings.
III. If any bearing is not touching or not moving in their own motion tap that bearing little-bit or loose there fasteners for their motion. As shown in Figure 4.2.
STEP 3

I. Now look back towards coil plate as per shown in figure 4.3, the L.H.S side of shaft is pointed to make approach to proper alignment of shaft.

II. Make sure the point of contact of shaft is touching to the foundation of the stainless steel, in this way we can make sure that coil plate is not interacting with the magnet plate.

III. If the second step is not followed up, the shaft while rotating can interact with stator or coil, also leads to frictional resistance during the motion.

IV. If this particular scenario happens the tap the shaft from L.H.S side towards R.H.S side as shown in figure 4.4.
V. This scenario also leads to happen when the shaft is been rotated in counter clock-wise direction.
VI. To prevent this there is arrow shown on flywheel on both side for rotational in particular direction as shown in figure 4.5.

Figure 4.4 COIL PLATE AND MAGNET CLEARANCE

Figure 4.5 CONNECTION COIL PLATE TO MULTIMETER
2) System check :-

I. Check that foundation is in even position and it’s not wiggling anymore.
II. Check that the shaft is rotating properly without any vibrations.
III. Check that the fixture has no more weird noises.
IV. Check that the bearing is rotating properly in its constraint motion and all the contact points are connected.
V. Check that the wires from the coil plate are connected properly to the multi-meter and it should work properly.
VI. Check that the labeling (reflecting strip) of tachometer on the flywheel is done properly.
VII. Check that the tachometer is placed at a perfect distance (5 inch) away from the flywheel to obtain proper reading.

3) Tools for Measurement :-

A. Taco-Meter
B. Multi- Meter

A) Taco- Meter :-

Tachometers or revolution counters on cars, aircraft, and other vehicles show the rate of rotation of the engine’s crankshaft, and typically have markings indicating a safe range of rotation speeds. This can assist the driver in selecting appropriate throttle and gear settings for the driving conditions. Prolonged use at high speeds may cause inadequate lubrication, overheating (exceeding capability of the cooling system), exceeding speed capability of sub-parts of the engine (for example spring retracted valves) thus causing excessive wear or permanent damage or failure of engines.

Figure 4.6 Techo-Meter

On analogue tachometers, speeds above maximum safe operating speed are typically indicated by an area of the gauge marked in red, giving rise to the expression of “redlining” an engine — revving the engine up to the maximum safe limit. Most modern cars typically have a revolution limiter which electronically limits engine speed to prevent damage. Diesel engines with traditional mechanical injector systems have an integral governor which prevents over-speeding the engine, so the tachometers in vehicles and machinery fitted with such engines sometimes lack a redline.
Speed sensing devices, termed variously "wheel impulse generators" (WIG), speed probes, or tachometers are used extensively in rail vehicles. Common types include opto-isolator slotted disk sensors and Hall effect sensors. Hall effect sensors typically use a rotating target attached to a wheel, gearbox or motor. This target may contain magnets, or it may be a toothed wheel. The teeth on the wheel vary the flux density of a magnet inside the sensor head. The probe is mounted with its head a precise distance from the target wheel and detects the teeth or magnets passing its face. One problem with this system is that the necessary air gap between the target wheel and the sensor allows ferrous dust from the vehicle's under frame to build up on the probe or target, inhibiting its function.

B) Multi-Meter:

A millimetre is a measuring instrument that can measure multiple electrical properties. A typical millimetre can measure voltage, resistance, and current, in which case it is also known as a volt-ohm-millimetre (VOM), as the unit is equipped with voltmeter, ammeter, and ohmmeter functionality. Some feature the measurement of additional properties such as temperature and volume. Analogue millimetres use a micro ammeter with a moving pointer to display readings. Digital millimetres (DMM, DVOM) have numeric displays and have made analogue millimetres virtually obsolete as they are cheaper, more precise, and more physically robust than analogue millimetres.
4) Tool Setup :-

For Techo-Meter:-

- As per shown in figure 4.9 place tachometer exactly perpendicular to shaft and almost facing to flywheel.
- Before placing tachometer make sure the white reflecting tape as per shown in figure 4.7, if the tape is not there put the reflective tape on the flywheel’s circumferential area.
- Now, place the tachometer as per shown in figure and make sure do not place far away from flywheel and also do not touch flywheel physically with tachometer. The length between flywheel and tachometer should be between 15cm maximum and 10 cm minimum.
- There is a button on tachometer for start taking reading of RPM, make sure you can press the button while the flywheel is in rotational motion, in this way we can take precise measurement.

![Figure 4.9 tachometer measurement](image)

For Multi-meter:-

- Setup of multimeter is kind of different as compared to tachometer as there are four wires coming out of coil plate in which two wires represent positive and negative terminal where one is ground and final terminal is neutral.
- In this way we have to connect multimeter black needle to negative terminal and red needle to positive terminal.
- We have to connect multimeter in between the demonstration light circuit of AC to DC converter which can help us to demonstrate electric output in physically as well as mathematically.
- The multimeter is useful to show us multiple output data such as ampere, resistance, continuity of circuit, volt as well as watt, as per shown in figure 4.10.
Figure 4.10 Multimeter Measurement
5) **Observation Table:**

This observation table shows the multiple constrain of our flywheel energy such as follows in both the condition while applying force and while not applied.

<table>
<thead>
<tr>
<th>Sr. no</th>
<th>Power In (nm)</th>
<th>Elapse time (in Sec)</th>
<th>Voltage (V +- 200) (AC)</th>
<th>Rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Input</td>
<td>Output</td>
<td>Input</td>
<td>Output</td>
</tr>
<tr>
<td>1.</td>
<td>10 nm</td>
<td>5</td>
<td>7</td>
<td>47</td>
</tr>
<tr>
<td>2.</td>
<td>15 nm</td>
<td>15</td>
<td>11</td>
<td>61</td>
</tr>
<tr>
<td>3.</td>
<td>20 nm</td>
<td>20</td>
<td>13</td>
<td>69</td>
</tr>
<tr>
<td>4.</td>
<td>25 nm</td>
<td>25</td>
<td>16</td>
<td>77</td>
</tr>
<tr>
<td>5.</td>
<td>30 nm</td>
<td>30</td>
<td>16</td>
<td>93</td>
</tr>
<tr>
<td>6.</td>
<td>35 nm</td>
<td>35</td>
<td>16</td>
<td>96</td>
</tr>
<tr>
<td>7.</td>
<td>40 nm</td>
<td>40</td>
<td>17</td>
<td>99</td>
</tr>
<tr>
<td>8.</td>
<td>45 nm</td>
<td>45</td>
<td>17</td>
<td>97</td>
</tr>
<tr>
<td>9.</td>
<td>50 nm</td>
<td>50</td>
<td>18</td>
<td>96</td>
</tr>
<tr>
<td>10</td>
<td>55 nm</td>
<td>55</td>
<td>18</td>
<td>85</td>
</tr>
</tbody>
</table>

Table no 5.1 Observation Table on multiple constrain

As Per Shown In Figure the mean output is provided for understanding the calculation from the observation table, This Data in observation table is collected from the experimental procedure performed on the prototype.

After all the calculation the mean efficiency is observed of the whole system is generated as per shown below :-

The mean efficiency of whole system we got around 42.45 %

In this case the efficiency of whole system is lower than 50 % but it can be incremented using further research and using multiple technologies such as levitation and lower and lesser frictional resistance.

![Figure 5.2 Mean observation data](image_url)

For further understanding of whole system efficiency we can use the pie chart or any kind of graphical representation for understanding the data given above.
Figure Shows Mean Elapse of whole system where you can clearly see the time we apply force is greater than the time flywheel on its own
As per shown in figure mean input time shown as blue area and mean output time shown is orange area but the thing is the orange are creating the free energy.

The whole system is not just concluded by only elapse time the other factors are also responsible for generating the efficacy of whole system.

We obtain mean Elapse time at output = 14.9 seconds
And similarly for the input values = 33 Sec

Similarly as Mean Elapse time Chart this figure shoes the mean voltage generated by the system at both the end input as well as output in this way we can find the total observation for the system efficacy.

While performing the Experiment the mail goal if the there experiment is to find out the total output voltage during that period of the system when the force is not acquired by the system and how much the angular velocity helps us to generate the free electricity with the help of our system.

As per shown in figure the blue area shows the input voltage while the force is been applied to system and the orange area shows the free force generated using the angular velocity.

We obtain Mean Voltage output = 39.4 volts
We obtain Mean Voltage Input = 82 volts
Similarly as per shown two pie charts above, this pie chart shows the mean RPM at both the end input and output. The procedure of experiment performance when you look the observation table sustainably the column of RPM looks very uneven.

When we are operating on whole system some times when the elapse time for input ranges longer time, the particular system can give us output of RPM generation multiple times that’s why we came to the conclusion that we have to take a reading on the pinch time when suddenly we reacted to release the force from the system.

As per shown in figure below the blue area represents input RPM and the orange area represent output rpm

We get input RPM = 931
We get output RPM = 389.8
Similarly as per shown two pie charts above, this pie chart shows the mean RPM at both the end input and output. The procedure of experiment performance when you look the observation table sustainably the column of RPM looks very uneven.

When we are operating on whole system some times when the elapse time for input ranges longer time, the particular system can give us output of RPM generation multiple times that’s why we came to the conclusion that we have to take a reading on the pinch time when suddenly we reacted to release the force from the system.

We get Efficiency for time = 48.8 %
We get Efficiency for Power = 18.84 %
We get Efficiency for voltage = 48.0 %
Basic FLYWHEELS and ENERGY STORAGE :-
A wheel winds up through some system of gears and then delivers rotational energy until friction dissipates it
stored energy = sum of kinetic energy of individual mass elements that comprise the flywheel

Kinetic Energy = 1/2*I*w*w

I = moment of inertia --> ability of an object to resist changes in its rotational velocity
w = rotational velocity (rpm)

I = k *M*R*R (M=mass; R=Radius); k = inertial constant (depends on shape)

Inertial constants for different shapes:–
Wheel loaded at rim (bicycle tire): k =1
solid disk of uniform thickness; k = 1/2
solid sphere; k = 2/5
spherical shell; k = 2/3
thin rectangular rod; k = ½

To optimize the energy-to-mass ratio the flywheel needs to spin at the maximum possible speed. This is because kinetic energy only increases linearly with Mass but goes as the square of the rotation speed.

Rapidly rotating objects are subject to centrifugal forces that can rip them apart. Centrifugal force for a rotating object goes as:
M*w*w*R

Thus, while dense material can store more energy it is also subject to higher centrifugal force and thus fails at lower rotation speeds than low density material.

Tensile Strength is More important than density of material.

Long rundown times are also required --> frictionless bearings and a vacuum to minimize air resistance can result in rundown times of 6 months --> steady supply of energy

Flywheels are about 80% efficient (like hydro)

Flywheels do take up much less land than pumped hydro systems

Some Network Resources Related to Flywheels

Design steps and formulas :-
Step 1 :-
Input required: Maximum & minimum speed

Flywheel inertia/size depends upon the fluctuations in speed. The difference between maximum & minimum speeds during a cycle is called maximum fluctuation of speed.

The ratio between maximum fluctuations of speed to mean speed is called coefficient of fluctuation of speed (Cs).

Consider, ω max =Max. Speed during the cycle
ω min = Min. speed during the cycle
ω mean =Mean speed = (ω max + ω min) /2 ……eq.1

Therefore, Coefficient of Fluctuation of speed,

Cs = [2*(ωmax−ωmin)]/[ωmax+ωmin] ……eq.2

Note: The smaller the Cs value, larger the flywheel, but smoother the operation.

Step-2: Mass moment of inertia calculation

Input required: kinetic energy of the system

The general equation of kinetic energy for a flywheel system is given as,

Ke = 0.5* I* (ωmax2 – ωmin2) ……….eq.3

Rewriting eq.3, we get
Ke = 0.5 I (Ѡmax +Ѡmin) (Ѡmax –Ѡmin)…………eq.4

Substituting eq.1 & 2 in eq.4, we get

I = Ke / CsѠmean2………………..eq.5

eq.5 is used to obtain necessary flywheel inertia corresponding to variations in speed.

We will try out a simplified problem on flywheel sizing and calculate the required moment of inertia.

Regarding units (Important):

Ke – N.m
Ѡ – rad/sec
I – Kg.m²

Step-1: Coefficient of fluctuation (Cs) calculation
The value is given as,
Cs=0.02

Step-2: Mass moment of inertia (I) calculation
Input required: kinetic energy of the system- to be calculated

Kinetic energy of the system (Ke) calculation:

Work done, W = 22*10³*3*0.25*0.15 (Assume rated load delivered during 15% of power stroke)

Therefore,
W = 825Nm

Thus,
Energy absorbed is 825Nm.

Now, let us calculate the mean torque acting on the shaft,

Tmean = 3*10³ / 2π*(1000/60)
Therefore,
Tmean = 28.66Nm

Work done per cycle is (Energy supplied),

WC = 2π*28.66*5 = 900 Nm

Therefore, Kinetic energy of the system is,
Ke=W–Wc*0.08 (Energy absorbed – Energy supplied* factor for loss)

Ke = 825 – 900 *0.08 (0.08 – factor for losses. Again dependent on the designer)

Ke = 753Nm

Therefore, mass moment of inertia as per eq.5 is

I = 753 / 0.02 (2π*1000/60)²

I = 3.43 Kg.m²

Hence, the flywheel sizing/design calculation for the above example shows that the required mass moment of inertia for this application should be = 3.43 Kg.m².
Gradually with advancing technology, the flywheels have become more sophisticated. Now a days, advanced Flywheels contain the kinetic energy in a fast moving rotary drum which acts as rotor of a generator. At the times when additional energy remains unconsumed, then it is used to boost the rotary drum’s speed. Whenever there is requirement of energy, then this drum drives the generator.

**Moment of inertia of a flywheel is calculated using the given formula:-**

Where \( I = \) moment of inertia of the flywheel. Here, the symbols denote;

- \( m = \) rings’ mass.
- \( N = \) flywheel rotation.
- \( n = \) number of windings of the string.
- \( h = \) height of the weight assembly.
- \( g = \) acceleration due to gravity.
- \( r = \) radius of the axle.

Then we make some assumptions. We will take the mass as \((m)\) for the weight hanger as well as the hanging ring. The height will be \((h)\). Now we consider an instance where the mass will descend to a new height. There will be some loss in potential energy and for which we write the equation as;

\[
P_{\text{loss}} = mgh
\]

Meanwhile, there is a gain in kinetic energy when the flywheel and axle are rotating. We express it as;

\[
K_{\text{flywheel}} = \frac{1}{2} I \omega^2
\]

\[
I = \text{moment of inertia}
\]

\[
\omega = \text{angular velocity}
\]

Similarly, the kinetic energy for descending weight assembly is expressed as;

\[
K_{\text{weight}} = \frac{1}{2} I v^2
\]

\[
Here, v = \text{velocity}
\]

We also have to take into account the work that is done in overcoming the friction. This can be found out by;

\[
W_{\text{friction}} = n W_f
\]

In this case,

\[
n = \text{number of windings of the string}
\]

\[
W_f = \text{work done in overcoming frictional torque}
\]

If we state the law of conservation of energy then we obtain;

\[
P_{\text{loss}} = K_{\text{flywheel}} + K_{\text{weight}} + W_{\text{friction}}
\]

We will substitute the values and the equation will now become;

\[
mgh = \left(\frac{1}{2}\right) I \omega^2 + \left(\frac{1}{2}\right) mv^2 + nW_f
\]

Moving on to the next phase, we look at the flywheel assembly’s kinetic energy that is used in rotating \((N)\) number of times against the frictional torque. We get;

\[
NW_f = \left(\frac{1}{2}\right) I \omega^2 \text{ and } W_f = \left(\frac{1}{2N}\right) I \omega^2
\]

Further, we establish a relation between the velocity \((v)\) of the weight assembly and the radius \((r)\) of the axle. The equation is given as;

\[
v = r \omega
\]

We have to substitute the values for \(W_f\) and \(v\).
\[ mgh = \left( \frac{1}{2} \right) I\omega^2 + \left( \frac{1}{2} \right) mr^2\omega^2 + (n / N) x \left( \frac{1}{2} \right) Io^2 \]

**Calculation Regarding The Observation Table no 5.1:**

**Output values :-**

For Elapse Time:

\[
\sum \text{time} = \frac{7+11+13+16+16+17+1718+18}{10}
\]

\[ \sum \text{time} = 149/10 \]

\[ \sum \text{time} = 14.9 \text{ seconds} \]

For Mean Voltage:

\[
\sum v = 24+35+40+42+48+42+43+39+41+40/10
\]

\[ \sum v = 394/10 \]

\[ \sum v = 39.4 \text{ volts} \]

For mean RPM:

\[
\sum \text{rpm} = 480+293.2+730.4+1080+103.1+112+104+206+400+390.1/10
\]

\[ \sum \text{rpm} = 3898/10 \]

\[ \sum \text{rpm} = 389.8 \text{ rpm} \]

**Input Values :-**

For Elapse Time:

\[
\sum \text{time} = 5+15+20+25+30+35+40+45+50+55/10
\]

\[ \sum \text{time} = 330/10 \]

\[ \sum \text{time} = 33 \text{ sec} \]

For Mean Voltage:

\[
\sum v = 47+61+69+77+93+96+99+97+96+85/10
\]

\[ \sum v = 820/10 \]

\[ \sum v = 82 \text{ v} \]

For mean RPM:

\[
\sum \text{rpm} = 500+665+1310+2967+717+681+806+556+603+505/10
\]

\[ \sum \text{rpm} = 9310/10 \]

\[ \sum \text{rpm} = 931 \text{ rpm} \]

The Mean Efficiency of the system on the basis of data from observation table :-

\[ \eta_{\text{mean}} = \frac{N_{\text{out}}+V_{\text{out}}+T_{\text{out}}}{N_{\text{in}}+V_{\text{in}}+T_{\text{in}}} * 100 \]

\[ \eta_{\text{mean}} = 14.9+39.4+389.8 / 33+82+931 \times 100 \]

\[ \eta_{\text{mean}} = 444.1/1046 \times 100 \]

\[ \eta_{\text{mean}} = 42.45 \% \]
Future Scope:–

- As we can represent whole and sole project in the form of prototype and sort of research examinations and trial and error process of manufacturing makes us learn to resolve all the problems we found out during the manufacturing and research.
- Flywheel is the proven technology from the beginning of industrial revolutionary era. This makes us to follow the path of research for flywheel conservation of energy in the form of mechanical energy.
- Many industries manly manufacturing industry from beginning till now using this piece of technology for more than hundred plus years. So it is proven we can understand the concept of flywheel energy conservation with directly compared to capacitors in both electrical and electronics, they conserve large amount of energy in it and release it when the energy is required, that’s how flywheel also works.
- The another side of flywheels is been conventionally used from past more than hundred years, is well known as automotive industry.
- If we talk about the basic flywheel design, there are not much changes conceptual theory of basic flywheel to store energy, to generate angular velocity and keep momentum even. That’s why the flywheel is the basic piece of mechanical drive but on the other hand it is really very effective and the flywheel is only that component in mechanical drive which has substantially higher factor of safety as well as lowest fatigue in the component.
- After manufacturing the flywheel is only component in mechanical drive system which last longer than any other component in same machinery.
- As our prototype consideration our theory states that the flywheel is also used as mechanical battery which can generate lots amount of free energy is been proven by our calculations and research techniques.
- Though we have not much amount of energy generated in our prototype, maximum about 38%, though we can consider that particular 38% is a free energy generated by our prototype.
- But the further studies and further research can make more and more efficient as well as sustainable mechanical batteries just we did. What we did is mechanical and mathematical representation of what we can do in future to generate sustainable source of energy.
- As per we said that the sustainable source of energy because, we doesn’t require any kind of fossil fuels, any kind of nuclear energy, or any kind of wind or solar energy.
- Our whole system is based on three basic laws of scientific representation such as follows:-
  1) Newton’s first law of motion states that the object is stable till the force is not applied on it.
  2) Angular velocity states that the circular object with the large weight on its circumference generates reserve rotational energy.
  3) Faraday’s law states that when the copper coil passes through the EMF of magnet, it generates electrical charge.
- As per all the laws of mechanics we can elaborate our whole system in a nominal way and this is the basic foundation of our research and prototype of our project.

Portable system for power generation :–

- If we use the compact size of our project with some additional inputs such as levitation we can generate electrical power more efficiently.
- In our own prototype we demonstrated that we can generate both AC and DC power, as per shown in figure 7.1 and figure 7.2.
Figure 7.1 AC direct output
The mean output voltage of AC as per shown in figure 7.1 is about 39.4V.
The mean output voltage of DC after conversion from AC as per shown in figure 7.2 is about 5V.
Hence we can conclude that the prototype generates both AC and DC.
As this project is based on trial and error, we are not able to get much output, but after doing more research and development we can get more current output from the same system.

**Pros :-**
1) We can generate free electricity.
2) Simple design.
3) Less complex mechanism.
4) Light weight.
5) Required less energy to input.
6) Can be mass produced easily.
7) Eco-friendly.
8) Sustainable for environment.
9) Less space is required.
10) Less labour required for transportation.
11) Rigid build quality.
13) Greater operational life span.
14) Simple to operate.
15) Can generate both AC and DC.

**Cons :-**
1) Balanced shaft is required.
2) Not cost efficient.
3) Calibration of whole system is required.
4) Power losses throughout the system.
5) Frictional resistance and moment of inertia.
Chapter 8
References

- https://en.wikipedia.org/wiki/Flywheel_energy_storage
- https://energystorage.org/why-energy-storage/technologies/flywheel-energy-storage-systems-fess/
- https://www.sciencedirect.com/topics/engineering/flywheel-energy-storage
- http://www.flywheelenergy.com/
- https://www.youtube.com/watch?v=yhu3s1ut3wM Tom Stanton
- TURNING THE FLYWHEEL: A MONOGRAPH TO ACCOMPANY GOOD TO GREAT. AUTHOR: JIM COLLINS
- FLYWHEEL AND FEEDBACK LOOPS. AUTHOR: - BERNIE THOMPSON

Chapter 9
CONCLUSION

- As we can represent whole and sole project in the form of prototype and sort of research examinations and trial and error process of manufacturing makes us learn to resolve all the problems we found out during the manufacturing and research.
- Flywheel is the proven technology from the beginning of industrial revolutionary era. This makes us to follow the path of research for flywheel conservation of energy in the form of mechanical energy.
- Many industries manly manufacturing industry from beginning till now using this piece of technology for more than hundred plus years. So it is proven we can understand the concept of flywheel energy conservation with directly compared to capacitors in both electrical and electronics, they conserve large amount of energy in it and release it when the energy is required, that’s how flywheel also works.
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- After manufacturing the flywheel is only component in mechanical drive system which last longer than any other component in same machinery.
- As our prototype consideration our theory states that the flywheel is also used as mechanical battery which can generate lots amount of free energy is been proven by our calculations and research techniques.
- But the further studies and further research can make more and more efficient as well as sustainable mechanical batteries just we did. What we did is mechanical and mathematical representation of what we can do in future to generate sustainable source of energy.
- As per we said that the sustainable source of energy because, we doesn’t require any kind of fossil fuels, any kind of nuclear energy, or any kind of wind or solar energy.
- In this way we conclude this whole system

Thank you