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DESIGN AND ANALYSIS OF FLYWHEEL IN A MULTI CYLINDER PETROL ENGINE

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***Abstract*— A flywheel used in machines serves as a reservoir which stores energy during the period when the supply of energy is more than the requirement and releases it during the period when the requirement of energy is more than supply.**

In I.C. engines, the energy is developed only in the power stroke which is much more than engine load, and no energy is being developed during the suction, compression and exhaust strokes in case of four stroke engines. The excess energy is developed during power stroke is absorbed by the flywheel and releases it's to the crank shaft during the other strokes in which no energy is developed, thus rotating the crankshaft at a uniform speed.

The flywheel located on one end of the crankshaft and serves two purposes. First, through its inertia, it reduces vibration by smoothing out the power stroke as each cylinder fires. Second, it is the mounting surface used to bolt the engine up to its load.

The aim of the project is to design a flywheel for a multi cylinder petrol engine flywheel using the empirical formulas. A 2D drawing is drafted using the calculations. A parametric model of the flywheel is designed using 3D modeling software CATIA. This tool is the standard in 3D product design, featuring industry-leading productivity tools that promote best practices in design. The forces acting on the flywheel are also calculated. The strength of the flywheel is validated by applying the forces on the flywheel in analysis software ANSYS. This tool is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements.

.Keywords—flywheel,

Introduction:

The **internal combustion engine** is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber. In an internal combustion engine the expansion of the high-temperature and -pressure gases produced by combustion applies direct force to some component of the engine, such as pistons, turbine blades, or a nozzle. This force moves the component over a distance, generating useful mechanical energy.

The term internal combustion engine usually refers to an engine in which combustion is intermittent, such as the more familiar four-stroke and two-stroke piston engines, along with variants, such as the Wankel rotary engine. A second class of internal combustion engines use continuous combustion: gas turbines, jet engines and most rocket engines, each of which are internal combustion engines on the same principle as previously described.

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The internal combustion engine (or ICE) is quite different from external combustion engines, such as steam or Sterling engines, in which the energy is delivered to a working fluid not consisting of, mixed with, or contaminated by combustion products. Working fluids can be air, hot water, pressurized water or even liquid sodium, heated in some kind of boiler.

Applications

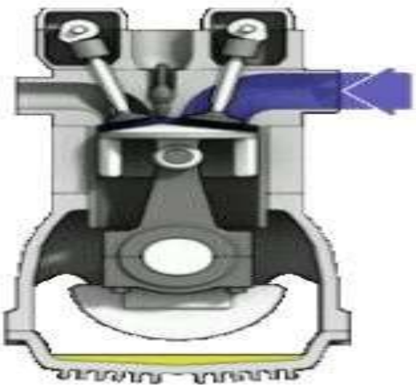
Internal combustion engines are most commonly used for mobile propulsion in vehicles and portable machinery. In mobile equipment, internal combustion is advantageous since it can provide high power-to-weight ratios together with excellent fuel energy density. Generally using fossil fuel (mainly petroleum), these engines have appeared in transport in almost all vehicles (automobiles, trucks, motorcycles, boats, and in a wide variety of aircraft and locomotives).

Where very high power-to-weight ratios are required, internal combustion engines appear in the form of gas turbines. These applications include jet aircraft, helicopters, large ships and electric generators.

Four Stroke Configuration Operations

Four-stroke cycle (or Otto cycle)

1. Intake
2. Compression
3. Power
4. Exhaust



As their name implies, operation of four stroke internal combustion engines have four basic steps that repeat with every two revolutions of the engine:

- **Intake:** Combustible mixtures are emplaced in the combustion chamber
- **Compression:** The mixtures are placed under pressure
- **Combustion (Power):** The mixture is burnt, almost invariably a *deflagration*, although a few systems involve *detonation*. The hot mixture is expanded, pressing on and moving parts of the engine and performing useful work.
- **Exhaust:** The cooled combustion products are exhausted into the atmosphere Many engines overlap these steps in time; jet engines do all steps simultaneously at different parts of the engines.

- **Combustion** All internal combustion engines depend on the exothermic chemical process of combustion: the reaction of a fuel, typically with oxygen from the air (though it is possible to inject nitrous oxide in order to do more of the same thing and gain a power boost). The combustion process typically results in the production of a great quantity of heat, as well as the production of steam and carbon dioxide and other chemicals at very high temperature; the temperature reached is determined by the chemical makeup of the fuel and oxidizers (see stoichiometry), as well as by the compression and other factors.

Flywheel

The flywheel is a cast iron, aluminum, or zinc disk that is mounted at one end of the crankshaft to provide inertia for the engine. Inertia is the property of matter by which any physical body persists in its state of rest or uniform motion until acted upon by an external force. Inertia is not a force, it is a property of matter.

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During the operation of a reciprocating engine, combustion occurs at distinct intervals. The flywheel supplies the inertia required to prevent loss of engine speed and possible stoppage of crankshaft rotation between combustion intervals.

During each stroke of an internal combustion engine, the flywheel, crankshaft, and other engine components are affected by fluctuations in speed and force. During the power event in a four-stroke cycle engine, the crankshaft is accelerated rapidly by the sudden motion of the piston and connecting rod assembly. The flywheel smooths out some of the rpm and force deviation by its resistance to acceleration. The inertia of the flywheel provides a dampening effect on the engine as a whole to even out radial acceleration forces and rpm deviations produced in the engine.

1.1 What does a flywheel do?

The flywheel or torque converter helps the engine to run smoothly by absorbing some of the energy during the power stroke and releasing it during the other strokes.

The vibration damper (harmonic balancer) dampens crankshaft torsional vibrations that result from the power impulses. As each cylinder fires, it causes the crank throw for that cylinder to speed up. The rest of the crankshaft tends to stay slightly behind, causing a twist. This causes torsion vibrations, which are dampened or partially absorbed by the vibration damper.

The flywheel contributes to the uniform rotation of the crankshaft and helps the engine overcome loads when starting the automobile from rest and also during operation. Even though the power impulses of a multi cylinder engine follow each other or overlap, additional smoothing out of the power impulses is desirable. The engine flywheel does this job. The flywheel is a relatively heavy metal wheel which is firmly attached to the crankshaft. Because of its rotation the flywheel acquires kinetic energy; when the flywheel speeds up, it stores additional kinetic energy, and when it slows down it gives back that energy. The amount of energy which a flywheel will store for a given change in speed depends on its inertia, which, in turn, depends on its mass and its effective diameter. The energy which the engine pistons deliver to the crankshaft fluctuates, being greatest when a piston has started on its power stroke, much less on the exhaust and suction strokes, and negative during the compression stroke. These fluctuations in energy to and from the crankshaft.

Cause corresponding fluctuations in its speed; the effect of the flywheel is to reduce the speed fluctuations by storing energy when the crankshaft accelerates and giving it back when the shaft starts to slow down. The heavier the flywheel or the larger its diameter the smaller will be the speed changes.

The flywheel resists any sudden change of crankshaft (engine) speed. Thus, when a power impulse starts (with its initial high pressure), the crankshaft is given a momentary hard push (through the connecting rod and crankshaft). But the flywheel resists the tendency of the crankshaft to surge ahead. Thus, the momentary power peaks are leveled off so the engine runs smoothly.

Since the flywheel also serves to form part of the engine clutch, its rear face is thoroughly machined. In the front face of the flywheel, there is a shallow indentation used to determine the position of the piston in the first cylinder. When this indentation is aligned with a special hole provided in the bell housing, the piston is at top dead center (TDC). In some engines, this indentation indicates the start of fuel injection into the first cylinder. The flywheels of some engines also carry marks indicating the serial numbers of the cylinders where the compression stroke occurs. The flywheel marks and indentation are used for setting the valve and ignition systems relative to prescribed positions of the crankshaft.

1.2 Physics of Flywheels

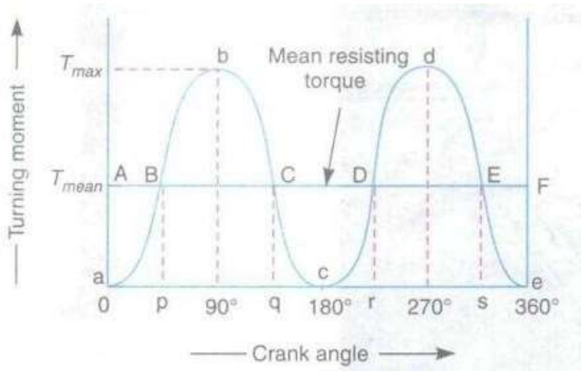
As far as I know, the flywheel is always dynamically linked to the piston rod, (s) Maybe not for; In electrical installations, the flywheel is on the rotor shaft to maintain momentum, so no piston. (Example, I had an old three phase electrical generator that had a great big fly wheel to stabilize the rpm and hold it up when there were changes in the load).

1.5 Turning Moment

The turning moment T is zero, when the crank angle Θ is zero. It is maximum when the crank angle is 90 and again zero whent angle is 180. This is shown by the curve abc represents represents the turning moment diagram for outstroke. The curve cde is the turning moment diagram for in stroke and is somewhat similar to the curve abc.

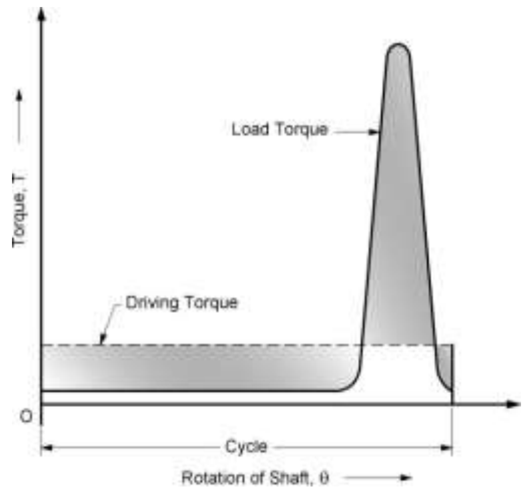
Since the work done is the product of the turning moment and the angle turned, therefore the area of the turning moment diagram represents the work done per revolution.

In actual practice, the engine is assumed to work against the mean resisting torque, as shown by a horizontal line AF. The height of the ordinate A represents the mean height of the turning moment diagram.



1.9.1 Constant driving torque and variable load torque:

- In this type of flywheel application, the energy is supplied by the prime mover at uniform rate, while the requirement of the energy by machine is at variable rate, as shown in Fig.



- The flywheel absorbs the energy from the prime mover during the greater portion of the cycle and delivers it during the very short duration of the cycle.
- The examples of this type of flywheel application are: electric motor driving punching machine, riveting machine, shearing machine, press, etc.
- By application of flywheels to such machines the smaller capacity prime mover is required.
  - **1.10 Material selection**
  - Flywheels are made from many different materials, the application determines the choice of material. Small flywheels made of lead are found in children's toys. Cast iron flywheels are used in old steam engines. Flywheels used in car engines are made of cast or nodular iron, steel or aluminum. Flywheels made from high-strength steel or composites have been proposed for use in vehicle energy storage and braking systems.
  - The efficiency of a flywheel is determined by the maximum amount of energy it can store per unit weight. As the flywheel's rotational speed or angular velocity is increased, the stored energy increases

Material	Specific tensile strength ($\frac{kJ}{kg}$)
Ceramics	200-2000 (compression only)
Composites: CFRP	200-500
Composites: GFRP	100-400
Beryllium	300
High strength steel	100-200
High strength Al alloys	100-200
High strength Mg alloys	100-200
Ti alloys	100-200
Lead alloys	3
Cast Iron	8-10

In this context, using lead for a flywheel in a child's toy is not efficient; however, the flywheel velocity never approaches its burst velocity because the limit in this case is the pulling-power of the child. In other applications, such as an automobile, the flywheel operates at a specified angular velocity and is constrained by the space it must fit in, so the goal is to maximize the stored energy per unit volume. The material selection therefore depends on the application.

The table below contains calculated values for materials and comments on their viability for flywheel applications. CFRP stands for carbon-fiber-reinforced polymer, and GFRP stands for glass-fiber reinforced polymer.

OBJECTIVES AND METHODOLOGY

The objective of this project work is to successfully and to develop a design of a flywheel for a Multi cylinder Petrol Engine. This mechanism is to be reliable, simple, cost-effective and practically feasible. The aim of this project of flywheel mechanism is to provide a design to the automobile engine on unbanked curves. This system is also supposed to enhance the engine comfort as the side force felt by the flywheel in an engine taking a position is comparatively less in a direct transmission system.

The methodology adopted to use standard and presently used components in design rather than to design all components from ground up. The advantage of this method is that, you do not have to spend ridiculous amount and time in testing the integrity of each part as they have already proved their worth in real world applications.

Initially the design was adopted from an already existing flywheel and minor changes were made to suite our purpose, the mechanism first devised was based on using of the engine by its study lifting and lowering each wheel of the car. This mechanism was later taken in testing phase due to following conditions.

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Engineering Design

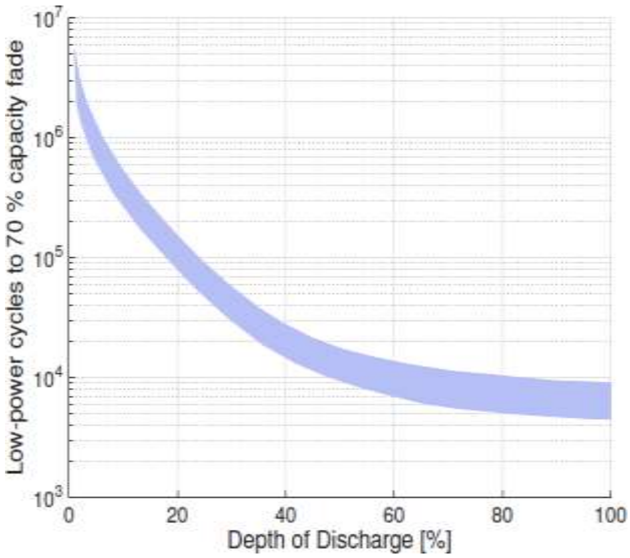
Catia Elements offers a range of tools to enable the generation of a complete digital representation of the product being designed. In addition to the general geometry tools there is also the ability to generate geometry of other integrated design disciplines such as industrial and standard pipe work and complete wiring definitions. Tools are also available to support collaborative development.

A number of concept design tools that provide up-front Industrial Design concepts can then be used in the downstream process of engineering the product. These range from conceptual Industrial design sketches, reverse engineering with point cloud data and comprehensive freeform surface tools.

3.6 Depth-of-Discharge

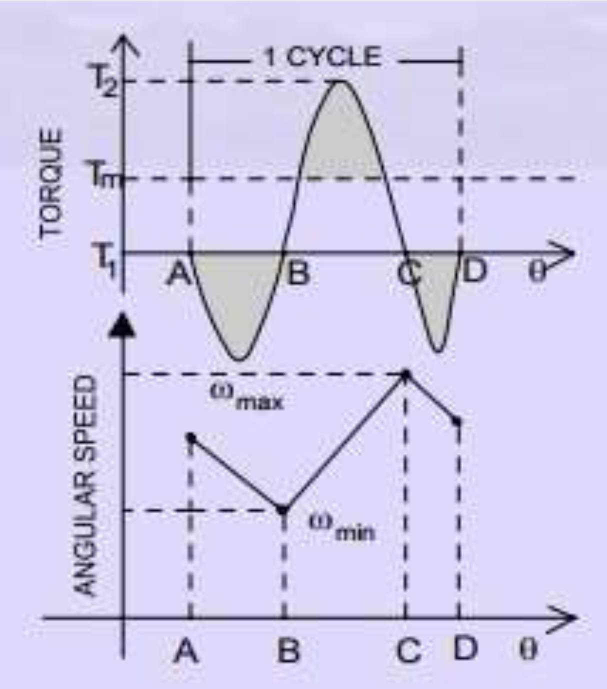
The cycle life of flywheels is not directly related to depth-of-discharge; however, this is the case for batteries. This is important when defining the niches for flywheel energy storage.

Batteries degrade when cycled, when discharging at high rates and at high temperature. The degradation affects energy capacity and power capacity,



DESIGN TERMINOLOGY OF FLYWHEEL

A flywheel is an inertial energy-storage device. It absorbs mechanical energy and serves as a reservoir, storing energy during the period when the supply of energy is more than the requirement and releases it during the period when the requirement of energy is more than the supply.



Flywheels-Function need and Operation The main function of a fly wheel is to smoothen out variations in the speed of a shaft caused by torque fluctuations. If the source of the driving torque or load torque is fluctuating in nature, then a flywheel is usually called for. Many machines have load patterns that cause the torque time function to vary over the cycle. Internal combustion engines with one or two cylinders are a typical example. Piston compressors, punch presses, rock crushers etc. are the other systems that have fly wheel.

4.2 Design Parameters

Flywheel inertia (size) needed directly depends upon the acceptable changes in the speed.

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Equation of energy stored in a flywheel

The kinetic energy stored in a flywheel depends on the angular velocity and moment of inertia of mass.

The relation is given below

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

ω = angular velocity

I = the moment of inertia of the mass about the center of rotation.

$$I = \frac{1}{2} mr^2$$

For a thin-walled empty cylinder

$$I = mr^2$$

For a thick-walled empty cylinder

$$I = \frac{1}{2} m({r_{external}}^2 + {r_{internal}}^2)$$

4.4 Speed fluctuation

The change in the shaft speed during a cycle is called the speed fluctuation and is equal to ω_{max}- ω_{min}

F1 = ω_{max}- ω_{min}

We can normalize this to a dimensionless ratio by dividing it by the average or nominal shaft speed (ω_{ave}).

C_f = (ω_{max}- ω_{min}) / ω

4.5 Co-efficient of speed fluctuation

The above ratio is termed as coefficient of speed fluctuation C_f and it is defined as

C_f = (ω_{max}- ω_{min}) / ω

Where ω is nominal angular velocity, and ω_{ave} the average or mean shaft speed desired. This coefficient is a design parameter to be chosen by the designer.

The smaller this chosen value, the larger the flywheel have to be and more the cost and weight to be added to the system. However the smaller this value more smoother the operation of the device.

Design Equation

The kinetic energy E_k in a rotating system

E_k = 1/2 I(ω^2)

Hence the change in kinetic energy of a system can be given as

E_k = 1/2 I_m (ω^2_{max}- ω^2_{min})

ω_{avg} = (ω_{max} + ω_{min})/2

Thus the mass moment of inertia I_m needed in the entire rotating system in order to obtain selected coefficient of speed fluctuation is determined using the relation.

The above equation can be used to obtain appropriate flywheel inertia I_m corresponding to the known energy change E_k for a specific value coefficient of speed fluctuation C_f.

DESIGN METHODLOGY OF FLYWHEEL IN A MULTI CYLINDER PETROL ENGINE

Introduction to CATIA

CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Dassault Systems. Written in the C++ programming language, CATIA is the cornerstone of the Dassault Systems product lifecycle management software suite. CATIA competes in the high-end CAD/CAM/CAE market with Cero Elements/Pro and NX (Unigraphics).

The 3D CAD system CATIA V5 was introduced in 1999 by Dassault Systems. Replacing CATIA V4, it represented a completely new design tool showing fundamental differences to its predecessor. The user interface, now featuring MS Windows layout, allows for the easy integration of common software packages such as MS Office, several graphic programs or SAPR3 products (depending on the IT environment).

The concept of CATIA V5 is to digitally include the complete process of product development, comprising the first draft, the Design, the layout and at last the production and the assembly. The workbench Mechanical Design is to be addressed in the Context of this CAE training course.

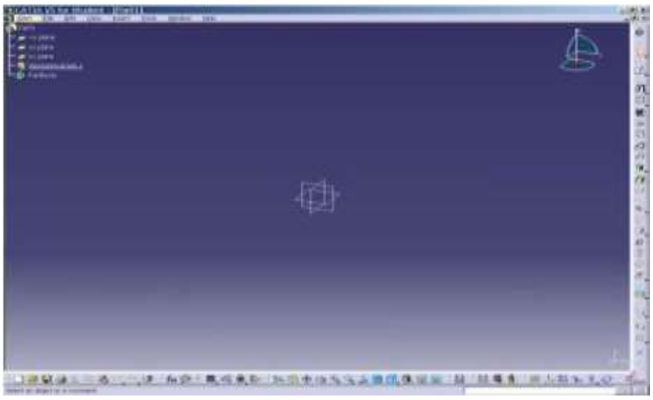
Sets of workbenches can be composed according to the user's preferences. Therefore Dassault Systems offers three different software installation versions. The platform P1 contains the basic features and is used for training courses or when reduced functionality is needed. For process orientated work the platform P2 is the appropriate one. It enables, apart from the basic design features, analysis tools and production related functions. P3 comprises specific advanced scopes such as the implementation of external software packages.

SIMULATION RESULTS

The simulations are run in MATLAB/Simulink and are displayed separately in Figures 5(a-d), 6(a-c), and 7(a-c) for the various energy sources (FC, battery, and SC), respectively, with the variable load profile as shown in Fig. 9(b) whose corresponding power consumption is shown in Fig. 9(c) (a). In addition, Fig. 8 shows the DC link voltage.

A. Fuel cell simulation results:

Figure 5 (a), (b), (c), (d) shows the simulation results of an FC connected to a boost converter, displaying the voltage and current variables of the FC and the converter. The effect of altering load current on the voltage and current of FC is shown in Figures 5 (a) and (b). Due to the PI regulator, the converter output voltage, as shown in Fig. 5 (c), remains constant at all times, even when the load current is large.



ANALYSIS OF FLYWHEEL IN A MULTI CYLINDER PETROL ENGINE

Procedure for FE Analysis Using ANSYS:

The analysis of the flywheel is done using ANSYS. For compete assembly is not required, is to carried out by applying moments at the rotation location along which axis we need to mention. Fixing location is bottom legs.

Preprocessor

In this stage the following steps were executed:

- **Import file in ANSYS window**

  File Menu > Import> STEP > Click ok for the popped up dialog box > Click

6.2.1 Meshing:

Mesh generation is the practice of generating a polygonal or polyhedral mesh that approximates a geometric domain. The term "grid generation" is often used interchangeably.

Meshing is an integral part of the computer-aided engineering (CAE) simulation process. The mesh influences the accuracy, convergence and speed of the solution. Furthermore, the time it takes to create a mesh model is often a significant portion of the time it takes to get results from a CAE solution.

6.2.2 Finite Element Method:

In mathematics, finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems. It uses variation methods (the Calculus of variations) to minimize an error function and produce a stable solution. Analogous to the idea that connecting many tiny straight lines can approximate a larger circle, FEM encompasses all the methods for connecting many simple element equations over many small sub-domains, named finite elements, to approximate a more complex equation over a larger domain.

CONCLUSION

It can be seen from the above result that, our objective to find out after the loads falling on the flywheel in the Multi Cylinder Petrol Engine the design has been successful. As shown above figures the displacement of the complete design assembly is meshed and solved using Ansys and displacement is 0.181 mm which is very less. This is showing us that clearly each component in assembly is having minor displacement.

Stress is at the fixing location (Minimum Stress which is acceptable). The value is -415.1 MPa which is very less compared to yield value; this is below the yield point.

The maximum stress is coming, this solution solving with the help of Ansys software so that the maximum stress is 713.1 MPa which is very less. So we can conclude our design parameters are approximately correct. Strain acting by the designed model is at the fixing location. The value is 0.481E-08 MPa.

The design of the flywheel in the Multi Cylinder Petrol Engine mechanism worked flawlessly in analysis as well. All these facts point to the completion of our objective in high esteem.

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