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Optimization of Petrol Engine Flywheel for Variable Speeds

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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. For example, 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 is 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 Pro/Engineer. 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. Analysis is done for two materials Cast Iron and Aluminum Alloy A360 to compare the results. Pro/ENGINEER is the standard in 3D product design, featuring industry-leading productivity tools that promote best practices in design. ANSYS 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.*

Key words*; IC Engine, Flywheel, pro/engineer, Ansys, Finite Element Analysis.*

I. Introduction to IC Engines

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.[1][2][3][4]

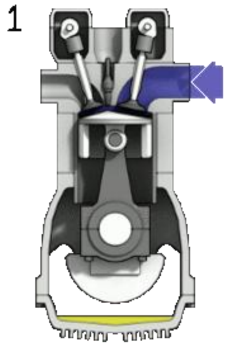
The internal combustion engine (or ICE) is quite different from external combustion engines, such as steam or Sterling engines, in which the energy is delivered to a working fluid not consisting of, mixed with, or contaminated by combustion products. Working fluids can be air, hot water, pressurized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

II. 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
Operation



Four-stroke cycle (or Otto cycle)
1.Intake
2.Compression
3.Power
4. Exhaust

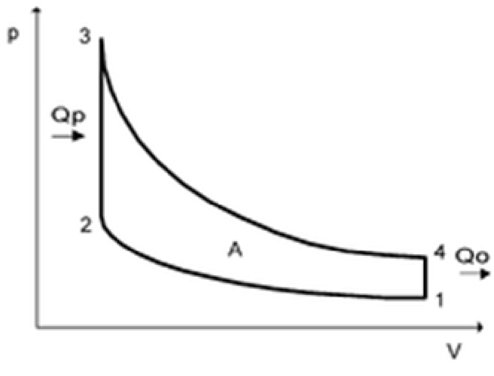
As their name implies, operation of four stroke internal combustion engines have four basic steps that repeat with every two revolutions of the engine:

1. **Intake:** Combustible mixtures are emplaced in the combustion chamber
2. **Compression:** The mixtures are placed under pressure
3. **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.
4. **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.
5. **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.
6. **Diesel Ignition Process:** Diesel engines and HCCI (Homogeneous charge compression ignition) engines, rely solely on heat and pressure created by the engine in its compression process for ignition. The compression level that occurs is usually twice or more than a gasoline engine. Diesel engines will take in air only, and shortly before peak compression, a small quantity of diesel fuel is sprayed into the cylinder via a fuel injector that allows the fuel to instantly ignite. HCCI type engines will take in both air and fuel but continue to rely on an unaided auto-combustion process, due to higher pressures and heat.

III. Engine Cycle

Four-stroke

Idealized Pressure/volume diagram of the Otto cycle showing combustion heat input Qp and waste exhaust output Qo, the power stroke is the top curved line, the bottom is the compression stroke Engines based on the four-stroke ("Otto cycle") have one power stroke for every four strokes (up-down-up-down) and employ spark plug ignition. Combustion occurs rapidly, and during combustion the volume varies little ("constant volume"). They are used in cars, larger boats, some motorcycles, and many light aircraft. They are generally quieter, more efficient, and larger than their two-stroke counterparts.

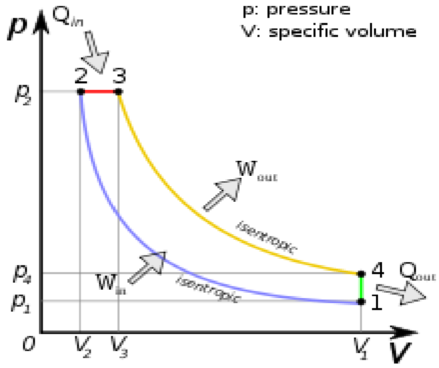


The steps involved here are:

1. Intake stroke: Air and vaporized fuel are drawn in.
2. Compression stroke: Fuel vapor and air are compressed and ignited.
3. Combustion stroke: Fuel combusts and piston is pushed downwards.

4. Exhaust stroke: Exhaust is driven out. During the 1st, 2nd, and 4th stroke the piston is relying on power and the momentum generated by the other pistons. In that case, a four-cylinder engine would be less powerful than a six or eight cylinder engine.

Diesel cycle



P-v Diagram for the Ideal Diesel cycle. The cycle follows the numbers 1-4 in clockwise direction.

IV. Introduction to Flywheel

A **flywheel** is a mechanical device with a significant moment of inertia used as a storage device for rotational energy. Flywheels resist changes in their rotational speed, which helps steady the rotation of the shaft when a fluctuating torque is exerted on it by its power source such as a piston-based (reciprocating) engine, or when an intermittent load, such as a piston pump, is placed on it.

Physics: A flywheel is a spinning wheel or disc with a fixed axle so that rotation is only about one axis. Energy is stored in the rotor as kinetic energy, or more specifically, rotational energy $E_k = \frac{1}{2} I\omega^2$

Where:

- ω is the angular velocity, and
- *I* is the moment of inertia of the mass about the center of rotation. The moment of inertia is the measure of resistance to torque applied on a spinning object (i.e. the higher the moment of inertia, the slower it will spin after being applied a given force).
- The moment of inertia for a solid-cylinder is $I_z = \frac{1}{2} mr^2$
- for a thin-walled empty cylinder is I= mr^2 ,
- and for a thick-walled empty cylinder is $I = \frac{1}{2} m\left(r_{external}{}^2 + r_{internal}{}^2\right)$

where *m* denotes mass, and *r* denotes a radius $\sigma_t = \rho r^2 \omega^2$

when calculating with SI units, the standards would be for mass, kilograms; for radius, meters; and for angular velocity, radians per second. The resulting answer would be in joules. The amount of energy that can safely be stored in the rotor depends on the point at which the rotor will warp or shatter. The hoop stress on the rotor is a major consideration in the design of a flywheel energy storage system, where: σ_t is the tensile stress on the rim of the cylinder, ρ is the density of the cylinder, *r* is the radius of the cylinder, and ω is the angular velocity of the cylinder.

Examples of Energy Stored

Object	**K (varies with shape)**	**mass**	**diameter**	**angular velocity**	**energy stored, [J]**	**energy stored, [Wh]**
bicycle wheel at 20 km/h	1	1 kg	700 mm	150 rpm	15 J	4 × 10−3 Wh
bicycle wheel, double speed (40 km/h)	1	1 kg	700 mm	300 rpm	60 J	16 × 10−3 Wh
bicycle wheel, double mass (20 km/h)	1	2 kg	700 mm	150 rpm	30 J	8 × 10−3 Wh
Millstone grinding wheel	1/2	245 kg	500 mm	200 rpm	1.68 kJ	0.47 Wh
wheel on train @ 60 km/h	1/2	942 kg	1 m	318 rpm	65 kJ	8 Wh
giant dump truck wheel @ 30 km/h (18 mph)	1/2	1000 kg	2 m	79 rpm	17 kJ	4.8 Wh
small flywheel battery	1/2	100 kg	600 mm	20000 rpm	9.8 MJ	2.7 kWh
regenerative braking flywheel for trains	1/2	3000 kg	500 mm	8000 rpm	33 MJ	9.1 kWh
electrical power backup flywheel	1/2	600 kg	500 mm	30000 rpm	92 MJ	26 kWh
the planet Earth Rotational energy	2/5	5.97×1027 g	12725 km	~1 per day (696 μrpm[4])	2.6×1029 J	72 YWh (× 1024 Wh)

V. High-Energy Materials

For a given flywheel design, the kinetic energy is proportional to the ratio of the hoop stress to the material density and to the mass:

$$E_k \alpha \frac{\sigma_t}{\rho} m, \quad \frac{\sigma_t}{\rho}$$

Could be called the specific tensile strength. The flywheel material with the highest specific tensile strength will yield the highest energy storage per unit mass. This is one reason why carbon fiber is a material of interest.

For a given design the stored energy is proportional to the hoop stress and the volume is $E_k\ \alpha \sigma_t V$

Calculations for Four Wheeler Petrol Engine Flywheel

Material: cast iron

Specifications of maruti zen estilo L× I

Displacement = 1061CC

Power = 64@ 10000 (ps @rpm)= 64ps=64× $735.4988 = 47071.9232 watts$

Torque = 842 @3500 (N m @ rpm

Number of cylinder = 4 (valve)

Values per cylinder = 4 (valve)

Bore = 68.5mm

Stroke = 72mm

Compression ratio = 9:1

Volume per cylinder = 265.25CC

Density of petrol = $C_8H_{18} = 737.22 \frac{kg}{m^3} 60\ F$ = 0.00073722 kg/cm^3

= 0.00000073722 kg/ mm^3

60 F = 288.555K =15.55^{0}C

$$N_1 = maximum\ speed\ in\ rpm\ during\ the\ cycle = 10000\text{rpm}$$

$$N_2 = minimum\ speed\ in\ rpm\ during\ the\ cycle = 3500 rpm$$

Angular speed $W_1 = \frac{2\pi N_1}{60} = 1046.66\ rad/s$

$$W_2 = \frac{2\pi N_2}{60} = 366.333\ rad/s$$

Co-efficient of fluctuation of energies

$$C_E = \frac{maximum\ flutuation\ of\ energys}{work\ done\ per\ cycle}$$

Work done/cycle =$T_{mean} \times \theta$

$$\theta = angle\ turned\ in\ radius$$

$$\theta = 4\pi\ for\ 4stroke\ IC\ engine$$

$$T_{mean} = \frac{P \times 60}{2\pi N_1}$$

Power p =47071.9232W

$$T_{mean} = \frac{P \times 60}{2\pi N_1} = \frac{47071.9232 \times 60}{2\pi \times 10000} = 44.973$$

Work done per cycle $W_D = T_{mean} \times \Theta = 44.973 \times 4\pi = 564.863$

$$C_E = \frac{\nabla E}{W_D}$$

$$C_E = 2.35 - 2.4$$

$2.4 = \frac{\nabla E}{44.973}$

$\nabla E = 1355.671$

Maximum fluctuation of energy

$\nabla E = MR^2 {W_1}^2 C_s$

$1355.671 = 5 \times R^2 \times 1046.66^2 \times 0.02$

M = mass of flywheel = 5Kg

R = 0.111242M = 111.242mm

Mass of flywheel rim = m = 2πRAδ

$\delta = 7260\ kg/m^3$

$5 = 2\pi \times 111.242 \times A \times 0.0000726$

$A = 985.83m^2$

Cross section of rim to be rectangular

$A = b \times t$ (b = 2t)

$A = 2t^2$

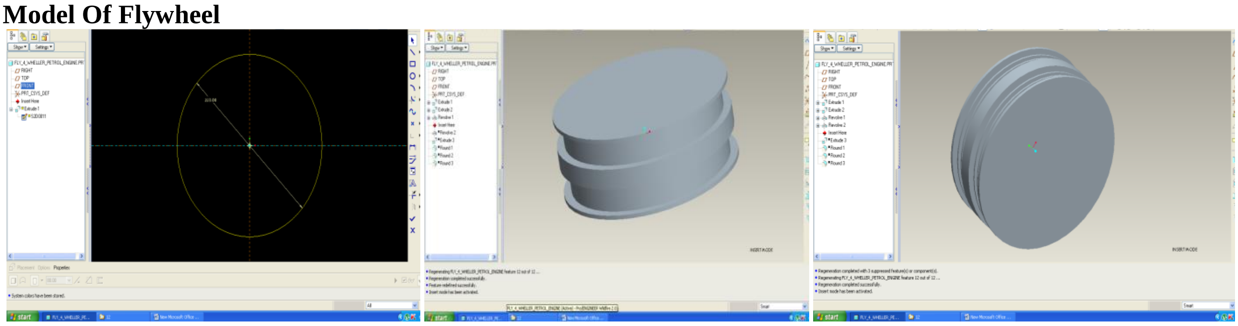
$t^2 = \frac{985.83}{2}$; $t = 22.201mm$: $b = 44.40mm$

VI. Introduction to Pro/Engineer

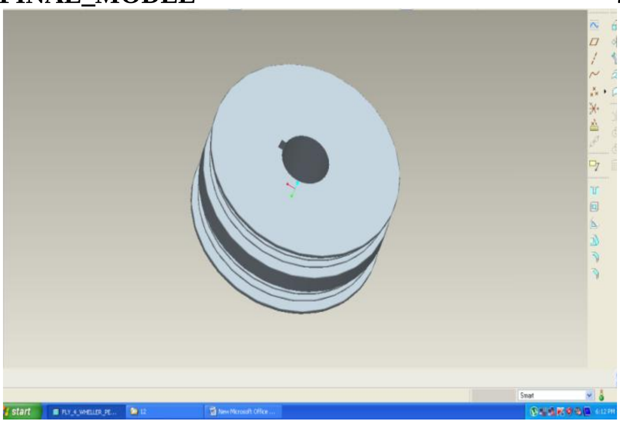
Pro/ENGINEER Wildfire is the standard in 3D product design, featuring industry-leading productivity tools that promote best practices in design while ensuring compliance with your industry and company standards. Integrated Pro/ENGINEER CAD/CAM/CAE solutions allow you to design faster than ever, while maximizing innovation and quality to ultimately create exceptional products.

Customer requirements may change and time pressures may continue to mount, but your product design needs remain the same - regardless of your project's scope, you need the powerful, easy-to-use, affordable solution that Pro/ENGINEER provides.

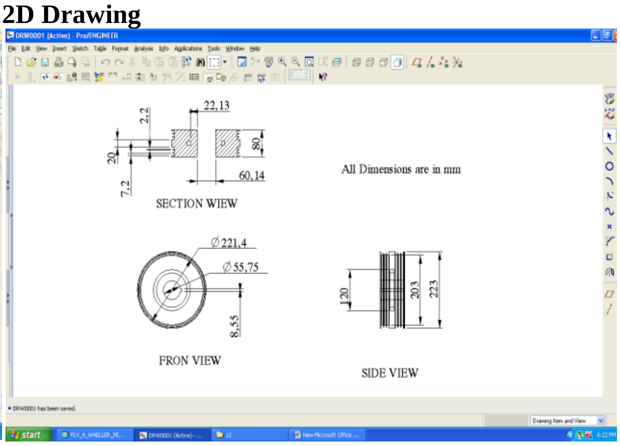
(i) Part Design, (ii) Assembly, (iii) Drawing and (iv) Sheet Metal Model Of Flywheel



FINAL_MODEL



2D Drawing



VII. Introduction to FEA

Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variational calculus to obtain approximate solutions to vibration systems. Shortly thereafter, a paper published in 1956 by M. J. Turner, R. W. Clough, H. C. Martin, and L. J. Topp established a broader definition of numerical analysis. The paper centered on the "stiffness and deflection of complex structures".

FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition.

A wide range of objective functions (variables within the system) are available for minimization or maximization:

- Mass, volume, temperature
- Strain energy, stress strain
- Force, displacement, velocity, acceleration
- Synthetic (User defined)

There are multiple loading conditions which may be applied to a system. Some examples are shown:

- Point, pressure, thermal, gravity, and centrifugal static loads
- Thermal loads from solution of heat transfer analysis
- Enforced displacements
- Heat flux and convection
- Point, pressure and gravity dynamic loads

Types of Engineering Analysis:

Structural analysis consists of linear and non-linear models. Linear models use simple parameters and assume that the material is not plastically deformed. Non-linear models consist of stressing the material past its elastic capabilities. The stresses in the material then vary with the amount of deformation as in.

Vibrational analysis is used to test a material against random vibrations, shock, and impact. Each of these incidences may act on the natural vibrational frequency of the material which, in turn, may cause resonance and subsequent failure.

Fatigue analysis helps designers to predict the life of a material or structure by showing the effects of cyclic loading on the specimen. Such analysis can show the areas where crack propagation is most likely to occur. Failure due to fatigue may also show the damage tolerance of the material.

Heat Transfer analysis models the conductivity or thermal fluid dynamics of the material or structure. This may consist of a steady-state or transient transfer. Steady-state transfer refers to constant thermo properties in the material that yield linear heat diffusion.

Results of Finite Element Analysis: FEA has become a solution to the task of predicting failure due to unknown stresses by showing problem areas in a material and allowing designers to see all of the theoretical stresses within. This method of product design and testing is far superior to the manufacturing costs which would accrue if each sample was actually built and tested.

In practice, a finite element analysis usually consists of three principal steps:

1. **Preprocessing**: The user constructs a model of the part to be analyzed in which the geometry is divided into a number of discrete sub regions, or elements," connected at discrete points called nodes." Certain of these nodes will have fixed displacements, and others will have prescribed loads. These models can be extremely time consuming to prepare, and commercial codes vie with one another to have the most user-friendly graphical “preprocessor" to assist in this rather tedious chore. Some of these preprocessors can overlay a mesh on a preexisting CAD file, so that finite element analysis can be done conveniently as part of the computerized drafting-and-design process.
2. **Analysis**: The dataset prepared by the preprocessor is used as input to the finite element Code itself, which constructs and solves a system of linear or nonlinear algebraic equations

   $$K_{ij}u_j = f_i$$

where u and f are the displacements and externally applied forces at the nodal points. The formation of the K matrix is dependent on the type of problem being attacked, and this module will outline the approach for truss and linear elastic stress analyses. Commercial codes may have very large element libraries, with elements appropriate to a wide range of problem types. One of FEA's principal advantages is that many problem types can be addressed with the same code, merely by specifying the appropriate element types from the library.

3. **Post processing**: In the earlier days of finite element analysis, the user would pore through reams of numbers generated by the code, listing displacements and stresses at discrete positions within the model. It is easy to miss important trends and hot spots this way, and modern codes use graphical displays to assist in visualizing the results. A typical postprocessor display overlays colored contours representing stress levels on the model, showing a full field picture similar to that of photo elastic or moiré experimental results.

VIII. Introduction to ANSYS

ANSYS 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. ANSYS is the standard FEA teaching tool within the Mechanical Engineering Department at many colleges. ANSYS is also used in Civil and Electrical Engineering, as well as the Physics and Chemistry departments. ANSYS provides a cost-effective way to explore the performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping.

Generic Steps to Solving any Problem in ANSYS

Like solving any problem analytically, you need to define (1) your solution domain, (2) the physical model, (3) boundary conditions and (4) the physical properties. You then solve the problem and present the results. In numerical methods, the main difference is an extra step called mesh generation. This is the step that divides the complex model into small elements that become solvable in an otherwise too complex situation. Below describes the processes in terminology slightly more attune to the software.

Build Geometry: Construct a two or three dimensional representation of the object to be modeled and tested using the work plane coordinate system within ANSYS.

Define Material Properties: Now that the part exists, define a library of the necessary materials that compose the object (or project) being modeled. This includes thermal and mechanical properties.

Generate Mesh: At this point ANSYS understands the makeup of the part. Now define how the modeled system should be broken down into finite pieces.

Apply Loads: Once the system is fully designed, the last task is to burden the system with constraints, such as physical loadings or boundary conditions.

Obtain Solution: This is actually a step, because ANSYS needs to understand within what state (steady state, transient… etc.) the problem must be solved.

Present the Results: After the solution has been obtained, there are many ways to present ANSYS' results, choose from many options such as tables, graphs, and contour plots.

X. Specific Capabilities of ANSYS

Structural Structural analysis is probably the most common application of the finite element method as it implies bridges and buildings, naval, aeronautical, and mechanical structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools.

Static Analysis - Used to determine displacements, stresses, etc. under static loading conditions. ANSYS can compute both linear and nonlinear static analyses. Nonlinearities can include plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces, and creep.

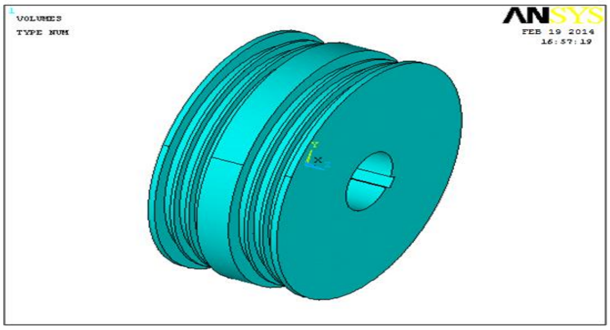
Transient Dynamic Analysis - Used to determine the response of a structure to arbitrarily time-varying loads. All nonlinearities mentioned under Static Analysis above are allowed.

Buckling Analysis - Used to calculate the buckling loads and determine the buckling mode shape. Both linear (eigen value) buckling and nonlinear buckling analyses are possible. In addition to the above analysis types, several special-purpose features are available such as **Fracture mechanics**, **Composite material analysis**, **Fatigue**, and both **p-Method and Beam analyses.**

Modal Analysis - A modal analysis is typically used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a harmonic response or full transient dynamic analysis.

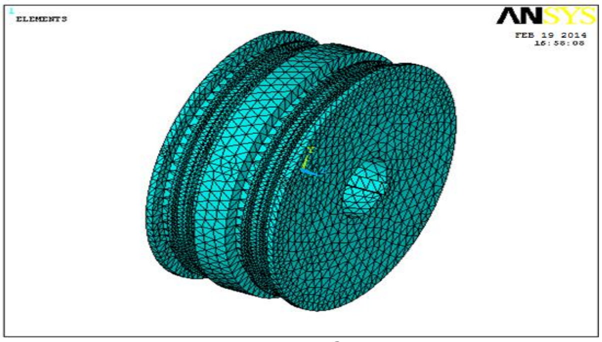
Harmonic Analysis-Used extensively by companies who produce rotating machinery, ANSYS Harmonic analysis is used to predict the sustained dynamic behavior of structures to consistent cyclic loading. Examples of rotating machines which produced or are subjected to harmonic loading are:

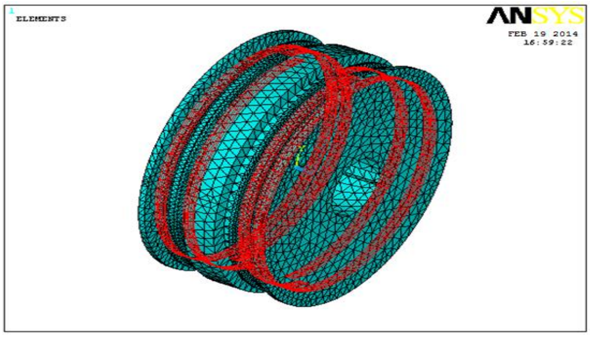
Cast Iron
Structural Analysis



Imported Model from Pro/Engineer
Element Type: Solid 20 node 95
Material Properties:
Young's Modulus (EX) : 103000N/mm^2
Poisson's Ratio (PRXY): 0.211
Density : 0.0000071 kg/mm^3

Meshed Model



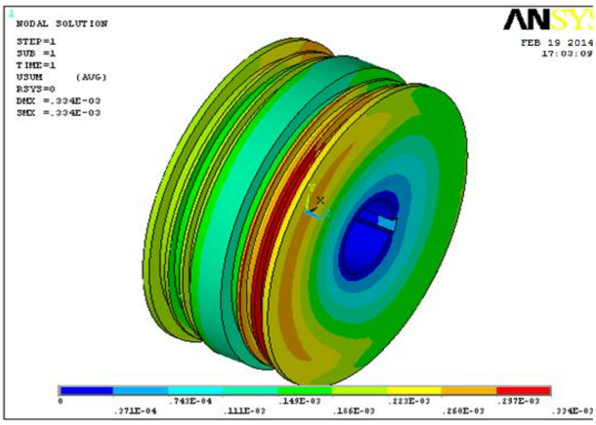


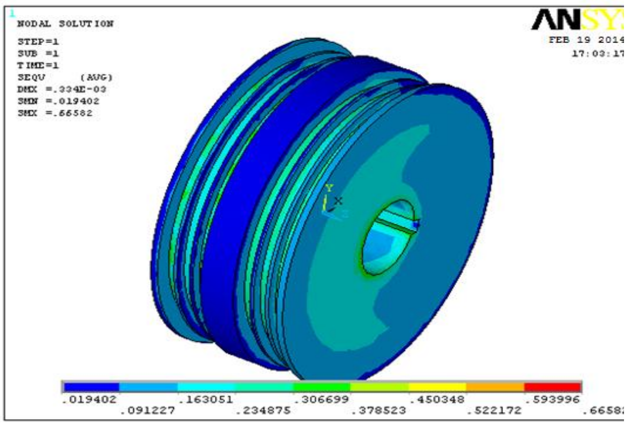
Loads : Pressure – 0.39N/mm^2
Solution : Solution – Solve – Current LS – ok

Post Processor

General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Displacement Vector Sum

General Post Processor – Plot Results – Contour Plot – Nodal Solution – Stress – Von Mises Stress

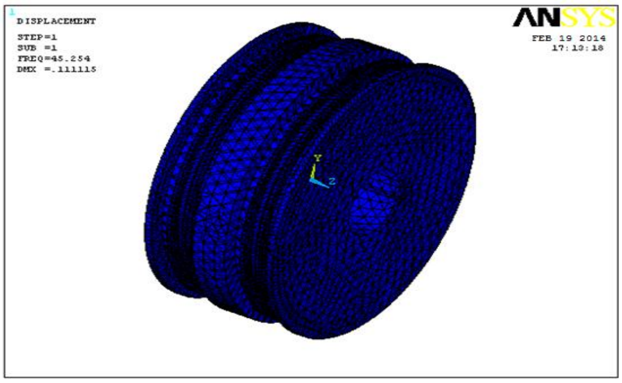




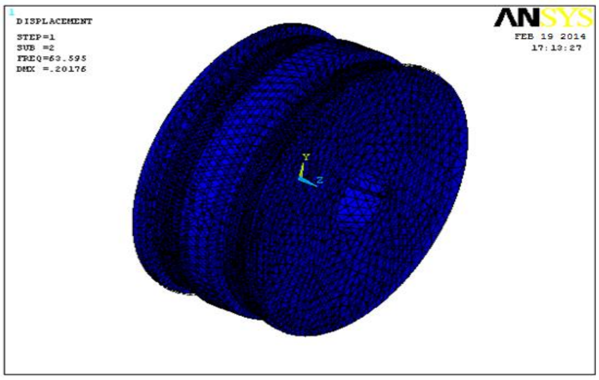
Modal Analysis
New Analysis> Select Modal>Click> OK
Main menu>Preprocessor>Loads>Analysis Type>
Analysis Options>
No. Of Modes to Extract: 5
Click> OK
Main menu>Solution>Solve>Current Ls>Ok

Results

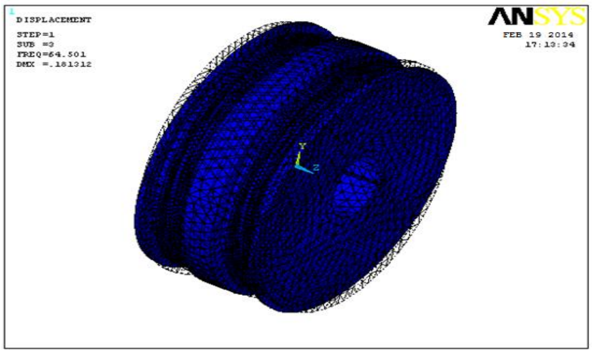
Main menu>General Postproc>Read Results> First Set Plot result>Deformed Shape>Def.+Undeform>Click>OK



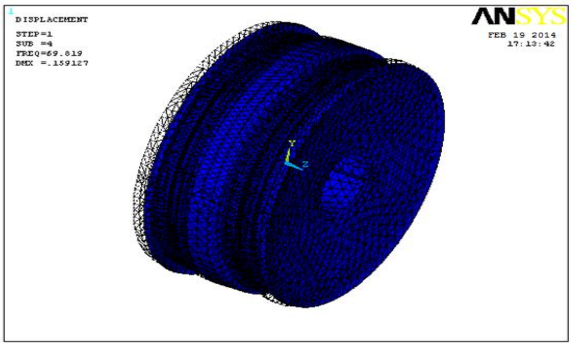
Main menu>General Postproc>Read Results> Next Set
Plot result>Deformed Shape> Def+Undeform>Click>OK



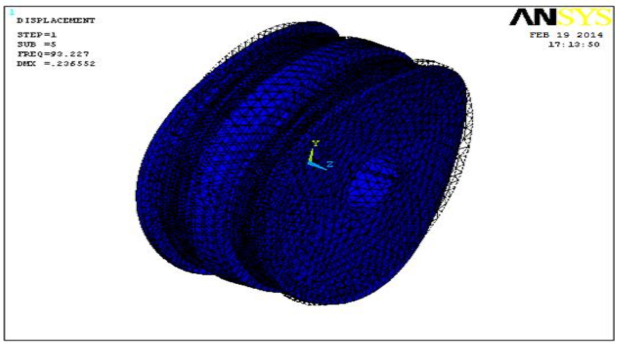
Main menu>General Postproc>Read Results> Next Set Plot result>Deformed Shape> Def+ Undeform>Click> OK



Main menu>General Postproc>Read Results> Next Set
Plot result>Deformed Shape>Def+ Undeform>Click>OK



Main menu>General Postproc>Read Results> Next Set Plot result>Deformed Shape> Def+ Undeform>Click>OK



Fatigue Analysis

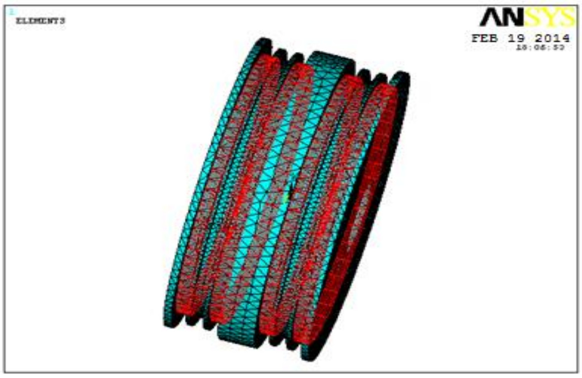
Solution
  Analysis type
    New analysis
      Transient
        Ok
        Ok

Four load cases are applied:

a. 0.39. The time at the end of the load step is 10 seconds.
b. -0.39. The time at the end of the load step is 20 seconds.
c. 0.29. The time at the end of the load step is 30 seconds.
d. -0.29the time at the end of the load step is 40 seconds.

The events to be used in the analysis are:

Event No.	Load No.	Loading	Number of Repetitions	Scale Factor
1	1	0.39	500,000	1
1	2	-0.39	500,000	1
2	1	0.29	5,000	1
2	2	-0.29	5,000	1

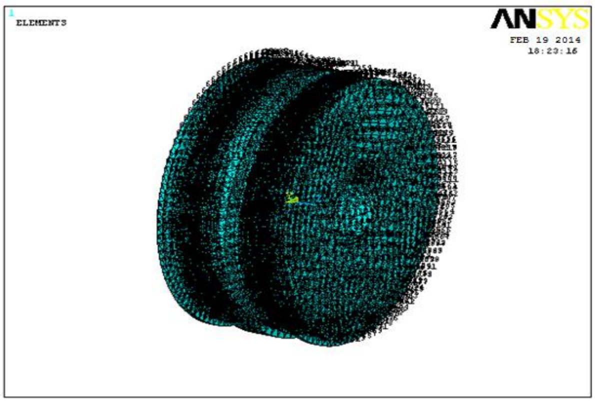


Stress Locations

NLOC = **1**
NODE = **12516**(node at the constrained area)
NLOC = **2**
NODE = **11975**(node at the pressure area)
NLOC = **1**NODE = **22949**(node at the open area)

General Postproc
Fatigue
Property Table
S-N Table

Results



Node at Constrained Area

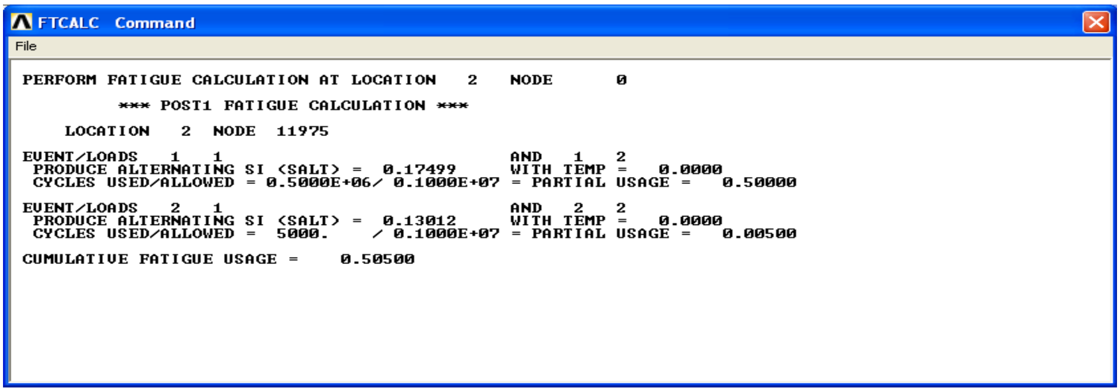
```
FTCALC Command
File

PERFORM FATIGUE CALCULATION AT LOCATION   1   NODE      0

        *** POST1 FATIGUE CALCULATION ***

    LOCATION   1  NODE  12516

EVENT/LOADS   1   1                         AND   1   2
 PRODUCE ALTERNATING SI (SALT) =  0.10417    WITH TEMP =   0.0000
 CYCLES USED/ALLOWED = 0.5000E+06/ 0.1000E+07 = PARTIAL USAGE =   0.50000

EVENT/LOADS   2   1                         AND   2   2
 PRODUCE ALTERNATING SI (SALT) =  0.77463E-01 WITH TEMP =   0.0000
 CYCLES USED/ALLOWED =  5000.    / 0.1000E+07 = PARTIAL USAGE =   0.00500

CUMULATIVE FATIGUE USAGE =    0.50500
```

Location: 1 Node 12516 at the constrained area.

The combination of event 2, load 1 and event 2, load 2 produces an alternating stress intensity of 0.77463-01 N/mm^2. The flywheel was subjected to 5000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000. The partial usage value, 0.005, is the ratio of cycles used/cycles allowed. The combination of event 1, load 1 and event 1, load 2 produces an alternating stress intensity of 0.10417 N/mm^2. The flywheel was subjected to 500,000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000. The partial usage value, 0.5, is the ratio of cycles used/cycles allowed.

The Cumulative Fatigue Usage value is 0.505, is the sum of the partial usage factors (Miner's rule).

Node at Pressure Area

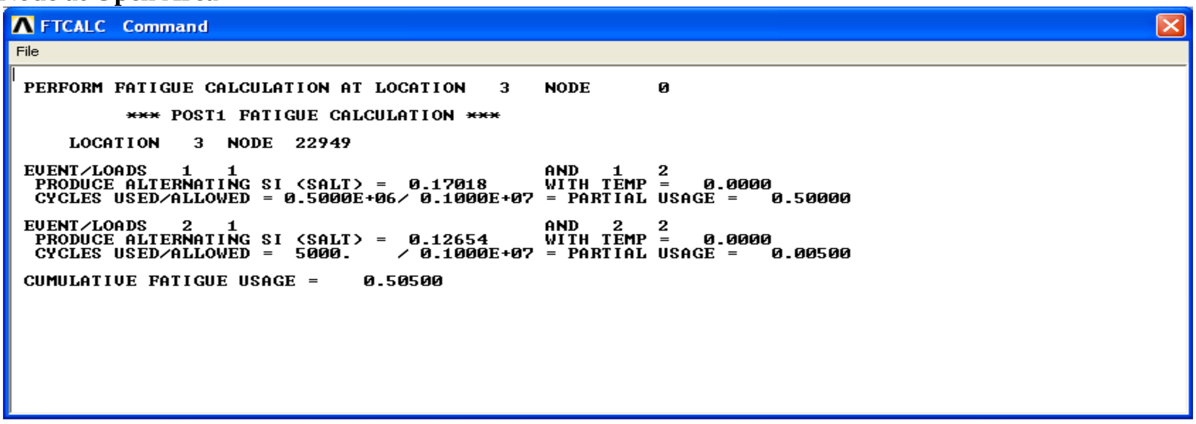

```
FTCALC Command
File
PERFORM FATIGUE CALCULATION AT LOCATION   2   NODE     0
         *** POST1 FATIGUE CALCULATION ***
    LOCATION   2  NODE  11975
EVENT/LOADS   1   1                            AND   1   2
 PRODUCE ALTERNATING SI (SALT) =  0.17499      WITH TEMP =    0.0000
 CYCLES USED/ALLOWED = 0.5000E+06/ 0.1000E+07 = PARTIAL USAGE =   0.50000
EVENT/LOADS   2   1                            AND   2   2
 PRODUCE ALTERNATING SI (SALT) =  0.13012      WITH TEMP =    0.0000
 CYCLES USED/ALLOWED =  5000.     / 0.1000E+07 = PARTIAL USAGE =   0.00500
CUMULATIVE FATIGUE USAGE =    0.50500
```

Location: 2 Node 11975 at the pressure area.

The combination of event 2, load 1 and event 2, load 2 produces an alternating stress intensity of 0.10312 N/mm^2. The flywheel was subjected to 5000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000. The partial usage value, 0.005, is the ratio of cycles used/cycles allowed. The combination of event 1, load 1 and event 1, load 2 produces an alternating stress intensity of 0.17499 N/mm^2. The flywheel was subjected to 500,000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000. The partial usage value, 0.5, is the ratio of cycles used/cycles allowed.

The Cumulative Fatigue Usage value is 0.505, is the sum of the partial usage factors (Miner's rule).

Node at Open Area


```
FTCALC Command
File
PERFORM FATIGUE CALCULATION AT LOCATION   3   NODE     0
         *** POST1 FATIGUE CALCULATION ***
    LOCATION   3  NODE  22949
EVENT/LOADS   1   1                            AND   1   2
 PRODUCE ALTERNATING SI (SALT) =  0.17018      WITH TEMP =    0.0000
 CYCLES USED/ALLOWED = 0.5000E+06/ 0.1000E+07 = PARTIAL USAGE =   0.50000
EVENT/LOADS   2   1                            AND   2   2
 PRODUCE ALTERNATING SI (SALT) =  0.12654      WITH TEMP =    0.0000
 CYCLES USED/ALLOWED =  5000.     / 0.1000E+07 = PARTIAL USAGE =   0.00500
CUMULATIVE FATIGUE USAGE =    0.50500
```

Location: 3 Node 22949 at the open areas.

The combination of event 2, load 1 and event 2, load 2 produces an alternating stress intensity of 0.12654 N/mm^2. The flywheel was subjected to 5000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000. The partial usage value, 0.005, is the ratio of cycles used/cycles allowed. The combination of event 1, load 1 and event 1, load 2 produces an alternating stress intensity of 0.17018 N/mm^2. The flywheel was subjected to 500,000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000. The partial usage value, 0.5, is the ratio of cycles used/cycles allowed. The Cumulative Fatigue Usage value is 0.505, is the sum of the partial usage factors (Miner's rule).

Aluminum Alloy A360

Structural Analysis

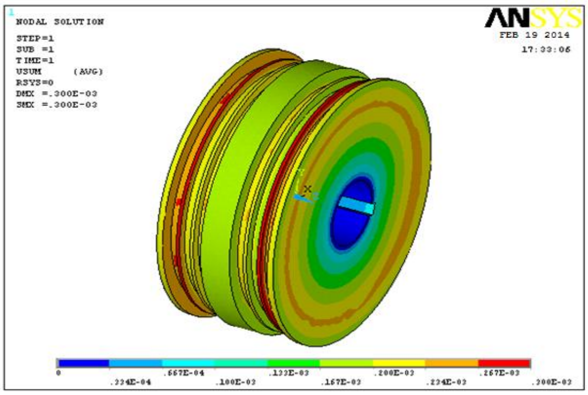
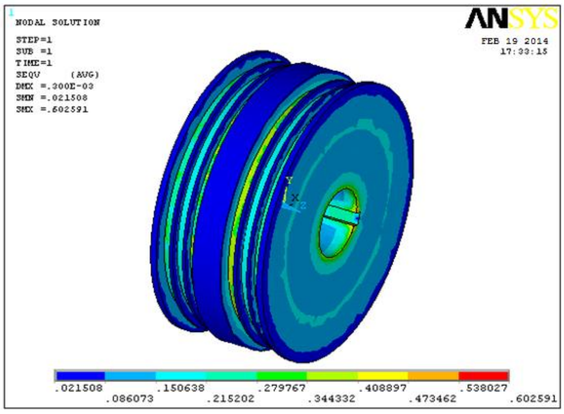
Element Type: Solid 20 node 95

Material Properties: Young's Modulus (EX) : 80000N/mm^2

Poissons Ratio (PRXY): 0.33

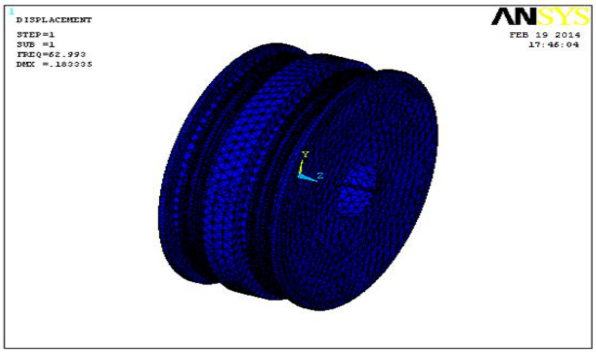
Density : 0.00000268 kg/mm^3

Post Processor

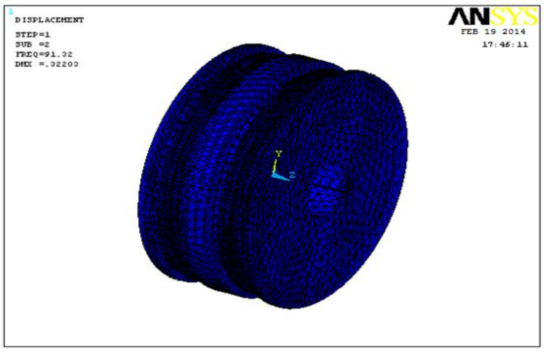
General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Displacement Vector Sum	General Post Processor – Plot Results – Contour Plot – Nodal Solution – Stress – Von Mises Stress
	

Modal Analysis
Results

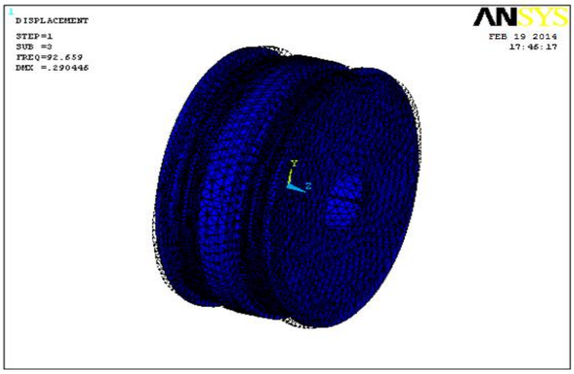
Main menu>General Postproc>Read Results> First Set Plot result>Deformed Shape> Def+Undeform >Click>OK



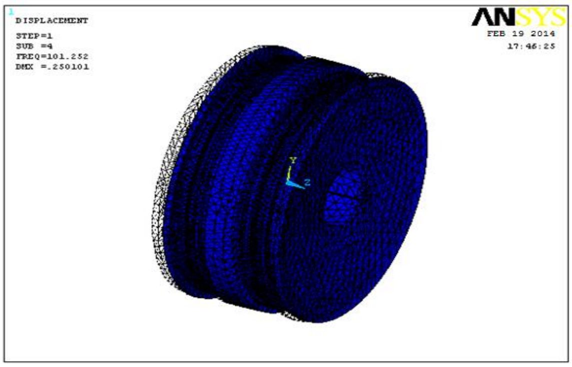
Main menu>General Postproc>Read Results> Next Set Plot result>Deformed Shape> Def+Undeform >Click>OK



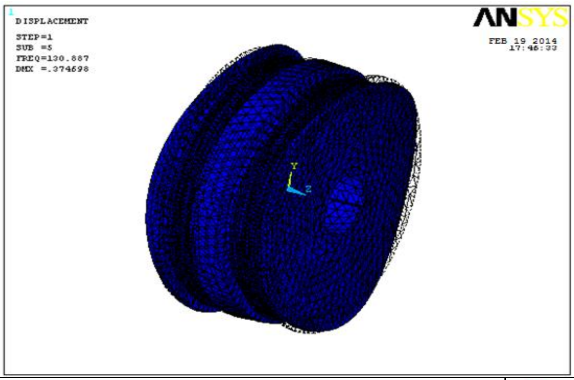
Main menu>General Postproc>Read Results> Next Set Plot result>Deformed Shape> Def+Undeform>Click>OK



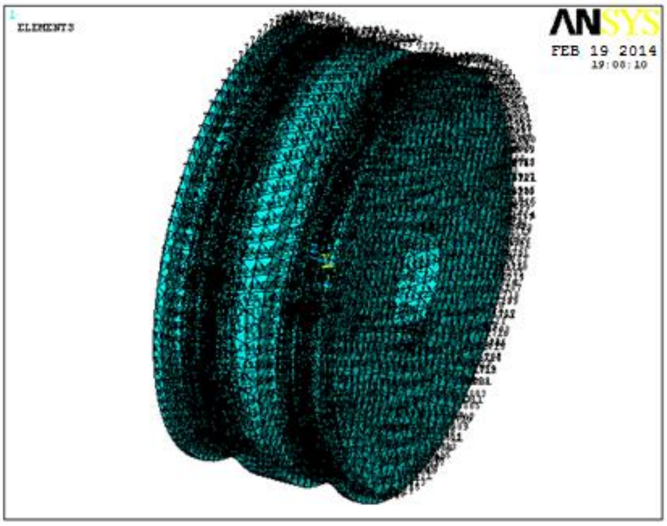
Main menu>General Postproc>Read Results> Next Set Plot result>Deformed Shape>Def+Undeform >Click>OK



Main menu>General Postproc>Read Results> Next Set Plot result>Deformed Shape>Def+Undeform >Click>OK



Fatigue Analysis
Solution
Analysis type
New analysis
Transient
Ok
Ok
Stress Locations
NLOC = **1**
NODE = **12536**(node at the pressure area
NLOC = **2**
NODE = **14377**(node at the open area)
NLOC = **3**
NODE = **23026**(node at the constrained area)
General Postproc
Fatigue
Property Table
S-N Table



Results

```
FTCALC Command
File

PERFORM FATIGUE CALCULATION AT LOCATION   1   NODE      0

          *** POST1 FATIGUE CALCULATION ***

    LOCATION    1  NODE   12536

EVENT/LOADS    1    1                          AND    1    2
 PRODUCE ALTERNATING SI (SALT) =  0.86604E-01 WITH TEMP =    0.0000
 CYCLES USED/ALLOWED = 0.5000E+06/ 0.1000E+07 = PARTIAL USAGE =    0.50000

EVENT/LOADS    2    1                          AND    2    2
 PRODUCE ALTERNATING SI (SALT) =  0.64398E-01 WITH TEMP =    0.0000
 CYCLES USED/ALLOWED =  1.000     / 0.1000E+07 = PARTIAL USAGE =    0.00000

CUMULATIVE FATIGUE USAGE =    0.50000
```

Node at Constrained Area

Location: 1Node 12536 at the constrained area.

The combination of event 2, load 1 and event 2, load 2 produces an alternating stress intensity of 0.64398e-01 N/mm^2. The flywheel was subjected to 5000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000. The partial usage value, 0.005, is the ratio of cycles used/cycles allowed. The combination of event 1, load 1 and event 1, load 2 produces an alternating stress intensity of 0.86604e-01 N/mm^2. The flywheel was subjected to 500,000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000. The partial usage value, 0.5, is the ratio of cycles used/cycles allowed. The Cumulative Fatigue Usage value is 0.505, is the sum of the partial usage factors (Miner's rule).

Location: 2 Node 14377 at the pressure area.

The combination of event 2, load 1 and event 2, load 2 produces an alternating stress intensity of 0.19221 N/mm^2. The flywheel was subjected to 5000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000. The partial usage value, 0.005, is the ratio of cycles used/cycles allowed. The combination of event 1, load 1 and event 1, load 2 produces an alternating stress intensity of 0.25849 N/mm^2. The flywheel was subjected to 500,000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000. The partial usage value, 0.5, is the ratio of cycles used/cycles allowed. The Cumulative Fatigue Usage value is 0.505, is the sum of the partial usage factors (Miner's rule).

Location: 3 Node 23026 at the open areas.

The combination of event 2, load 1 and event 2, load 2 produces an alternating stress intensity of 0.51714e-01 N/mm^2. The flywheel was subjected to 5000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000. The partial usage value, 0.005, is the ratio of cycles used/cycles allowed. The combination of event 1, load 1 and event 1, load 2 produces an alternating stress intensity of 0.69546e-01 N/mm^2. The flywheel was subjected to 500,000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity is 1,000,000. The partial usage value, 0.5, is the ratio of cycles used/cycles allowed. The Cumulative Fatigue Usage value is 0.505, is the sum of the partial usage factors (Miner's rule).

Structural Analysis Results

Cast Iron

	RESULTS	**PERMISSIBLE**
DISPLACEMENT (mm)	0.334e^{-3}	
VONMISES STRESS (N/mm^2)	0.66582	620
	Frequency	**Displacement**
MODE 01	45.254	0.111115
MODE 02	63.595	0.20176
MODE 03	54.501	0.181312
MODE 04	69.819	0.159127
MODE 05	93.227	0.266552

A360 ALLOY

	RESULTS	**PERMISSIBLE**
DISPLACEMENT (mm)	0.300e^{-3}	
VONMISES STRESS (N/mm^2)	0.602591	344
	Frequency	**Displacement**
MODE 01	62.993	0.183335
MODE 02	91.32	0.32203
MODE 03	92.659	0.290446
MODE 04	101.252	0.250101
MODE 05	130.887	0.374698

Fatigue Analysis Results

	Castiron	A360 Alloy
Constrained area Event 1 Load1, Event 1 500000cycles Load 2	0.10417/mm^2	0.86604e-01N/mm^2
Event 2 Load1, Event 2 50000cycles Load 2	0.77463e-01 N/mm^2	0.64398e-01 N/mm^2
Pressure area Event 1 Load1, Event 1 500000Cycles Load 2	0.17499 N/mm^2	0.25849 N/mm^2
Event 2 Load1, Event 2 50000cycles Load 2	0.13012 N/mm^2	0.19221 N/mm^2
Open area Event 1 Load1, Event 1 500000cycles Load 2	0.17018 N/mm^2	0.6954e-01N/mm^2
Event 2 Load1, Event 2 50000cyclesLoad 2	0.12654 N/mm^2	0.51714e-01 N/mm^2

IX. Conclusions

In our project we have designed a four wheeler flywheel used in a petrol engine using theoretical calculations. 2d drawing is created and modeling of flywheel is done using Pro/Engineer. We have done structural and modal analysis on flywheel using two materials Aluminum Alloy A360 and Cast Iron to validate our design. By observing the results, for all the materials the stress values are less than their respective permissible yield stress values. So our design is safe. We have also done modal analysis for number of modes to see the displacement of flywheel for number of frequencies. By comparing the results for two materials, the stress value for Aluminum Alloy A360 is less than that of Cast Iron. So we conclude that for our design, Aluminum A360 is better material for flywheel. By using Aluminum A360 we can reduce Weight. Also it is rust free. Fatigue analysis is also done on flywheel to verify the stress values at the selected nodes. The nodes are selected at constrained area, pressure area and open area. In this project its having some disadvantages is by replacing with Aluminum A360 energy storage is reduced. In this project mainly we done material optimization. For both the materials the number of cycles allowed for flywheel is 500000 cycles.

References

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[7]. Automotive Production Systems and Standardization by WERNER.