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Design and Analysis of Various Shapes of Flywheel

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ABSTRACT

In present investigation, to counter the requirement of smoothing out the large oscillations in velocity during a cycle of a mechanism, a flywheel is designed, optimized and analyzed. By using optimization approach to optimize various parameters like cost, stresses, energy etc. for flywheel and to apply an approach for modification of various working parameter like efficiency, output, energy storing capacity, the results compared with existing flywheel result. Based on the dynamic functions and specifications, of the system the main features of the flywheel is initially determined, the detail design study of flywheel is done and by using any one of the optimization techniques and approach for modification, structural analysis is done.

Heavy wheel attached to a rotating shaft to smooth out delivery of power from a motor to a machine. The inertia of the flywheel opposes and moderates fluctuations in the speed of the engine and stores the excess energy for intermittent use. In automobile engines, the flywheel smooths out the pulses of energy provided by the combustion in the cylinders and provides energy for the compression stroke of the pistons. In power presses the actual punching, shearing, and forming are done in a fraction of the operating cycle. During the longer, non-active period, the speed of the flywheel is built up slowly by a comparatively low-powered motor. When the press is operating, most of the required energy is provided by the flywheel, heavy metal wheel attached to a drive shaft, having most of its weight concentrated at the circumference. Such a wheel resists changes in speed and helps steady the rotation of the shaft where a power source such as a piston engine exerts an uneven torque on the shaft or where the load is intermittent, as in piston pumps or punches. By slowly increasing the speed of a flywheel a small motor can store up energy that, if released in a short time, enables the motor to perform a function for which it is ordinarily too small.

The flywheel was developed by James Watt in his work on the steam engine. The difficulty of casting stress-free spoked flywheels leads the modern designer to use solid web castings or welded structural steel assemblies. For large, slow-turning flywheels on heavy duty diesel engines or large mechanical presses, cast-spoked flywheels of two-piece design are standard.

New optimization problems arise every day - for instance, what is the quickest path to work? Where and how congested is the road construction? Am I better off riding my bike? If so, what is the shortest path? Sometimes these problems are easily solved, but many engineering problems cannot be handled satisfactorily using traditional optimization methods. Engineering involves a wide class of problems and optimization approaches.

For the machine acting a variable motion, its equivalent drive moment does not always equal to the equivalent resistant moment even during the stable status. Since its equivalent inertia of moment cannot vary correspondingly to this change, the angular velocity of its equivalent component, generally the main shaft or crank, fluctuate periodically.

Serving as a reservoir by storing energy during the period when the supply of energy is more than the requirement and releasing it during the period when the requirement of the energy is more than the supply, a flywheel provides an effective way to smooth out the fluctuation of speed. The efficient flywheel design should maximize the inertia of moment for minimum material used, and guarantee high reliability and long lifetime .Under such a situation and being aimed at partial mechanism system, the project is presented and worked out on the platform of PRO-E and ANSYS.

Keywords : ANSYS, PRO-E, Flywheel, FEA

I. INTRODUCTION

In this chapter, basic introduction of flywheel, their role in machines to get desired outputs like moment of inertia, energy fluctuations, torque, etc.., with respect to corresponding inputs will explained. Based on the dynamic functions, specifications of the system the main features of the flywheel is initially determined, the detail design study of flywheel is done .Then more and more designs in diverse areas of engineering are being analyzed through the software. FEA provides the ability to analyze the stresses and displacements of a part or assembly, as well as the reaction forces to other elements are imposed. This thesis guides the path through flywheel design and analysis to the material selection process. The FEA model is described to achieve a better understanding of the mesh type, mesh size and boundary conditions applied to complete an effective FEA model. At last the design objective could be simply to minimize cost of flywheel by reducing material or control the fluctuations of flywheel.

II. METHODS AND MATERIAL

Formulation of Problem : After exhaustive literature survey from previous chapter it is to be concluded that in today's world, major objectives of flywheel designers are to achieve the performance with lowest possible material used. Many researchers have focused on the finite element method and optimum design of flywheel, clutch plate and other parts of the engine like connecting rod. So, on the basis of above literature, the object of this work is to control the fluctuations of the flywheel to get the required inertia of the flywheel with safe working stresses. The flywheels are of two types 1) Web type and 2) Arm type

In older days, the flywheels were overdesigned in which the moment of inertia of the flywheel was more. But in modern days the attention imposes on optimal design. The optimal flywheel design will be a flywheel having minimum weight, to provide a particular moment of inertia and to control the fluctuating energy with safe stresses in all parts of the flywheel.

The present work is an attempt to optimize the existing flywheel of Fischer punching machine (German manufactured). The stress analysis by F.E.M method will be done to solve the purpose. In FEM analysis,3D model of flywheel will be developed in PRO-E and stress analysis will be done using ANSYS software.

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SPECIFICATION OF PUNCHING MACHINE:

Speed=1440rpm
Power =13.5HP
Capacity (at normal working pressure) = 100tons
Capacity (at max. pressure) = 125tons

SPECIFICATION OF FLYWHEEL:

Design parameters Of Flywheel:
Mass of flywheel=500kg
Material of flywheel=Mild Steel
Outer dia. Of flywheel=25inch = 612.5mm
Inner dia. Of flywheel = 3.5inch.= 85.75mm
Width of flywheel = 6.5inch.= 159.25mm

GERMAN FISCHER PUNCHING PRESS

This press is used for expanding the metal. Asian streck metals ISO 9001:2008 Company cut die, slit and stretch a metal sheet upto 5mm thick with no welded joints to make a one piece heavy-duty grating (mesh).

Structural Analysis of Flywheel :-

Solid model

The flywheel of German Fischer Punching Press is of solid disc type heavy flywheel used to store the energy for punching operation.

Calculation of I_f

By a simple and easy method, in which I_r is regarded as a constant, the required I_f can be calculated as fallows,

$\omega = 2\pi N/60 = 2\pi x1440/60 = 150$ rad/sec
$V = \omega \times r = 150 \times 42.875 x10^{-3}$
$= 6.431$m/sec
$a = v^2/r = 6.431^2/(42.875x10^{-3}) = 964.68$m/sec^2

Drive Force,

$F_d = m \times a = 500 \times 964.68 = 482.34$ KN

Specific weight density, W = (r/4) x 482.34 = $42.875x10^{-3}$ x 482.34/4
= 5.17KN-m
$I_1 = W/K_S\,\omega^2 = 5.17/.05x150^2$
$I_2 = mk^2 = 500 \times (42.875x10^{-3})^2$
$= 0.9191$kg.m^2

Actual Inertia of Moment I_f
$I_f = I_1 - I_2$
$= 3.6764$kg.m^2
$\Delta E = I_f \times C_s \times \omega^2$
$= 3.6764 \times 0.04 \times (150)^2$
$= 3308.76$ kg m^2/s^2
Power, P = 2πNT/60
P=13.4HP=13.4x0.746=9.991KW
T=Px60/(2πN)=9.991x60/(2x3.14x1440)=0.0662N-m

Angular acceleration,
α= T/I=0.0662/3.6764=0.0180 rad/sec^2
Moment,
$M = I_f\, x\omega$
=3.6764x150=551.46 N-m

MODELLING AND ANALYSIS OF FLYWHEEL

i. Modelling

A flywheel model of FISCHER PUNCHING POWER MACHINE is created initially in ANSYS classic software. Then optimized flywheels are constructed in Pro-E Modelling.

ii. Analysis and Optimization:

Analysis: Structural analysis (FEA analysis) of flywheel is done in ANSYS software The stresses and total deformation is shown in this software.

Optimization: Optimization is done with the help of application software of FINITE ELEMENT METHOD (i.e. ANSYS) and Pro-E.

AN APPROACH TO FIND OUT DEFLECTIONS AND STRESSES IN FLYWHEEL:

In advent of the above discussion the present work is planned, which is basically focus on an estimation of deflections and von-mises stresses at different loading conditions for four different working stages. This is done as follows:

a) MODELING OF SOLID DISC TYPE FLYWHEEL:

Initially a CAD model of the solid disc type flywheel was created using the software ANSYS classic.

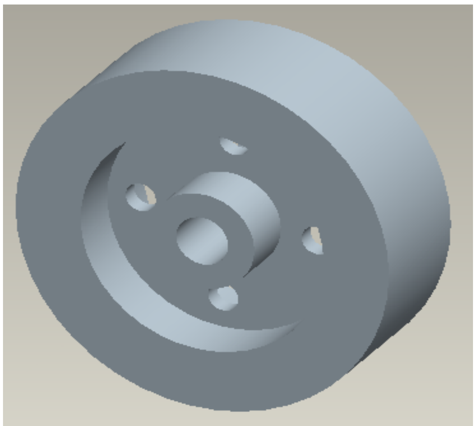
b) FINITE ELEMENT MODELING USING ANSYS 11:

Geometry derived from the ANSYS classic model was used to construct the finite element model. The purpose of a finite element analysis is to recreate mathematically the behavior of an actual engineering system. In other words, the analysis must be an accurate mathematical model of a physical prototype. This model comprises all the nodes, elements, material properties, real constants, boundary conditions, and other features that are used to represent the physical system. Model generation means generating the nodes and elements that represent the spatial volume and connectivity of the actual system, and defining the geometric configuration of the model's nodes and elements.

c) Structural Analysis (Solid Flywheel):

The analysis was conducted under the effects of different condition of loads,at four working stages viz. motionless, starting, speed changing and constant speed. The analysis consist of pre-processor, solver and post-processor. Input parameters like boundary conditions, element type, material properties are entered, then after creating model solver reads the data defined by pre-processor and then stresses are evaluated in post-processor.

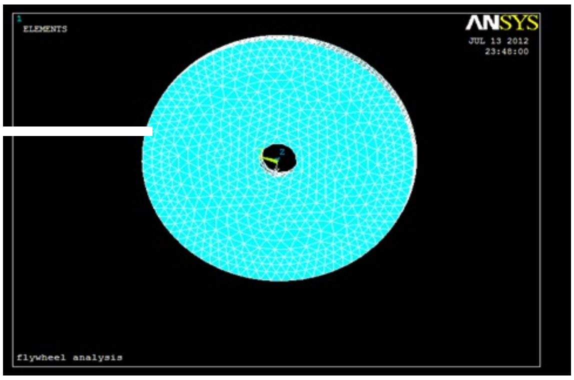
MODELLING OF EXISTING FLYWHEELOF PUNCHING PRESS



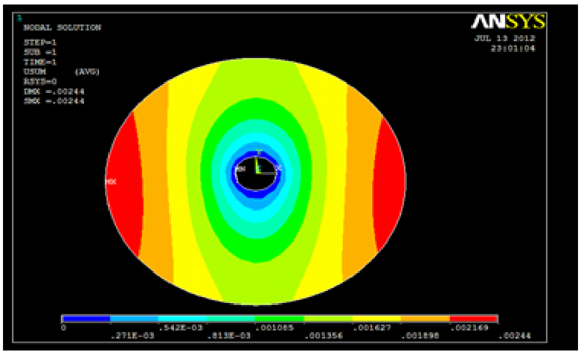
FSTRUCTURAL ANALYSIS OF SOLID FLYWHEEL

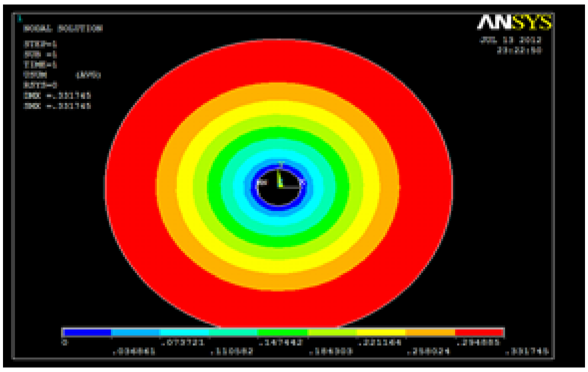
Structural analysis comprises a set of physical laws and mathematics required to study and predicts the behavior of structures. It includes the following methods:

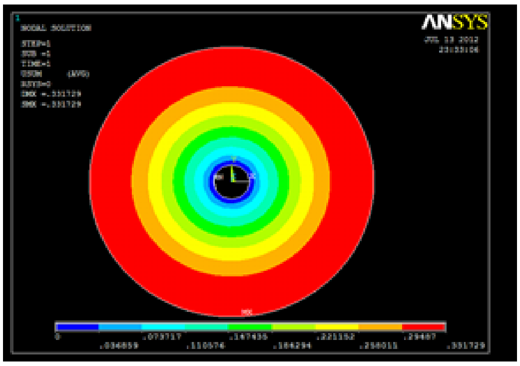
- Analytical methods
- Strength of materials methods
- Elastic methods
- Finite element methods

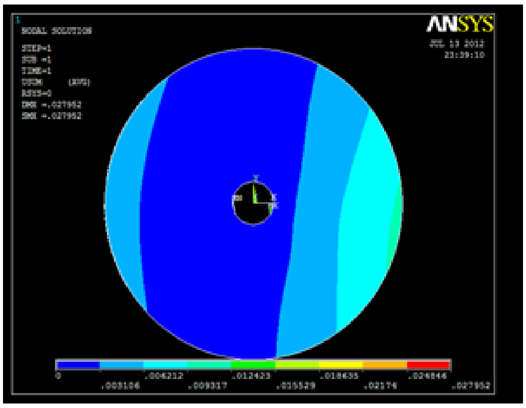


Variation in Displacement

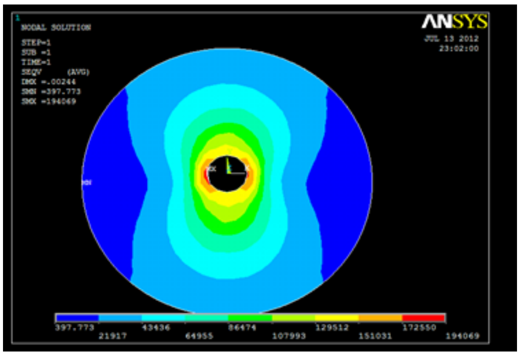


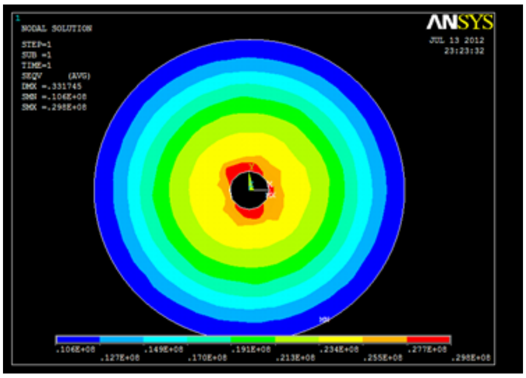


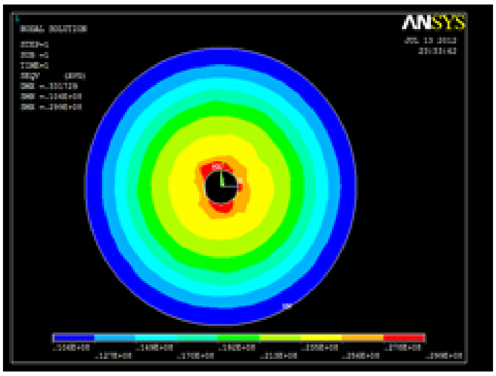




Variation in Von-Mises Stress







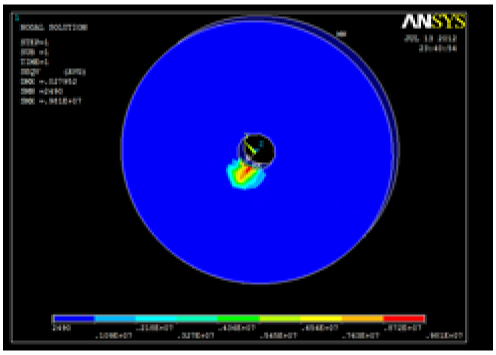


Table1. Analysis and Result for solid flywheel

Stage	Loads	Von Mises Stress (Pa)	Maximum Deflection (m)
stage-1	Acel_y =9.80 m/s^2	194069	0.00244
stage-2	Acel_y =9.80 m/s^2 MZ =551.46 Nm Omega_z = 0.0180 rad/s^2	0.298e8	0.331745
stage-3	Acel_y =9.80 m/s^2 MZ =551.46 Nm Domega_z= 0.0180 rad/s^2 Omega_z =150 rad/s	0.299e8	0.331729
stage-4	Acel_y =9.80 m/s^2 Omega_z= 25 rad/s	0.981e7	0.027952

STRUCTURAL ANALYSIS OF WEB FLYWHEEL

When web is created in the flywheel (i.e. somewhat material is reduced) mass of flywheel reduces.

Now, Mass of flywheel=430kg

Drive Force

$F_d = m \times a = 430 \times 964.68 = 414.812$ KN

Specific Weight Density

$W = (r/4)\text{x}482.34 = 42.875\text{x}10^{-3} \text{ x } 414.812/4$

$= 4.44627\text{KN-m}$

$I_1 = W/K_S\ \omega^2 = 4.44627/.05\text{x}150^2 = 3.9522 \text{ kg-m}^2$

And, $I_2 = 430(42.875\text{x}10^{-3})^2$

$= 0.79045\text{kg-m}^2$

$I_f = 3.9522 - 0.79045 = 3.16179\text{kg-m}^2$

$\Delta E = I \text{ x } C_S \text{ x } \omega^2 = 3.16179 \text{ x } 0.04(150)^2 = 2845.5\text{kg-m}^2/\text{s}^2$

Table 2. Combinations of loads(web flywheel)

Working Stage	Combination of loads
Motionless (stage-1)	Gravity
Starting (stage-2)	Gravity + MZ + Domega_z
Speed Changing (stage-3)	Gravity + MZ + Domega_z + Omega_z
Constant speed (stage4)	Gravity + Omega_z

Structural Analysis of web flywheel is done using following steps:-

a) Importing the iges file from PRO-E to ANSYS.
b) Clicking on solution ,then define loads ,then delete ,then all load data and press enter
c) Applying the displacement through structural.
d) Applying gravity, inertia, and angular acceleration, inertia and angular velocity, and moment from structural.
e) Then press the solve.
f) Repeating the general post-processor for getting the output.

Variation in Displacement

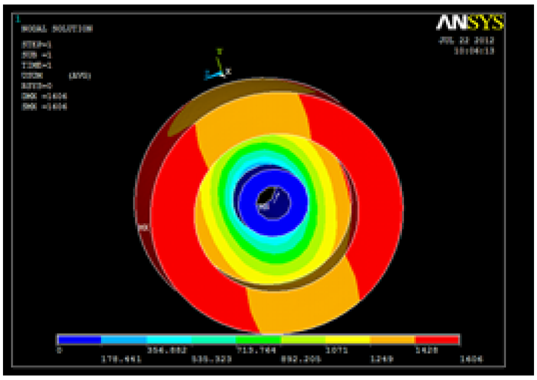


Figure 1. Displacement stage –I

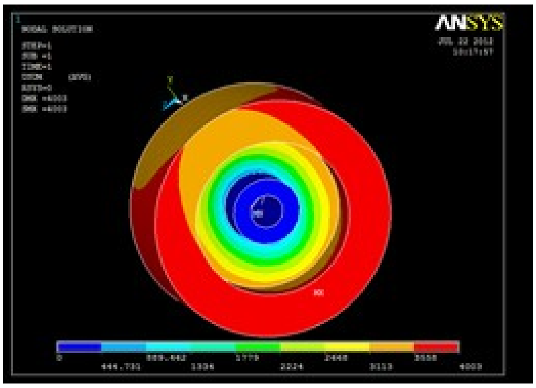


Figure 2. displacement stage –II

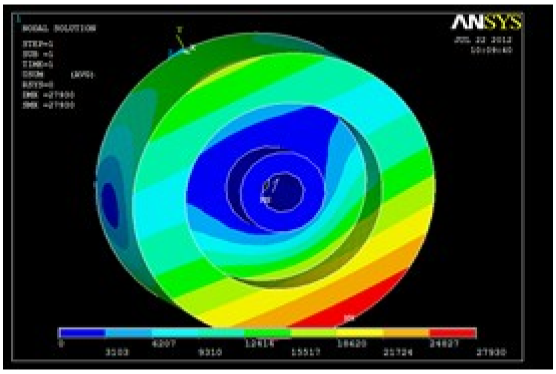


Figure 3. displacement stage –III

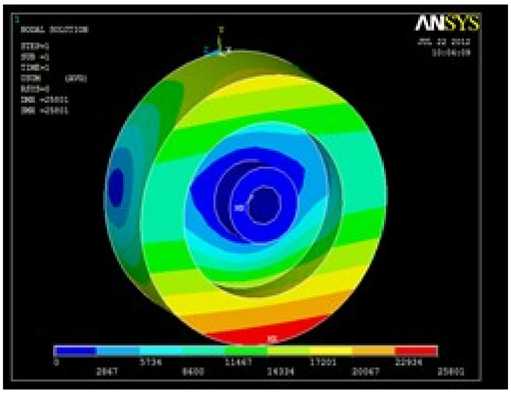


Figure 4. Displacement stage –IV

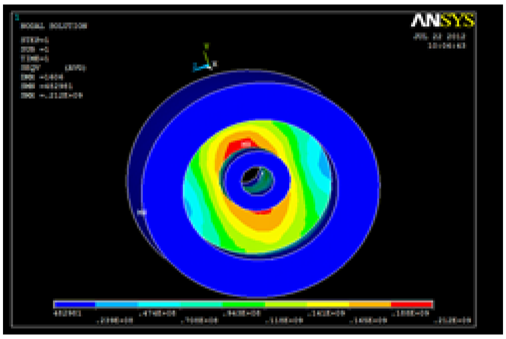


Figure 5. von mises stress stage –I

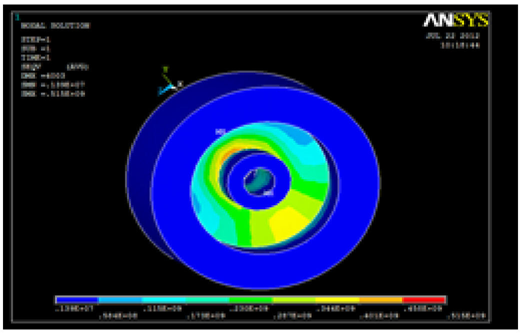


Figure 6. von mises stress stage –II

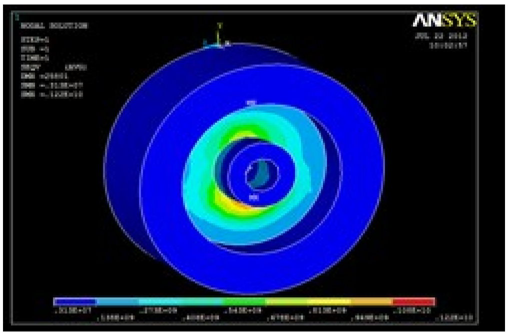


Figure 7. von misses stress stage –III

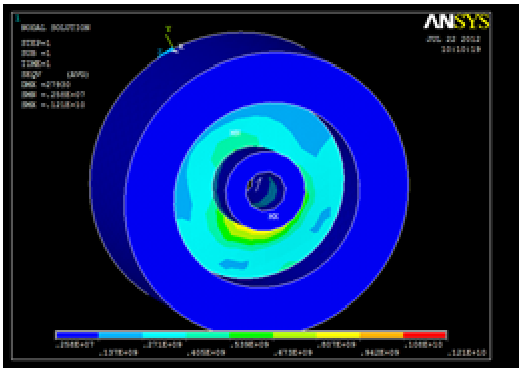


Figure 8. von misses stress stage –IV

Analysis and Result for web flywheel:-

Table 3. Analysis of web flywheel

Stage	Loads	Von Mises Stress (Pa)	Maximum Deflection (m)
stage-1	Acel_y =9.80 m/s^2	0.212e9	0.001606
stage-2	Acel_y =9.80 m/s^2 MZ =551.46 Nm Domega_z= 0.0180 rad/s^2	0.515e9	0.004003
stage-3	Acel_y =9.80 m/s^2 MZ =551.46 Nm Domega_z= 0.0180 rad/s^2 Omega_z =150 rad/s	0.122e10	0.025801
stage-4	Acel_y =9.80 m/s^2 Omega_z= 25 rad/s	0.121e10	0.027930

Comments: - The deflection at all the four stages, especially stage-1 and stage-2, has been decreased obviously. It shows that there is change of design parameters with respect to change in mass of flywheel.

STRUCTURAL ANALYSIS OF WEB FLYWHEEL WITH HOLE

Improvement

Tentatively, four sectional blocks are cut from the flywheel . Then mass of flywheel reduced again,

Now, Mass of flywheel=380kg

Drive force,

$$F_d = m \times a = 380 \times 964.68 = 366.5784 \text{ KN}$$

Specific weight density, W = (r/4)x366.578 = $42.875x10^{-3}$ x 366.578/4

= 3.929KN-m

I_1 = W/K_S ω^2 = 3.929/.05x150^2 =3.4927

So,I_2 =380($42.875x10^{-3}$)^2

=0.698kg-m^2

I_f =3.4927-0.698=2.79kg-m^2

ΔE=I.C $_{S.}$ ω^2 =2.79x.04$(150)^2$ =2515.2kg-m^2 /s^2

Web flywheel with hole

Table 4. Combinations of loads

Working Stage	Combination of loads
Motionless (stage-1)	Gravity
Starting (stage-2)	Gravity + MZ + Domega_z
Speed Changing (stage-3)	Gravity + MZ + Domega_z + Omega_z
Constant speed (stage4)	Gravity + Omega_z

Structural Analysis of web flywheel with holes is done using following steps:-Similar analysis will be done on four sectional blocks cut in flywheel as done previously in solid flywheel and web flywheel.

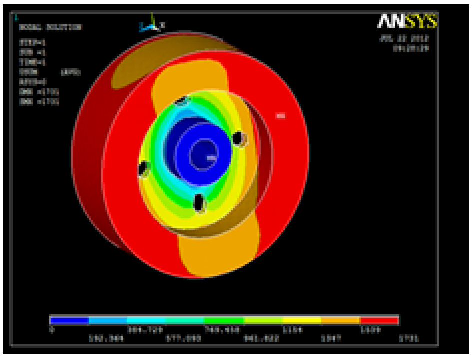


Figure 9. displacement stage –I

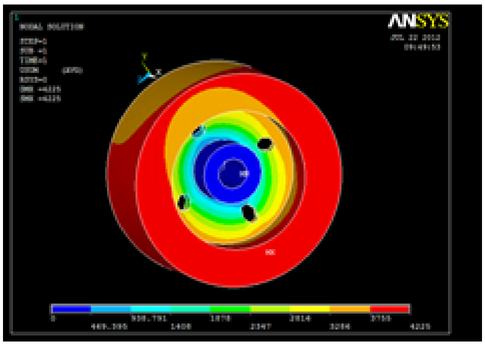


Figure 10. displacement stage –II

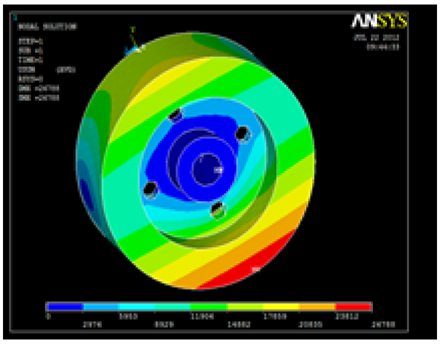


Figure 11. displacement stage –III

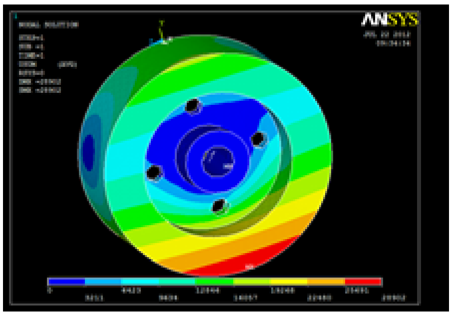


Figure 12. displacement stage –IV

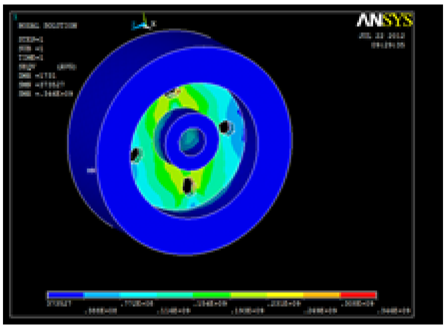


Figure 13. von mises stress stage –I

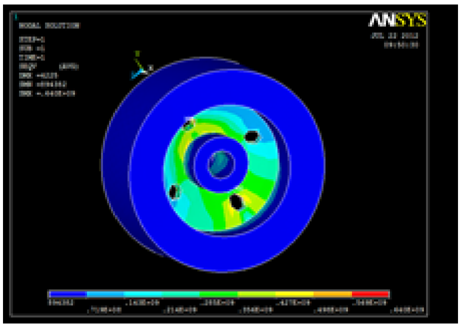


Figure 14. von mises stress stage –II

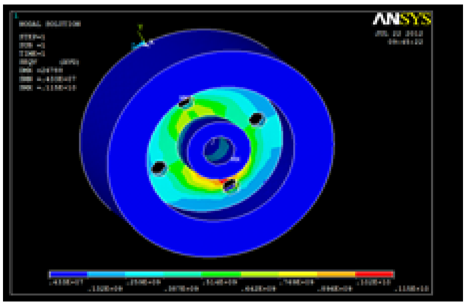


Figure 15. von mises stress stage –III

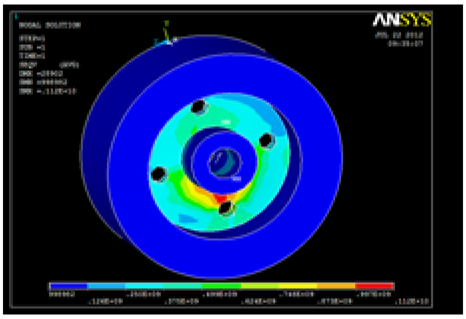


Figure 16. von mises stress stage –IV

Analysis and Result for web with hole flywheel:-

Table 5. Analysis of web with hole flywheel

Stage	Loads	Von Mises Stress (Pa)	Maximum Deflection (m)
stage-1	Acel_y =9.80 m/s^2	0.346e9	0.001731
stage-2	Acel_y =9.80 m/s^2 MZ =551.46 Nm Domega_z= 0.0180 rad/s^2	0.640e9	0.004225
stage-3	Acel_y =9.80 m/s^2 MZ =551.46 Nm Domega_z= 0.0180 rad/s^2 Omega_z =150 rad/s	0.115e10	0.026788
stage-4	Acel_y =9.80 m/s^2 Omega_z= 25 rad/s	0.112e10	0.028902

Comments:- The deflection at all the four stages, especially stage-1 and stage-2, has been decreased obviously. Similarly, it shows that there is change of design parameters with respect to change in mass of flywheel. And there is less effect on energy fluctuations.

III. RESULTS AND DISCUSSION

This chapter deals with the comparison of results obtained by Ansys software . Thus the results are comparing the fluctuation of energy and moment of inertia with respect to the reduction in mass of flywheel. Also, deflections and von-Mises stresses obtained by Ansys software are compared for all four stages with different modificated flywheel. The heavy flywheel is considered and modified for reducing the fluctuations of energy .

- In this project all the modifications done in existing flywheel are designed and modelled with dimensions in the Pro-E software.
- In the Pro-E software after modeling, it has been analyzed in ANSYS software for deflection and von-misses stresses for all modifications in flywheel.
- A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that includes inertia and don't include vibrations.
- The deflection at all the four stages, especially stage-1 and stage-2, has been decreased in case of web flywheel.

- The deflection at all the four stages, especially stage-1 and stage-2, has been decreased obviously. Similarly, it shows that there is change of design parameters with respect to change in mass of flywheel. And there is less effect on energy fluctuations.

Table 6. Comparison of Results

TYPE OF FLYWHEEL	MASS OF FLYWHEEL	MOMENT OFINERTIA	FLUCTUATION OF ENERGY
SOLID FLYWHEEL	500	3.67kg-m^2	3308.76kg-m^2 /s^2
FLYWHEEL WITH WEB	430	3.16kg-m^2	2845.5kg-m^2 /s^2
FLYWHEEL WITH WEB WITH HOLE	380	2.79kg-m^2	2515.2kg-m^2 /s^2

Table 7. Comparison of Results of Deflection and Von-Misses Stresses

Type of flywheel	Stage	Maximum deflection(m)	Von-misses stresses (Pa)
Solid flywheel	stage-1	0.00244	194069

	stage-2	o.3317	0.298e8
	stage-3	0.3317	0.299e8
	stage-4	0.0279	0.981e7
Flywheel with web	stage-1	0.001606	0.212e9
	stage-2	0.004003	0.515e9
	stage-3	0.025801	0.122e10
	stage-4	0.027930	0.122e10
Flywheel with web with hole	stage-1	0.001731	0.346e9
	stage-2	0.004225	0.640e9
	stage-3	0.026788	0.115e10
	stage-4	0.028902	0.112e10

IV. CONCLUSION

Based on the above design and analysis, the following conclusions can be drawn:

There are rotational deformations due to the torsion effect of the drive moment MZ and the inertia moment caused by the angular acceleration (α). The maximum stress occurs on the hub and near shaft-hole surface at the stage-2 and stage 3, however the maximum deflection is along the right outer-edge of the rim at the stage-3. Compared to the situations of stress and deflection at stage-2 and stage-3, those at stage-1 and stage-4 are much better. Some efforts should be done to improve the design and thus reduce the stress on the hub.

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