Design and Thermal analysis of Disc Brake

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Abstract— These day technologies go beyond us. For automotive field, the technology of engine develops very fast even the system of the car, luxury or comforts everything that develops by the innovation of engineer. Although the engineer gives priority for safety measure, but most consumers still have inadequate of knowledge in safety system. Thus safety is the first important thing we must focus. This project is presented with disc brake analysis “force and friction on disc brake analysis” which studies about action on disc brake by analysis the normal force, shear force, and piston force. Therefore, we can estimate the efficiency of the disc brake. Hopefully this project will help everyone to understand action force and friction force on the disc brake and how disc brake works more efficiently, which can help to reduce the accident that may happen in each day.

Keywords: automotive field, luxury or comforts everything, force and friction, efficiently

I. Introduction

A. *Importance:*

While braking, most of the kinetic energy are converted into thermal energy and increase the disc temperature. This project consists of thermal stress analysis on pulsar brake disc rotor for steady state and transient condition. The heat dissipated along the brake disc surface during the periodic braking via conduction, convection and radiation. In order to get the stable and accurate result of element size, time step selection is very important and all of these aspects are discussed in this paper. The findings of this research provide a useful design tool to improve the brake performance of disc brake system.

B. *Need:*

- A problem in Disc Brake occurs because of uneven stress & heat dissipation during braking of two wheeler as follows:-
- Scarring, Cracking, Rusting, Poor stopping, noise, Vibration, Pulling, Grabbing, Dragging, Pulsation etc

C. *Principle of Working:*

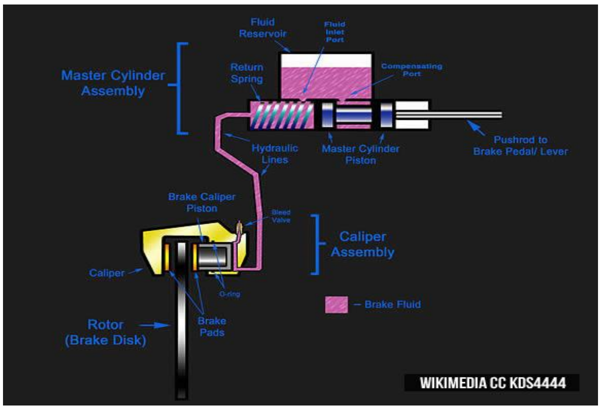


Fig. 1: Principle of Working of Disc Brake

When hydraulic pressure is applied to the calliper piston, it forces the inside pad to contact the disc. As the pressure increases, the calliper moves to the right and cause the outside pad to contact the disc. Braking force is generated by friction between the disc pads as they are squeezed against the disc rotor. Since disc brakes do not use friction between the lining and rotor to increase braking power as drum brakes do, they are less likely to cause a pull. The friction surface is constantly exposed to the air, ensuring good heat dissipation, minimizing brake fade. It also allows for self-cleaning as dust and water is thrown off, reducing friction difference.

Unlike drum brakes, disc brakes have limited self-energizing action making it necessary to apply greater hydraulic pressure to obtain sufficient braking force. This is accomplished by increasing the size of the caliper piston. The simple design facilitates easy maintenance and pad replacement.

1) *Disc rotor:*

Generally, the disc rotor is made of gray cast iron, and is either solid or ventilated. The ventilated type disc rotor consists of a wider disc with cooling fins cast through the middle to ensure good cooling. Proper cooling prevents fading and ensures longer pad life. Some ventilated rotors have spiral fins which create more air flow and better cooling. Spiral finned rotors are directional and mounted on a specific side of the vehicle. Solid type disc rotor is found on the rear of four-wheel disc brake system and on the front of earlier model vehicles.

A third style rotor can be either the ventilated or solid type which incorporates a brake drum for an internal parking brake assembly.

2) *Caliper:*

The caliper, also called the cylinder body, houses one to four pistons, and is mounted to the torque plate and steering knuckle or wheel carrier. The floating caliper design is not only more economical and higher weight but also requires fewer parts than fixed caliper counterpart. Depending on the application, the floating caliper has either one or two piston.
The piston is located in one side of the caliper. Hydraulic pressure from the raster cylinder is applied to piston and thus presses the inner pad against the disc rotor. At the same time, an equal hydraulic pressure creation force acts on the bottom of the cylinder. This causes the caliper to move to the right, and presses the outer pad located opposite the piston against the disc rotor.

3) *Brake pad:*

Different brake design applications require different kinds of friction materials. Several factors are considered in the development of brake pads; the coefficient of friction must remain constant over a wide range of temperatures, the brake pads should not wear out rapidly, should not wear the disc rotors, should withstand the highest temperature without fading and it should be able to do all this without any noise. Therefore, the material should maximize the good points and minimize the negative points.

Materials that make up the brake pad include friction modifiers, powdered metal, binders, fillers and curing agents. Powdered metal such as lead, zinc, brass, aluminum and other metals increase materials resistance to heat fads. Binder is the glue that holds the friction material together. Phenolic rein is the most common binder in current use. Fillers are added to friction materials in small quantities to accomplish specific purposes such as rubber chips to reduce brake noise.

The brake pad material is bonded to a stamped steel backing plate with a high temperature adhesive to which heat and pressure are applied to make the assembly. A slit is provided on the face of the pad to indicate the allowable limit of pad wear and provide a path for brake dust and gas to escape.

D. Input & Output Parameter:

Input Parameter	Output Parameter
Thickness, Materials, Cut section, Vane pattern	Brake torque, Heat dissipation, Stress distribution, Deformation

Table 1: Input & Output Parameter

E. Characteristics of Disc Brake:

1) Peak Force:

The peak force is the maximum decelerating effect that can be obtained. The peak force is often greater than the traction limit of the tires, in which case the brake can cause a wheel skid.

2) Continuous Power Dissipation:

Brakes typically get hot in use, and fail when the temperature gets too high. The greatest amount of power (energy per unit time) that can be dissipated through the brake without failure is the continuous power dissipation. Continuous power dissipation often depends on e.g., the temperature and speed of ambient cooling air.

3) Fade:

As a brake heats, it may become less effective, called brake fade. Some designs are inherently prone to fade, while other designs are relatively immune. Further, use considerations, such as cooling, often have a big effect on fade.

4) Smoothness:

A brake that is grabby, pulses, has chatter, or otherwise exerts varying brake force may lead to skids. For example, railroad wheels have little traction, and friction brakes without an anti-skid mechanism often lead to skids, which increases maintenance costs and leads to a "thump thump" feeling for riders inside.

5) Power:

Brakes are often described as "powerful" when a small human application force leads to a braking force that is higher than typical for other brakes in the same class. This notion of "powerful" does not relate to continuous power dissipation, and may be confusing in that a brake may be "powerful" and brake strongly with a gentle brake application, yet have lower (worse) peak force than a less "powerful" brake

6) Pedal Feel:

Brake pedal feel encompasses subjective perception of brake power output as a function of pedal travel. Pedal travel is influenced by the fluid displacement of the brake and other factors.

7) Drag:

Brakes have varied amount of drag in the off-brake condition depending on design of the system to accommodate total system compliance and deformation that exists under braking with ability to retract friction material from the rubbing surface in the off-brake condition.

8) Durability:

Friction brakes have wear surfaces that must be renewed periodically. Wear surfaces include the brake shoes or pads, and also the brake disc or drum. There may be tradeoffs, for example a wear surface that generates high peak force may also wear quickly.

9) Weight:

Brakes are often "added weight" in that they serve no other function. Further, brakes are often mounted on wheels, and unsprung weight can significantly hurt traction in some circumstances. "Weight" may mean the brake itself, or may include additional support structure.

10) Noise:

Brakes usually create some minor noise when applied, but often create squeal or grinding noises that are quite loud

F. Advantages:

- High accuracy of doing braking.
- Reducing the braking distance.
- The uniformity of braking effort.
- Reducing the response time of braking mechanisms.
- Improved heat dissipation.
- Independence from the weather and road conditions.
- Longer life abrasive pads and discs.
- Greater braking power.
- Ease of maintenance and replacement pads.
- Cooling more rapid.
- Self-adjusting service

G. Disadvantages:

- Price High.
- These brakes are not sticky.
- Rotors warp easier.
- Not self-energizing.
- Hard to use as parking brakes

H. Objectives:

- The given disk brake rotor of its stability and rigidity
- Best combination of parameters of disk brake rotor like, Wall thickness and material there by a best combination is suggested.
- Design of the rotor component for a disc brake system using load analysis, stress analysis and thermal analysis system approach.
- Heat absorption and dispersion
- Federal Safety Requirements
- Price
- Increase pad and rotor life

II. DESIGN OF DISC BRAKE

A. A Design of Disc Brake for Find Suitable Dimensions Calculation- Disc Brake Standard:

In this project study standard of two wheeler name "BAJAJ" model PLUSOR Factor;

- Rotor disc dimension = 240 mm.
- (Rotor disc material = Gray cast iron)
- Pad brake area = 2000 mm2 (2000×10-6 m)
- Pad brake material = Asbestos
- Coefficient of friction (Wet) = 0.08-0.12
- Coefficient of friction (Dry) = 0.2-0.5
- Maximum temperature = 250 ºC
- Maximum pressure = 1 MPa (106 Pa)

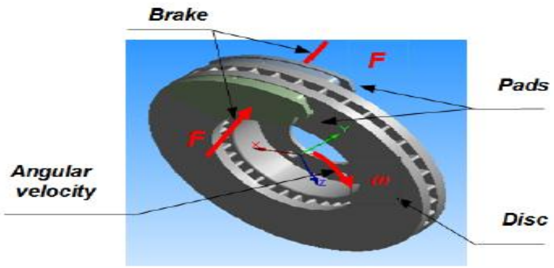


Fig. 2: Forces act on Disc Brake During Rotation

1) *Tangential Force:*

a) *Tangential Force Between Pad And Rotor. (Inner Face), FTRI:*

FTRI = µ1.FRI
Where FTRI = Normal force between pad brake and rotor (inner)
µ1 = Coefficient of friction = 0.5
FRI = Pmax/2 × Apad brake area
So, FTRI = µ1.FRI
FTRI = (0.5) (0.5) (1×106 N/m2) (2000×10-6 m2)
FTRI = 500 N.

b) *Tangential Force between Pad and Rotor (Outer Face), FTRO:*

In this FTRO equal FTRI because same normal force and same material.

B. Brake Torque (TB):

With the assumption of equal coefficients of friction and normal forces FR on the inner and outer faces:

TB = FT.R

Where TB = Brake torque
µ = Coefficient of friction
FT = Total normal forces on disc brake, FTRI + FTRO
FT = 1000 N.
R = Radius of rotor disc.
So, TB = (1000) (120×10-3)
TB = 120 N.m

C. Brake Distance (x):

We know that tangential braking force acting at the point of contact of the brake, and

Work done = FT. x

Where FT = FTRI + FTRO
x = Distance travelled (in meter) by the vehicle before it come to rest.
We know kinetic energy of the vehicle.

Kinetic energy = (mv2) / 2 (Equation B)

Where m = Mass of vehicle
v = Velocity of vehicle

In order to bring the vehicle to rest, the work done against friction must be equal to kinetic energy of the vehicle. Therefore equating (Equation A) and (Equation B)

FT. x = (mv2) / 2

Assumption v = 100 km/hr = 27.77 m/s
M = 132 kg. (Dry weight)

So we get x = (mv2) / 2 FT

x = (132×27.772)/ (2×1000) m.
x = 50.89 m

D. Rotor Disc Non Standard Calculation:

In this case calculate same rotor disc standard but difference rotor dimension.

~ Rotor disc dimension = 275 mm
FTRI = 500 N.
FTRO = 500 N.
FT = 1000 N.
TB = 137.5 N.m
x = 50.89 m
~ Rotor disc dimension = 300 mm
FTRI = 500 N.
FTRO = 500 N.
FT = 1000 N.
TB = 150 N.m
x = 50.89 m.
~ Rotor disc dimension = 200 mm
FTRI = 500 N.
FTRO = 500 N.
FT = 1000 N.
TB = 100 N.m
x = 50.89 m.
~ Rotor disc dimension = 225 mm
FTRI = 500 N.
FTRO = 500 N.
FT = 1000 N.
TB = 112.5 N.m
x = 50.89 m.
~ Rotor disc dimension = 240 mm
FTRI = 500 N.
FTRO = 500 N.
FT = 1000 N.
TB = 120 N.m
x = 50.89 m.

E. A Calculation Result and Discussion:

Forces and torque analysis on the rotor disc was studied which, are divided by tangential force, brake torque, and the motorcycle's stopping distance. Brake force that can be converted into tangential force during rotation of disc brake. The result of force value on rotor disc by tangential force and the motorcycle's stop distance are similar. When dimension of disc brake was changed, the value of brake torque was different by rotor disc dimension at 300 mm, which has the most value of brake torque, and rotor dimension at 200 mm, which has the least value of brake torque.

Dimensions (mm)	200	225	240	275	300
Brake Torque(Nm)	100	112.5	120	137.5	150

Table 2: Relationships between Dimension of Rotor Disc and Brake Torque

III. DESIGN OF DISC BRAKE FOR MATERIAL SELECTION

The Material Properties of grey Cast Iron:

- Thermal co-efficient of expansion (Kxx) = 1.7039e-5 /°C
- Thermal conductivity (K = 52.0 W / m k
- Specific heat (Cp) = 586.0 J/Kg k
- Density of cast iron (ρ) = 7100 kg/m3
- Tensile strength=137.8 MPA
- Compressive strength=571.87 MPA
- Poisson ratio (υ) = 0.25
- Modulus of Elasticity=
- For Tension=66.144-99.46 MPA
- For Torsion =26.87-38.58 MPA

Calculation-

- Factor Of Safety =(Material Strength)/(Working Stress)
- Assumption FOS=2
- FOS=137.8/Working Stress
- Working Stress=68.9 MPA.

In computational analysis result shows that new disc 5 max stress 25.653 MPA respectively. So design is safe for grey Cast Iron material

Stress=68.9 MPA. ……….. (I)

Properties	Grey Cast Iron
Modulus of elasticity of material(E)-Mpa	1.52 x 1011
Material density (p)- (Kg/m3)	7400
Poisson's ratio	0.211
Thermal Conductivity(k)-(w/m.k)	55
Specific Heat Capacity - (KJ/Kg.K)	0.46

Table 3: Properties of Grey Cast Iron

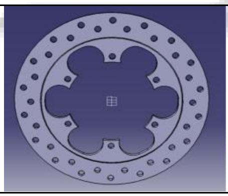
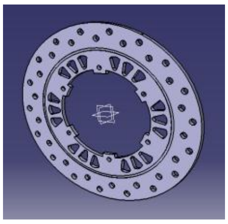
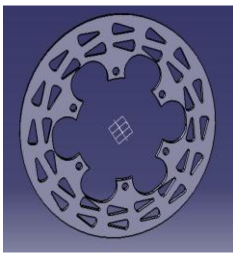
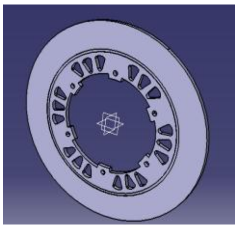
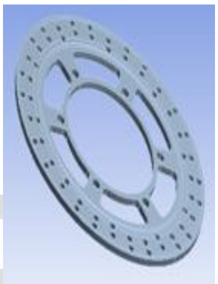
No	Modification	Description
Baseline Original disc		6 holes dia 8 mm arranged equally. There are 36 holes Surrounding disc Dia 8 mm arranged equally. Solid disc
New Disc 1		Original disc brake has been reduces 6 holes dia 6 mm. There are 36 holes Surround Dia 8 mm arranged equally. Original disc brake has been added with 18 cutsecton & changes central structure.
New Disc 2		Original disc brake has been 6 holes dia 8 mm arranged equally same .Original disc brake has been added with cutsection inlet & outlet airflow is large & small respectively. The thickness has been 5mm.
New Disc 3		15 Vanes have been arranged. 15 Elliptical shapes arranged between Vanes clockwise Inlet of air flow & outlet of air flow between the vanes is same. 15 vanes have been arranged clockwise. 15 Elliptical shape arranged between Vanes clockwise
New Disc 4		Original disc brake has been Reduces 6 holes dia 6 mm .There is 36 holes Surrounding disc are not contain. Original disc brake has been added with 18 cutsecton & changes central structure.
New Disc 5		Original disc brake has been Reduces diameter of Surrounding holes 7 mm arranged equally & increases no of holes. There are 60 holes Surrounding disc area. Original disc brake has been added with different cutsecton & changes central structure. Solid disc

Table 4: Disc Structure Modifications

IV. MECHANICAL MODELING

CATIA V5 is mechanical design software, addressing advanced process centric design requirements of the mechanical industry. With its feature based design solutions, CATIA proved to be highly productive for mechanical assemblies and drawing generation. CATIA, with its broad range of integrated solutions for all manufacturing organization. CATIA is the best solution capable of addressing the complete product development process, from product concept specification through product service in a fully integrated and associative manner. CATIA mechanical design solutions provide tools to help you implement a sophisticated standard based architecture

CATIA V5 users access the highest productivity for specific advanced processes with focused solutions.

- Sketcher
- Part design
- Assembly design
- Wireframe and surface design
- Drafting

V. MESHING OF DISC BRAKE

A. *Mesh Generation:*

In the finite element analysis the basic concept is to analyze the structure, which is an assemblage of discrete pieces called elements, which are connected, together at a finite number of points called Nodes. Loading boundary conditions are then applied to these elements and nodes. A network of these elements is known as Mesh.
Symmetry Conditions

B. *Finite Element Generation:*

The maximum amount of time in a finite element analysis is spent on generating elements and nodal data. Pre processor allows the user to generate nodes and elements automatically at the same time allowing control over size and number of elements. There are various types of elements that can be mapped or generated on various geometric entities. The elements developed by various automatic element generation capabilities of pre processor can be checked element characteristics that may need to be verified before the finite element analysis for connectivity, distortion-index etc. Generally, automatic mesh generating capabilities of pre processor are used rather than defining the nodes individually. If required nodes can be defined easily by defining the allocations or by translating the existing nodes. Also on one can plot, delete, or search nodes. The finite element method is numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. Because of its diversity and flexibility as an analysis tool, it is receiving much attention in almost every industry It is not possible to obtain analytical mathematical solutions for many engineering problems. An analytical solutions is a mathematical expression that gives the values of the desired unknown quantity at any location in the body, as consequence it is valid for infinite number of location in the body. For problems involving complex material properties and boundary conditions, the engineer resorts to numerical methods that provide approximate, but acceptable solutions.
The finite element method has become a powerful tool for the numerical solutions of a wide range of engineering problems. It has been developed simultaneously with the increasing use of the high- speed electronic digital computers and with the growing emphasis on numerical methods for engineering analysis. This method started as a generalization of the structural idea to some problems of elastic continuum problem, started in terms of different equations.

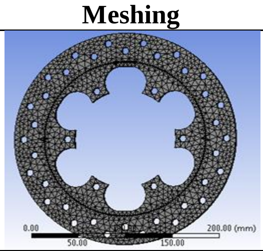
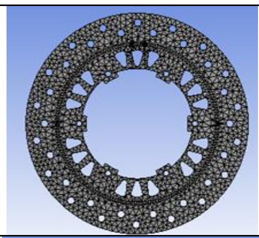
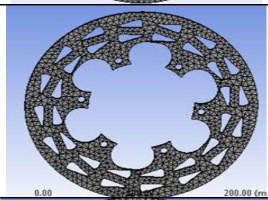
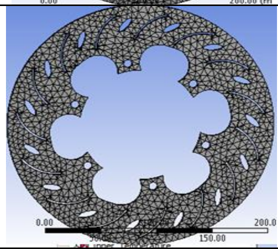
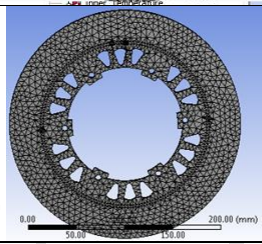
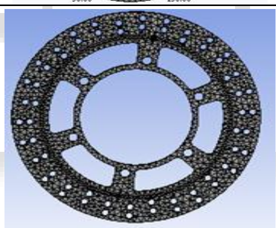
No	Meshing	Nodes	Element
Baseline Original disc		28760	15658
New Disc 1		28811	14907
New Disc 2		16277	7859
New Disc 3		19286	9356
New Disc 4		29036	15450
New Disc 5		28760	13651

Table 5: Brake Disc CONVERTS Finite no of Elements

VI. ANALYSIS OF DISC BRAKE

A. *Structure Analyses by Ansys Software:*

Structural analysis is probably the most common application of FEM. Seven types of structural analysis available in the ANSYS. Families of products are shown below.

1) Static Analysis
2) Modal Analysis
3) Harmonic Analysis
4) Transient Dynamic analysis
5) Spectrum Analysis
6) Buckling Analysis
7) Explicit Dynamics Analysis

B. *Boundary Conditions and Loading:*

In this project study about stress, deformation on rotor disc under condition of static equation. After completion of the finite element model it has to constrain and load has to be applied to the model. User can define constraints and loads in various ways.
This helps the user to keep track of load cases.

1) Force along x-axis
2) Fixed inside surface of hole.
3) Total tangential forces 1000 N.

Material properties reference grey Cast Iron

1) *Stress Distribution Result:*

From figure of stress analysis we found maximum stress at red area and found minimum stress at blue area.

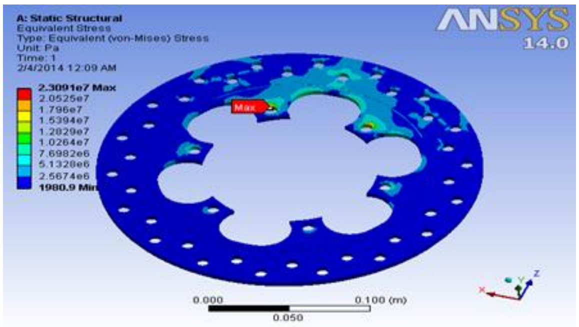


Fig. 2: Stress Distribution of Original Disc

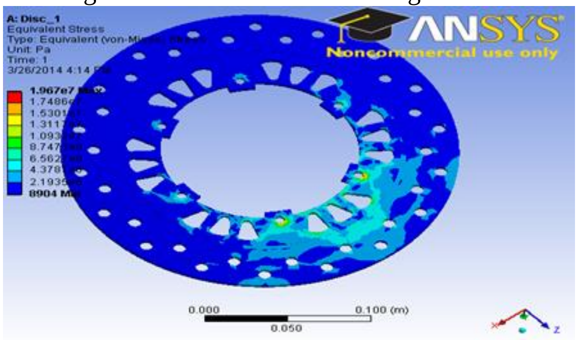


Fig. 3: Stress Distribution of New Disc 1

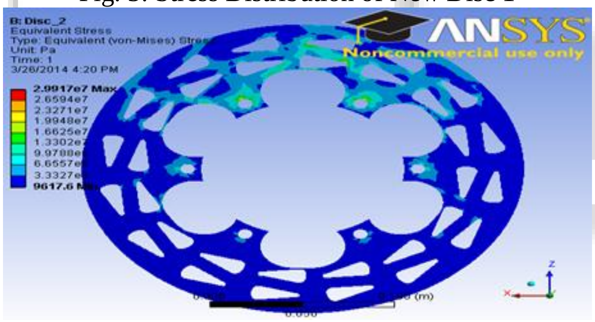


Fig. 4: Stress Distribution of New Disc 2

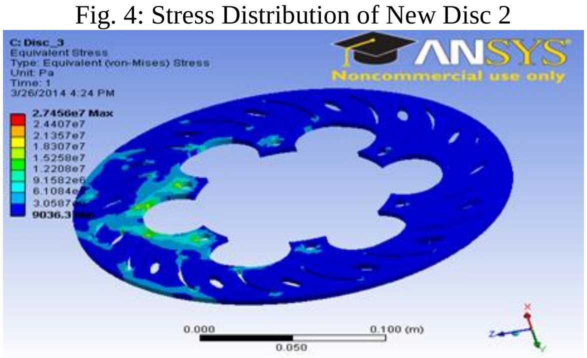


Fig. 5: Stress Distribution of New Disc 3

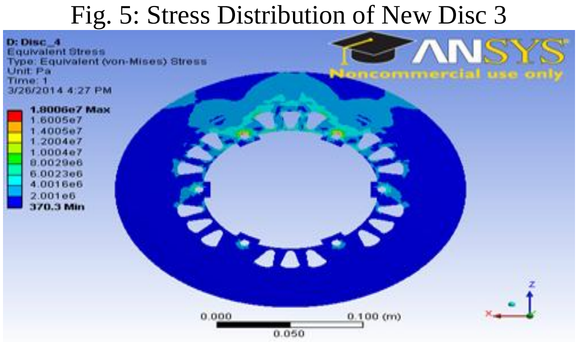


Fig. 6: Stress Distribution of New Disc 4

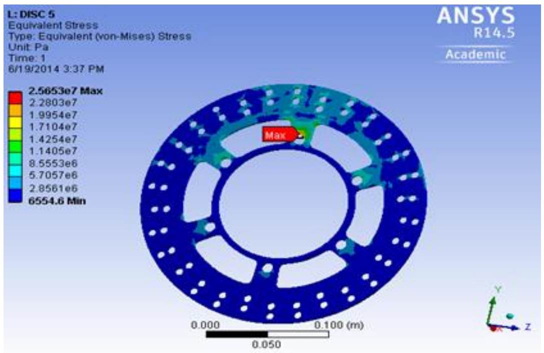


Fig. 7: Stress on New Disc 5

In computational analysis result & above design (I) shows those new disc 5 maxes stress 25.653 MPA respectively. So design is safe for grey Cast Iron material

2) *Deformation:*

From figure of static we found maximum deformation at red area and found minimum deformation at blue area.

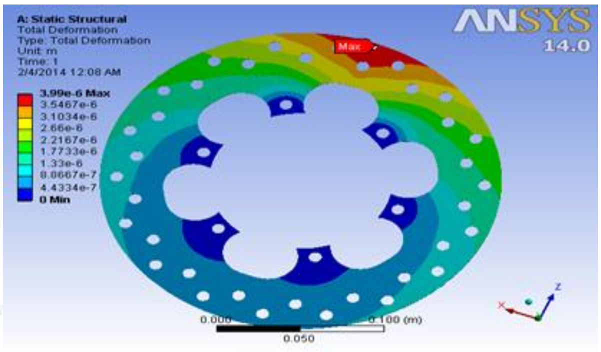


Fig. 8: Deformation on Original Disc

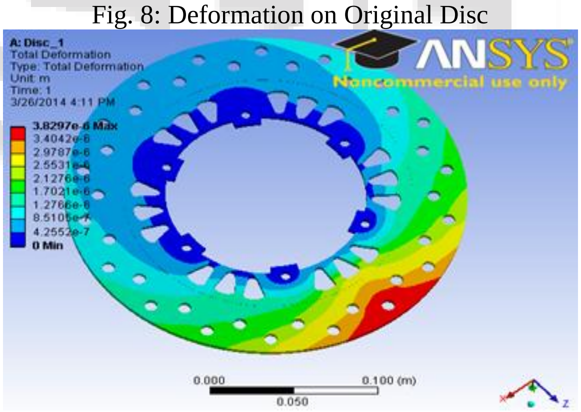


Fig. 9: Deformation on New Disc 1

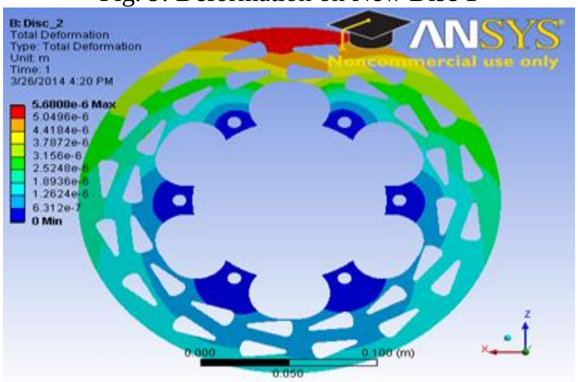


Fig. 10: Deformation on New Disc 2

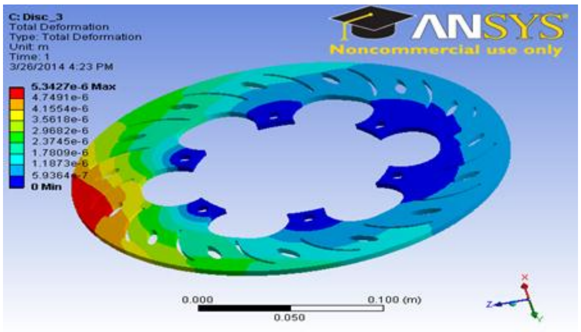


Fig. 11: Deformation on New Disc 3

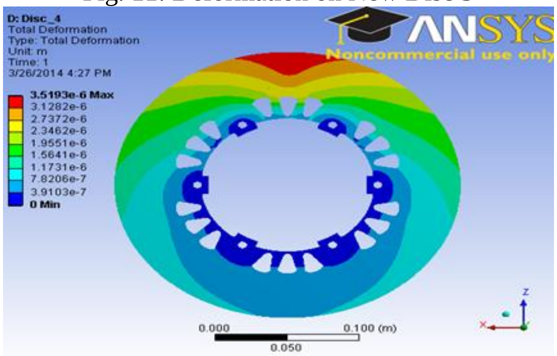


Fig. 12: Deformation on New Disc 4

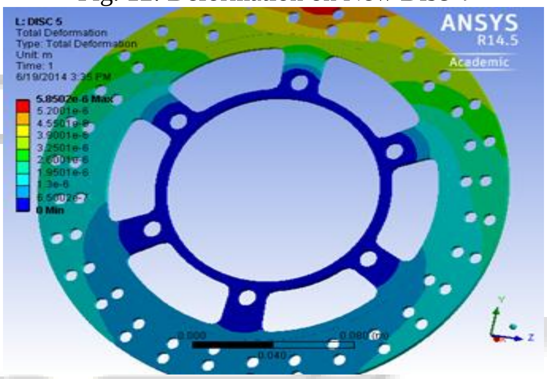


Fig. 13: Deformation on New Disc 5

Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as "3.5-inch disk drive."

Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation

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