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Design and Analysis of Ventilated Disc Brake

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Abstract : *Braking is a technique which converts the kinetic energy of an automobile into mechanical energy, which must dissolute in the form of heat A brake disc usually made of cast iron or ceramic composites, is attached to the wheel. Rubbing material in the form of brake pads is enforced mechanically, hydraulically, pneumatically or electromagnetically in opposition to both sides of the disc and prevents the wheel to rotate. The current study essentially deals with the modeling and analyzing ventilated disc brake by solid works and ANSYS. Finite element (FE) models of the brake-disc are shaped with solid works and simulated using ANSYS which is based on the finite element method (FEM). This study Thermal analysis is done so as to get the strength of the disc brake. The design is found and in thermal analysis, heat flow rates, and heat fluxes are considered by varying the dissimilar cross sections and materials of the disc brake rotor.*
Keywords – *Braking system, Thermal Analysis, Disc Brake, Finite Element Method (FEM), ANSYS.*

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I. INTRODUCTION

In the present developing automotive market the opposition for better execution vehicle is developing colossally. The circle brake is a gadget utilized for moderating or halting the revolution of the wheel. A brake is generally made of cast iron or ceramic composites incorporate carbon, aluminum, Kevlar and silica which are associated with the wheel pivot to stop the vehicle. A grinding material created as brake pads are constrained mechanically, using pressurized water, pneumatically and electromagnetically against the both side of the plate. This contact makes the circle and connected wheel back off. The slowing mechanisms utilized in the vehicle are regenerative stopping mechanism and rubbing stopping mechanism. An erosion brake produces the frictional power in at least two surfaces to rub against each other to diminish the development. In view of the plan arrangements vehicle rubbing brakes are assembled into plate brakes and drum brakes. Our undertaking worries about circle brakes demonstrating and examination.

Tedious braking of a vehicle creates expansive measure of warmth. This warmth must be dispersed for better execution of brake. Braking execution to a great extent influenced by the temperature ascend in the brake segments. High temperature may cause warm breaks, brake blur, wear and decrease in coefficient of rubbing.

Amid braking, the motor and potential energies of a moving vehicle get changed over into warm vitality through erosion in the brakes. The warmth produced between the brake pad and circle must be disseminated by disregarding air them. This warmth exchange happens by conduction, convection and to some degree by radiation. To accomplish appropriate cooling of the plate and the pad by convection, investigation of the warmth transport wonder between circle, pad and the air medium is fundamental. At that point it is vital to investigate the warm execution of the plate brake framework to foresee the expansion in temperature amid braking. Convective warmth exchange show has been created to break down the cooling execution. Brake circles are furnished with various plans with various examples to build the territory of contact with the air for the better warmth exchange.

In this venture three diverse outline examples of circle rotors are contemplated for better heat dissipation rate. Heat dissipation rate increments with number of cuts in the circle. This is on the grounds that expansive region is presented to air which makes more warmth exchange through conduction and convection. As more number of cuts increments in the plate brake prompts an issue by lessening the quality of the circle.

II. WRITING REVIEW

Gao and Lin (2002) presented Transient temperature field analysis of a brake in a non-axisymmetric three-dimensional model [1]. An analytical model is presented in this paper for the determination of the contact temperature distribution on the working surface of a brake. To consider the effects of the moving heat source (the pad) with relative sliding speed variation, a transient finite element technique is used to characterize the temperature fields of the solid rotor with appropriate thermal boundary conditions. Numerical results shows that the operating characteristics of the brake exert an essentially influence on the surface temperature distribution and the maximal contact temperature.

Voller, et al.(2003) perform an Analysis of automotive disc brake cooling characteristics[2].The aim of this investigation was to study automotive disc brake cooling characteristics experimentally using a specially developed spin rig and Singh and Shergill 85 numerically using finite element (FE) and computational fluid dynamics (CFD) methods. All three modes of heat transfer (conduction, convection and radiation) have been analyzed along with the design features of the brake assembly and their interfaces. The influence of brake cooling parameters on the disc temperature has been investigated by FE modeling of a long drag brake application. The thermal power dissipated during the drag brake application has been analyzed to reveal the contribution of each mode of heat transfer.

Zaid, et al. (2009) presented a paper on an investigation of disc brake rotor by Finite element analysis. In this paper, the author has conducted a study on ventilated disc brake rotor of normal passenger vehicle with full load of capacity [6]. The study is more likely concern of heat and temperature distribution on disc brake rotor. In this study, finite element analysis approached has been conducted in order to identify the temperature distributions and behaviors of disc brake rotor in transient response. Thus, this study provide better understanding on the thermal characteristic of disc brake rotor and assist the automotive industry in developing optimum and effective disc brake rotor.

III. BACK GROUND HYPOTHESIS

3.1. Braking system

A brake is a machine which generates non-natural frictional resistance on a moving device element to prevent the movement of a machine. In this course of action the brakes take up either kinetic energy of the moving element or the potential energy given up by objects being lowered by heaves elevators etc. The energy captivated by disc brake is dissolute in the form of heat. This heat is disseminated into the encompassing climate to stop the vehicle, so a perfect stopping mechanism ought to have the accompanying prerequisites:

i. The brakes must be strong enough to stop the vehicle with in a minimum Distance in an emergency.
ii. The driver must have proper control over the vehicle during braking and the vehicle must not skid.
iii. The brakes must have good ant fade characteristics i.e. their effectiveness should not decrease with constant prolonged application
iv. The brakes should have good anti-wear properties.

Based on mode of operation brakes are classified as follows:

1. Hydraulic brakes,
2. Electric brakes,
3. Mechanical brakes.

The mechanical brakes according to the direction of acting force may be sub divided into the following two groups:

i. Radial brakes: In these brakes the force acting on the brake drum is in radial direction. The radial brake may be subdivided into external brakes and internal brakes.

ii. Axial brakes: In these brakes the force acting on the brake drum is only in the axial direction.

E.g. Disc brakes Cone brakes.

3.1.1 Disc Brakes:

A circle brake contains a plate shot to the wheel focus point and a stationary hotel called caliper. The caliper is related with some stationary bit of the vehicle, like the rotate bundling or the stub center point and is tossed in two segments, each part containing a cylinder. Amidst each cylinder and the hover, there is a contact pad held in position by holding pins, spring plates et cetera passages are infiltrated in the caliper for the fluid to enter or leave each cabin. These passages are also connected to another one for bleeding. Each cylinder contains rubber-sealing ring between the cylinder and piston. A schematic diagram is shown in the figure (1).

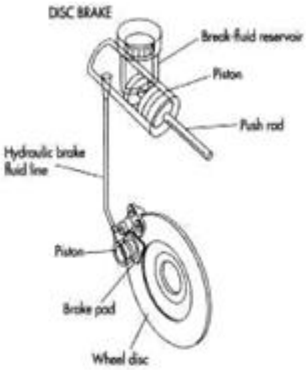


Figure (1) Braking System of Two Wheeler

The disc brake is a wheel brake which slows rotation of the wheel by the friction caused by pushing brake pads against a brake disc with a set of calipers. The brake disc (or rotor in American English) is usually made of cast iron, but may in some cases be made of composites such as reinforced carbon–carbon or ceramic matrix composites. This is connected to the wheel and/or the axle. To stop the wheel, friction material in the form of brake pads, mounted on a device called a brake caliper, is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop. Brakes convert motion to heat, and if the brakes get too hot, they become less effective, a phenomenon known as brake fade. Disc-style brakes development and use began in England in the 1890s. The first caliper-type automobile disc brake was patented by Frederick William Lanchester in his Birmingham, UK factory in 1902 and used successfully on Lanchester cars. Compared to drum brakes, disc brakes offer better stopping performance, because the disc is more readily cooled. As a consequence discs are less prone to the "brake fade"; and disc brakes recover more quickly from immersion (wet brakes are less effective). Most drum brake designs have at least one leading shoe, which gives a servo effect. By contrast, a disc brake has no self-servo effect and its braking force is always proportional to the pressure placed on the brake pad by the braking system via any brake servo, braking pedal or lever, this tends to give the driver better "feel" to avoid impending lockup. Drums are also prone to "bell mouthing", and trap worn lining material within the assembly, both causes of various braking problems.

3.1.2 Brake Pads

Brake cushions change over the dynamic vitality of the vehicle into warm vitality in perspective of the contact. Brake caliper contains two brake cushions with their grinding surfaces going up against the rotor. Right when the brakes are associated using power through weight or some other vitality source, the caliper joins the two cushions into the turning rotor and rubs them to direct/stop the vehicle. Exactly when a brake cushion is warmed when it gets came to with a rotor, it trades little proportions of contact material to the circle, turning it dull dim. The brake cushion and plate (both now with contact material), by then "stick" to each other, giving the grinding that stops the vehicle.
The different types of brake pads that are most commonly used can be found below.

i. Metallic pads – metallic pads are undoubtedly the most common variety of brake pads and are found on many of today's vehicles. A unique blend of different metals creates metallic brake pads and they're affordable, durable and offer good performance. They're best installed on small vehicles that don't witness very aggressive driving.
ii. Organic pads – organic pads are made up of organic materials like rubber, glass and resin which as the binding agent. Asbestos was the material of choice in earlier years as it dissipated heat well. However, the dust created was dangerous to health and the environment so it was replaced by more natural materials. Unlike metallic pads, organic pads are lightweight and produce very little noise. They're ideal for small vehicles and vehicles that don't see a lot of aggressive driving. However, their softness means they wear out faster so more dust is produced.
iii. Ceramic pads – ceramic brake pads are recommended for high performance vehicles that witness sharp turns, high speeds and frequent stops. Ceramic pads are the most expensive of the brake pads that are available as a consequence of its high performance and this means that they are usually found on performance or racing cars as their distinctive advantages are best suited to these performance models.

3.2. Heat transference:

When a system is at a different temperature than its surroundings, the Nature tries to reach thermal equilibrium. To do so, as the second law of thermodynamics explains, the thermal energy always moves from the system of higher temperature to the system of lower temperature.

This transfer of thermal energy occurs due to one or a combination of the three basic heat transport mechanisms: Conduction, Convection and Radiation.

$$q = -hA(T_\infty - T_s)$$

3.2.1. Conduction:

Is the transference of heat through direct molecular communication, i.e. by physical contact of the particles within a medium or between medium. It takes place in gases, liquids and solids. In conduction, there is no flow of any of the material mediums. The governing equation for conduction is called the Fourier's law of heat conduction and it express that the heat flow per unit area is proportional to the normal temperature gradient, where the proportionality constant is the thermal conductivity:

$$q = -kA\frac{\partial T}{\partial x}$$

Where q is the heat flux perpendicular to a surface of area A, [W]; A is the surface area through which the heat flow occurs, [m2] ; k is the thermal conductivity, [W/(mK)]; T is the temperature, [K] or [°C]; and x is the perpendicular distance to the surface traveled by the heat flux.

3.2.2. Convection:

Convection is the heat transfer by mass motion of a fluid, when the heated fluid moves away from the heat source. It combines conduction with the effect of a current of fluid that moves its heated particles to cooler areas and replace them by cooler ones. The flow can be either due to buoyancy forces (natural convection) or due to artificially induced currents (forced convection).The equation that represents convection comes from the Newton's law of cooling and is of the form:

Where h is the convective heat transfer coefficient [W/ (m2K)]; T_∞ is the temperature of the cooling fluid; and Ts is the temperature of the surface of the body.

3.2.3. Radiation:

In general, radiation is energy in the form of waves or moving subatomic particles. Among the radiation types, we are specifically interested in the Thermal radiation. Thermal radiation is heat transfer by the emission of electromagnetic waves from the surface of an object due to temperature differences which carry energy away from the emitting object. The basic relationship governing radiation from hot objects is called the Stefan-Boltzmann law:

$$q = -hA(T_\infty - T_s)$$

Where ε is the coefficient of emissivity (=1 for ideal radiator); σ is the Stefan-Boltzmann constant of proportionality (5.669E-8 [W/(m2K4)]); A is the radiating surface area; T1 is the temperature of the radiator; and T2 is the temperature of the surroundings.

3.3. Material used for disc brake manufacturing

Properties to be considered

1. Coefficient of friction,
2. Wear rate,
3. Heat resistance,
4. Withstanding pressure.
5. Heat dissipation.
6. Thermal expansion,
7. Mechanical strength,
8. Moisture.

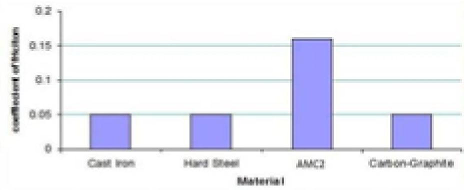
There have been two principal materials used for their production in recent years. Cast Iron and Stainless Steel.

3.3.1Cast Iron:

Cast iron is more affordable and gives great friction coefficients however cast iron is delicate, it isn't good with numerous cutting edge cushion materials, especially sintered cushions, cast iron is overwhelming and it likewise rusts. Dark cast iron plates can smash and bendable cast iron is delicate, extremely whimsical with cushions and we would say can twist effectively. We appropriated a scope of plates produced using pliable cast iron for quite a long while and needed to return unreasonably numerous that were distorted. The appropriate response more often than not returned that the issue had happened because of the utilization of improper cushions yet in all actuality it occurred awfully regularly.

3.3.2 Stainless Steel:

Stainless steel is minimal more costly and has part more focal points. It doesn't rust, or if nothing else not to any incredible degree. It is exceptionally hearty; it is perfect with all brake cushions and especially to sintered brake cushions. It is profoundly impervious to wear, it doesn't smash and it opposes warm exceptionally well. When it was first utilized the friction coefficients were not on a par with cast iron and this persuades some that cast iron is as yet the correct material. In any case, I got some information about it and he stated, that was genuine 30 years prior however the friction coefficients of stainless steel plates and sintered cushions went past cast iron around 20 years back Not surprisingly, for verification he indicated the race results and called attention to that except for carbon circles in GP, Since they are the triumphant brakes in relatively every real title year in year out it is hard to contend. The correct determination they utilize has never been discharged however it is made particularly for them.



Graph 2.1: Material analysis

3.4. Manufacturing process:

In current days, the utilization of metal is huge and there are a variety of techniques of manufacturing a product from only use of clean molten metal or from any other state of metal as well. When considering the dissimilar techniques of manufacturing, the majority of accepted techniques that are used in outsized commerce are as follows:

i. Metal Casting,
ii. Metal Forming and shaping,
iii. Fabrication and welding

The above mentioned are few that are used by industries to produce different products that could make up a machine such as a vehicle, electronic components or other day to day tools.

3.4.1. Dissimilar Models:

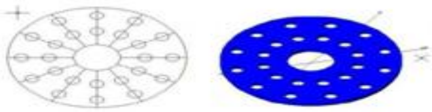


Figure2.2: Inclined row drilled disc.

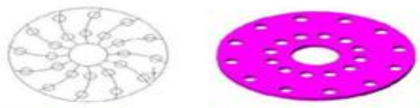


Figure 2.3: Curved row of drilled disc.

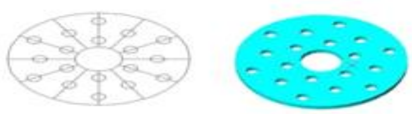


Figure2.4: Crossed row of drilled disc


Figure2.5: Slotted disc.


Figure2.6: Slot and drilled disc.


Figure2.7: Inclined row of slotted disc.

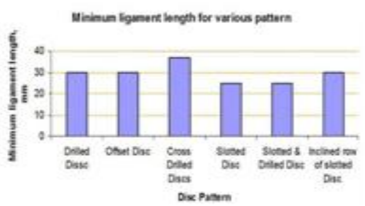


Figure 2.8: Minimum alignment

IV. FINITE ELEMENT METHOD

4.1 Introduction to finite element method:

The finite element technique is an awesome gadget to procure the numerical game plan of broad assortment of planning issue. The technique is adequately broad to manage any complex shape or geometry, for any material under different limit and stacking conditions. The improvement of the finite element strategy fits the investigation need of the present complex building structures and diagrams where closed shape courses of action of administering balance conditions are normally not open. Moreover, it is capable arrangement instruments by which originators can perform parametric framework ponders by considering diverse arrangement cases, (unmistakable shapes, materials, burdens, et cetera.) and inspect them to pick the perfect arrangement.

4.2. General system of finite element method:

The finite element technique is a strategy for piecewise gauge in which the structure or body is disengaged into little elements of finite estimations considered finite elements and a while later the primary body or the structure is considered as a social affair of these elements related at finite number of joints called nodal centers or centers. Since the genuine assortment of field factors like movement, push, temperature, weight or speed inside the continuum are not known, the assortment of the field variable inside a finite element can be approximated by a clear limit. These gauge limits called expansion models are described the extent that the estimations of the field components of the center points. The nodal estimations of the field variable are gotten by unwinding the field conditions, which are all things considered as structure conditions.

4.3. Joining need:

The finite element technique gives a numerical response for a complex issue. It may along these lines be ordinary that the course of action must center to the right arrangement of the structure. In this manner as the work is improved the game plan should converge to the correct result and this would be refined if the going with three conditions were satisfied by the acknowledged removing limit.

4.4. Advantages of FEM:

The properties of every element are assessed independently, so a conspicuous favorable position is that we can consolidate distinctive material properties for every element. In this way any level of non-homogeneity can be incorporated. There is no limitation on to the state of medium; subsequently self-assertive and sporadic shapes because no trouble like every numerical estimate FEM depends on the idea of depiction. By and by as the varieties or leftover approach, the innovation perceives the multidimensional consistent yet additionally requires no different insertion procedure to stretch out the inexact answer for each point with the continuum. One of the essential favorable circumstances of FEM is that it makes utilization of limit conditions as amassed conditions. This is moderately a simple procedure and requires no extraordinary innovation. As opposed to requiring each preliminary answer for fulfill limit conditions, one recommends the conditions in the wake of acquiring the arithmetical conditions for person's limited elements.

4.5. Limitations in FEM:

FEM achieved abnormal state of improvement as arrangement innovation; anyway the strategy yields sensible outcomes just if coefficient or material parameters that depict essential wonders are accessible. The dreariest parts of utilization of FEM are fundamental procedure of sub-isolating the continuum of producing mistake free information for PC.

4.6. Utilizations of FEM:

The limited element technique was produced initially for the investigation of flying machine structures. In any case, the general idea of its hypothesis makes it relevant to wide assortment of limit esteem issue in building. A limit esteem issue is one in which an answer is looked for in area or locale of a body subject as per the general inclination of endorsed limit conditions.

V. FEA SOFTWARE – ANSYS

5.1. Introduction to ANSYS Program:

Dr. John Swanson established ANSYS. Inc. in 1970 with a dream to popularize the idea of computer simulated engineering, setting up himself as one of the pioneers of Finite Element Analysis (FEA). ANSYS Inc. bolsters the progressing advancement of imaginative innovation and conveys adaptable, undertaking wide engineering frameworks that empower organizations to understand the full scope of investigation issue, boosting their current interests in programming and equipment.

5.2. Advancement of ANSYS Program:

ANSYS has advanced into multipurpose outline examination programming program, perceived the world over for its numerous abilities. Today the program is amazingly intense and simple to utilize. Each discharge has new and upgraded capacities that make the program more adaptable, more usable and speedier. Along these lines ANSYS enables architects to meet the weights and requests current item improvement condition.

5.3. Outline of the program:

The ANSYS program is adaptable, strong plan examination and streamlining bundle. The product works on significant computers and working frameworks, from PCs to workstations and to super computers. ANSYS highlights record similarity all through the group of items and over all stages. ANSYS plan information get to empowers client to import computer helped configuration models in to ANSYS, dispensing with rehashed work. This guarantees undertaking wide, adaptable engineering answer for all ANSYS client. There are four graphical methods to instruct the ANSYS program:

i. Menus

ii. Dialog Boxes

iii. Tool bar

iv. Direct input of commands.

5.4. Decreasing the plan and assembling costs using ANSYS (FEA):

The ANSYS program empowers pros to assemble PC models or trade CAD models of structures, things, parts, or systems, apply loads or other diagram execution conditions and focus physical responses, for instance, sentiments of uneasiness, temperature dispersal or the impact of vector alluring fields. In a couple of circumstances, demonstrate testing is undesirable or stunning. The ANSYS program has been used in a couple of occurrences of this create including biomechanical applications, for instance, hello substitution intraocular central focuses. Other specialist applications go from overpowering apparatus parts, to a joined circuit chip, to the bit-holding game plan of a consistent coal-mining machine.

Program availability:

The ANSYS program operates on Pentium based PCs running on Wndows95 or Windows NT and workstations and super computers primarily running on UNIX operating system. ANSYS Inc. continually works with new hardware platforms and operating systems**.**

Analysis types available:

1. Structural static analysis.
2. Structural dynamic analysis.
3. Structural buckling analysis.
4. Linear buckling
5. Nonlinear buckling
6. Structural non linearity's.
7. Static and dynamic kinematics analysis.
8. Thermal analysis.
9. Electromagnetic field analysis.
10. Electric field analysis
11. Fluid flow analysis
12. Computational fluid dynamics
13. Pipe flow
14. Coupled-field analysis
15. Piezoelectric analysis.

5.5. Procedure for ANSYS analysis:

Static analysis is utilized to decide the relocations, stresses, strains and powers in structures or parts because of burdens that don't initiate noteworthy idleness and damping impacts. Unfaltering stacking accordingly conditions are expected.

The procedure for static analysis consists of these main steps:

i. Building the model.

ii. Obtaining the solution.

iii. Reviewing the results.

5.6. Build the model

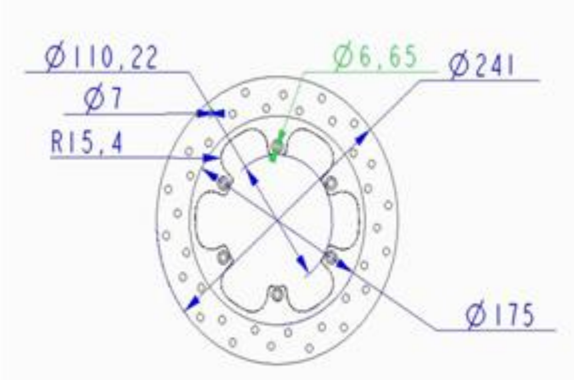


Figure 5.1 Schematic Diagram of a Disc brake

In this step we specify the job name and analysis title use PREP7 to define the element types, element real constants, material properties and model geometry element types both linear and non-linear structural elements are allowed. The ANSYS element library contains over 80 different element types. A unique number and prefix identify each element type. E.g. BEAM 3, PLANE 55, SOLID 45 and PIPE 16.

5.7. Material properties:

Young's modulus(EX) must be characterized for a static investigation .If we intend to apply idleness loads(such as gravity) we characterize mass properties, for example, density(DENS).Similarly in the event that we intend to apply warm loads (temperatures) we characterize coefficient of warm expansion(ALPX).

5.8 Obtain the arrangement:

In this progression we characterize the investigation compose and alternatives, apply loads and start the finite element arrangement. This includes three stages:
a) Pre – processor stage
b) Solution stage
c) Post-processor stage

5.8.1. Pre – Processor:

Preprocessor has been created with the goal that a similar program is accessible on smaller scale, little, super-smaller than normal and centralized computer PC framework. This moderates simple exchange of models one framework to other. Preprocessor is an intuitive model manufacturer to set up the FE (finite element) model and information.

5.8.1.1. Geometrical definitions:

There are four diverse geometric elements in preprocessor to be specific key focuses, lines, regions and volumes. These elements can be utilized to get the geometric portrayal of the structure. Every one of the substances is free of other and has special recognizable proof names.

5.8.1.2. Demonstrate ages:

Two distinct strategies are utilized to create a model:
a) Direct age.
b) Solid displaying
With strong displaying we can portray the geometric limits of the model, build up controls over the size and wanted state of the elements and after that educate ANSYS program to create every one of the hubs and elements consequently.

5.8.1.3. Mesh generation:

In the finite element investigation the essential idea is to break down the structure, which is a collection of discrete pieces called elements, which are associated, together at a finite number of focuses called Nodes. Loading boundary conditions are then connected to these elements and hubs. A system of these elements is known as Mesh.

5.8.1.4. Finite element generation:

The greatest measure of time in a finite element investigation is spent on creating elements and nodal information. Preprocessor enables the client to create hubs and elements consequently in the meantime permitting control over size and number of elements. There are different kinds of elements that can be mapped or produced on different geometric elements.

5.8.1.5. Boundary conditions and loading:

After finish of the finite element show it needs to oblige and stack must be connected to the model. Client can characterize limitations and loads in different ways. All requirements and burdens are appointed set 1D. This causes the client to monitor stack cases.

5.8.1.6. Model display:

Amid the development and check phases of the model it might be important to see it from various points. It is helpful to pivot the model regarding the worldwide framework and view it from various edges. Preprocessor offers this ability. By windowing highlight preprocessor enables the client to amplify a particular territory of the model for lucidity and points of interest

5.8.1.7. Material definitions:

All elements are characterized by hubs, which have just their area characterized. On account of plate and shell elements there is no sign of thickness. This thickness can be given as element property. Property tables for a specific property set 1-D must be input. Distinctive kinds of elements have diverse properties for e.g. Pillars: Cross sectional zone, snapshot of inactivity and so forth. Shells: Thickness Springs: Stiffness Solids: None.

5.8.2. Solution:

The solution stage manages the solution of the issue as per the issue definitions. All the repetitive work of planning and amassing of grids are finished by the PC lastly removals and stress esteems are given as yield. A portion of the abilities of the ANSYS are direct static investigation, non-straight static examination, transient powerful examination, and so forth.

5.8.3. Post – Processor:

It is a great easy to use post-preparing program utilizing intuitive shading designs. It has broad plotting highlights for displaying the outcomes got from the finite element investigation. One photo of the examination results (i.e. the outcomes in a visual frame) can frequently uncover in seconds what might take an architect hour to asses from a numerical yield, say in forbidden Shape.

VI. DISC BRAKE CALCULATION

6.1. ASSUMPTIONS:

1. The analysis is prepared by considering the circulation of the braking torque involving the front wheel and back wheel.
2. Brakes are applied on the front wheel only.
3. The examination is based on thermal load. The analysis does not conclude the reliability of the disc brake.
4. No enforced convection is taken.
5. The kinetic energy of the automobile is gone through the brake discs i.e. no heat loss between the tyres and
6. The road surface and the deceleration are uniform.
7. The disc brake models are different material.
8. The thermal conductivity of the material used for the analysis is consistent throughout.
9. The specific heat of the material used is steady all through and does not alter with the heat.

10 Heat flux on every front wheel is applied on one side of the disc only.

6.2. Calculation for input parameters:

`In the characteristic of the accident avoidance, the braking function of automobiles has been a serious concern. The rotor replica heat flux is considered for the automobile speeding with a velocity of 100km/h and the below is the calculations.

Procedure:

Data:

- Mass of the vehicle = 132 kg
- (u)= 27.77 m/s (100 km/h)
- speed after braking (v) = 0 m/s
- g =9.81m/s2
- Coefficient of friction for dry pavement μ=0.45
- Diameter of the rotor disc- 241mm
- Rotor disc material- cast iron and stainless steel

- Coefficient of friction (μ)- stainless steel - 0.5, cast iron - 0.5
- Maximum temperature - 350o c, Maximum pressure- 1Mpa

Tangential force between the brake pad and rotor:

FTRI= normal force between brake pad and rotor

μ = coefficient of friction = 0.5

A = pad brake area = 0.0067 m2

FTRI = μ.FRI ----------- EQ (1)

FRI = (Pmax /2) ×A --------EQ (2)

FTRI = μ.FRI

FTRI = 0.5 × 0.5 × 1E6 × 0.0067 = 1675N

Tangential force between the pad and rotor is equal to FTRI because of the same normal force and material.

Brake torque Tb = FT.R

FT is the normal forces on the disc brake = 1675N

R is the radius of the rotor

Tb = FT.R

= 1675 × (120× 10e-3) = 201NM

Brake distance:

Work done = FT ----------EQ (4)

FT = normal forces acting on the disc brake.

X = distance travelled by vehicle before coming to rest.

Kinetic energy = mv2. /2 -----------EQ(5)

Where, m = mass of the vehicle

v = velocity of the vehicle

Comparing EQ (4) and EQ (5)

FT.X = mv2. /2

V = 100 km/h = 27.77 m/s

Mass = 132kg X = mv2/ 2FT

= 132 × 27.772/ (2 × 1675)

= 30.38m

Thermal calculations:

Heat generated through braking:

Heat generated in rotor (J/S)

Q = m. CP. ΔT ---------------EQ (6)

Heat flux (W/M2)

Heat flux = Q/A

Mass of the disc	Stainless steel	Cast iron
Model 1	1.3kg	1.2kg
Model 2	1.26kg	1.18kg
Model 3	1.36kg	1.22kg

Stainless steel calculations:	**Cast iron calculations:**
Model 1 calculation: Heat generated in rotor (J/S) Q = m. CP. ΔT ---------------EQ (6) Heat flux (W/M2) Heat flux = Q/A m = mass of the disc = 1.3kg ΔT = Temperature difference = 15oc A = 0.06328 m2 Specific heat = 320 J/kg k Q = m. CP. ΔT = 1.3 × 320 × 15 = 6240J Heat flux = (heat generated/sec)/ Area of the disc= (6232/5)/ 0.06328 = 19696 W/m2 Thermal Gradient = Heat flux / Thermal conductivity = 19696 / 36 = 547.12 k/m	**Model 1 calculation:** Heat generated in rotor (J/S) Q = m. CP. ΔT ---------------EQ(6) Heat flux (W/M2) Heat flux = Q/A m = mass of the disc = 1.2kg ΔT = Temperature difference = 15oc A = 0.06328 m2 Specific heat = 380 J/kg k Q = m. CP. ΔT = 1.2 × 380 × 15 = 6840J Heat flux = (heat generated/sec)/ Area of the disc = (6840/5)/ 0.06328 = 21618 W/m2 Thermal Gradient = Heat flux / Thermal conductivity = 21618 / 50 = 432.36 k/m

Model 2 calculation: Heat generated in rotor (J/S) Q = m. CP. ΔT ---------------EQ(6) Heat flux (W/M2) Heat flux = Q/A m = mass of the disc = 1.26kg ΔT = Temperature difference = 15oc A = 0.05892 m2 Specific heat = 320 J/kg k Q = m. CP. ΔT = 1.26 × 320 × 15 = 6048J Heat flux = (heat generated/sec)/ Area of the disc = (6048/5)/ 0.05892 = 20529 W/m2 Thermal Gradient = Heat flux /Thermal conductivity =20529 / 36 = 570.26 k/m	**Model 2 calculation:** Heat generated in rotor (J/S) Q = m. CP. ΔT ---------------EQ(6) Heat flux (W/M2) Heat flux = Q/A m = mass of the disc = 1.18kg ΔT = Temperature difference = 15oc A = 0.05892 m2Specific heat = 380 J/kg k Q = m. CP. ΔT = 1.18 × 380 × 15 = 6726J Heat flux = (heat generated/sec)/ Area of the disc = (6726/5)/ 0.05892 = 22830 W/m2 Thermal Gradient = Heat flux / Thermal conductivity = 22830 / 50 = 456.61 k/m
Model 3 calculation: Heat generated in rotor (J/S) Q = m. CP. ΔT ---------------EQ(6) Heat flux (W/M2) Heat flux = Q/A m = mass of the disc = 1.36kg ΔT = Temperature difference = 15oc A = 0.06628 m2 Specific heat = 320 J/kg k Q = m. CP. ΔT = 1.36 × 320 × 15 = 6048J Heat flux = (heat generated/sec)/ Area of the disc = (6528/5)/ 0.06628 = 19698 W/m2 Thermal Gradient = Heat flux / Thermal conductivity = 19698 / 36 = 547.17 k/m	**Model 3 calculation:** Heat generated in rotor (J/S) Q = m. CP. ΔT ---------------EQ(6) Heat flux (W/M2) Heat flux = Q/A m = mass of the disc = 1.22kg ΔT = Temperature difference = 15oc A = 0.06628 m2 Specific heat = 380 J/kg k Q = m. CP. ΔT = 1.22 × 380 × 15 = 6954J Heat flux = (heat generated/sec)/ Area of the disc = (6954/5)/ 0.06628 = 20983 W/m2 Thermal Gradient = Heat flux / Thermal conductivity = 20983 / 50 = 419.67 k/m

6.3. Analytical Temperature Rise Calculations:

In the contact region between the pads and disc brake mechanism, heat is produced due to rubbing. For estimation of heat at the boundary of these two descending bodies, two methods are recommended. On the base of "law of conservation of energy which states that the kinetic energy of the automobile for the period of motion is the same to the dissipated heat after automobile stop". The material properties and parameters espouse in the calculations are as shown in table.

Table.6.2: Material Properties for Stainless Steel and Cast Iron

Material Properties	**Stainless Steel (Model I)**	**Cast Iron (Model II)**
Thermal conductivity(w/m k)	36	50
Density , ρ (kg/m3)	7100	6600
Specific heat , c (J/Kg c)	320	380
Thermal expansion , α (10-6 / k)	0.12	0.16
Elastic modulus, E (GPa)	210	110
Coefficient of friction, μ	0.5	0.5
Film co-efficient h(w/km2)	240	280
Angular velocity,(rad /s)	50	50
Braking Time Sec	5	6
Hydraulic pressure, P (M pa)	1	1

VII. SOLID WORKS AND ANSYS MODELS

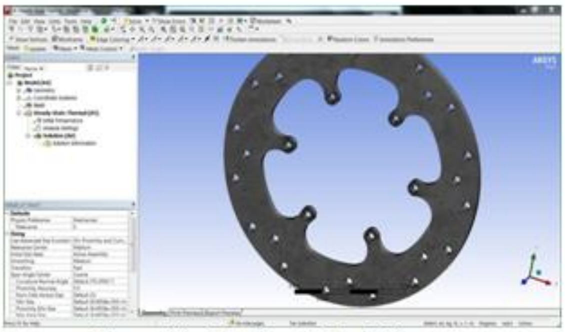


Figure 7.1: Meshing of Model 1

Figure 7.2: Meshing of Model 2

Figure 7.3: Meshing of Model 3

VIII. RESULTS

8.1. Stainless Steel:

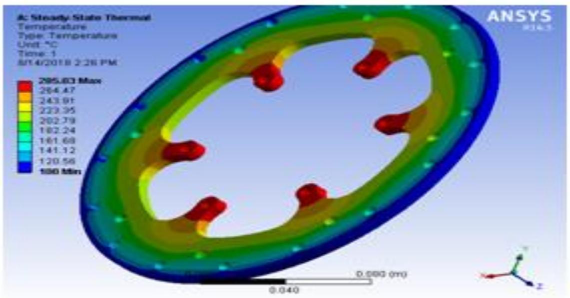


Figure8.1: Temp. Distribution values for SS Model No. 1

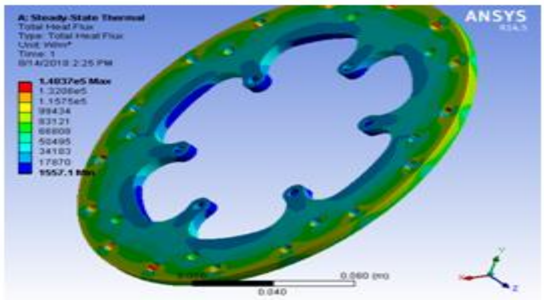


Figure8.2: Heat flux values for SS Model No. 1

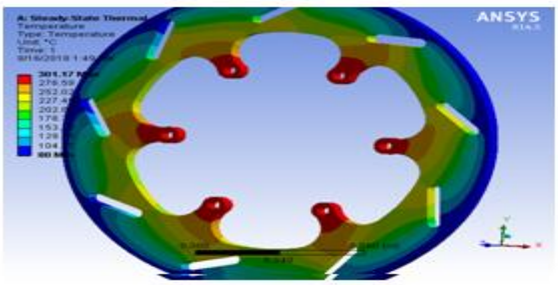


Figure8.3: Temp. Distribution values for SS Model No. 2

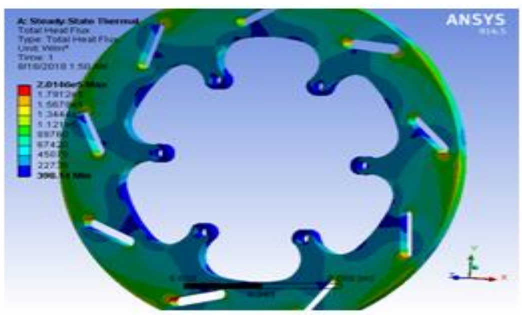


Figure8.4: Heat flux values for SS Model No. 2

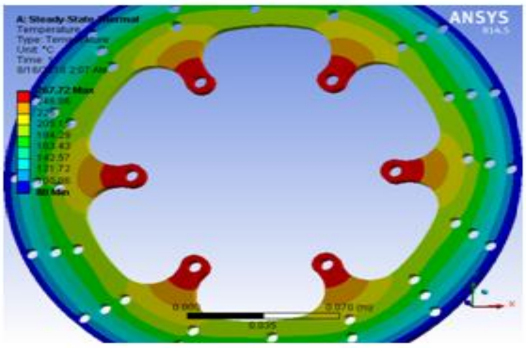


Figure8.5: Temp. Distribution values for SS Model No. 3

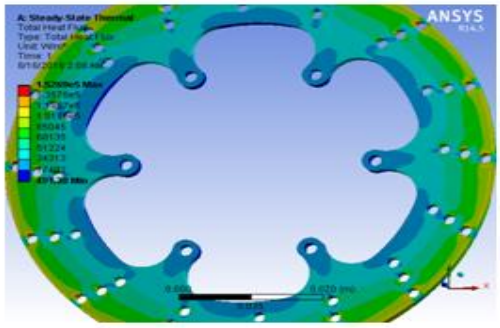


Figure8.6: Heat flux values for SS Model No. 3

8.2. Cast iron

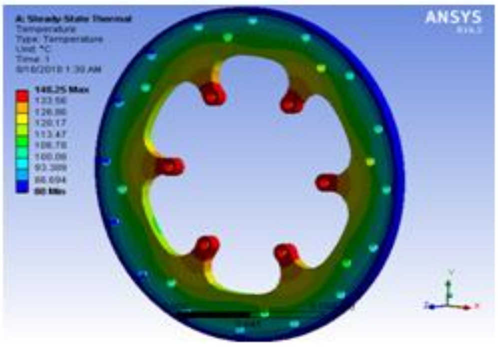


Figure8.7: Temp. Distribution values for CI Model No. 1

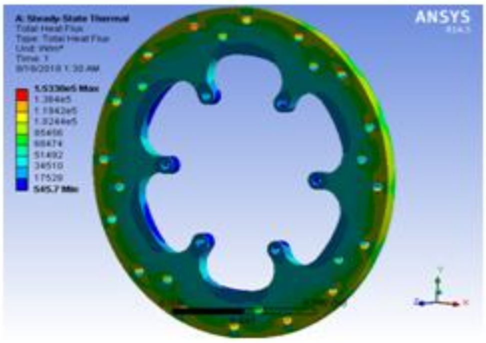


Figure8.8: Heat flux values for CI Model No. 1

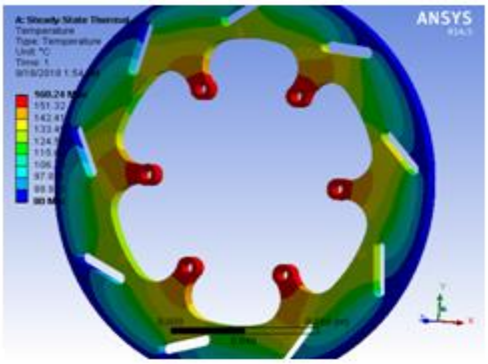


Figure8.9: Temp. Distribution values for CI Model No. 2

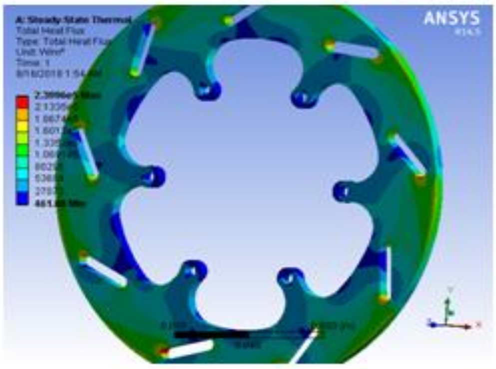


Figure8.10: Heat flux values for CI Model No. 2

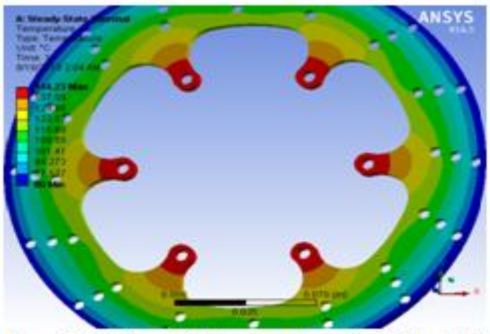


Figure8.11: Temp. Distribution values for CI Model No. 3

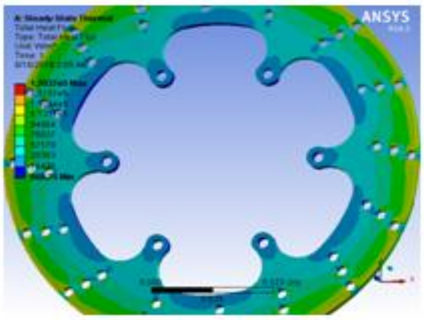


Figure8.12: Heat flux values for CI Model No. 3

IX. Discussions

From the information, given over, we can review the results in the following method:

Table no. 9.1 Temperature Distribution

Results	Temperature Distribution(o C)			
Material	Stainless Steel		Cast Iron	
	Min	Max	Min	Max
Model No.1	100	285.03	86.425	140.25
Model No.2	80	381.17	80	160.24
Model no.3	80	267.72	80	144.23

Table no. 9.23 Total Heat Flux

Results	Temperature Distribution(o C)			
Material	Stainless Steel		Cast Iron	
	Min	Max	Min	Max
Model No.1	1557.1	1.48×10^5	545.7	1.53×10^5
Model No.2	398.14	2.01×10^5	461.88	2.39×10^5
Model no.3	491.38	1.52×105	568.75	1.70×10^5

X. Conclusion

In according to the study on a variety of design models of disc brakes with dissimilar materials, we have perceived that increase in temperature is maximum in stainless steel when matched up to cast iron. Therefore, on the basis of thermal analysis, cast iron is the finest considerable material for building-up the disc brake. However cast iron disc brake undergo a snag of getting corroded while it comes in contact with moisture and therefore it cannot be used in two wheeler and hence, we consider stainless steel.

Heat dissipation from disc brake also related to the type of design model used. The dissimilar design models studied are:-

i. Model No. 1- With fewer no. of round holes.
ii. Model No. 2- With kidney shaped holes.
iii. Model No. 3- With extra no. of round holes.

By taking the above three models into consideration, finest heat dissipation is seen in model 2 with kidney shaped holes and made up of cast iron.

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[3]. "Thermal analysis guide"-http://orange.engr.ucdavis.edu/Documentation12.0/120/ans_the.pdf
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