Review on Improvement in Performance Characteristics of Brake Disc by Design & Analysis

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Abstract— The disc brake is a device for slowing or stopping the rotation of a wheel. Repetitive braking of the vehicle leads to heat generation during each braking event. Thermal and Structural Analysis of the Rotor Disc of Disk Brake is aimed at evaluating the performance of disc brake rotor of a car under severe braking conditions and there by assist in disc rotor design and analysis. Disc brake model is created in CATIA v5 and analysis is done using ANSYS workbench 16.2. The main purpose of this study is to analysis the thermo mechanical behavior of the dry contact of the brake disc during the braking phase. The coupled thermal-structural analysis is used to determine the deformation and the Von Mises stress established in the disc for the both solid and ventilated disc with two different materials to enhance performance of the rotor disc. A comparison between all materials taken is tabulated and according to that results best suitable design, material and rotor disc is suggested based on the performance, strength and rigidity criteria.

Keywords: Brake Disc, Computer Aided Engineering (CAE), FEA

I. INTRODUCTION

In today's growing automotive market, the competition for better performance vehicle is growing enormously. The racing fans involved will surely know the importance of a good brake system not only for safety but also for staying competitive. The disc brake is a device for slowing or stopping the rotation of a wheel. A brake disc usually made of cast iron or ceramic composites includes carbon, Kevlar and silica, is connected to the wheel and the axle, to stop the wheel. A friction material in the form of brake pads is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. This friction causes the disc and attached wheel to slow or stop. Generally, the methodologies like regenerative braking and friction braking system are used in a vehicle. A friction brake generates frictional forces as two or more surfaces rub against each other, to reduce movement. Based on the design configurations, vehicle friction brakes can be grouped into drum and disc brakes. If brake disc is in solid body the heat transfer rate is low.

Time taken for cooling the disc is low. If brake disc is in solid body, the area of contact between disc and pads are more. In disc brake system a ventilated disc is widely used in automobile braking system for improved cooling during braking in which the area of contact between disc and pads remains same. Brake assembly which is commonly used in a car as shown in fig.

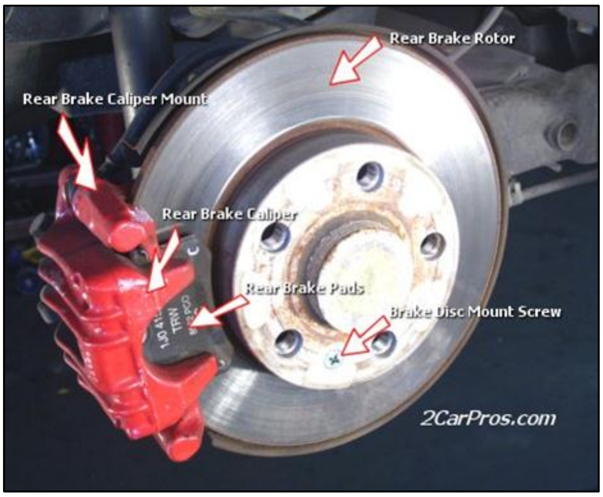

Fig. 1: Brake Assembly

II. PROBLEM STATEMENT

In Breaking system there are various problems occurred such as a response of stopping of vehicle, Heating of Brake shoe which causes thermal stresses in brake shoe, Friction & wear of surfaces which causes the worn out of friction surfaces. To overcome such a problem in conventional breaking system disc brake system is developed. Which gives better breaking effect, stopping response but other than this advantages some disadvantages also occurred In disc brake system due to friction which produces squeal, thermal stresses, & worn out of rotor surfaces so braking efficiency will be affected. So in to avoid this we have to find some material which gives less wear than now a day's rotor & also which produces a less temperature and best alternative to conventional one.

III. OBJECTIVE & NEED

Today's industry became an smart industry in all aspects like design, development, Automation or etc. to compute with global market industry want to reduce the production and development cost of product. To reduce the cost of product in last 2-decade computer aided design and analysis became most popular.

Because it allows us to visualize and redetect the failure of object before they manufacture them in actual. Before some year industry applied trial and error method to ensure that their product is safe or not for use but it require too much time and cost also. To overcome this CAD and CAE is introduced.

– To Understand the design procedure of Brake disk
– Pre-Detect the failure before manufacturing the object
– To Reduce development time and ultimately reduce cost
– To Reduce manufacturing complexes & To Increase workability.

IV. SCOPE

As discuss above to compete with global market they want better design which is sustain the given loading condition as well as they have lower cost as compare to previous design. Present work has scope in following ways.

- Optimization in vehicle design
- By using special material, it can also increase performance specially in F1 cars.

V. MATERIAL SPECIFICATION

A. Grey Cast Iron

The popularity of grey cast iron components is because grey iron is one of the cheapest types of iron castings to produce. It has acceptable ductility, tensile strength, yield strength, and impact resistance for most applications. Grey Iron is also excellent in its ability to dampen vibrations making it ideal for machinery bases and as well as many housing applications. Grey iron has high thermal conductivity meaning it moves heat more easily through the metal. A final benefit of grey iron is its ability to withstand thermal cycling well. Thermal cycling is where the component goes back and forth between warmer and colder temperatures. While thermal cycling can create stress and premature failure in some types of metal castings, grey iron has proven to endure the strain of thermal cycling quite well and not stress as easily. While grey cast iron has less tensile strength and shock resistance than most other castings or even steal, it has compressive strength that is comparable to low- and medium-carbon steel. These mechanical properties are controlled by the size and shape of the graphite flakes present in the microstructure.

Gray cast iron has the following chemical component range: Carbon (C) 2.8 - 3.9%, Silicon (Si) 1.1 - 2.6%, Manganese (Mn) 0.5 - 1.2%, $P \leq 0.3\%$, $S \leq 0.15\%$.

grey cast iron has different mechanical properties. Their tensile strength is between 72500 psi to 188500 psi. The yield strength is between 21700 psi to 72500 psi. Grey iron castings almost has no elongation. The impact toughness is less than 11 J/cm2, so if your parts need to stand impact, then ductile iron will be the better choice. The hardness of gray iron is between 145 to 280 HBS (Brinell Hardness).

B. Aluminium Alloy

Aluminum has a far higher heat capacity than most metals, at 0.9 J/g-C. Cast iron by comparison is only 0.45J/g-C. Of course, aluminum has a lower density, but thicker rotors never bothered anyone.

Aluminum alloy is having following properties,

1.Light Weight,2. Corrosion Resistance, 3. Electrical and Thermal Conductivity 4.Reflectivity,5. Ductility, 6. Impermeable and Odorless, 7. Recyclability.

C. Carbon Ceramics

- Carbon Ceramics has ability to maintain their functionality at high temperatures due to the fact that they don't keep the heat. This is their greatest advantage. In high performance vehicles as much as six tons of force can be applied to stop your vehicles producing alot of heat, over 1000 degrees F and the boiling point for brake fluid will be between 550 to 700 degrees F but carbon ceramic brakes can dispurse the heat before it reaches the brake fluid. Frequent and heavy braking from high speeds is effectively achieved for longer.
- There is less dust build up from carbon ceramic brakes. The dust from the metal pads have static electricity which causes the dust to have magnetic properties so the dust remains on the metal parts around the brakes.
- Carbon ceramic brake pads will not wear down as fast as the regular brake pads in similar driving conditions and because of the material composition of the carbon ceramic brakes the pads alone will wear down without any wear to the rotor
- The rotor of disc of the carbon ceramic brakes weighs less than cast iron rotors. The weight of the rotor can be approximately half the weight. The total weight of the four rotors can equal a difference of 30 pounds if compared to cast iron rotors with similar dimensions
- Carbon ceramic brakes produce less noise during braking.

VI. COMPUTER AIDED ENGINEERING (CAE)

Computer-aided design (CAD) is the use of computer systems to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. Each stage requires specific knowledge and skills and often requires the use of specific software.

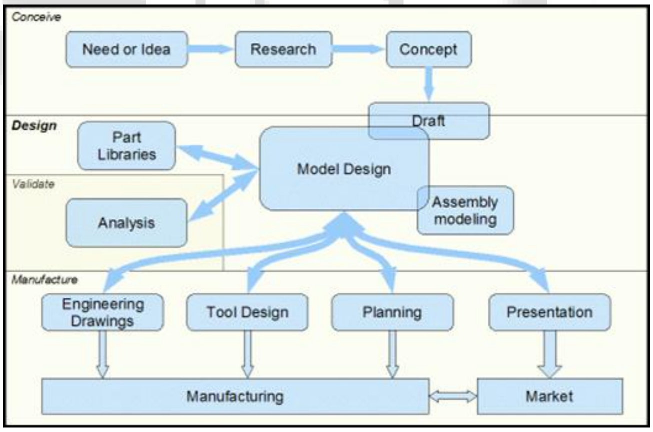

Fig. 2: Commuter Aided Manufacturing Procedure

A. Need or Idea

Usually, the design process starts with a defined need. The need can be defined by market research, by the requirements of a larger body of work (for example airplane part). Sometimes, but more rarely than you may think, the design process is begun with a new idea or invention. At any rate, a needs analysis should precede any decision to undertake a project. This includes defining the need in a highly detailed way, in writing. This is similar to the requirements specification process in software engineering.

B. Research

Professionals tend to research available solutions before beginning their work. There is no need to "reinvent the wheel". You should study existing solutions and concepts, evaluating their weaknesses and strengths. Your research should also cover available parts that you can use as a part of your design. It is obvious, that Internet and search engines like Google are very helpful for this task. There are also many libraries of standardized parts which you can import into your project.

C. Concept

Based on your research, start with a high level concept. You should specify the main principles and major parts. For example, you can consider Diesel or Sterling engines for stationary electric generators.

D. Draft

You can choose to create a draft by pen and paper. Some prefer to use simple vector graphics programs, others even simple CAD (for example Smart Sketch), yet others prefer to start directly in their main CAD system.

E. Model Design

2D and 3D modeling in CAD. The designer creates a model with details, and this is the key part of the design process, and often the most time consuming. This will be described in greater detail in further lessons. asa ceva

F. Part Libraries

Standard parts, or parts created by other team members, can be used in your model (you don't have to reinvent the wheel). Files representing a part can be downloaded from the Internet or local networks. They are also distributed on CD ROMs or together with CAD as an extension (library). By putting these predefined parts into your project, you ensure that they are correct and save a lot of time and effort. When working on a large project, this becomes a requirement to ensure the parts operate together, swap out equivalent parts, and coordinate distributed teams' work. This was, a standard part can be inserted into the project by one team member.

G. About CATIA V5

CATIA (an acronym of computer aided three-dimensional interactive application) is a multi-platform software suite for computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), PLM and 3D, developed by the French company Dassault Systems. CATIA started as an in-house development in 1977 by French aircraft manufacturer Avions Marcel Dassault, at that time customer of the CADAM software to develop Dassault's Mirage fighter jet. It was later adopted by the aerospace, automotive, shipbuilding, and other industries.

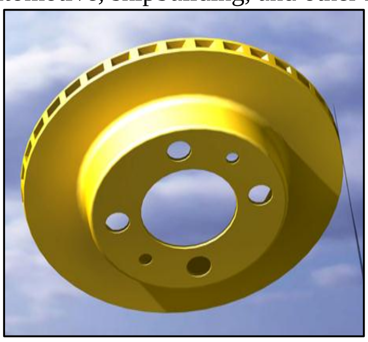

Fig. 3: Brake Disc Model in CATIA

VII. Finite Element Analysis

FEA is a numerical method. It is very commonly used in finding the solution of many problems in engineering. The problem includes deigning of the shaft, truss bridge, buildings heating and ventilation, fluid flow, electric and magnetic field and so on. The main advantage of using finite element analysis is that many designs can be tried out for their validity, safety and integrity using the computer, even before the first prototype is built. Finite element analysis uses the idea of dividing the large body in to small parts called elements, connected at predefine points called as nodes. Element behavior is approximated in terms of the nodal variables called degrees of freedom. Elements are assembled with due consideration of loading and boundary condition. This results in a finite number of equations. A solution of these equations represents the approximate behavior of the problem. The design and analysis have done with the 3D modeling software and FEA technique standard FEM tool. The analysis is carried out by using the ANSYS software. This gives the comparison between analytic and numerical value. Part is drawn in CAD software. The CAD software which is involved in this is CATIA and this part is a call to ANSYS in (.igs) format.

A. Procedure for FE Analysis

There are a number of steps in the solution procedure using finite element method. All finite element packages require going through these steps;

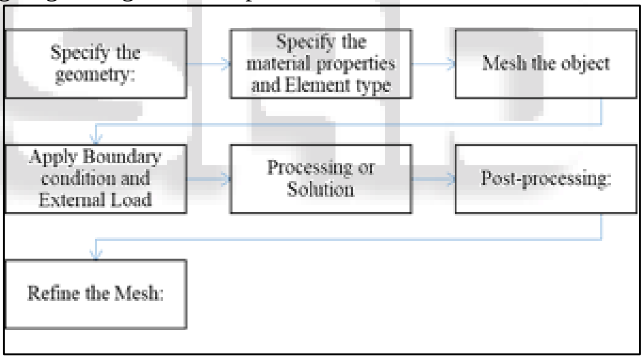

Fig. 4: FEA Procedure

1) Specify the Geometry:

In this import the geometry from CAD software to FEA software.

2) Specify the material properties and Element type:

In this step, the selection of element type is done and the material properties are given. The Young’s modulus and Poisson’s ratio are the input for material properties.

3) Mesh the Object:

Here the object is broken in to small elements. This involves defining the type of element into which structure will be broken as well as specifying how the structure will be divided in to the element. This subdivision in to elements can either be input by the user or with same finite element programs can be chosen automatically.

4) Apply Boundary Condition and External Load:

This is followed by specifying the boundary condition and the external loads are specified.

5) Processing or Solution:

The modified algebraic equations are solved to find the nodal values of the primary variable.

6) Post-processing:
It involves improving the result of processing in to the model. These results are graphically displaced to enable user case of high deflection and stress.
7) Refine the Mesh:
For the case of a judge of the accuracy of the result, there is need to increase or decrease no of elements of an object.

VIII. Literature Review

A. [1] Swapnil R. Abhang

Abhang is investigated and state that the method for single system has been studied and developed in order to meet safety requirement. Instead of having air bag, good suspension systems, good handling and safe cornering, there is one most critical system in the vehicle which is brake systems. In this paper carbon ceramic matrix disc brake material use for calculating normal force, shear force and piston force. And also calculating the brake distance of disc brake. The standard disc brake two wheelers model using in Ansys and done the Thermal analysis and Modal analysis also calculate the deflection and Heat flux, Temperature of disc brake model. This is important to understand action force and friction force on the disc brake new material, how disc brake works more efficiently, which can help to reduce the accident that may happen in each day.

B. [2] N. Balasubramanyam

He discusses about a transient analysis for the thermo elastic contact problem of the disk brakes with heat generation is performed using the finite element analysis. To analyze the thermo elastic phenomenon occurring in the disk brakes, the occupied heat conduction and elastic equations are solved with contact problems. The numerical simulation for the thermo elastic behavior of disk brake is obtained in the repeated brake condition. The computational results are presented for the distribution of heat flux and temperature on each friction surface between the contacting bodies. Also, thermo elastic instability (TIE) phenomenon (the unstable growth of contact pressure and temperature) is investigated in the present study, and the influence of the material properties on the thermo elastic behaviors (the maximum temperature on the friction surfaces) is investigated to facilitate the conceptual design of the disk brake system. Based on these numerical results, the thermo elastic behaviors of the carbon-carbon composites with excellent mechanical properties are also discussed.

C. [8] Graham L. Donne and peter M. Watson (1981),

Discussed about the effect of cast iron disc brake metallurgy on friction and wear characteristics. The author presented the noticeable differences between the friction and wear characteristics of the four gray cast irons. The basic concept of friction and wear characteristics of suitable grade of cast iron has been taken from this literature and incorporated in this work.

D. [9] Fash J.W. Dalka T.M. and Karthik R. (1998)

Deals with the influence of brake system properties on motor cycle braking. This literature gives an elaborate idea about the material for brake discs and pads. The authors also suggested the various treatments applied to brake disc/pad combinations. The concepts and the experimental results presented in this literature has been used for the comparison of designed brake disc performance.

IX. Mathematical Calculations

A. Kinetic Energy of Vehicle

$$K.E = \frac{m \times v2}{2}$$

Where, K. E − kinetic Energy (J)
M − Mass of vehicle (Kg) = 500 Kg
V − Linear velocity of vehicle (m/s) = 16.66 m/s

$$K.E = \frac{500 \times 16.662}{2}$$

K.E = 138888.8 J = 138.88 KJ

B. Stopping Distance of Vehicle

Braking distance of vehicle refers to the distance a vehicle will travel from the point when its brakes are fully applied to when it comes to a complete stop.
The maximum friction force,
F = μ ∗ M ∗ g
= 0.55 x 500 x 9.81
= 2697.75
Hence deceleration of the vehicle: $a = F/M$
= 2697.75/500
= 5.3955
Time taken to stop the vehicle: $t = V/a$
= 16.666/ 5.3955
= 3.08 Sec

C. Stopping Distance

Now, following is other equitation to calculate total stopping distance by considering reaction time of driver is
Total Stopping distance (SD) = $(V \times reaction\ time) + \frac{v2}{2\mu g}$
(SD) = (16.666 x 0.5) + $\frac{16.662}{2 \text{ x } 0.55 \text{ x} 9.81}$
= 20.91 m.

D. Breaking force

Brake force, also known as Brake Power, is a measure of braking power of a vehicle. Here following process is given to calculate exact force required to stop vehicle within stopping distance or stopping time.
1) Tangential braking force: $(BF)\ t = K.\ E/(S\ D)$
= 138888.8/ 20.91
= 6639.55 N
2) Tangential force on each wheel $Ft = (BF)t/4$
= 6639.55/4
= 1659.88 N
3) Braking torque on wheel $Tw = Ft \times R$
= 1659.88 x 0.3175
= 527.1Nm
Where, R − Radius of the tyre (m)

E. Effective rotor radius

$$Re = \left(\frac{\text{rotor diameter}}{2}\right) - \left(\frac{\text{Caliper piston diameter}}{2}\right)$$

$= \left(\frac{0.2}{2}\right) - \left(\frac{0.019}{2}\right)$
= 0.0905 m

F. Braking Torque on Disc

$$Tb = Tw \times \frac{R}{r}$$

$= 527.1 \text{ x } \frac{0.3175}{0.1}$
$= 1673.26$

G. Clamping force

$$C = \frac{Tb}{2\times\mu\times Re}$$

$= \frac{1673.26}{2\times0.55\times0.1}$
$= 15211.45$ N

H. Angular velocity of rotor

$$\text{Velocity } V = (\pi\times D\times N)$$

16.66 = (3.14 x 0.2 x N)
N = RPM = 26. 52
We know the relation between W & V
i.e. $\mathbf{v = r\,w}$
16.66 = (0.1) **w**
w=166.6rad/sec.

I. Heat Flux

In a braking system, the mechanical energy is transformed into a calorific energy. This energy is characterized by a total heating of the disc and pads during the braking phase. The energy dissipated in the form of heat can generate rises in temperature ranging from 300 °C to 800 °C. Generally, the thermal conductivity of material of the brake pads is smaller than that of the disc. We consider that the heat quantity produced will be completely absorbed by the brake disc. Heat generated when applying braking action on disc brake = kinetic energy
Hg = K.E
Also, heat generation is $Hg = m_d \times Cp \times \Delta t$
Where,
m_d − Mass of disc (Kg)
C_p − specific heat (J/Kg. K)
Δt − temperature difference (°C)
Where,

$$\Delta t = (t_f - t_i)$$

As kinetic energy is entirely converted for 5 seconds the power produced will be
P = K.E/t
P = 138.88 / 5
P = 27 .77 KJ/s.

$$\text{Heat flux } H.F = (P/t)/A$$

Where
A = 2×contact area of piston of caliper
$=2\times (\pi/4) \times [(\text{diameter of rotor})^2 - (\text{diameter of rotor - diameter of piston})^2]$
$= 2 \text{ x } (\pi/4) \text{ x } [(o.2)$ ^2 – (0.2 – 0.019) ^2]
= 0.0114 m2.

$$\text{Heat flux } H.F = (P/t)/A$$

= (27.77/ 5) / 0.0114
H.F = 487.192 w/m2

X. CONCLUSION

From this we can conclude by comparing & analyzing the quality of three different material the best suitable material for bake disc in term of maximum von misses Stress, maximum total deformation and weight reduction.

By this we can reduce weigh of vehicle to some extend & it will help to improve efficiency of braking & performance of vehicle too.

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