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Analysis of Disc Brake Rotor Coning

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ABSTRACT

Disc brakes operate on the principle of friction by converting kinetic energy into heat energy. The main objective of a disc brake rotor is to store this heat energy and dissipate it as soon as possible. During the repeated braking the heat generated accumulates within the rotor and the heat transfers through convection on both the sides of the rotor are not uniform due to the wheel rim covering so heat accumulates on the wheel covered side, during next instance of braking the surface acts like an plastic material due to accumulated heat and it deforms due to the force acting in it and this deformation fails to make surface contact with the pad instead it makes line contact which further paves way to temperature increase and hence lead to break failure. My work in this project to do thermal analysis and structural analysis and couple them by suitable method and find the deformation gradient for various temperatures generated during braking process. Based on the deflection results produced various combination of material for improving the heat dissipation is analyzed by adopting the procedure followed for better comparison of data

INTRODUCTION

A brake is a device by means of which artificial frictional resistance is applied to moving machine member, in order to stop the motion of a machine. In the process of performing this function, the brakes absorb either kinetic energy of the moving member or the potential energy given up by objects being lowered by hoists, elevators etc. The energy absorbed by brakes is dissipated in the form of heat. This heat is dissipated in the surrounding atmosphere to stop the vehicle, so the brake system should have following requirements:

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

CLASSIFICATION OF BRAKE SYSTEMS

According to the direction of acting force mechanical brakes can be subdivided in two groups as:

Radial brakes

In this type the applied force or pressure acting on the brakes disc is in radial direction. e.g. external and internal brakes.

Axial brakes

In this type the applied force or pressure acting on the brakes disc is only in the axial direction e.g. disc and cone brakes

DISC BRAKE

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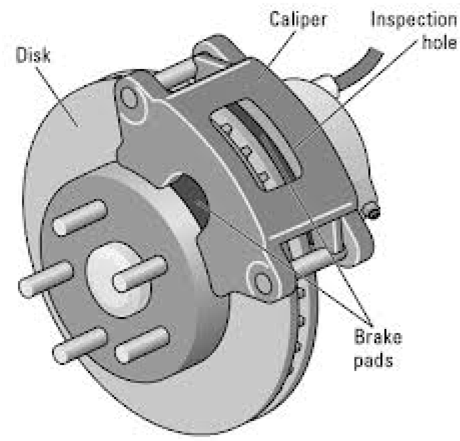
Disc-style brakes development and use start at England in the 1890's which is the first ever automobile disc brakes were patented. (F.W.Lanchester,1890). It was patented at Birmingham factory in 1902, though it took another half century for the innovation to be widely adopted. The first designs resembling modern-style disc brakes began to appear in Britain in the late 1940 and early 1950. The first appeared on the low-volume Crosley Hotshot in 1949, although it had to be discontinued in 1950 due to design problems. Modern-style disc brakes offered much greater stopping performance than comparable drum brakes, including much greater resistance to "brake fade" which is caused by the overheating of brake components. Meanwhile, from the late 1990 to present, North American automotive industry accelerated the pace on brake research and application to catch up with Japanese quality performance.

Disc brakes in an automotive are expected to work properly with a minimum amount of service. The purpose of a brake is to reduce the velocity or to maintain it when the vehicle is driving downhill. Without brakes it would not be possible to control the speed of vehicle, nevertheless the design of brakes is generally underestimated. In brakes high amount of energy are transformed during short period, this is underlined by the fact that often braking power is several times higher than the power of engine.



COMPONENTS OF DISC BRAKE

Disc brakes are fairly simple to work with. Typically, there are four main parts of a disc brake system as given below.

i) Mounting Bracket: Mounting Brackets are used to hold the caliper in place. Other than keeping the surface clean and free of rust and road grime, there is very little to be done with this part.

ii) Rotor: Rotors are metal discs supported by the suspension. The calipers clamp on to them to slow their rotation, and then slow or stop the car. Rotors are mainly fabricated from grey cast irons because of its high thermal conductivity, high thermal diffusivity and low cost. Vented rotors have fins in the spaces between their machined surfaces. These spaces allow air to pass through, which helps carry heat away. Non-vented rotors are used on smaller vehicles, and have no cooling fins.

iii) Caliper: Calipers are the housings that contain the pistons and the brake pads. The calipers are connected to the hydraulic system, and hold the brake pads to the rotor.

There are two types of calipers as:

a) Fixed Caliper: - Applies two pistons to opposite sides of rotor. Fixed calipers [figure1.4] are disc brakes that use a caliper, which is fixed in position

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and does not slide. They have pistons on both sides of the disc. There may be two or four pistons per caliper. Motorcycles and some import trucks and cars use this type.

b)Sliding Caliper :-There are two pistons between which fluid under pressure is sent which passes one friction pad directly on to the disc where as the other pad is passed indirectly via caliper.

iv) Pads:-In between each piston and the disc, there is a friction pad held in the position by retaining pins. The most common type of service required for brakes is changing the pads. Disc brake pads usually have a piece of metal on them called a wear indicator as shown in figure1.6. When enough of the friction material is worn away, the wear indicator will contact the disc and make a squealing sound. This means it is time for new brake pads. Pads are mainly composed of organic materials.

WORKING PRINCIPLE OF DISC BRAKE

Disc brake is a mechanical device used to absorb energy processed by a moving system or mechanism by means of friction. Disc brake consists of a cast iron disc bolted to the wheel hub and stationary housing called caliper as shown in figure 1.7. The caliper is connected to some stationary part of vehicle like axle casing. In between each piston and the disc there is a friction pad held in the position by retaining pins. Here the principle is applied force acts on the brake pads, which comes in contact with moving disc. At this point of time due to friction relative motion is constrained.

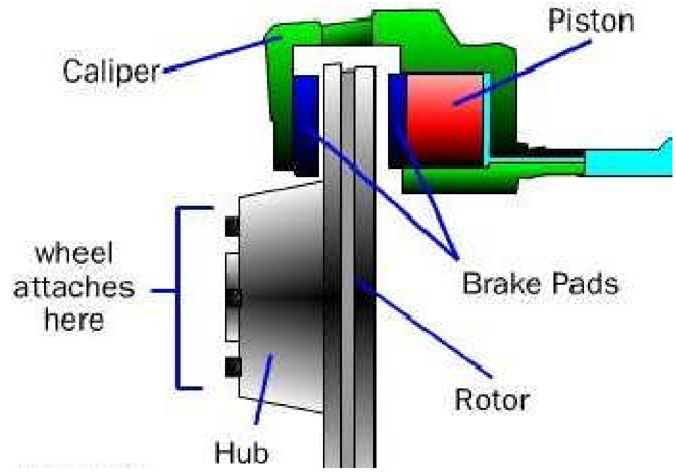

Fig 1.2 Schematic of the hydraulic fluid flow into the rotor of disc brake system

Disc brakes are widely used for reducing velocity for their characteristics of braking stability, controllability and their ability to provide a wide ranging torque. The braking processes in the friction units of a brake are very complicated. In the course of breaking all parameters of processes like load, temperature, physicomechanical and tribological characteristics of the materials of the couple and conditions of contact vary with time. The frictional heat generated on the interface of the rotor and the parts can cause high temperature. Particularly temperatures may exceed the critical value for a given material which leads to undesirable effects such as brake fade phenomena, local scoring, thermal cracking and thermo-elastic instability. Furthermore the physicomechanical state of the interface of the disc and pads is determined not only by the contact temperature but by the non-stationary temperature field. Therefore, the transient thermal analysis of brake has become one of the main references in the early design stage which is the main goal of this project.

PROJECT BACKGROUND

Due to the application of brakes on the car disc brake rotor, heat generation takes place due to friction. The frictional heat generated on the interface of the rotor and the pads can cause high temperature and this temperature so generated has to be conducted and dispersed across the disc rotor cross section. Particularly, the temperature may exceed the critical value for a given material, which leads to undesirable effects, such as brake fade phenomenon that is Brakes convert friction to heat, but if the brakes get too hot, they will cease to work because they cannot dissipate enough heat. This condition of failure is known as brake fade.

LITERATURE REVIEW

HISTORY

To avoid the friction, wear, squeal, friction coefficient, thermo elastic instability caused by increase in temperature between pad and rotor (stage known as fade) many researchers have performed extensive investigations over the years to develop transient analysis monitoring techniques. Most of the techniques are based on tribological study of disc and pad material, FEM analysis, thermal stress analysis. It is always require that braking assembly must safely work during its service life; however Disc brakes are exposed to large thermal stresses during routine braking and extraordinary thermal stresses during hard braking. It is unanimous that friction, wear and cracks at bolted area are among the most failure types in disc rotor. Focus of the present dissertation work is to develop a newer material for disc and pad, Develop finite element model of both brake pads and Simulation of the heat transfer using FEA software for the finite element models. In the Literature review several studies based on thermal, structural and dynamic study for brake failure modes are being discussed. Different researchers have discussed brake failure mode detection of disc brake in various ways. They are summarized below

The analytical power and design flexibility offered by the finite method is the reason for extensive use of FEA tools in research and development sector all over the world, following paragraphs gives the brief explanation about ongoing research in the area of disc brake analysis and use of FEA as a support tool.

REVIEW OF PAPERS

The literature was collected related to analysis of influence of heat i.e. thermal and transient analysis and new materials that replace present material of disc rotor and pad. The majority papers were collected from journal of Wear and science direct. The following paragraphs review the research that was done by earlier researchers related to failure analysis of disc brake.

Thomas Valvano and KwangjinLee (2000)

The severe thermal distortion of a brake rotor can affect important brake system characteristics such as the system response and brake judder propensity. This paper will propose a technique to determine the thermal distortion under transient or steady state conditions. The technique involves utilizing a PC-based computer program to calculate the necessary thermal parameters and apply the results as input to a finite element-based thermal stress analysis. This unique approach provides a reliable methodology to determine the heat input and cooling characteristics of a given brake system in addition to resultant distortion and stress components within the brake rotor. Analysis results are also compared to measured temperature and distortion data.

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G. Babukanthrt al. (2012)

The thermo elastic phenomenon occurring in the disk brakes, the occupied heat conduction and elastic questions are solved with contact problems. The numerical simulation for the thermo elastic behavior of disk brake is obtained in there heated 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.

PROBLEM DEFINITION: To determine the coning with respect to temperature raise.

Number of papers published so far have been surveyed and reviewed. The various researchers had done a lot of works for attempts to improve disc rotor cooling by Aerodynamic cooling of high performance disk brake systems is investigated.

A transient thermal analysis will be carried out to investigate the temperature variation across the disc using axisymmetric elements. Further structural analysis will also be carried out by coupling thermal analysis. The behavior of the disc brake system in term of heat properties was determined. The properties of the stress and deflection of the component due to the heat generated can be determined where both results are very useful to predict the disc brake performance in term of the mechanical strength. Therefore, the overall performance of the system can be evaluated more thoroughly both using the maximum temperature and maximum stress failure criteria and able to raise the level of confidence for the system design.

METHODOLOGY AND CONSIDERATIONS

TRANSIENT THERMO-STRUCTURAL ANALYSIS

Heat flux boundary condition formulation

To apply thermal model with a FEM to full rotor it is assumed that

- The brake pressure is uniformly distributed over the contact area of the disc and the pads on both inboard and outboard surfaces thus the temperature distribution is the same on both flanks of the disc
- Coefficient of friction remains constant during braking and
- The materials of disc and pad are homogeneous and their material properties are not changing with temperature.

The disc brake pad brake consists of two parts; a rotating disc, geometrically axisymmetric and stationary pad of which the geometry is three dimensional. The contact conditions between the disc and pads correspond to a heat flux, which is function of time. The thermal boundary conditions outside the contact region correspond to a convection and known temperature. The sliding speed and frictional heat flux are time dependent and their intensity is related with the pressure increasing mode. So, in the present work, considering a moving heat flux with a variable speed effects and the operating characteristics of the brakes like variationes of velocity, conventional

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coefficient of disc and the duration of braking are also taken into account.

HEAT POWER CALCULATION

As the vehicle is braked, the rotor is spinning and the brake pads are rubbing against the surface of the rotor, creating friction and heat energy. Much of the kinetic energy of the car is being transferred to thermal energy through the brake pads. The heat power will be applied to the brake rotors in the area that the pads touch. The amount of heat power can be calculated from the amount of kinetic energy carried by the car. If we assume the mass of the car is 1005kg and the car is travelling by 45m/s [11].

TRANSIENT STRUCTURAL ANALYSIS OF SOLID DISC

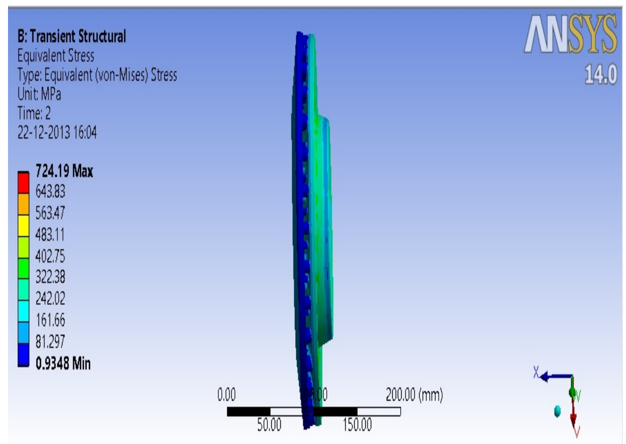
After estimating the temperature distribution in the disc/ rotor to find out the stress distribution, a transient structural analysis is performed on the disc/ rotor. If the mode containing thermal solid elements is also to be analyzed structurally the element should be replaced by an equivalent structural element i.e. change element type from thermal to structural. In this case, the thermal SOLID 70 elements should be replaced by an equivalent structural SOLID 45 element.

RESULTS AND DISCUSSIONS

In this analysis, the both the transient thermal and structural analysis are made. The analysis are made as a coupled analysis that is first the transient thermal analysis are made for the rotor and the result obtained are utilized for obtaining the results for transient structural analysis.

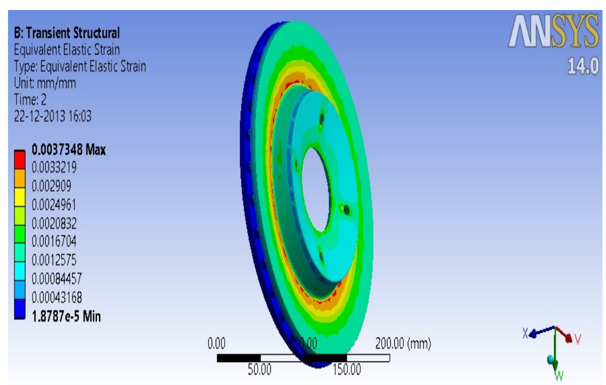
COUPLED TRANSIENT STRUCTURAL ANALYSIS

By importing the model with the thermal boundary conditions and as well applying the structural boundary conditions the coupled transient structural analysis is performed and its resulted are represented in the pictorial view.



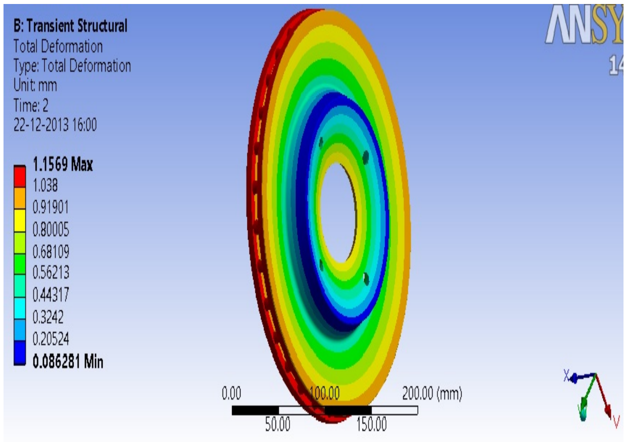
Von-Mises stress developed in the rotor

The output of the postprocessor is nodal displacement and stress in elements. In the above analysis the maximum Von-Mises stress developed for 1kn force is found to be 643.83Mpa.



Elastic strain in rotor

The strain developed due to the applied load is determined by plotting the strain values and the minimum and the maximum values are found to be as $1.875x10^{-5}$ and $3.3x10^{-3}$.



Total deformation of the rotor

The above figure shows the deformation values with respect to stress and strain for the applied 1KN load and the deformed value is the combination of both thermal and structural load and it is found to be minimum of 0.086mm and maximum of 1.038mm

CONCLUSION

In the above analysis done the convective heat transfer coefficient is assumed to be the same and hence the resultant of the analysis is same on the both sides of the disc but in real scenario this isn't possible as we have stated in the problem statement the air flow will not be same on both the sides of the disc and it leads to temperature accumulation on one side comparatively more than the other which is much exposed to air flow.

The above setup didn't provide the required temperature as it was simulated using ANSYS software as the power output from the motor is very less compared to that of reality setting as well in reality the kinetic energy is converted into heat energy but in this setup the pulley doesn't provide the necessary kinetic energy as the mass of the pulley is nill when compared with vehicle weight. As well the braking time is nothing when compared to the r unning vehicle.

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