Design, Analysis &Optimization of Disk Brake

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ABSTRACT

The main goals of this paper which presents the results of a thermal analysis of a braking system of two wheel vehicles using analytical and numerical modeling of thermal effects during long-term braking for maintaining a constant speed on a down-grade railroad in order to analyze damages of solid wheels braked by blocks, especially on railway .Preliminary works in this area have pointed out the problem of insufficient accuracy of the estimation coefficient. That was specifically expressed in conditions of Many research results have confirmed the dominant influence of thermal loads in regard to mechanical loads and residual stresses induced by high thermal loads in block-braked solid wheel have been registered. Therefore, it is important to determine with high precision the temperature field of the braking system, as well as to emphasize that high thermal loads, in other words, overloads, of wheel very often occur as a result of long-term braking on down-grade railroads or unwanted locking of wheels.

Keywords- *thermal effects, mechanical loads, residual stresses etc.*

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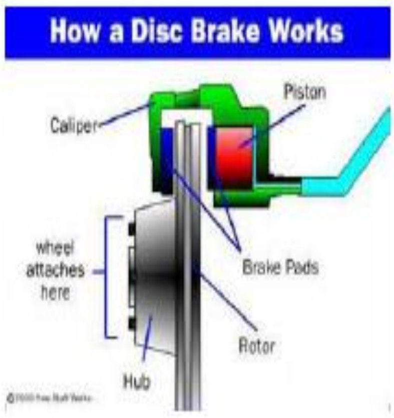
1 . INTRODUCTION

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 [1- 3]. 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 are in solid body the heat transfer rate is low [4-6]. Time taken for cooling the disc is low. If brake disc are 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 [7,8].

Thermal analysis is involved in almost every kind of physical processes and it can be the limiting factor for many processes. Therefore, its study is of vital importance, and the need for powerful thermal analysis tools is virtually universal.



Furthermore, thermal effects often appear together with, or as a result of, other physical phenomena. The modeling of thermal effects has become increasingly important in product de-sign including areas such as electronics, automotive, aerospace, railway (*e. g.* wheel and rail rolling contact, braking systems, and so on), medical industries, *etc*. Computer simulation has allowed engineers and researchers to optimize process efficiency and explore new designs, while at the same time reduce costly experimental trials. The finite element method (FEM) has become the preferred method in performing thermal analysis on many systems and processes in recent years .

With the advances in computer technology and computer aided design (CAD) systems, complex problems can be modeled relatively simply. A FEA thermal analysis is a finite element analysis that looks at how heat affects certain materials and engineering designs. This heat can come in the form of an environmental load such as an ambient temperature of a certain degree affecting a model, or due to friction in a system, effectively converting it into thermal energy. It can also come from processes of conduction through two solids, convection between a liquid and a solid, or radiation such as in space. A thermal analysis is a great way to test a model before the model is built and real world tested in a thermal chamber. It can reduce the time to test a design by weeks, allowing for several redesigns and improvements to be made in the meantime.

Precise prediction of the maximum temperature is needed for the design of many systems, as well as braking systems, especially for both discs and linings. How to handle the high speed spinning of discs is the point of the heat/structure coupled analysis . Transient thermal analysis determine temperatures and other thermal quantities that vary over time. The variation of temperature distribution over time is of interest in many applications such as cooling of electronic packages or quenching analysis for heat treatment. Also of interest are the temperature distribution results in thermal stresses that can cause failure. In such cases, the temperatures from a transient thermal analysis are used as inputs to a structural analysis for thermal stress evaluations. Heat generation controlling is a prerequisite for qualitative weld creation during the friction stir welding process, and it is important to have an adequate mathematical model that is capable of estimating heat generation with satisfying accuracy .

Thermal analysis is the primary stage in the study of braking systems, because the temperature determines the thermo mechanical behavior of the structure. In the braking phase, kinetic energy transforms into thermal energy, resulting in intense heating of the railway wheel. This generates stresses and deformations, whose consequences are manifested by the appearance and the accentuation of cracks on treads of wheel, and eventually fractures of the whole wheel .

2. LITERATURE REVIEW

Ameer Fareed Basha [1] et al, studied about the model of a disc brake used in Honda Civic. Coupled field analysis (Structural+Thermal) is done on the disc brake. The materials used are Cast Iron. Analysis is also done by changing the design of disc brake. Actual disc brake has no holes; design is changed by giving holes in the disc brake for more heat dissipation.

V.M.M.Thilak [2] et al, made an attempt to investigate the suitable hybrid composite material which is lighter than cast iron and has good Young’s modulus, Yield strength and density properties. Aluminum base metal matrix composite and High Strength Glass Fiber composites have a promising friction and wear behavior as a Disk brake rotor. The transient thermo elastic analysis of Disc brakes in repeated brake applications has been performed and the results were compared. The suitable material for the braking operation is S2 glass fiber and all the values obtained from the analysis are less than their allowable values. Hence the brake Disc design is safe based on the strength and rigidity criteria. By identifying the true design features, the extended service life and long term stability is assured.

M.A. Maleque [3] et al, the widely used brake rotor material is cast iron which consumes much fuel due to its high specific gravity. The aim of this paper is to develop the material selection method and select the optimum material for the application of brake disc system emphasizing on the substitution of this cast iron by any other lightweight material. Material performance requirements were analyzed and alternative solutions were evaluated among cast iron, aluminium alloy, titanium alloy, ceramics and composites. Mechanical properties including compressive strength, friction coefficient, wear resistance, thermal conductivity and specific gravity as well as cost, were used as the key parameters in the material selection stages. The analysis led to aluminium metal matrix composite as the most appropriate material for brake disc system.

Y. Yildiz and M. Duzgun [4] have studied on a stress analysis of ventilated brake discs using the finite Element method. In this study, three different ventilated brake discs, the cross drilled disc, the cross-slotted disc, and the cross-slotted with a side groove disc, were manufactured, and their braking force performances were investigated experimentally together with a solid disc. Stress analyses were subsequently performed by the finite element method. Analyses results showed that the maximum stress generations were formed on the ventilated discs in comparison to the solid disc. However, these comparisons indicate that the application of varying force distributions along brake pads reduces the stresses on ventilated discs by 8.8% to 19.1%.

Mesut Duzgun [5] has studied Investigation of thermo-structural behaviors of different ventilation applications on brake discs. In this study, the thermal behaviors of ventilated brake discs using three different configurations were investigated at continuous brake conditions in terms of heat generation and thermal stresses with finite element analysis. The results were compared with a solid disc. Heat generation on solid brake discs reduced to a maximum of 24% with ventilation applications. The experimental study indicated finite element temperature analysis results in the range between 1.13% and 10.87%. However, thermal stress formations were higher with ventilated brake discs in comparison to those with solid discs.

M. Pevec et al [6] have studied prediction of the cooling factors of a vehicle brake Disc and its influence on the results of a thermal numerical simulation. In this study the common method that is used for predicting the temperatures in the brake disc during braking is numerical simulation analysis. With the help of Computational Fluid Dynamics, the flow through a vehicle ventilated brake disc of known geometry was determined, and the wall heat transfer coefficients for all vehicle speeds and brake disc temperatures were calculated. The results were then imported into a thermal numerical simulation of a sequential braking vehicle test. The results showed that the consideration of cooling factors has a significant impact on temperature courses.

Sung Pil Jung et al [7] have studied Thermal Characteristic Analysis and Shape Optimization of a Ventilated Disc. In this study, an analysis technique that can estimate the temperature rise and thermal deformation of the ventilated disc considering vehicle information, braking condition and properties of the disc and pad is developed. The analytical process of the braking power generation during braking is mathematically derived. The thermal energy that is applied to the surface of a disc as heat flux is calculated when a vehicle is decelerating from 130 km/h to 0 km/h with deceleration of 0.4 g. Then, the temperature rise and thermal deformation of a disc are calculated. The shape of the cross section of the disc is optimized according to the response surface analysis method in order to minimize the temperature rise and thermal deformation. Pyung Hwang and Xuan Wu [5] have studied Investigation of temperature and thermal stress in ventilated disc brake based on 3D thermo-mechanicalcoupling model. In this study, object of the present study is to investigate the temperature and thermal stress in the ventilated disc-pad brake during single brake. The brake disc is decelerated at the initial speed with constant acceleration, until the disc comes to a stop. The ventilated pad-disc brake assembly is built by a 3D model with a thermo-mechanical coupling boundary condition and multi-body model technique.

Ali Belhocine and Mostefa Bouchetara [8] have studied Thermal analysis of a solid brake disc. The objective of this study is to analyze the thermal behavior of the full and ventilated brake discs of the vehicles using computing code ANSYS. The modeling of the temperature distribution in the disc brake is used to identify all the factors and the entering parameters concerned at the time of the braking operation such as the type of braking, the geometric design of the disc and the used material. The results obtained by the simulation are satisfactory compared with those of the specialized literature.

Jaeyoung Kang [8] has studied Squeal analysis of gyroscopic disc brake system based on finite element method. In this paper, the dynamic instability of a car brake system with a rotating disc in contact with two stationary pads is studied. For actual geometric approximation, the disc is modeled as a hat-disc shape structure by the finite element method. From a coordinate transformation between the reference and moving coordinate systems, the contact kinematics.

3. FINITE ELEMENT ANALYSIS

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. In this step it defines the analysis type and options, apply loads and initiate the finite element solution.

This involves three phases:

Preprocessor phase

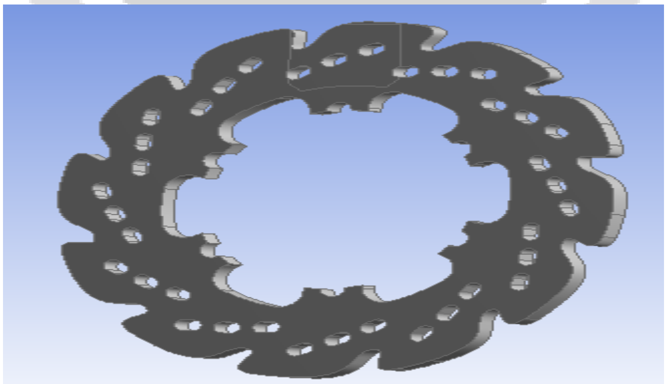
Solution phase

Post-processor phase

The ANSYS Workbench, together with the Workbench projects and tabs, provides a unified working environment for developing and managing a variety of CAE information and makes it easier for set up and work with data at a high level. Workbench includes the following modules “ANSYS Design Space” is referred to as Simulation “ANSYS AGP” is referred to as Design Modeler and ”ANSYS Design explorer” referred to as Design explorer. Workbench provides enhanced interoperability and control over the flow of information between these task modules. Various tools and techniques are incorporated for efficiently manage to large models. Like tree filtering tagging tree Objects, connections worksheet, object generator, sub modeling. Data can be transferred from a 2D coarse model [Full Model] to a 3D submodel. Submodeling is available for structural and thermal analysis types with solid geometry.

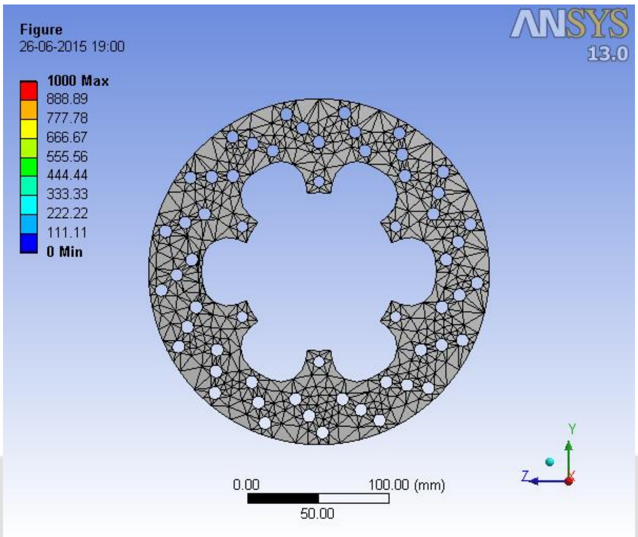
3.1 MODEL OF SOLID DISC BRAKE

The finite element model of disc brake constructed for the dimensions as shown in fig.2 the inner radius, outer radius and flange thicknesses of discs are as 0.08, 0.0131 and 0.024m for cast iron and stainless steel respectively to both cases solid and ventilated disc.



Initial model of brake rotor

ANALYSIS USING ANSYS-

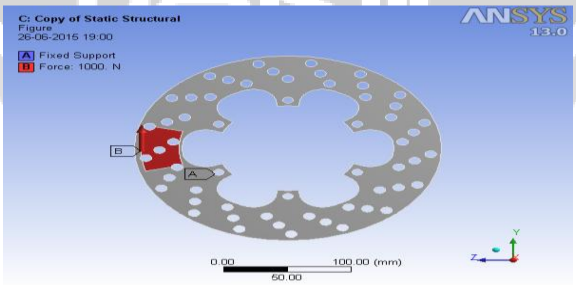


B)MESHED MODEL

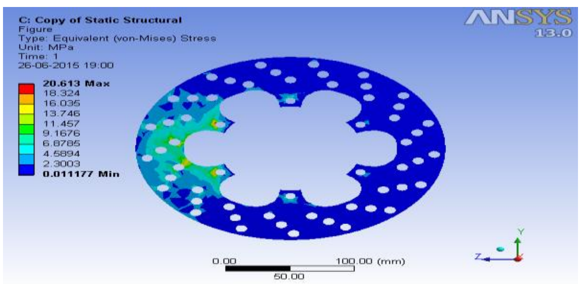
The goal of meshing in Workbench is to provide robust, easy to use meshing tools that will simplify the mesh generation process. The model using must be divided into a number of small pieces known as finite elements. Since the model is divided into a number of discrete parts, in simple terms, a mathematical net or "mesh" is required to carry out a finite element analysis. A finite element mesh model generated is shown in fig.3.The mesh results are as shown in table No 2.The elements used for the mesh of the model are tetrahedral three-dimensional elements with 8 nodes.

3.2 THERMAL AND STRUCTURAL BOUNDARY CONDITIONS

The boundary conditions are introduced into module ANSYS Workbench, by choosing the mode of simulation and by defining the physical properties of materials and the initial conditions of simulation. In this work, a transient thermal analysis will be carried out to investigate the temperature variation across the both disc by applying heat flux value for repeated braking applications using ANSYS. Further structural analysis is carried out by coupling thermal analysis. In addition convection heat transfer coefficient is applied at the surface of the ventilated disc for the analysis as shown in fig 4.

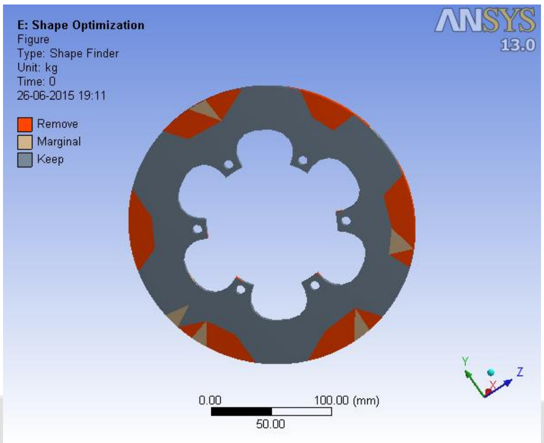


Static Structural Analysis



During each braking cycle, the temperature on surface of the disc is raises. During 1st braking, the temperature rises from ambient temperature 22 to 166 . The maximum temperature rise is indicated in red color and green color shows average temperature rise at the friction surface around the circumference of the disc.

SHAPPE OPTIMIZATION



4. RESULTS AND DISCUSSIONS

Intervel(min.)	Temp. From Experimentation(°C)	Temp. From FEA(°C)
Normal	34.3	30.4
5	38.6	34
10	40.7	42.2
15	43.0	47
20	42.6	46.1
25	43.6	39.2
30	43.9	41.4
35	41.1	45.6
40	43.2	47.3
45	43.2	44.7
50	43.3	48.9
55	44.9	42.2
60	40.8	47.5

5. CONCLUSION

Equivalent stress values of gray cast iron which in less than the permissible values therefore design of disc is safe & it is also experimentally verified. Shape optimized disc brake will have lesser weight & mass of selected one hence it will reduce the cost.

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