RESEARCH ARTICLE OPEN ACCESS

COUPLED THERMOMECHANICAL ANALYSIS OF DISC BRAKE ROTOR

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ABSTRACT:
The importance of vehicle safety is increasing with the rapid increase in the vehicle population and corresponding increase in the number of accidents. Vehicle braking system is considered as one of the most fundamental safety-critical systems in modern vehicles as its main purpose is to stop or decelerate the vehicle. Brakes are exposed to large thermal stresses during routine braking and extraordinary thermal stresses during hard braking. With the introduction of disc brakes the effectiveness of braking has improved to higher level. Brake disc can mechanically fail if the heat and the stress which is developed are not properly dissipated. In order to meet these requirements, we have designed a ventilated disc and it is compared with conventional solid disc for structural, modal and Couple field analysis (thermal + structural). 3D design of disc is created in Solid Works whereas analysis is done in ANSYS WORKBENCH by using thermal-structural coupled method. We have compared the result on the basis of dissipation of the heat and the compressive stress which was developed while breaking. Also we have studied the influence of changing the rotor stiffness on braking effect.

Keywords: Modal analysis, natural frequency, heat flux, mode shape, thermomechanical analysis, moment of inertia (MI).

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I. INTRODUCTION:

Breaking system is one of the most important active safety systems of the vehicle. This system is used to reduce an acceleration of vehicles from a high speed to a required. A friction between brake pads and rotor faces causes a conversion of kinetic energy into thermal energy by using friction based braking systems. The modernization facilities of multi-lane promote high-speed driving of vehicles. The drum braking systems could not meet all the requirements of high speed breaking system of passenger & racing vehicle. We are using a disc breaking system to fulfil high speed breaking system. The fraction between brake pads and rotor faces induce excessive thermal loading which results in surface cracking as well as high wear of the brake pad and rotor rubbing surfaces. It increases a temperature of the system. This temperature leads to overheating of brake seals, brake fluid, as well as the other components of the braking system. The stopping capability of brake increases by the rate at which heat is dissipated due to forced convection and the thermal capacity of the system. The heat dissipation rate decides the stopping capability of the breaking system. The rate of heat dissipation is depends on thermal capacity

as well as force convection of the system. Saravanan [1] showed that ventilated disc brakes were more effective in the compressive stress and dissipation of heat which were developed while braking. He compared result of ventilated disc with that of conventional solid disc. Belhocine [2-3] studied the analysis of thermomechanical behaviour of the dry contact during the braking phase of the brake disc surface and brake pads. He used the thermal-structural analysis to determine the deformation as well as the Von Mises stresses induced in the disk brake rotor, the contact pressure distribution in pads. He shown that the ventilation disc brake system provides a very good high temperature resistance and played a major role to cool a disk brake rotor system. Talati [4] studied heat conduction during braking process also he analytically studied an effect of heat generation on various parameter in transient state. Akop [5] studied a thermal stress analysis on disc brake rotor for steady state and transient condition. He shown effect of heat dissipation along the disc brake rotor surface during the periodic braking via conduction, convection and radiation. Jung [6] analysed the thermal elastic instability due to heat generation into disc brake rotor surface and brake pads system during breaking process by using a technique of the finite element analysis. Belhocine [7-8] analysed thermal and mechanical behaviour of the dry contact in disc brake system and showed that a coupling between temperature and stress field during a breaking process. Also, he proved that increasing temperature increases an induced stress into a breaking system. He studied the effect of surface roughness and wear of the rotor as well as brake pad interface by using finite element method also he presented a numerical simulation of the

thermal behaviour of a total disc brake system of car. Guru Murthy [9] did an attempt to investigate an effect of strength, stiffness as well as variations in design of brake disc rotor on the distribution of temperature and stress prediction. Nouby [10] studied as well as analysed a different designs of disc brake rotors. He suggested a various modification into a design of disc brake rotor by considering a various parameters.

Problem Definition:

To design a solid and ventilated disc brake rotor as well as to analyse a fully coupled thermal and structural analysis of sold and ventilated disc brake rotor system by using specified standard literature.

II. ANALYSIS PROCEDURE:

Modelling Of Disc Brake:

The rotor of the disc brake is modelled in Solid Works and the design specification has been considered from a reference journal [10]. The required dimensions of design are mention in Table 1. The ventilated rotor of disc brake is designed by considering the total weight of the ventilated rotor disc should not exceed that of a weight of solid disc rotor which is given below. The moment of inertia of the ventilated disc rotor is calculated. It satisfies the required condition of solid rotor disc. The modelled disc is imported in ANSYS 14.0.

TABLE 1: Dimensions of the disc and vehicle

Parameter	Unit	value
Inner disc diameter	mm	66
Outer disc diameter	mm	262
Disc thickness	mm	29
Disc thickness, (TH)	mm	51
Vehicle mass, m	Kg	1385
Initial speed, v0	Km/hr	28
Deceleration, a	m/s^2	8
Effective rotor radius	mm	100.5
Rate distribution of the braking forces, ϕ	%	20
Surface disc swept by the pad, Ad	mm	35993

Analysis:

A standard brake disc system consists of a rotor which rotates about a wheel axis, a piston slides inside a caliper–piston assembly, which is placed at a suspension system and on a pair of disc brake pads of a vehicle. The piston is pushed, when pressure is applied by the driver, to press a pad against the disc rotor surface and simultaneously another pad is operated by a caliper against the rotation of the disc. Numerical simulations is done by using ANSYS WORKBENCH, a finite element analysis is performed in this study. Various boundary conditions are applied on the model of disc brake rotor, taking into account its environmental condition, which are shown in figure. The finite element mesh is generated by using three-dimensional solid element. There are 113367 elements which have 185901 nodes as shown in figure1 and 2. Thermal condition is used to carry out the thermal mechanical couplings which are shown in table 2.

III. MATERIAL PROPERTIES

TABLE 2: Thermo Mechanical property of Disc material

Parameter	Units	value
Thermal conductivity, k	W/m. °C	57
Density,	kg/m^3	7250
Specific heat, c	J/kg. °C	460
Poisson's ratio	-	0.28
Elastic modulus, E	GPa	138
Angular velocity	rad/s	157.89
Coefficient of friction	-	0.2
Thermal expansion,	$(10^{-6}$ / °C)	10.85

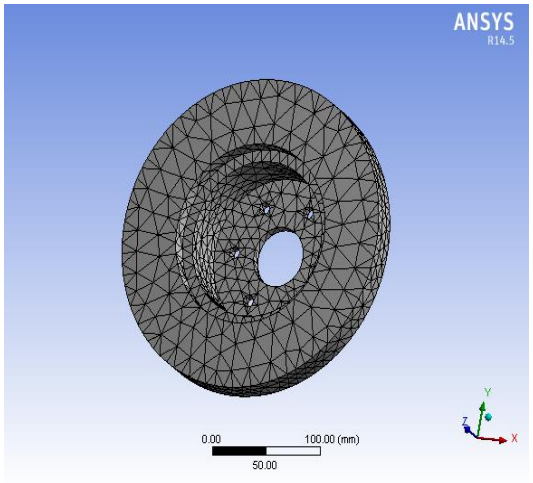

Figure 1: Solid disc brake rotor with meshing.

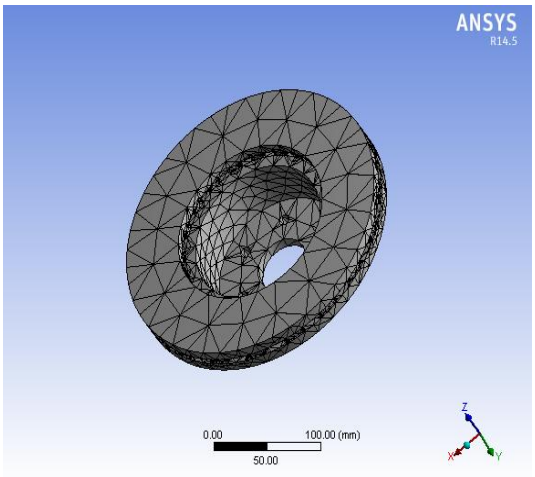

Figure 2: ventilated disc brake rotor with meshing**.**

Modal Analysis:

A modal analysis is performed to determine natural frequencies and mode shapes of the system. It is also used to study vibration characteristics of a structure or a component of machine. The mode shapes and natural frequencies are one of the important parameters in the design as well as analysis of a structure for dynamic loading. The modal analysis is performed for both ventilated disc and solid disc.

IV. MODE SHAPES:

For solid disc:

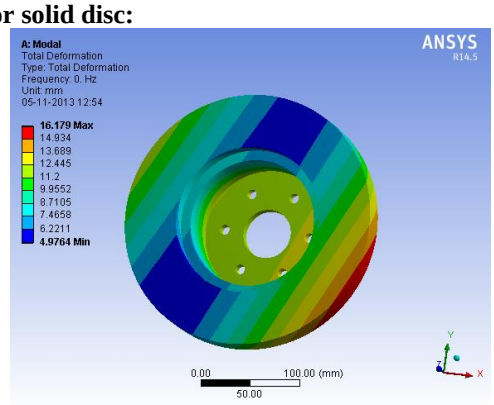

Figure 3: First mode shape of solid disc**.**

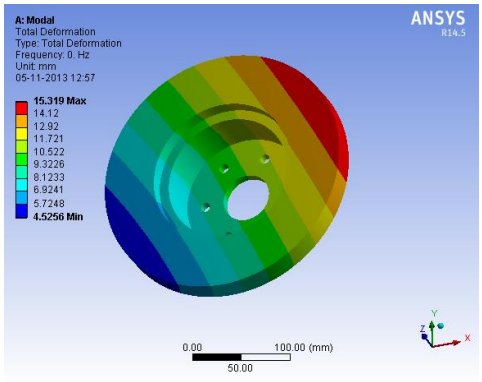

Figure 4: Second mode shape of solid disc.

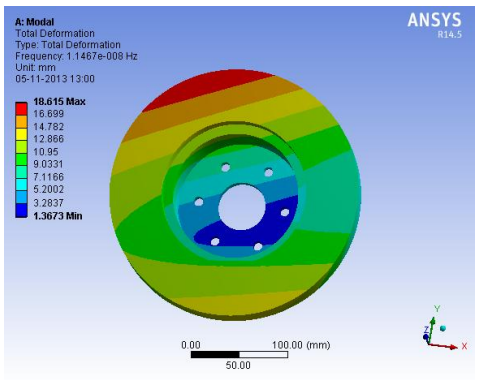

Figure5: Third mode shape of solid disc.

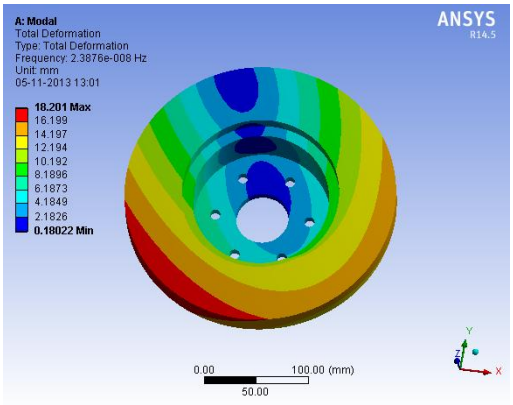

Figure 6: Fourth mode shape of solid disc .

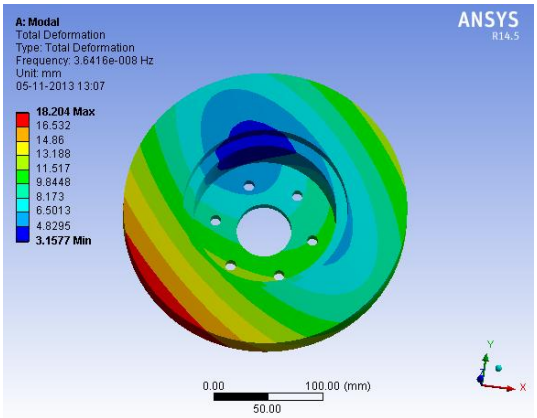

Figure 7: Fifth mode shape of solid disc.

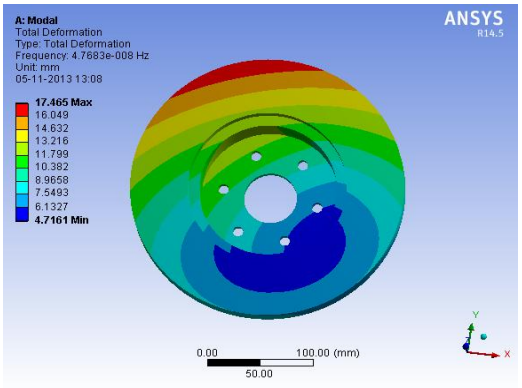

Figure 8: Sixth mode shape of solid disc.

For ventilated disc:

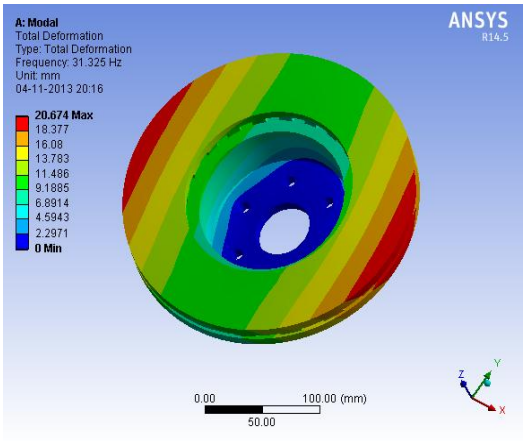

Figure 9: First mode shape of ventilated disc.

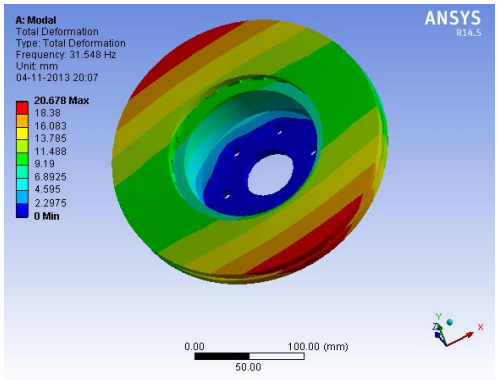

Figure 10: Second mode shape of ventilated disc.

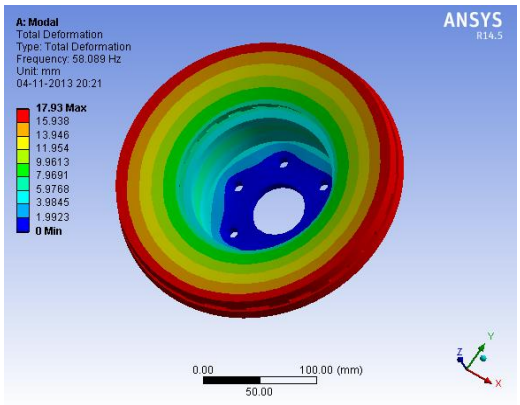

Figure 11: Third mode shape of ventilated disc.

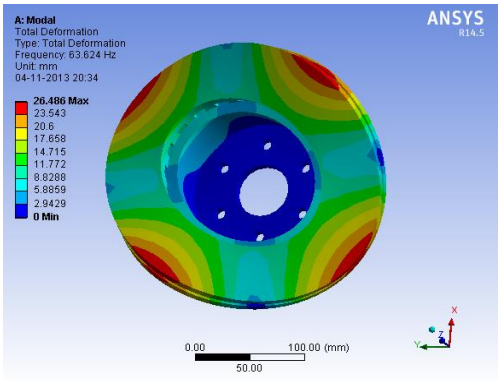

Figure 12: Forth mode shape of ventilated disc.

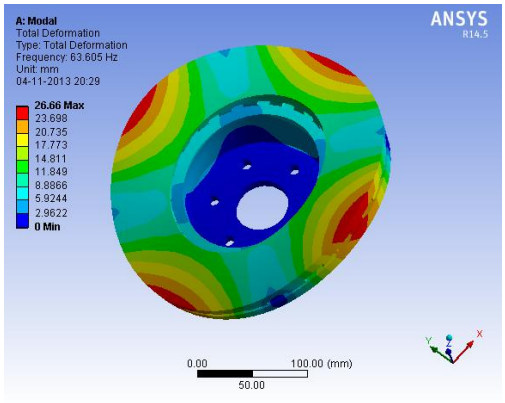

Figure 13: Fifth mode of ventilated disc.

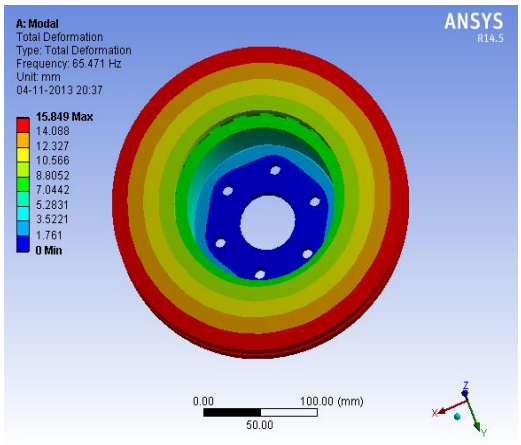

Figure 14: Sixth mode shape of ventilated disc.

TABLE 3: Comparison of normal mode deformations of solid disc and ventilated disc.

Mode number	Solid disc deformations (in mm)		Ventilated disc deformations (in mm)	
	Maximum	minimum	Maximum	minimum
First	16.179	4.976	20.674	0
Second	15.319	4.529	20.678	0
Third	18.615	1.373	17.93	0
Fourth	18.201	0.180	26.66	0
Fifth	18.204	3.157	26.486	0
Sixth	17.465	4.716	15.849	0

V. COUPLE FIELD ANALYSIS:

This analysis is used to determine the effect of thermal loads on the design of the disc rotor are shown in table 4. High amount of temperature is generated when the pad rubs against the disc due to breaking action. The disc has fixed constrain, this prevents it for free expansion. It is much knows that ventilated disc has good temperature distribution property than solid due to presence of vent.

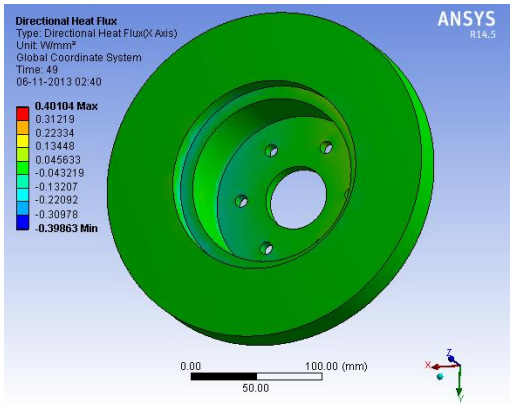

Figure 14: Directional heat flux for a solid disc.

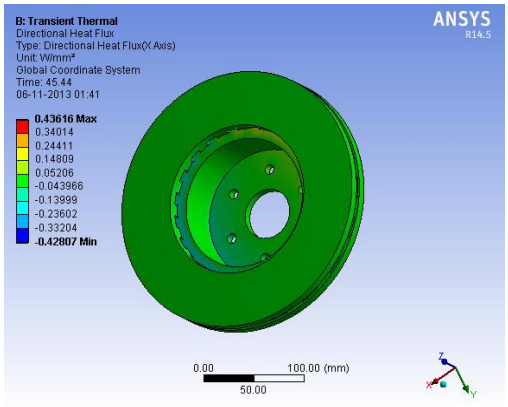

Figure 15: Directional heat flux for a ventilated disc.

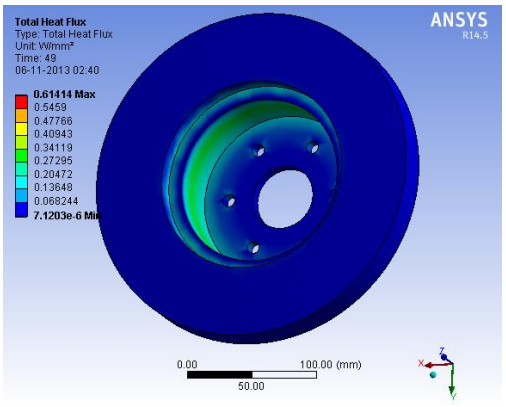

Figure 16: Total heat flux for a solid disc

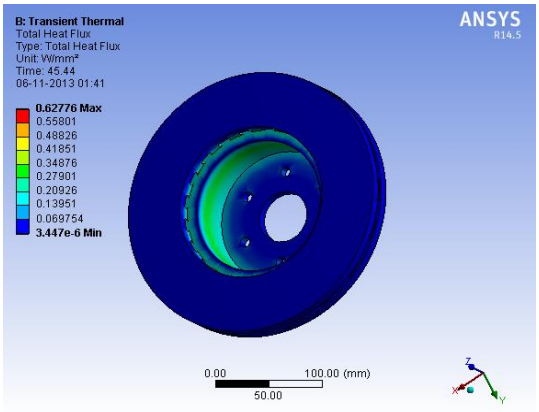

Figure 17: Total heat flux for a ventilated disc.

TABLE 4: Comparison of direction heat flux, total heat flux for a solid disc and ventilated disc.

	Solid disc		Ventilated disc	
	maximum	minimum	maximum	minimum
Directional heat flux	0.4010	-0.39863	0.43616	-0.42807
Total heat flux	0.61414	7.1203e-6	0.62776	3.447e-6

VI. RESULT:

From the analysis it is observed that at a given parameter the ventilated disc rotor has a much higher natural frequency than that of given solid disc rotor this may be caused due to the geometry and the mass distribution into the disc.
The coupled thermomechanical analysis also shows that there is a higher directional heat flux in ventilated disc than sold disc rotor where as a there is higher total heat flex in ventilated disc than sold disc.

VII. CONCLUSSION

The Modal analysis and Couple field analysis is done on the disc rotor to determine the variation in the deflections & temperature distribution. The analysis results shows that the ventilated disc rotor has lesser deflection as well as more total heat flux distribution than solid disc rotor. It shows that ventilated disc has better design than solid disc for a given condition in terms of total as well as directional heat flux. These effects will increase the improved safety to the vehicle and the passengers by increasing braking effectiveness.

REFERANCES:

[1] D. Saravanan, R. Ramsai, (2012), Thermo mechanical analysis of solid and ventilated disc, SAE International, ISSN 0148-7191.

[2] Ali B, Mostefa B. Thermomechanical modelling of disc Brake contact phenomena. FME Transactions. 2013; 41: 59-65.
[3] Ali B, Mostefa B. Thermo-mechanical Analysis of a Disc Braking System. TSEST. 2013;2(6): 302-309.
[4] Talati F, Jalalifar S. Analysis of heat conduction in a disk brake system. Heat Mass Transfer. 2009; 45:1047-1059.
[5] Akop M.Z, Kien R, Mansor M.R, Mohd Rosli M.A. Thermal stress analysis of heavy truck brake disc rotor. Journal of Mechanical Engineering and Technology. 2009; 1(1):43-2180-1053.
[6] Jung S.P, Park T.W, Lee J.H, Kim W.H, Chung W.S. Finite element analysis of thermoelastic instability of disc brakes, Proceedings of the World Congress on Engineering. 2010;2:WCE 2010.
[7] Ali B, Mostefa B. Thermal- mechanical coupled analysis of a brake disc rotor, Elixir Mech. Engg. 2013; 55A:13244-13250.
[8] Ali B, Mostefa B. Simulation of fully coupled thermomechanical analysis of disc brake rotor, SIMULATION. 2012;88(8):921-935.
[9] Nathi G.M, Charyulu T.N, Gowtham K, Satish Reddy P. Coupled structural / thermal analysis of disc brake, IJRET. 2012; 1(4):539-553.
[10] Nouby M, Srinivasan K. Parametric Studies of Disc Brake Squeal using Finite Element Approach. Jurnal Mekanikal. 2009; 29:52-66.

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