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Novel Design and Analysis of a Brake Rotor

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***Abstract*—**Over the course of the past century, the global automotive industry's stance towards safety has evolved from one of contempt to one nearing reverence. A suspension system that provides safe handling and cornering capabilities can, with the help of an efficient braking system, improve safety to a large extent. The aim of this research is to propose a new automotive brake rotor design and to compare it with automotive vented disk rotor. Static structural and transient thermal analysis have been carried out on the vented disk rotor and proposed rotor designs to evaluate and compare their performance. Finite element analysis was employed for both static structural and transient thermal analysis. Structural analysis was carried out to study the stress and deformation pattern of the rotors under extreme loads. Time varying temperature load was applied on the rotors and the temperature distribution was analysed considering cooling parameters (convection and radiation). This dissertation illustrates the use of Finite Element Methods to examine models, concluding with a comparative study of the proposed rotor design and the conventional vented disk rotor for structural stability and thermal efficiency.

***Keywords*—**Disk brakes, CAD model, rotor design, structural and thermal analysis

I. 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 kinetic energy of the moving member and dissipate the absorbed energy in the form of heat. In the present study, current model of a disk brake of an automotive passenger car has been modeled. By keeping the existing brake design as a reference, a new design has been evolved. The evolved design is subjected to static structural and transient thermal analysis. The proposed design is found to be better from the perspective of structural and thermal stability.

II. Case Study: Vented Disk Rotor

A. Existing Rotor Design

Rotors used in the automotive disk brakes are generally vented disks and are made of cast iron or cast steel. By introducing radial vents air flow is channeled through the rotor thus increasing heat transfer through forced convection.

Stress induced in the disk rotor due to brake pressure is compressive stress which is favorable as maximum permissible compressive/tensile stress in the case of cast iron is very high as compared to its maximum permissible shear stress. Cross drilling is done in some high performance applications to increase rate of heat transfer.

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B. Drawbacks and Scope for Improvements

When subjected to continuous braking the surface of the disk rotor reaches temperatures higher than 500 °F and this results in excessive rotor and brake pad wear. The rise in temperature also leads to decrease in the efficiency of the brakes i.e. increase in required force at the pedal and increase in stopping distance. Thus braking efficiency can be increased by increasing the rate of heat transfer from the brake rotor to the surrounding atmosphere.

III. Proposed Design

The main aim of the proposed design is to increase the area of brake force application and to induce compressive stress in the rotor. Rotor design is shown in Fig.1. Two pads on the inside of the drum shaped rotor *2&3* are actuated by a single slave cylinder, external pad *1* (towards the chassis) is actuated by an independent slave cylinder, and the external pad *4* (away from the chassis) is rigidly connected to the kingpin (similar to the floating caliper type disk brakes). Since the number of braking surfaces has been increased from two to four the force required at the brake pads and hence pedal is almost halved as shown in the relation below.

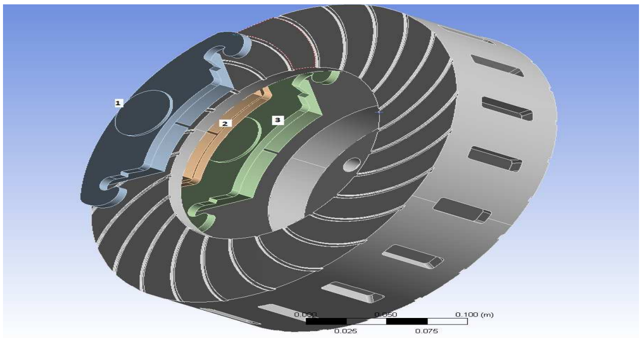

Fig.1a Proposed design of brake rotor

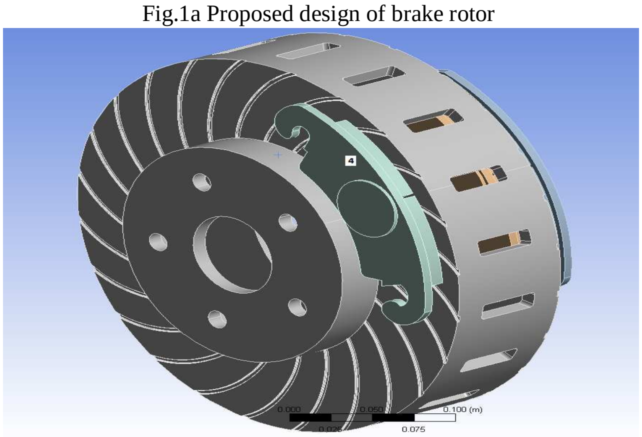

Fig. 1b Proposed rotor design.

In any automotive braking system the maximum retarding force per wheel is given by:

$$F_r = \mu_r * R \text{ (N)} \quad (1)$$

Where,
F_r = maximum retarding force of the road on tire (N)
μ_r = coefficient of friction between road and tire
R = normal force per wheel of the vehicle (N)

This retarding force is achieved during extreme braking conditions and is equal to the frictional force generated by the brakes [1].

$$\mu_r*R = \mu_b*P*A*n \qquad (2)$$

Where,
μ_b = coefficient of friction between brake pad and rotor
P = pressure applied on the slave cylinder (N/m^2)
A = area of slave cylinder piston (m^2)
n = number of contact frictional forces acting on one rotor (2 for existing design and 4 for proposed design).

From the above relation it can be proved that since n has increased by a factor of two the force acting per pad has been decreased by a factor of two. Since pressure at slave cylinder is directly related to the pressure applied at the pedal the driver's braking effort is also significantly reduced. Further as the number of surfaces undertaking braking force has increased the heat supplied to individual surfaces is also decreased (calculations shown under thermal analysis).

IV. STATIC ANALYSIS OF BRAKE ROTOR DESIGN

A. Static structural analysis

Static structural analysis is done to evaluate the behavior of the proposed model under the action of braking forces. Static structural analysis evaluates the deformation, strain produced, stress induced and other structural parameters. All static analyses have been carried out for the following data:

Bake pressure (pressure at slave cylinder) = 6.9Mpa
Coefficient of friction between rotor and pads = 0.55

B. Results and discussions

The results of static analysis are presented in table I.

TABLE I
RESULTS FOR STATIC ANALYSIS

Model	Maximum total Deformation (m)	Equivalent Elastic Strain	Equivalent Stress (Pa)
Existing disk rotor	$1.6*10^{-5}$	$2.07*10^{-4}$	$4.14*10^{7}$
Proposed brake rotor	$5.2*10^{-6}$	$9.2*10^{-5}$	$2.15*10^{7}$

From the static analysis, proposed design is found to posses higher structural strength. This can also be contributed to the fact that in proposed design, the nature of stress induced in the faces of rotor is compressive. For the same amount of retarding force the force applied at the brake pedal is reduced by 50%. Thus proposed rotor significantly reduces the force required at the brake pads thus decreasing the stress developed.

Static analysis results for proposed design have been shown in Fig. 2.

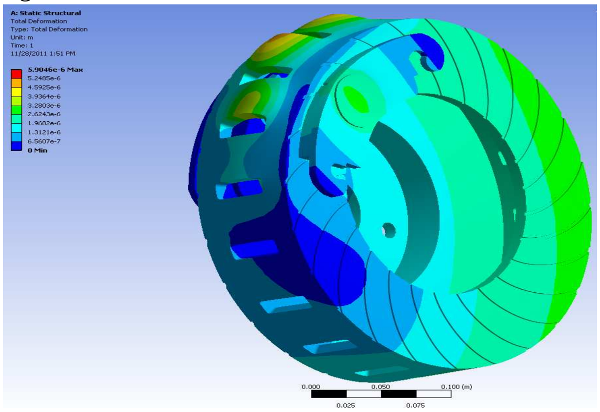

Fig. 2a total deformation of rotor after static analysis

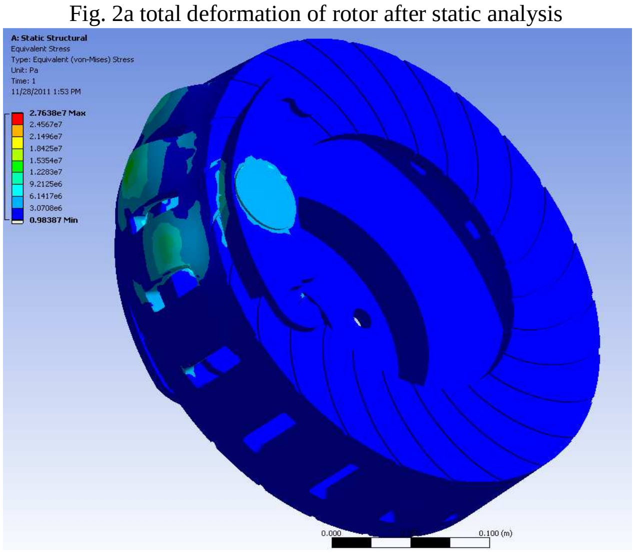

Fig. 2b equivalent stress distribution after static analysis

Thus from the static analysis it is found that stress and deformation developed in the proposed design is comparatively less as compared to that of the vented disk rotor.

V. THERMAL ANALYSIS OF BRAKE ROTOR DESIGN

A. Thermal analysis of rotor designs:

In transient thermal analysis a time varying thermal load (temperature load) is applied and its behavior is analyzed. Both convection and radiation parameters are considered for evaluation of results. Although the convection coefficient varies with velocity and surface a general convection coefficient of 53 W/(m^2.°C) is taken for both internal and external convection [2]. The emissivity of cast iron is taken to be 0.45 [3]. In this case study, a time varying temperature load is calculated for a car of mass 1700Kg travelling at 100 Km/hr brought to a complete stop (one complete stop). Instantaneous heat input to the brakes q is given by the equation (3) [4].

$$q = \partial/\partial t(½*m*v^2) \text{ joules/sec} \qquad (3)$$

$$q(t) = magv(0)(1-t/t_s) \quad (4)$$

$$q(0) = magv \quad (5)$$

(total heat input to all four brake rotors.)

Where,

t_s = stopping time (s).
a = deceleration rate of vehicle, percentage of g
g = acceleration due to gravity (m/s^2)
v(0) = initial speed of vehicle (m/s)

q(0) for one surface is calculated from equation(5) and is applied in equation(6). For a linearly decreasing heat input into the surface of a semi-infinite body, the surface temperature rise can be estimated from the expression (6), [5].

$$T(t) = [2*q(0)*\sqrt{(t/(A*\sqrt{(\pi*K*\rho*c)}))}]*(1-2t/3t_s) \quad (6)$$

Where,

q(0) = initial heat input per surface , Btu/s
t = time, s
t_s = total stopping time, s
c = specific heat of body, Btu/(lb*°F)
K = thermal conductivity of body, Btu/(in.s.°F)
ρ = density of body, lb/(in^3)
A = surface area, in^2.

On solving the function (6) for temperature as a function of time we get the temperature input at required time steps which form the input to the transient thermal analysis. The temperature vs. time graph for vented disk rotor is shown in Fig. 3, and for the proposed design is shown in Fig.4.

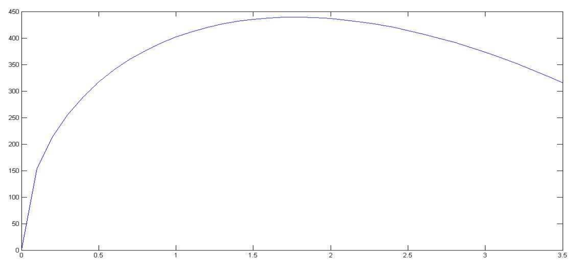

Fig. 3 Temperature vs. time graph for vented disk rotor

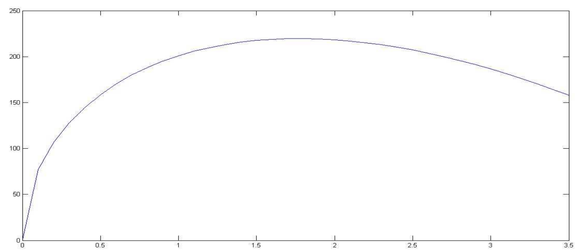

Fig. 4 Temperature vs. time graph for proposed rotor design

B. Results and discussions of thermal analysis:

The temperature and heat flux distribution of the proposed model is shown in Fig. 5.

From the input graph it can be clearly seen that the temperature load on each surface is reduced to 50% of its initial value when compared between existing vented disk rotor and the proposed rotor. The cooling rate is further enhanced by the larger surface area of exposure of the proposed design. Thus thermally the proposed design is found to be more efficient than the existing disk rotor.

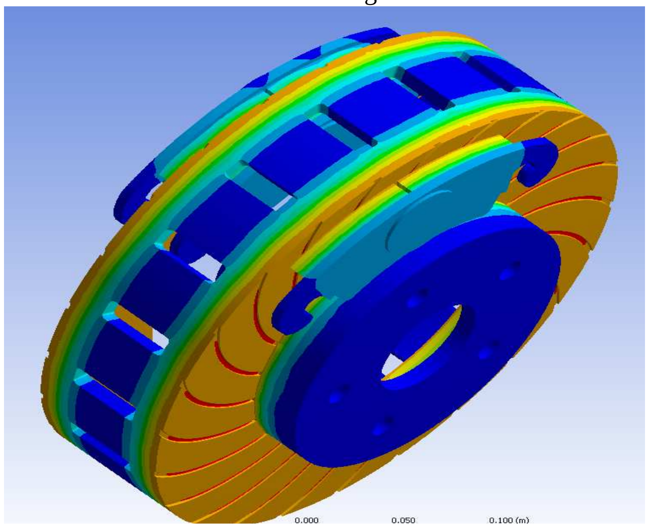

Fig. 5 Temperature distribution after thermal analysis of rotor

VI. Conclusion

Initial tests on the proposed design show that it is significantly more efficient than the existing design. Some of the advantages with the proposed system are: Proposed design will cause reduced damage to the brake pads and thereby increases the pad life; operating temperature of the rotor is drastically reduced; defects like brake fade are unlikely to occur; the braking effort by the driver is reduced; during repeated high intensity braking the performance of the brakes is drastically improved.

Convection coefficient used in the above analysis is the convection coefficient of existing disk brake rotor. Exact convection coefficient can only be found out through experimental analysis. Moreover the mounting of the proposed rotors has to be designed to suit the steering knuckle without major alterations to the same. The air flow through or around the rotor has to be studied in detail for further improvement of the rotor design.

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