Axisymmetric analysis of bolted disc brake assembly to evaluate thermal stresses

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Abstract:

Typically thermo-mechanical analysis including complexities such as contacts and bolt preloads are carried out using three dimensional models. These analyses require significant time and effort in FE model building, analysis setup, solution, and results processing. It also requires special effort to ensure it is error free.

In order to get stable and accurate results element size and time step selection is very important in transient analysis. These aspects are discussed in this paper.

This paper also talks about simplified yet almost equally accurate modeling and analysis method for thermo-mechanical analysis using brake fade test simulation as an example. This methodology is based on use of Abaqus/Standard Axisymmetric analysis technique modified to represent effect of discrete bolting, bolt preloads, and contacts within various components of the assembly.

Analysis results as well as analysis turnaround times are compared between this new method and the conventional method. Up to 80% time can be saved with significant improvement in the accuracy of the results.

Introduction

Repetitive braking of the vehicle leads to heat generation during each braking event. The resulting rise in temperatures has very significant role in the performance of the braking system. Problems such as premature wear of brake pads and thermal cracking of brake discs are attributed to high temperatures. Consequently controlling the temperature profiles and thermo-mechanical stresses are critical to proper functioning of the braking system. CAE simulations are often used to for evaluating the brake disc design using thermo-mechanical analysis techniques. Conventional approach is to use three dimensional FE models of the brake discs. This approach has major drawbacks of higher pre and post processing as well as solution times. Need is felt to develop a quick and reliable method to evaluate the thermal stresses in brake discs. This paper describes one such approach based on modified axisymmetry analysis.

Thermal analysis of brake disc – basic steps

An overview of the process adopted in performing the brake thermal analysis is shown in the Figure 1.

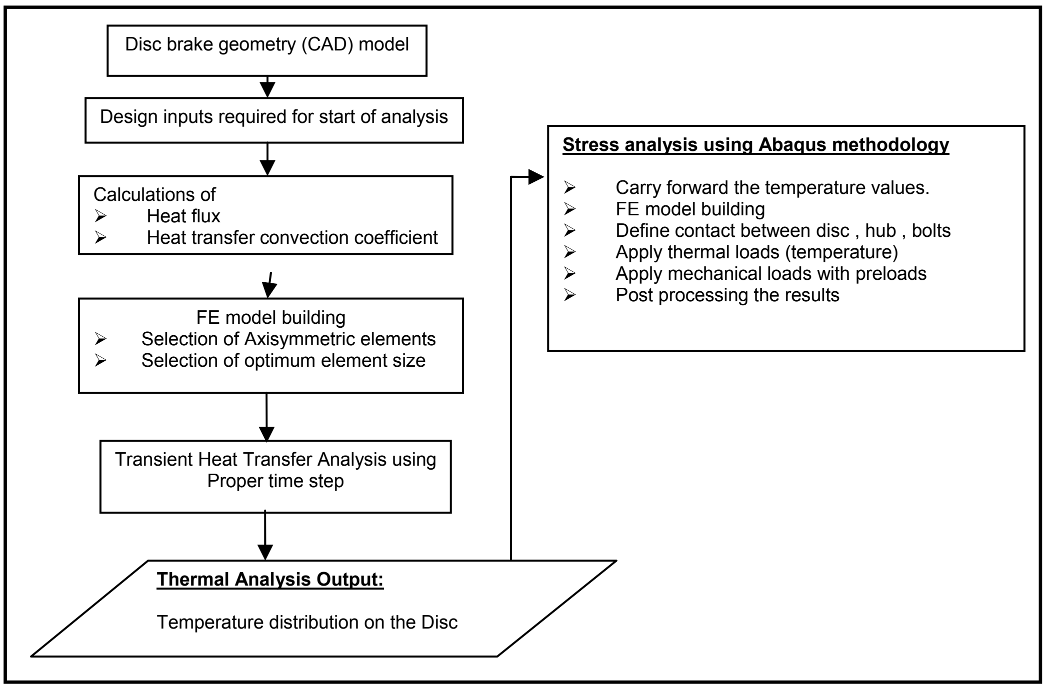

Figure 1: Brake thermal analysis process for a vehicle under a given braking schedule

First, a transient heat transfer analysis is carried out in order to predict the temperature distribution over the disc during the brake fade test (repeated acceleration and braking events). Subsequently, a mechanical analysis is performed introducing the computed temperature as thermal loads and considering the bolt pretension.

Drawbacks of the conventional simulation approach

In the conventional simulation for such problems it is typical to use 3D FE models to represent the various components. This approach has the following drawbacks –

- High preprocessing times – mainly due to hexahedral meshing and setting up of contacts
- High solution times – due to large model sizes
- High post processing times – mainly due to results data size which can be very huge if results are required at frequent intervals of the transient analysis

A need was felt to reduce the analysis cycle times through development of alternate simulation methodology. This has been achieved through using axisymmetry analysis method modified to include representation of discretely bolted assembly. It also incorporates bolt preloading and contacts.

FE model for the modified axisymmetry analysis

Figure 2 shows details of the FE model used for the modified axisymmetry approach.

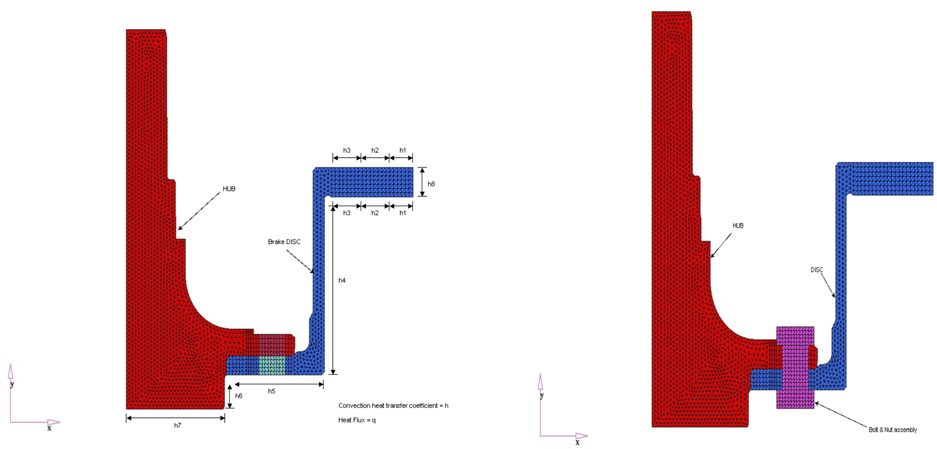

Figure 2: FE models of a disc brake system used in the modified axisymmetry analysis.

The same FE mesh has been used for the both thermal and mechanical analysis. For the transient thermal analysis, second order elements are used for discretization of the disc and hub whereas CAX6M (second order element with modified integration) are used for the structural analysis. The bolts are modeled as CPS6 (second order plane stress elements). Matching mesh pattern is required between the mating components at the interface.

In order to get stable and accurate results element size and time step has been selected using Time Integration method which is relation between thermal diffusivity and minimum time.

$\Delta x = [4 * (a * t_{min})^{0.5}] / N$, where '**a**' is thermal diffusivity and t_{min} is minimum time required to model physical event accurately.

Representation of bolts

To account for all eight bolts used in the joint, the combined cross-sectional areas of the shank and the head of the bolts is calculated and redistributed to the bolt mesh appropriately using the area attributes for the solid elements.

Following procedure is used to calculate effective bolt element layer thicknesses, contact surfaces involved in interaction between plain stress bolt elements and axisymmetric disc elements and material properties for hole region in axisymmetric model.

Figure 3 below shows the schematic representation of discretization of the bolt using plane stress elements.

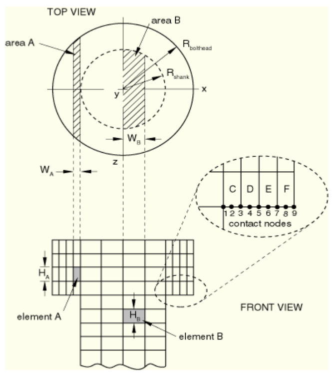

Figure 3: Contact surface interaction of bolt

Each plane stress element represents a volume that extends out of the x–y plane. Element A represents a volume calculated as (HA) x (Area A). Likewise, element B represents a volume calculated as (HB) x (Area B).The sectional area in the x–z plane pertaining to a given element can be calculated as

$$\boxed{Area = 2\int_{X_1}^{X_2}[(R^2 - x^2)^{\frac{1}{2}}]dx = [x(R^2 - x^2)^{\frac{1}{2}} + R^2 \arcsin(\frac{x}{|R|})]|_{X_1}^{X_2}}$$

Where R is the bolt head radius or the shank radius, depending on the element location, and X1 and X2 are x-coordinates of the left and right side of the given element, respectively. This sectional area is divided by the respective element width, and then we obtain representative element thickness. Multiplying each element thickness by the number of bolts in the model gives the effective element thicknesses.

Sectional areas that are associated with bolt head elements located on the model's contact surfaces are used to calculate the surface areas of the nodes used in defining the node-based surfaces of the model.

A the presence of the bolt holes in Axisymmetric disc brake system is represented by assigning smear material properties in the bolt hole area of the mesh and using inhomogeneous material properties that correspond to a weaker material in this region.

Analysis results:

Thermal Analysis:

In this thermal analysis a time-dependent heat source is activated for 15 braking events. The heat flux, heat transfer coefficients, test conditions such as initial operating temperature of the disc and duty cycle define the loading conditions for this analysis.

A transient heat transfer solution is used to predict the temperature distribution under these loading conditions. The comparison of temperature results between “Conventional approach” and “Modified axisymmetry approach “in the disc is shown in Figure 4.

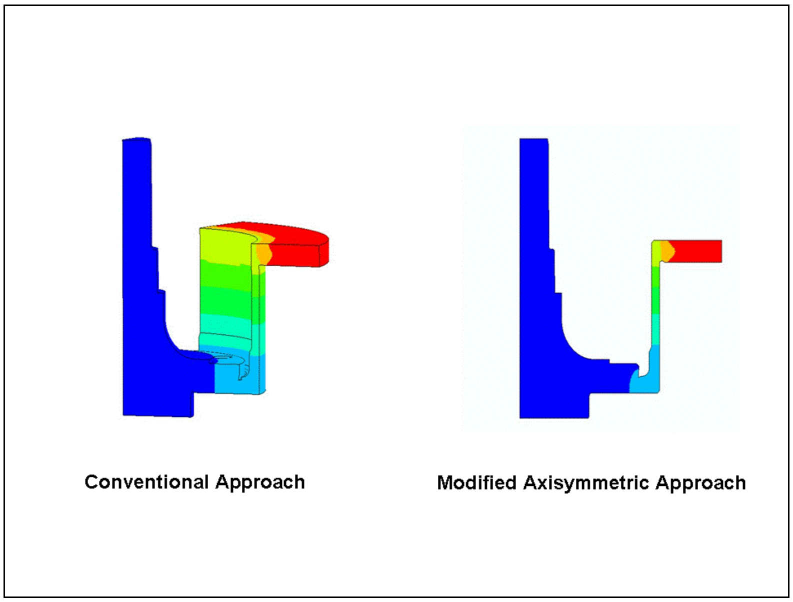

Figure 4: Temperature distribution plot for brake disc.

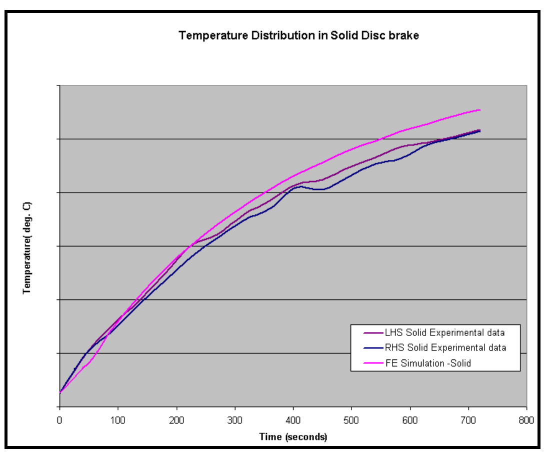

Figure 5: Experimental Correlation.

The temperature on the disc, predicted at the centre of the contact area with pad is compared with the experimental data. Figure 5 shows simulation results in comparison with experimental data. FE results predicted are quite close to measured temperatures, the maximum deviation is within 7%.

Structural Analysis:

Temperatures computed in the previous thermal analysis are introduced as thermal loads in the structural analysis. In addition to the existing FE model, bolt pretension is considered.

The figures 6 and figures 7 illustrate the results for the displacement contour plot for conventional & modified axisymmetric approach.

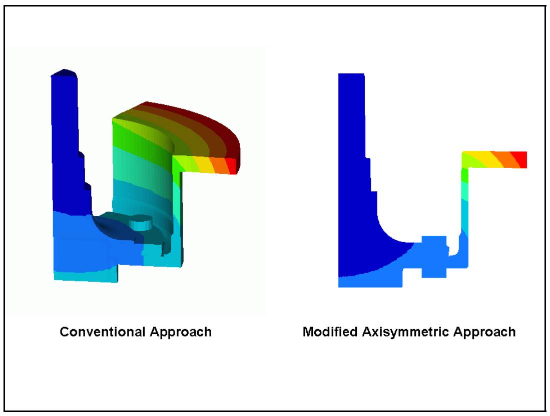

Figure 6: Displacement plot comparison

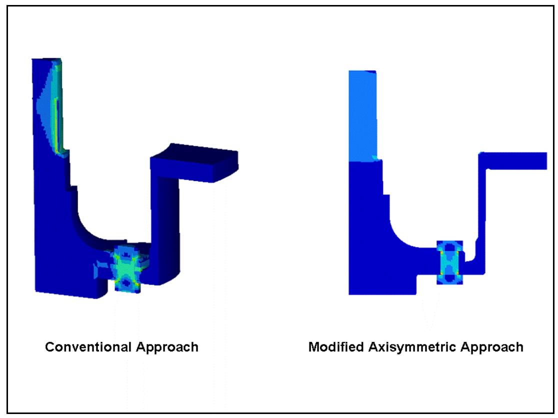

Figure 7: Displacement plot comparison

As shown in figures 6 and 7, there is maximum deviation of 15 % for the stress and displacement results respectively. The modified axisymmtery based analysis shows higher stresses and displacements which are attributed to better mesh density and considering the through thickness element size effect. Stresses predicted in the bolts are very close to theoretical values.

Analysis turnaround times

Table1: Analysis time comparison

Operation	3D model approach	Modified axisymmetry approach
Thermal analysis solution	3 hr	5min
Mechanical analysis solution	3 hr	10min
Preprocessing	15hr	3 hr

Conclusion

- The modified axisymmetry analysis used is significantly faster. The time to process a typical brake disc analysis has been reduces substantially from several hours to minutes. Upto 80-85% savings in time are seen.
- It is shown that even the bolt stresses predicted in axisymmetric method are accurate.

Acknowledgments

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