

Thermal Performance of Disc Brake and CFD Analysis

Bongkeun Choi
Hyundai Mobis

ABSTRACT

In this paper an effective technology of virtual thermal test of disc brake with several advanced analytic techniques was presented. With the virtual thermal test process, thermal performance of brake system could be easily evaluated without any possibility of great errors that used to happen in the past.

In addition to the classical result of CFD, this virtual thermal test produced several valuable applications such as thermal deformation of rotor, optimization of thermal performance and estimation of braking distance.

CITATION: Choi, B., "Thermal Performance of Disc Brake and CFD Analysis," *SAE Int. J. Passeng. Cars - Mech. Syst.* 7(4):2014, doi:10.4271/2014-01-2497.

INTRODUCTION

Overheat in brake system is apt to cause vapor lock, brake fade and brake judder which make the safety and performance of brake system worse. To restrain temperature rise in disc brake, automotive manufacturers have adopted many kinds of ventilated disc brakes that have better performance of cooling than rigid ones. However, high performance of disc brake with intuitive design is not always guaranteed and time-consuming trial and errors are not avoidable either.

CAE (Computer Aided Engineering) has come to be one of the fascinating tools to reduce time and errors when developing high performance brake system. However there used to exist many kinds of simplifications and limitations when evaluating the thermal performance of disc brakes using the analytic technologies established before.

In this survey, the process of virtual thermal test is suggested in order to overcome the long lasting limitations of old trials with the help of the commercial CFD software Starccm+. And the reliability of the virtual thermal test is presented as well by examining both the results of real test and virtual test. Moreover, some valuable engineering applications are expanded as below with the help of the virtual thermal test technology.

- Estimation of thermal deformation
- Optimization of thermal performance
- Prediction of braking distance

VIRTUAL THERMAL TEST

Overall Process

Overall process of the virtual test technology consists of three different sub-processes shown in [Figure 1](#). In the beginning 3D

turbulent steady-state flow analysis is performed to simulate air flow around brake assembly. After that distribution of HTC (heat transfer coefficient) can be calculated on the specific surfaces of brake assembly by steady-state thermal analysis.

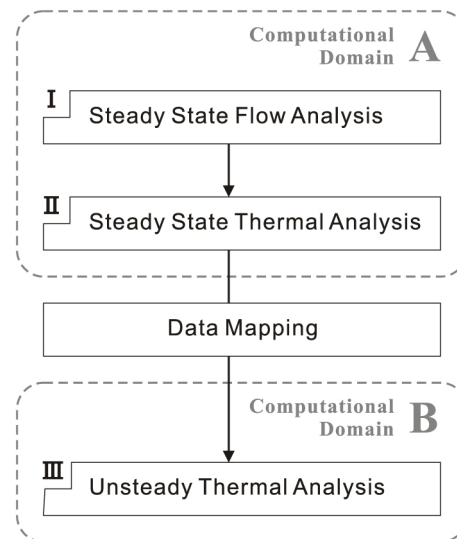


Figure 1. Overall process of cooling analysis

Additional computational domain of rotor solid is prepared to perform unsteady thermal analysis. The distribution of surface HTC acquired from steady-state thermal analysis is to be applied on the solid domain as boundary condition for unsteady thermal analysis.

The expected problem of applying HTC to new domain is the mismatch of grids between two domains, but it can be solved by adopting data mapping methodology.

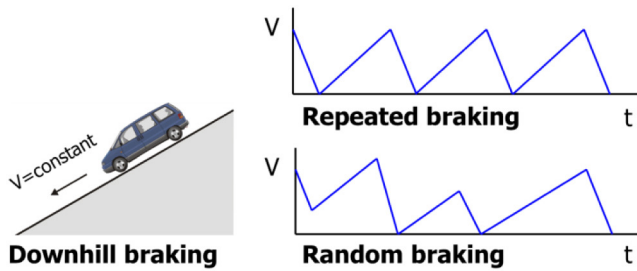


Figure 2. Driving speed during typical braking modes

Heat generation is calculated based on the braking mode (Figure 2) and is applied to the frictional surfaces of rotor. Solid domain is rotated to realize the cooling environment of physical test.

Steady State Analysis

During physical dynamometer test, complex 3D turbulent flow field is produced by rotating motion of parts and the additional cooling air introduced by a blower. To simulate air flow around rotor, most of the geometries of brake assembly are included in the computational domain shown in Figure 3. Computational domain consists of several million polyhedral cells. (Figure 4)

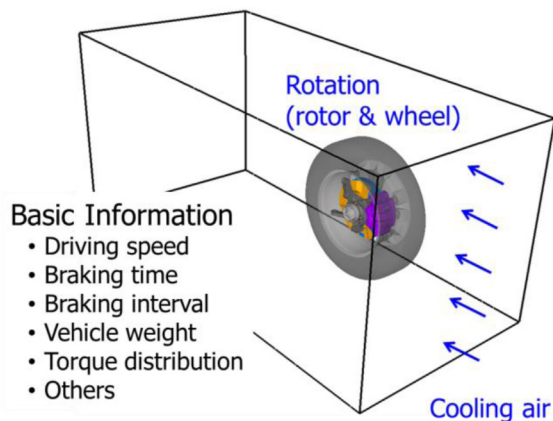


Figure 3. Computational domain for flow analysis

Velocity and atmospheric pressure is applied respectively to the inlet and outlet of computational domain. Rotating effect of engaged parts is simulated by moving reference frame. And the average value of rotating speed is calculated based on braking mode shown in Figure 2.

Some results of steady-state analysis are shown in Figure 5&6 and the rotational direction of rotor in those figures is counter clock wise. The interaction between rotational motion and air flow from inlet produces hardly-expected flow field. Figure 6 shows the distribution of surface HTC which is as complex as flow field.

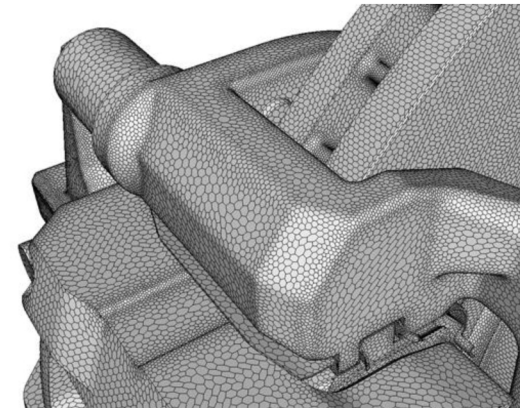
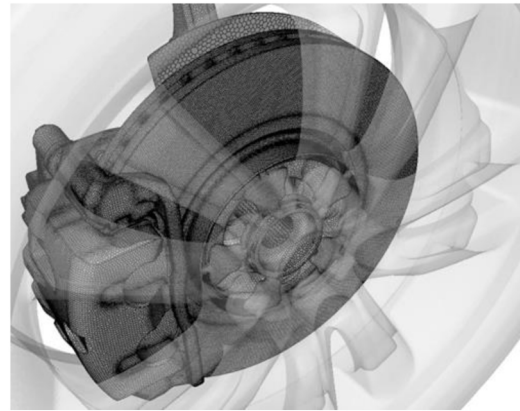


Figure 4. Polyhedral grid system around brake assembly

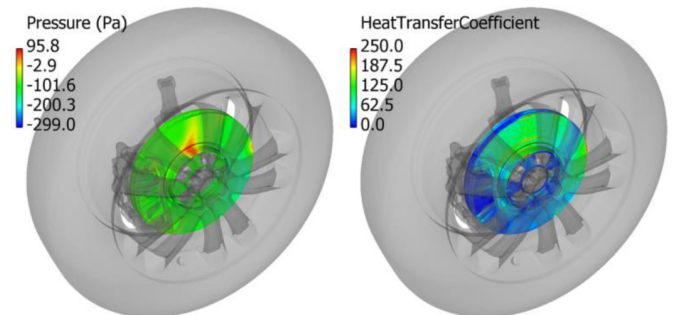


Figure 5. Contours of pressure and HTC on rotor surface

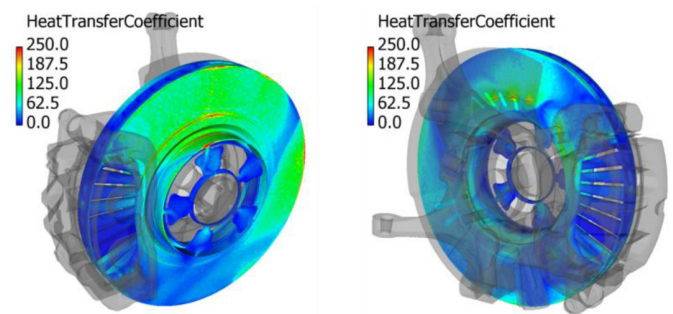


Figure 6. Contours of HTC on rotor surface

Data Mapping

Although total time of physical test is under an hour, computing time of unsteady thermal analysis would be over several days with the same domain and grids used in the former steady state analysis.

Additional solid domain is prepared to reduce computing time as mentioned before. The distribution of surface HTC is now mapped on the surface of new solid domain (Figure 7) for unsteady thermal analysis.

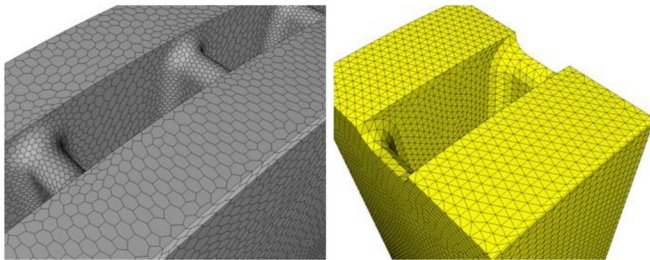


Figure 7. Two types of grid for data mapping

Unsteady Thermal Analysis

As temperature of rotor increases, it was found that specific heat tends to increase but thermal conductivity tends to decrease. Variation of both specific heat and thermal conductivity is applied to unsteady thermal analysis with the help of polynomial curves (Figure 8).

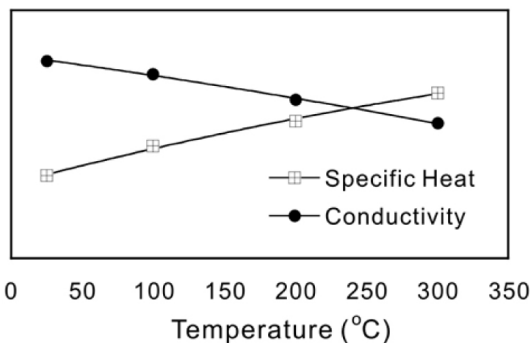


Figure 8. Variation of material properties

Frictional heat is calculated by the information of torque and driving speed during braking period (Figure 2). And the heat generation is applied to the thin volume mesh generated on corresponding frictional surface.

As rotor temperature rises, the amount of thermal radiation becomes considerable. In this paper the variable emission of thermal radiation from each surface is considered in order that rotor can be cooled down faster when it is hotter.

Since the mapped HTC is always applied to the same location where it was acquired, it would be impossible to get reasonable

result without further treatment on the solid domain, that is to say, the region where larger value of HTC was mapped will be cooled down faster. But if solid domain rotates during unsteady thermal analysis, the mapped stationary HTC would evenly affect whole domain in rotational direction and reasonable distribution of temperature will be calculated. In this paper, the rotational speed for moving mesh is set to be same as the rotational speed of rotating walls.

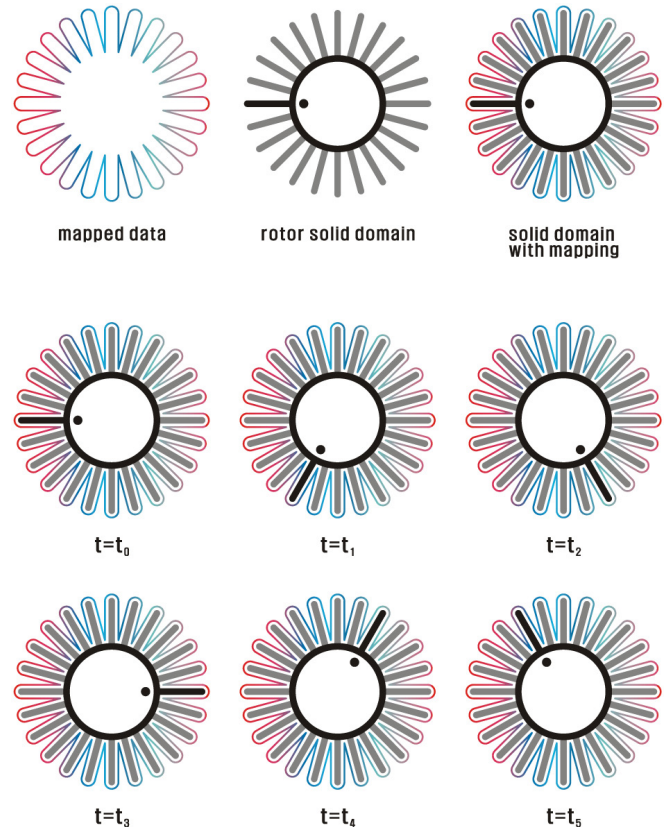


Figure 9. Schematic representation of moving mesh scheme

The fact that mapped HTC is acquired for a certain position of rotor says that the rotor position at every time step for unsteady thermal analysis must be same as that in steady-state thermal analysis (Figure 9). It suggests that time step size for unsteady thermal analysis cannot be arbitrary. Time step size is determined as shown in equation (1).

$$\Delta t = \frac{1}{\Omega} \times \frac{K}{N} \quad (1)$$

Δt , Ω , K , and N in equation (1) means time step size (sec), rotational speed of solid domain (rps), integer, and total number of fins of rotor respectively. Equation (1) means that each time step size is same as the time consumed when rotor rotates at the angle of $(K/N) \times 360^\circ$.