Coupled Thermo-Mechanical FE Analysis of Brake Systems Considering a Temperature-Dependent Nonlinear Friction Coefficient

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Nonlinear friction coefficient is the most important parameter that determines the braking characteristics of the brake system. A dynamic friction coefficient of a braking system under braking is calculated computationally through a brake dynamometer experiment. The nonlinear friction coefficient obtained by the experimental method is a temperature-dependent variable. However, there was no method to obtain the temperature-dependent nonlinear friction coefficient analytically, and most of the analytical studies were assumed to be fixed or linear friction coefficient [1, 2].

In this study, temperature-dependent nonlinear friction coefficient was calculated from the specifications of the brake system and the experimental results. A three-dimensional coupled thermo-mechanical FE analysis was performed by constructing a multi-body brake system considering calculated friction coefficient. Brake Torque Variation(BTV) results were compared to confirm the effect of temperature-dependent nonlinear friction coefficient.

A braking performance of the brake system can be evaluated from the results of the BTV. The BTV(τ) equation is expressed as the product of friction coefficient(μ), effective radius(r), braking pressure(P), piston area(A) and correction constant(k). The friction coefficient derived from the BTV equation is as follow.

$$\mu(t) = k\,\tau(t)/rAP(t) \tag{1}$$

The friction coefficient calculated using equation (1) is a time dependent variable. However, the friction coefficient is a temperature-dependent variable determined by the frictional heat generation during a braking. A time-dependent average temperature of the disc and pad is used to set the temperature-independent variable. Therefore, the recalculated temperature-dependent nonlinear friction coefficient is shown in Fig. 1.

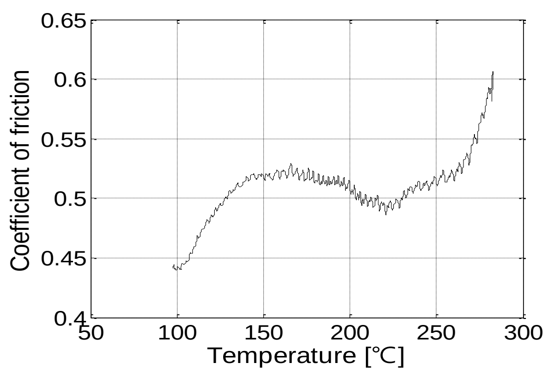

Fig. 1: Temperature-dependent nonlinear friction coefficient.

The calculated friction coefficient is the input parameter of the braking analysis. The three-dimensional finite element analysis model is a multi-body system consisting of a disc, pads, and pistons. Braking boundary conditions is that the brake disc with an initial rotational speed of 160 km/h is stopped for a constant pad pressure of 5 MPa. To calculate the frictional heat generation during braking, the heat flux coupling condition was applied to the coupled thermo-mechanical analysis was used. The finite element analysis model and boundary conditions of the three-dimensional braking system are shown in Fig. 2.

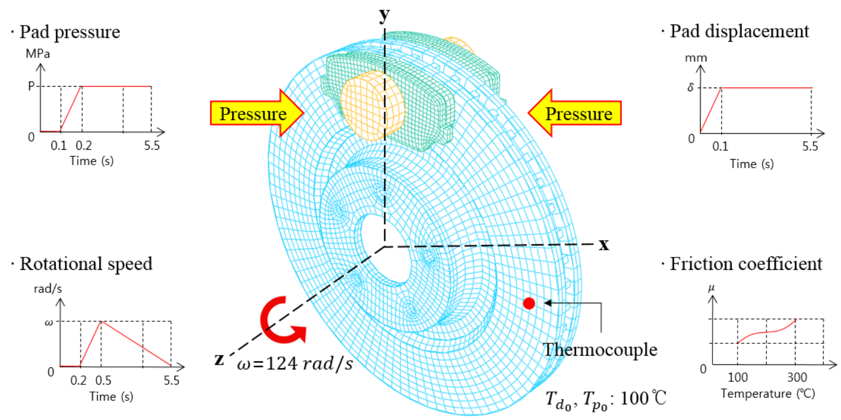

Fig. 2: The finite element analysis model and boundary conditions of the three-dimensional braking system.

To verify the effect of the temperature-dependent nonlinear friction coefficient, reaction torque at the center of rotation was confirmed as the result of braking analysis. The reaction torque of the center of rotation is the same as BTV. Therefore, from Eq. (1), BTV is a variable of temperature-dependent nonlinear friction coefficient since all other variables are fixed constants. It can be seen that the BTV analysis result depends on the friction coefficient. The BTV comparison results for the analysis and experiment are shown in Fig. 3.

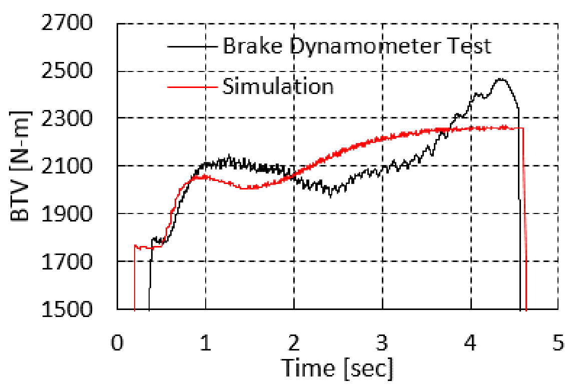

Fig. 3: Results of BTV.

During the braking, BTV increases nonlinearly with increasing and decreasing repetition. The error between experimental and analytical results is the large nonlinearity of experimental results in high speed braking and the difficulty of calculating accurate average temperature. If these are complemented, it is meaningful to be able to analytically evaluate the dynamic characteristics of the brake system applying the temperature dependent nonlinear friction coefficient. This study is the basis of nonlinear dynamic analysis of vehicle multi-body system using finite element analysis. Based on this study, nonlinear dynamics analysis of a multi-body system composed of wheels and tires will be conducted in the future study.

References

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