Development of Stiffness Analysis Program for Automotive Wheel Bearing

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Abstract: Automotive wheel bearing is an essential component of the vehicle and transmits engine power into wheels and supports vehicle weight. As comfortable ride has recently been the common interest, the stiffness of bearing which affects the steering performance becomes significant. In this study, the program BSAP was developed to carry out the stiffness analysis by designer easily and quickly. BSAP has three templates; CATIA template, AFC template, and Report template. In CATIA template, 3D analysis model was generated from the CAD model by eliminating useless fillets and holes and assigning heat treatment parts. Material property, boundary conditions and loadings were applied and analysis was performed in AFC template. Finally, analysis results was reported automatically in Report template. Bearing stiffness analysis was performed by using the BSAP. To verify the reliability of BSAP, the analysis results were compared with experiment results. They showed good agreement with the experiment results.

Keywords: Automotive wheel bearing, stiffness analysis, FEM

1. Introduction

Steering characteristic is one of the important performances of the vehicle which it relates comfortable ride during the driving. In response to recently increasing needs for ride comfort and steering feeling, it has been emerged as design requirements from automobile manufacturers. The key components in determining the steering performance are tires, wheels, wheel bearings, knuckles, brakes, and so on. Automotive wheel bearing is an essential component of the vehicle which transmits engine power into wheels and supports vehicle axle load. The stiffness of wheel bearing has a significant influence on the ride comfort and the steering feeing.

To consider and satisfy customer's request, vehicle development process has been improved actively for the purpose of shortening development period and reducing development cost. In order to improve the development process, the usage of CAE is increasing. To predict stiffness of wheel bearing, it is common to use commercial software. However, this commercial program, which is necessary for professional knowledge about finite element method (FEM), is not easy to use. Therefore, development of stiffness analysis program is helpful for designer to use easily and quickly is required.

Numata calculated the stiffness of the entire wheel components by adding the values computed for each component (Numata, 2005). However, this approach does not consider the overall stiffness of the wheel components exactly. Lee et al. adopted the parametric method to get the optimal bearing design to satisfy the bearing life, contact stress, stiffness simultaneously (Lee, 2010). And they also developed the analysis model which can consider the stiffness behavior by varying the ball contact angle (Lee, 2011). After reviewing the above studies, there is few bearing stiffness analysis program for bearing designer.

In this study, the program BSAP (Bearing Stiffness Analysis Program) was developed to carry out the stiffness analysis by designer easily and quickly. For CAD software, CATIA was used and for CAE software, Abaqus for CATIA was adopted to give us the same user interface environment. BSAP had three templates. In CATIA template, design CAD model converted into analysis CAD model. Material property, boundary conditions and loading were applied and analysis was performed in AFC template. Finally, analysis report was generated automatically in Report template. Bearing stiffness analysis was performed by using the BSAP. To verify the reliability of BSAP, the analysis results were compared with experiment results. They showed good agreement with the experiment results.

2. Development of the BSAP

The bearing stiffness analysis program, called BSAP, was developed. CATIA is used for CAD software. Abaqus for CATIA is adopted for CAE software because it gives the same user interface environment as CATIA so that designer can use easily and run quickly. Figure 1 shows the process flow for BSAP. As shown in Figure 1, it has three templates; CATIA template, AFC template, and Report template. In CATIA template, analysis CAD model is generated from the design CAD model by eliminating small fillets and holes and making and assigning the heat treatment parts for hub and outer ring. For the convenience of convergence, ball is assumed to springs. In this template, the numbers and positions to locate the springs are designated. Figure 2 shows the CATIA template menu and example of analysis CAD model.

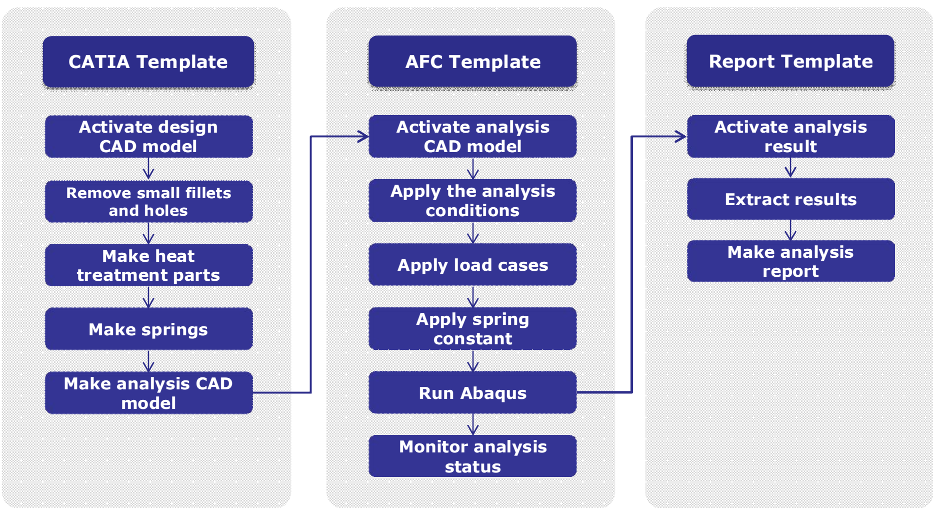
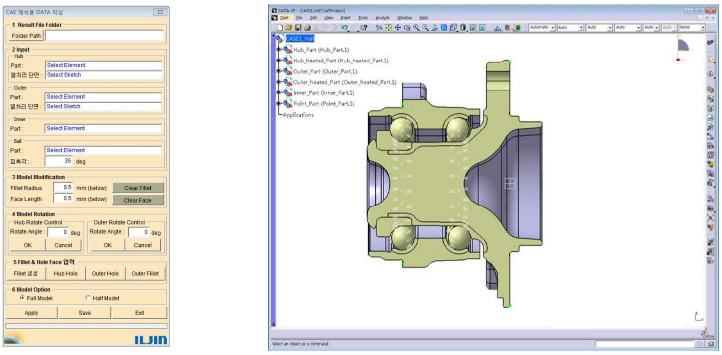
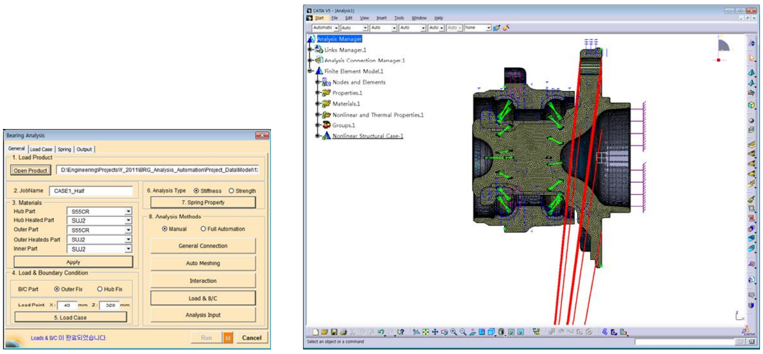


Figure 1. BSAP Process flow.

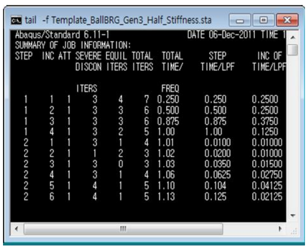


(a) CATIA template menu (b) Example of the analysis CAD model

Figure 2. Example of CATIA template.



(a) AFC template menu (b) Example of the analysis model

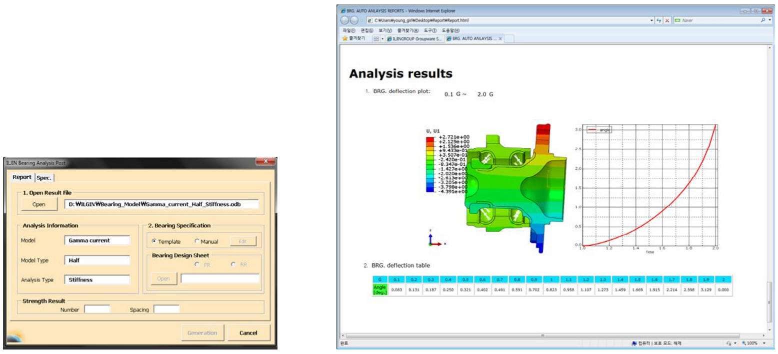


(c) Example of monitored analysis status

Figure 3. Example of AFC template.

In AFC template, material property, boundary conditions and loading are applied. Especially, number of spring and spring constant are applied in this template. After analysis condition inputs are completed, Abaqus for CATIA is performed. Analysis status is monitored in real time. The AFC template menu, example of the analysis model, and example of monitored analysis status are shown in Figure 3.

Finally, analysis report with HTML format was made automatically in Report template. Figure 4 shows the Report template menu and example of the analysis report.

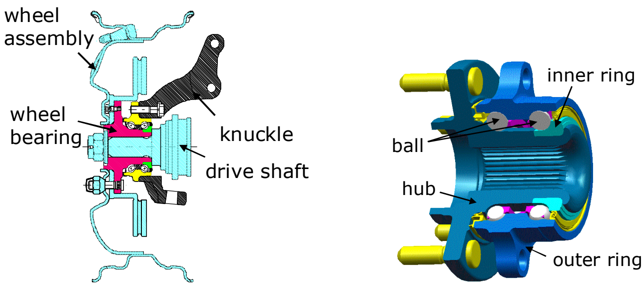


(a) Report template menu **(b) Example of the analysis report**

Figure 4. Example of Report template.

3. Bearing stiffness analysis with BSAP

Bearing stiffness analysis was performed by using the BSAP. As mentioned before, CATIA and Abaqus for CATIA are used for CAD and CAE software, respectively. Figure 5 shows the configuration of the wheel bearing for automotive.



(a) Wheel components **(b) wheel bearing**

Figure 5. Configuration of the wheel components and wheel bearing.

Because of geometric symmetry, half was modeled (see Figure 6). Automatic mesh generation technique was chosen for designer to use easily and run quickly. Therefore, C3D4 tetrahedral element having first order shape function was used in Abaqus for CATIA. The elasto-plastic material properties were given to simulate the bearing deflection behavior more precisely. Table 1 describes the material properties and Figure 7 shows the stress-strain curves. Analysis considered large displacement was performed to make an accurate estimate the bearing deformation.

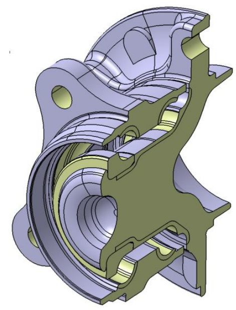


Figure 6. 3D half model of wheel bearing generated by CATIA.

Table 1. Material properties of wheel bearing.

Parts	Material	Young's modulus (GPa)	Poisson's ratio	Yield strength (MPa)
Hub	SAE 1055	207	0.3	456
Hub hardened	Heat treatment	239	0.3	1480
Outer ring	SAE 1055	207	0.3	456
Outer ring hardened	Heat treatment	239	0.3	1480
Inner ring	SAE 52100	239	0.3	1480

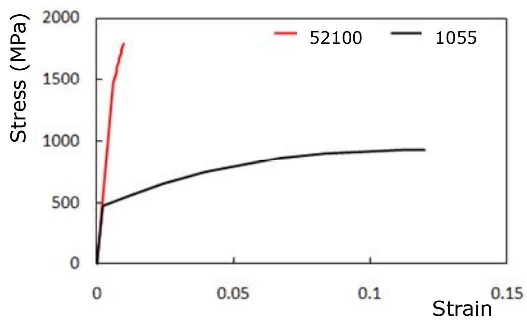


Figure 7. Stress-strain curves for SAE 1055 and SAE 52100.

The surface to surface contact was applied to simulate the contact behavior between hub and inner ring. The compression only spring, CONN3D2 axial connector, was modeled for ball stiffness. The spring constant is 6,000 kgf/mm. Outer ring tap holes were fixed for boundary condition as shown in Figure 8. Loading point is at wheel center. For simplicity of analysis, tire and wheel did not be modeled. Instead, kinematic coupling was used to connect between hub bolt holes and loading point as shown in Figure 8. T_r, T_a , and applied loading, M can be written as

$$T_r = \frac{R_s}{2} + \frac{R_s G h}{T_s} \quad (1)$$

$$T_a = G \times T_r \quad (2)$$

$$M = T_a \times r + T_r \times B_o \quad (3)$$

where R_s is axle load, G is cornering acceleration, h is C.G. height, T_s is track width, and B_o is bearing offset. According to cornering acceleration, applied loadings are described in Table 2.

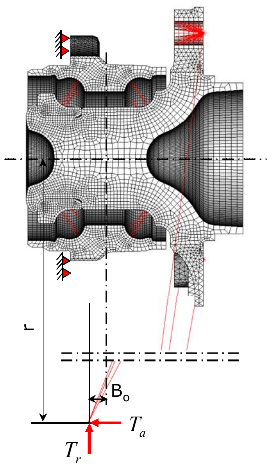


Figure 8. Boundary conditions and loadings.

Table 2. Applied loadings.

Cornering acceleration, G	0.0	0.1	0.2	0.3	0.4	0.5	0.6
Tr (kgf)	575	620	665	709	754	799	844
Ta (kgf)	0	62	133	213	302	400	506
M (Nm)	38	236	461	715	996	1306	1644

By the above mentioned method, bearing stiffness analysis was performed using AFC template. Figure 9 shows the deformation of wheel bearing applied above boundary conditions and loadings. The bearing stiffness, κ can be calculated as

$$U = \left| \delta_A - \delta_B \right| \quad (4)$$

$$\theta = \tan^{-1}\left(\frac{U}{D} \right) \quad (5)$$

$$\kappa = \frac{M}{\theta} \quad (6)$$

where δ_A, δ_B are deformation at point A, B, respectively, D is hub flange length, and M is calculated from Equation 3.

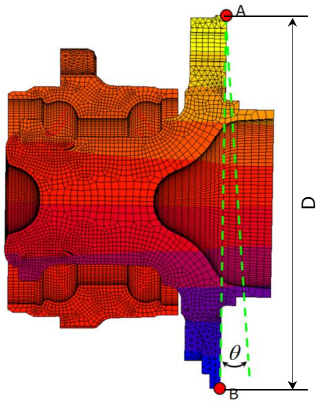


Figure 9. Deformation of the wheel bearing.

To verify the reliability of BSAP, the analysis results were compared with experiment results. As shown in Figure 10, they showed good agreement with the experiment results.

4. Conclusions

In this study, the Bearing Stiffness Analysis Program, called BSAP, was developed to carry out the stiffness analysis for automotive wheel bearing by designer. CATIA and Abaqus for CATIA were used for CAD and CAE software, respectively. Through BSAP, non-experts engineer can perform the stiffness analysis and embedding this within CATIA make for earlier decisions.

BSAP contains three templates; CATIA Template, AFC Template, Report Template. The bearing stiffness analysis was performed by BSAP. To verify the reliability of BSAP, experiment was carried out and compared with the analysis results. They showed good agreement with analysis results.

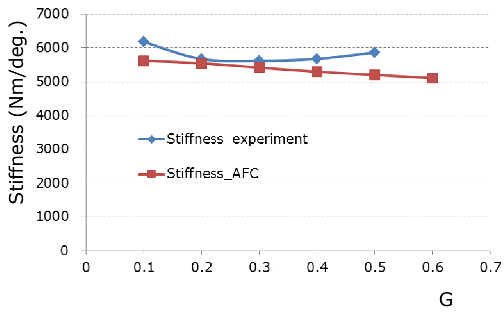


Figure 10. Comparison of the stiffness.

References

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