Application of CAE to Optimize the Durability of Suspension Air Spring

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Abstract*: Application of the CAE is needed to obtain optimized performance of the air spring under the consideration of many design factors. This Paper presents a method for estimating the durability of the air spring by applying it to the suspensions of a vehicle. We developed FE analysis techniques based on Abaqus, which enables us to evaluate and enhance the durability of the air spring at the initial design stage. Also, we validated the results by applying it to a mass production vehicle.*

Keywords*: Air spring, Bellows, Cord, Pin Hole*

1. Introduction

The air spring applied to luxury vehicle for improved ride comfort is under the load not only by the expansion force due to air pressure but also the torsion force caused by the suspension movement during running. Therefore, performance optimization in consideration of these loading conditions is required when designing the air springs. In this study, based on the suspension system model, an analysis method was developed, for evaluating the durability of the air spring to the input load such as steering force and inertial force. Also, the optimization of the performance was implemented in accordance with a variety of factors in durability.

2. Overview of the durability of the air spring

2.1 The air spring of vehicle

The air spring of the vehicle suspension operates by the spring stiffness obtained from compression and expansion of the air inside airbags made from composite materials originating from rubber. The air spring is more excellent in ride comfort and stability to the coil spring that is commonly used. In addition, it has an advantage of the automatic adjustment of the vehicle height, spring stiffness adjustment and constant resonant frequency along the load changes. Therefore, the air spring is generally used in large luxury vehicle and high-speed rail. The air spring consists of panels, rubber composite bellows, piston and a bumper.

Figure 1. General structure of the air spring.

2.2 Problem definition of the air spring endurance (the outbreak of pinholes)

The bellows are the most sensitive parts of the air spring when it comes down to the durability of the components. And because of this, frequent breakage problem occurs with the bellows. The bellows consists of laminated layers of the rubber and a reinforcement cord. Therefore, predicting durability life of the bellows using characteristic of the material is not easy. The breakage of the bellows is caused by the local folding from various loads induced from the suspension movement. Repeated folding causes the breakage of the reinforcement cord and makes the pinholes. The resulting pinhole creates air leakage problems, which makes the function of the air spring useless.

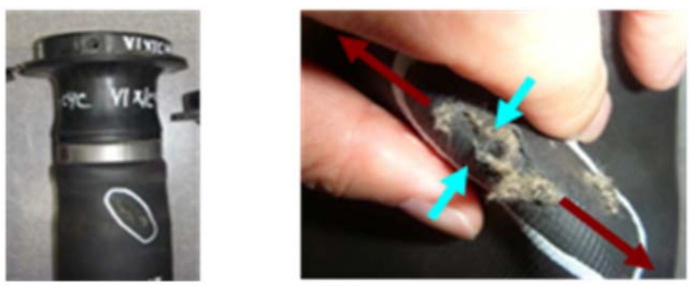


Figure 2. The durability breakage of the bellows by the pinhole.

2.3 Procedure of the air spring durability problem analysis

The procedure of durability analysis of the air spring is described in Fig.3, and basically predicts the presence of pinholes which induced from the suspension behavior. In this case, the evaluation factor is the generated force of the bellows. If the compression force occurs in the bellows, durability of the air spring is unsatisfied.

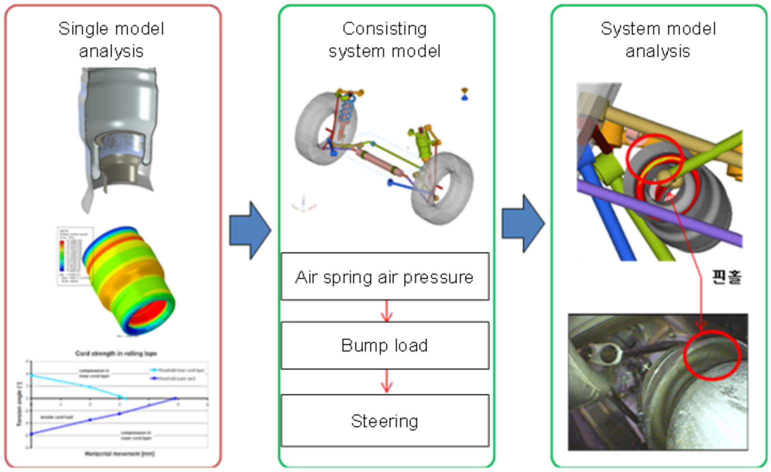


Figure 3. Procedure of the air spring analysis.

3. The composition of the analysis model

3.1 Definition of the material properties

The physical properties defining the air spring is determined by the bellows material constituting the rubber and the reinforcement cord. The property of the rubber is important input in the analysis. Therefore, the static test for the rubber is essentially required. The measured properties are defined by the Mooney-Rivlin energy function. Material properties of the reinforcement cord can be defined by characteristics of the cord itself (elastic modulus, diameter) and characteristics among multiple cords (thickness, angle). Each characteristic can be obtained from cord manufacturers.

3.2 Composition of single-unit analysis model

The finite element analysis model for single-unit air spring is composed based on the status of the free height. Bellows is modeled in detail in accordance with the laminate structure of the reinforcing cord and rubber, and is completed by adding components such as the upper piston and the mounting.

Figure 4. The air spring model of the front suspension.

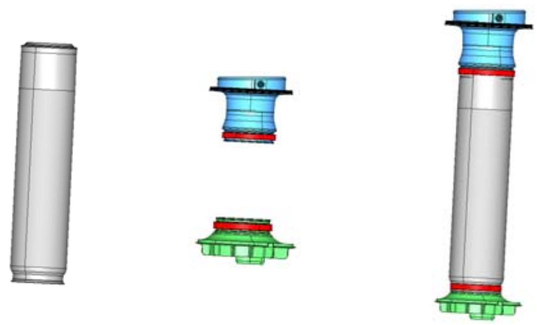


Figure 5. The air spring model of the rear suspension.

3.3 Composition of the analysis model by suspension system

The dynamic model of the suspension system based on S/W (Motion View) was configured to evaluate the correct behavior of the air spring according to behavior of the suspension system. The air spring in the system is also considered by free-height state and all of the suspension components are considered as the rigid body. As shown in fig 6, as after verify of the kinematic motion of the rigid system, and use the finite element model of the air spring as a substitute for the rigid model using Abaqus.

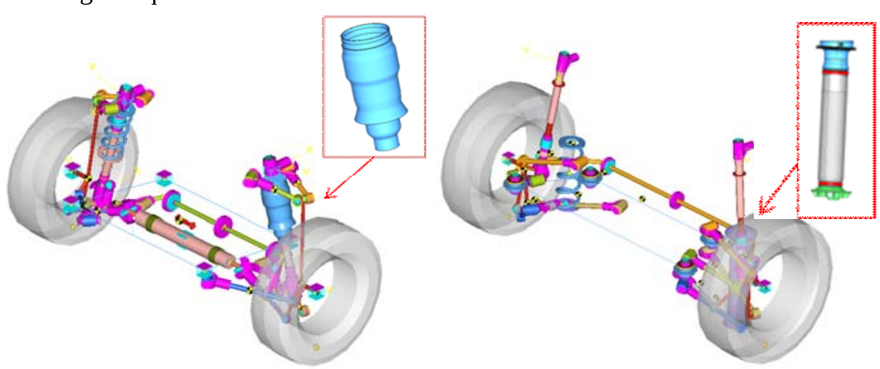


Figure 6. The system model of front and rear suspension.

4. Durability evaluation of the air spring

To verify the validity of the consisted model of the suspension system, analyzed for the vehicle model having durability problem.

4.1 Front suspension system

In the case of a mass production vehicle ‘A’, front air spring durability problems caused by outbreak of pinholes were frequently occurred in the field. When steering suspension, excessive load of torsion force was applied to the air spring. Also, the load was not absorbed due to the structure of suspension and caused the excessive deformation of the bellows. For reproduction analysis of ‘A’, suspension system model was developed including the detailed air spring model. Analysis results as shown in fig.7, present that the compressive force was generated in the same place of the bellows cord where the pinhole occurred in the field.

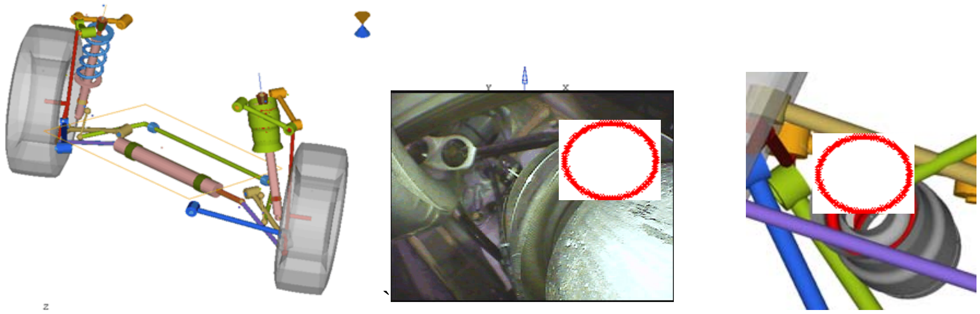


Figure 7. Analysis result of front suspension.

4.2 Rear suspension system

There are no torsional loads to the air spring in the rear suspension. If the vertical motion of the suspension in considered only, probability of occurrence of the pinholes are smaller than front. However, in the case of the multi-link suspension such as in car ‘A’, the vertical movements of the suspension induce large rotation of the lower control arm. In accordance with behavior of the lower control arm, torsion deformation appeared in the mounted air spring, which creates compressive force. That causes the compressive force which can make the pinhole. Therefore, the car "A" also has durability problem in field. Fig.8 is the analysis result of the rear suspension system. Similar to the front, the pinhole occurrence can be accurately reproduced.

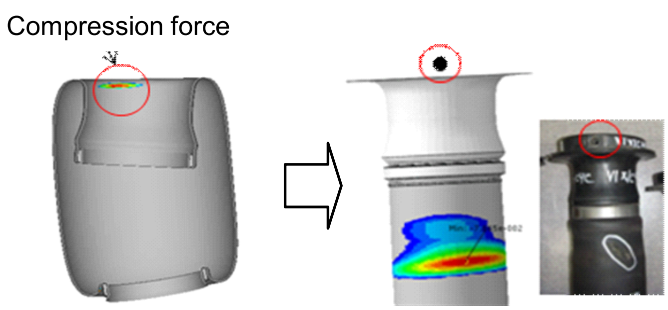


Figure 8. Analysis result of rear suspension.

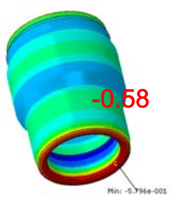
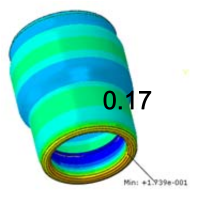
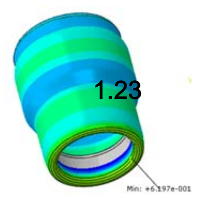
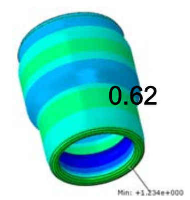
5. Improvement of the air spring design

Hitherto, the concept of the suspension system analysis model of air spring durability was applied and the validity was verified by implementing reproduction analysis. The advantages of the system unit analysis model are that it can improve the performance and optimize for different factors.

5.1 Improvement of the durability of front air spring

The improvement of the durability of the air spring can be made by the absorbance of torsion loads. Table.1 compares the cord force from the system analysis result by influential factors. It is shown that the durability has a significant impact on the outbreak of pinholes.

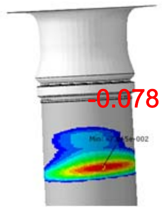
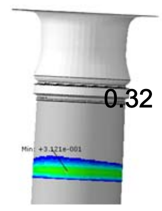
Table 1. Analysis result by influential factors.

Durability problem case	Mounting bush stiffness adjustment	Adopting bearing at upper mount	Adopting ball-joint at lower mount
			

5.2 Improvement of the durability of rear air spring

Table.2 is the analysis result of the rear air spring with respective influential factors, which presents obvious improvement effects.

Table 2. Analysis result by influential factors.

Durability problem case (install angle α^{o})	Adopting bearing at upper mount	Install angle ($-\alpha^{o}$)	Bearing & Install angle(0^{o})
			

By comparing the results of analysis and reproduction test by influential factors, it is found that the durability of air spring has improved.

6. Conclusions

The below is the conclusion resulted from defining analysis method to evaluate the durability of the air spring in the initial design step and implementing optimization analysis by influential factors on design.

(1) An integrated analysis model including the finite element model using Abaqus and the concept of dynamics was originally developed to evaluate the durability of air spring.

(2) The air spring durability problem was defined by the presence of pinholes. In addition, the deformation and durability by various loads such as vehicle weight, bumping, and steering of suspension can be evaluated.

(3) The reliability and validity were verified by reproduce test and improvement analysis on the durability of mass production and development vehicle models.

7. References

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