Finite element analysis of an air spring for automobile suspension

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Abstract: This paper is concerned with deformation and static characteristic analysis of air spring for automobile suspension. As an example, the type of EQ6111 air spring has been analyzed in its performance characteristics of deformation with variations in cord elastic modulus and cord angle. FEA results on the load vs. the displacement and the internal pressure vs. the displacement are compared with the test results, which agree with the FEA results. The analysis method can play an important role in the design of air spring.

Key words: air spring; nonlinear finite element method; fiber-reinforced rubber composite; cord angle

An air spring serves as a spring component with the elastic effect of compression and expansion of air in a composite rubber bag. It has high carrying capacity and low natural frequency, so that it can greatly enhance stability and comfort of vehicles. It has been more and more widely used for automobile suspension in advanced countries. However, it's not a long history since an air spring came to China, and there exist some difficulties in its design and manufacture. Therefore, research and development of an air spring with high performance is in exigent demand.

Stiffness is an important performance parameter of an air spring. The traditional design method is based on thermodynamics theory i. e. PV^n = constant. Using a graghical method and related assumptions, the empirical formulas of various air springs[1] can be deduced. But the accuracy of this method is too low to reflect the influence of the inner structure on the stiffness. Currently, the stiffness of an air spring is obtained primarily through experiment. Although the accuracy of experimental method is high, it's still at the expense of time and money, and it is too difficult to optimize the structure.

In recent years, the finite element method has been used to calculate and analyze the air spring due to the limitation of traditional calculation methods[2-4]. Based on the research on the dynamical performance simulation of the radial tire[5-6] and the characteristics of large deformation of the air spring, we analyzed EQ6111 air spring. The influence of the cord angle and the Young's modulus on the deformation of the inflated air spring has been studied as the follows.

1 Simulation of air spring

1.1 Structure analysis

An air spring is similar to a tire in structure. The bag for general use is made up of rubber material in the outer part and fiber-reinforced rubber composite in the inner part (as shown in Fig. 1). When it is inflated with compressed air, the load on the air spring is primarily born by the cord fabric. The steel wire ring and the inside rubber layer play the function of sealing. The mechanical behavior of an air spring presents not only geometry nonlinearities, material nonlinearities and load nonlinearities but contact nonlinearities.

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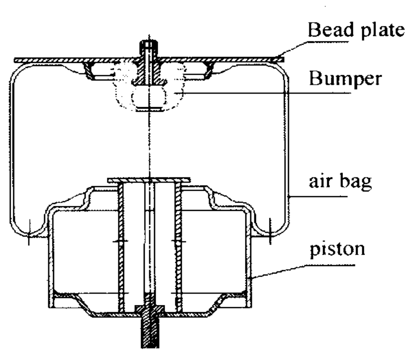
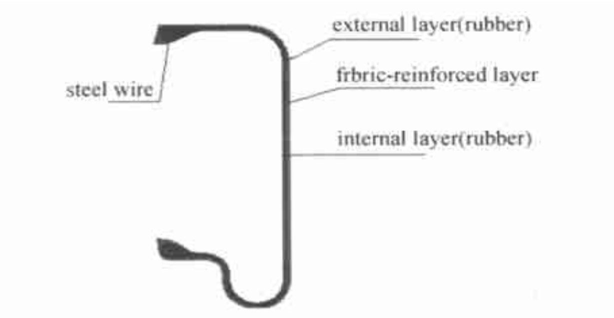


(a) Mounting drawing of EQ6111 air spring



(b) Material distribution of the air spring section

Fig. 1 Sketch map of an automobile air spring

1.2 FEM model

1.2.1 Material properties Compared with a tire, an air spring behaves very large deformation. Rubber in a working air spring has an exceeding linear deformation range. Therefore the Mooney-Rivlin constitutive model is adopted for the study of rubber material in the structure with large deformation. C_{10} and C_{01} are achieved by a simple tension test, a planar tension test and a biaxial extension test. The feature of the fiber-reinforced rubber composite is non-linear, viscoelasticity and anisotropic. According to the theory of composite material, the cord-rubber composite is usually assumed as a combination of two elastic materials, which can be considered isotropic respectively, and the viscoelasticity can be neglected[7]. Therefore, the fiber-reinforced rubber composite can be assumed as an elasticity, orthotropy and homogeneous material.

1.2.2 The changing of the internal pressure Due to the large deformation of the air bag, the volume is changing, and as a result the internal pressure is not constant. In the calculation, an iterative method is used to simulate the change. Considering PV = constant in a static analysis, we can deduce the transient pressure in each step after the volume is calculated, then the next step of the calculation proceeds continuously.

Using CAD software, we can get the numeric outline of an air spring. The fiber-reinforced rubber composite is defined with an element solid46 in ANSYS software. The inner rubber layer, outer rubber layer and the trigonal rubber are defined with an element hyper58, the steel wire rings are defined with solide45. The contact area is defined with targe170 and conta173. There are 987 nodes defined in an axial cross section, 256 elements for the composite layer, 58 elements for the steel wire ring and 495 elements for the rubber. The bead plate and piston are fixed. And, the pressure load is put on the inner surface. At first, the inflated shape is calculated as the original state. And then the total displacement of ± 90 mm is added with an increment of 10 mm in each step. The changed pressure can be calculated. Therefore, the relation curve of the internal pressure with the displacement can be obtained.

1.3 Analysis results

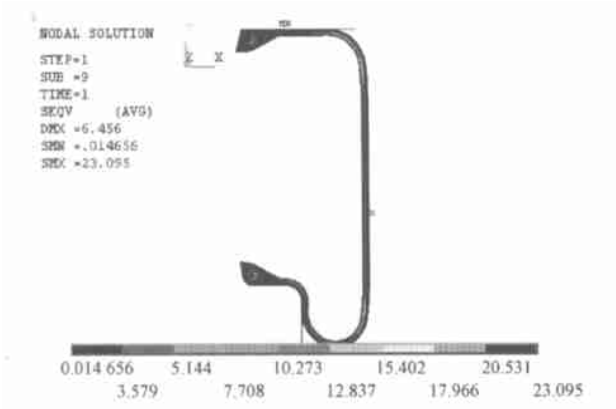
1.3.1 Results of inflated deformation Analysis condition: fix the plate and piston in the design height, inflate the air bag with 0.3 MPa pressure until the system is balanced

(1) Effect of cord angle on the maximum outer radius

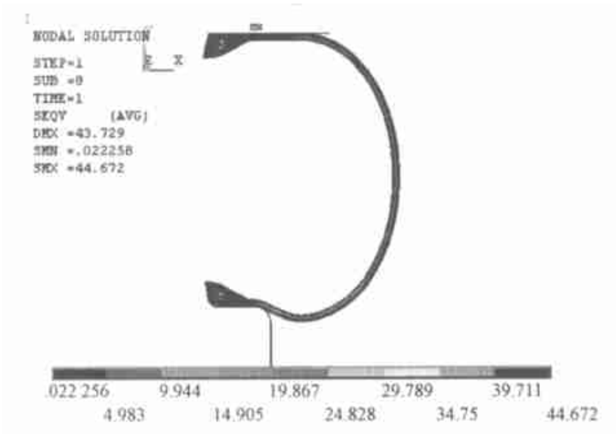
The cord angle is one of the most important parameter. From the calculated results, Fig. 2 and 3 show that the outer radius notably changes with the cord angle. The outer radius will increase dramatically when the cord angle is small. On the contrary, the increment of the outer radius will be small if the cord angle is large. The calculated results turn out that the outer radius is sensitive within a range of the cord angle from 30 degree to 60 degree.

(2) Effects of Young's modulus of the fabric-reinforced rubber composite on the outer radius

Except that the cord angle strongly affects the performance of an air spring, the material property of the fabric composite is also quite an important factor.



(a) Cord angle: 80 degree



(b) Cord angle: 40 degree

Fig. 2　Strain distribution and deformation with a varied cord angle

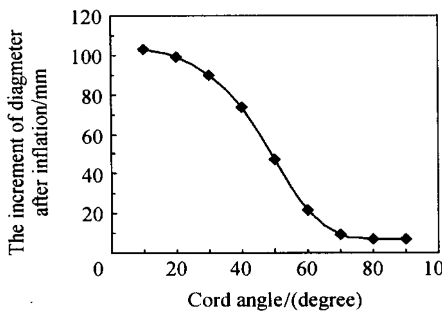


Fig. 3　Increment of diameter with respect to a cord angle

From the analysis results in Fig. 4, it can be concluded that the diameter of the air spring will increase and the stresses in the steel wire ring are quite large when the Young's modulus of the cord fabric material is small, vice versa. But when the Young's modulus increases up to a certain degree, the diameter of the air spring will change mildly.

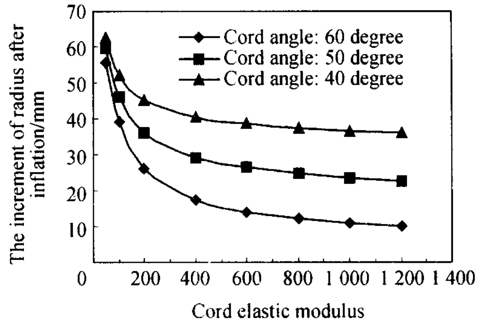
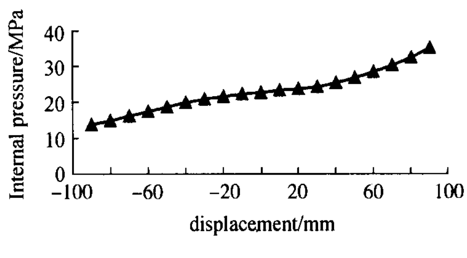


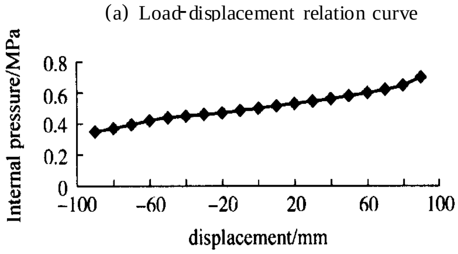
Fig. 4　Increment of radius with respect to a cord modulus

1.3.2　Analysis result of stiffness　Analysis Condition: fix the plate and piston in the design height, inflate the air bag with 0.5 MPa pressure until the system is balanced, then compress the plate with 90 mm displacement, be back to design height, next, extend the plate with 90 mm displacement, and at last be back to the original position. In this process, the force on the upper cover plate and the internal air pressure will be calculated in each step of 10 mm displacement.

Characteristic curves of the air spring include the load vs. the displacement curve, the internal pressure vs. the displacement curve while the stiffness characteristic curve is described by the load vs. the displacement curve. The results of the finite element analysis are shown in Fig. 5:



(a) Load-displacement relation curve



(b) Internal pressure-displacement relation curve

Fig. 5　FEA results with the static characters on an air spring

2 Experimental results

2.1 Equipment and Method

The static characteristic test was carried out according to GB/ T 13061 - 91 of China. Install the air spring on a load displacement tester to give a vertical displacement to the air spring, which is shown in Fig. 6. Set the air spring at standard height, and

Fig. 6　Experimental equipment for EQ6111 air spring

then supply compressed air into the air spring. Measure and record the load and the internal pressure in the air spring under this condition, and then compres the air spring down to a possible maximum compression, measure the load and find the relation between the pressure and the deformation. Furthermore extend it up to a possible maximum length, give again the displacement up to the standard height, record the load and the internal pressure for every 10 mm displacement.

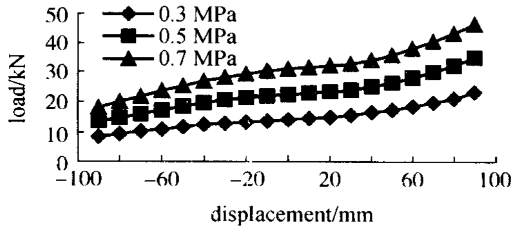
2.2 Experimental results and discussion

(1) Experimental results

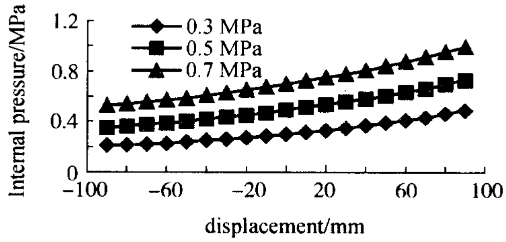
Using the above method, the static characteristic tests were done at different internal pressures, which is 0.3, 0.5 and 0.7 MPa respectively. The load vs. the displacement curve and the internal pressure vs. the displacement curve are shown in Fig. 7.

(2) Discussion

The experimental results demonstrate that the air spring can provide varied loads by adjusting the internal pressure, and the stiffness of the air spring varies with the load, which will lead to a constant natural frequency. Those advantages make the air suspension more comfortable and smoother than a steel spring.



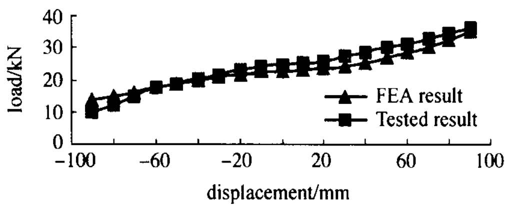
(a) Load-displacement relations given by experiments



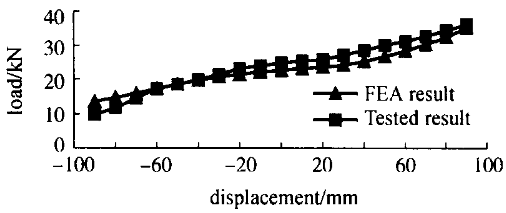
(b) Internal pressure-displacement relations given by experiments

Fig. 7　Static characteristic tested results with EQ6111 air spring

In condition of 0.5 MPa internal pressure, the tested results and Finite Element Analysis results were compared in Fig. 8. Obviously there is a good correlation between them.



(a) Load-Displacement relation curve



(b) Internal pressure-displacement relation curve

Fig. 8　Comparison between tested results and FEA results

3 Conclusion

The analysis was carried out for the deformation behavior and the static stiffness characteristics of an air spring with fiber-reinforced rubber composites. The analysis results demonstrate that the cord angle and the fabric elastic modulus have a great effect on the deformation, and consequently those factors will have a great effect on the static characteristics of the air spring.

The application of Finite Element Method to the air spring has broken the limitation of the traditional experiential formula, which can be used to analyse the structure are manufacture parameters of an air spring. And application of FEA to an air spring will play a more and more important role for the design and manufacture in the future.

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汽车减震用空气弹簧的有限元分析

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摘　要: **论文研究了汽车减震用空气弹簧在变形情况下的静力学特征。以 EQ6111 型空气弹簧作为研究对象,改变空气弹簧帘布层的弹性模量和帘线角,然后用实验分析其在变形情况下的力学性能。用有限元分析方法研究了空气弹簧在外力作用下的变形以及对应的内部压力。有限元方法和实验结果吻合良好。**

关键词: **空气弹簧;非线性有限元方法;纤维增强橡胶成分;帘线角**

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Application of multilayer fuzzy synthetic evaluation to analysis of injury

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Abstract: A new model to evaluate anti-dumping injury and the injury degree by multiplayer fuzzy synthetic evaluation was proposed for injury research on anti-dumping cases. In this model, injury indexes were quantified and classified scientifically and reasonably, and then the injury and injury degree were evaluated by multiplayer fuzzy synthetic evaluation, so that higher scientific evaluation of injury and injury degree and more transparent and fair adjudge to anti-dumping injury research were obtained. This model can offer an assistance to government departments for the final judgment of dumping and anti-dumping cases.

Key words: anti-dumping; injury; injury degree; multilayer fuzzy synthetic evaluation　**(责任编辑　刘同帅)**