NVH Characteristics Analysis of Car Tire Structure

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Abstract—Using the finite element modal analysis technology, Noise, Vibration and Harshness (NVH) characteristics of car tires were analyzed. Through the establishment of finite element model of tire structure, the modal analysis and harmonic response analysis have been carried. From the the modal analysis results of tire structure, the wheel structure panel endured relatively strong local changes, the first three order modal natural frequency was the main causes of the pavement noise; the harmonic response analysis showed that the tire structure proned to resonance when the car tires was under 60 Hz frenquency. The tires forces were mainly concentrated in the tire lateral upper surface, tire deformation were mainly concentrated in the upper and lower part of tires, and easy to cause vibration and noise. Through the finite element study of the modal and harmonic response analysis of tire structure, we can better grasp the mechanism of vibration and noise, and guide the further design for the optimization tire to obtained the better NVH characteristics.

***Keywords-** NVH characteristics; car tire; finite element model; modal analysis; harmonic response analysis*

I. INTRODUCTION

The inner and outside noises of vehicle have a significant impact on the comfort and product recognition. The tire/road noises and wind noises and other noises became the research focus.

Tires as a connected components between car body and roads, is a key factor to influence the vehicle steering stability, security, and harshness. Many important performances of car were related to the mechanical properties of tires. As car developed toward large-scale, quick running and specialty development, the use conditions of pneumatic tire have grown ever more harsh and the tires prompted towards the direction of the meridian, flat, tubeless[1].

Tire/road noise can be divided into low frequency noise 0-100 Hz and high-frequency noise above 100 Hz. Low frequency noise was easily to cause the discomfort when the crew aboard, even caused the phenomenon such as nausea and vomiting. Now all countries attaches great importance to controlling the traffic noise pollution. In literature [2], the differences of the tread (including tire ground front edge and the edge) and sidewall has been studied and proposed the prediction method of the tread vibration level.

The tires were also the quite important vibration element of vehicle body, under broadband vibration excitation, many resonance peaks can appear within the scope of the whole excitation frequency, and then radiating noise into the surrounding. Due to the direct contact with the ground, the entire tire were under the low-order modal, could lead to resonance phenomenon. So the suitable vibration and resonance control can effectively inhibit the interior noise level, thus improve the NVH characteristics of the whole car. These finite element analysis results can provide the basis for performance analysis, thus improve the accuracy of automobile comprehensive performance analysis[3-5].

As more and more attentions have been paid on the auto NVH characteristics, the controlling of noise and vibration was increasingly important[6]. The reasonable matching between tire and ground was the key to vibration noise control of. This article preliminary discussed the automobile tire modal matching and frequency planning problem. Using the finite element modal analysis technology, a finite element model of the tires structure have been established and the model analysis have been carried. The harmonic response analysis of automobile tires has also been studied. Finally the design improvements pointing about NVH characteristics of automobile tire structure have been discussed.

II. THE ESTABLISHMENT OF FINITE ELEMENT MODEL OF TIRE STRUCTURE

The following two aspects must be considered to establish the finite element model[7]. The one was the reduced computation cost must be guaranteed under the premise of the calculation accuracy. If only considering from the perspective of accuracy, without do any simplification when modeling, which will make modeling workload increasing greatly. It was a clear violation economy requirements, therefore reasonable simplified modeling must be adopted in the model establishment of the actual structure. The other was the model must have a sufficient accuracy. After all necessary simplification, the received model can basically reflect the actual situation of the structure. Both the consistency of shape and structure, and the consistency of boundary conditions must be considered.

Because the tire was a multilayer structure consisting of a variety of materials, such as rubber and cord fabric layers, so the cross section shape was quite complicated. The adjacent areas between sidewall and beam layer had a long and narrow geometric angle. So the failure of operation will be caused when meshing, or the unit serious deformation will be generated. In order to guarantee the smooth mesh can be obtained, the car tire model must be simplified. Firstly, change the narrow angle to chamfer angle in the adjacent areas between tire and steel beam layer; then make a fillet for the smooth transition in the adjacent place between triangle rubber and steel wire circle bundle layer; because the materials of the different parts of the car tires was different, so they were independent individuals, such as tire crown, tire, belt beam layer and triangle glue etc. these individuals were independent of each other in the finite element conditions, but must be connected as a whole through a certain method. We choice bonding method, which can both keep the independence of each part of tires, and conform to the actual contact[8,9].

III. TIRE MODAL ANALYSIS OF TIRE STRUCTURE

The modal parameters of car tire can reflect the natural vibration characteristics of tire structure, it has an important influence on the noise control of the car. The Analysis of tire structure mode can better grasp the mechanism of vibration and noise, which provide the basis for the noise prediction and noise source diagnosis[10].

First 3D car tire structure diagram be drawn by using PROE, as shown in Fig .1. Assemble of the tires modeling, through the interface between ANSYS and PROE, the model was imported into ANSYS, through surface to generate body, and then define the unit type . Then leading the 3D diagram into Ansys finite element for meshing, the meshing results was shown in Fig .2.

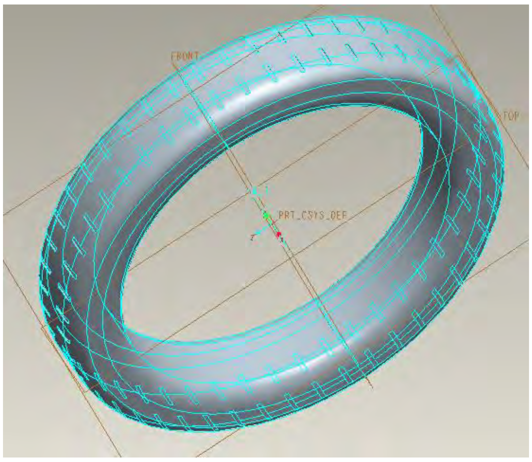


Figure 1. 3D diagram of car tire structure

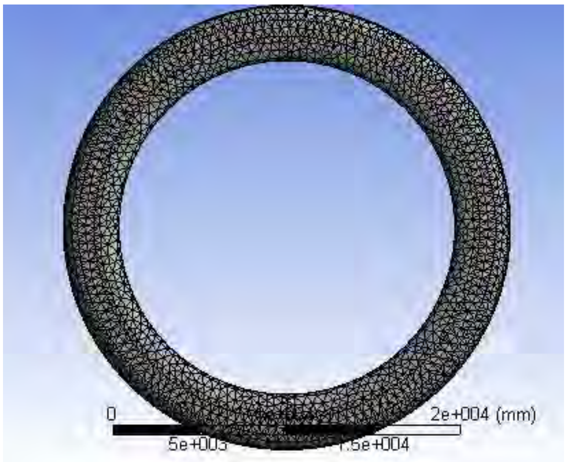
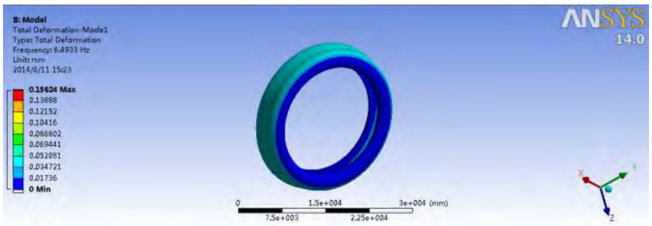


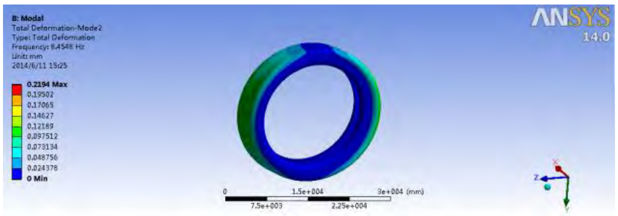
Figure 2. The meshing of car tire structure

TABLE I. THE FIRST SIX ORDER MODAL FREQUENCY OF CAR TIRE

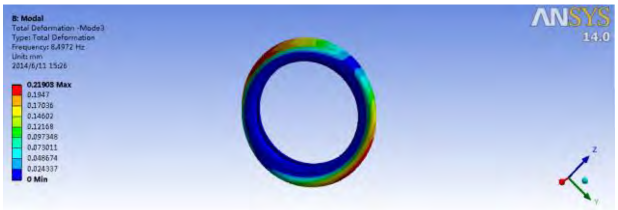
Mode	Frequency(Hz)
1	6.4933
2	8.4548
3	8.4972
4	12.806
5	12.808
6	13.621



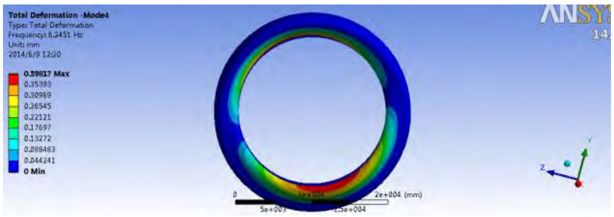
(a) The first order inherent vibration mode



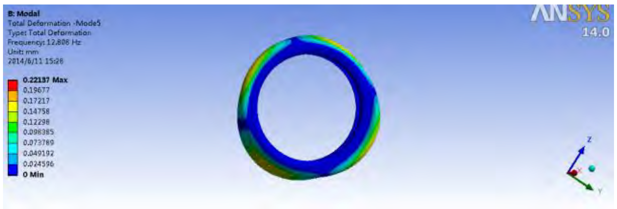
(b) The second order inherent vibration mode



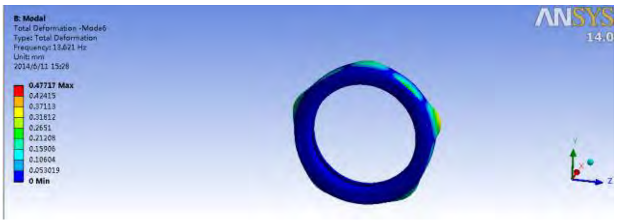
(c) The third order inherent vibration mode



(d) The fortht order inherent vibration mode



(e) The fifth order inherent vibration mode



(f) The sixth order inherent vibration mode

Figure 3. Inherent vibration mode of car tire

The first six order modal vibration calculated using the finite element method were shown in Fig .3. Under each inherent frequency, the vibration deformations were different from each other, the first three modes were under the bending loads, the last three modes were under the torsion loading, the position and values of the largest deformation in each mode were also different. But the main deformation areas in the simulation figures were concentrated in the inner and outer surface of the tires. To strengthen the rigid of the tires structure, we can start to study how to strengthen the inner and outer surface of the tires by the using different tires materials and change the tire pattern design in the future work.

Fig .3(a) illustrates the first order modal frequency was the modal vibration mode of 6.5 Hz, the stress distribution was basically identical of the tire contacting with the ground. Fig .3(b) illustrates the second order modal frequency of 8.45 Hz, the tire force was distributed evenly by the first order force to the other side of the tire contact with the ground. The stress of the tire contact with the ground is greater than the second order in the Fig .3(c), which showed the third order modal frequency of 8.49 Hz.

From the first three order modal results, the tires produced translation motion under the inherent frequencies, the excitation force transmitted to the car axle was the largest, which was the main causes of road noise.

Tire force transmitted from outside to inside as shown in Fig .3(d) when the fourth-order modal frequency was 12.806 Hz. The Fig .3(e) shows the modal vibration mode of the fifth order modal frequency is 12.808 Hz, tire force was concentration in the four parts divided a tire circle. The Fig .3(f) shows that under the modal frequency 13.6 Hz, the tire force was concentrate in the multiple directions around the tire. From the fourth order to six order modal vibration results, the vibration mode appeared axisymmetric, so the force created by the tire surface vibration in the axis center offset each other, make the entire tire vibration in the gravity centre position was smaller.

IV. HARMONIC RESPONSE ANALYSIS OF TIRES STRUCTURE

Harmonic Response Analysi was used to determine the steady-state response of the linear structure under the sine (Harmonic) rule changing load, only the steady forced vibration in the analysis process was calculated and regardless of the transient vibration at the beginning of the vibration. The purpose of Harmonic Response Analysis was to calculate the frequency curves of the structure response values(usually displacement) under several frequencies, the “peak” response can be found from these curves, and further inspected the stress corresponding to the frequency, so that designers can predict the continuous dynamic characteristics of structures, and verify whether the design can overcome resonance, fatigue and other forced vibration caused by harmful effects[11].

The stress, deformation and acceleration harmonic response on the frequency of car tires were shown in Fig .4, 5 and 6, respectively. As you can see from Fig .4, there are three stress peaks before 60 Hz, the maximum peak appeared at 20 Hz, the other two peaks appeared at 40 Hz and 60 Hz, but it has a declining trend after 60 Hz. There are large phase angles from 40 Hz to 50 Hz. As you can see from Fig .5, there are two peaks of tire deformation at 10 Hz and 60 Hz, there are large phase angles from 30 Hz to 50 Hz. In Fig .6, a peak acceleration presented at 60 Hz and the minimum phase angle existed from 30 Hz to 50 Hz. From the above harmonic response analysis, 60 Hz was determined as the resonance frequency point of the car tire. In order to reduce the resonance phenomenon, the working frequency must be designed to avoiding 60Hz in the common working conditions.

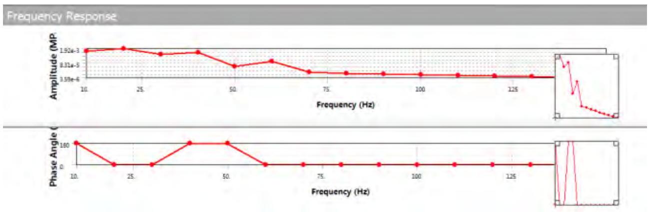


Figure 4. Stress harmonic response of car tires

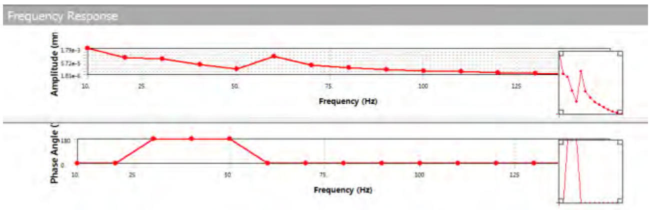


Figure 5. Deformation harmonic response of car tires

Figure 6. Acceleration harmonic response of car tires

V. THE STRESS AND DEFORMATION UNDER 100HZ

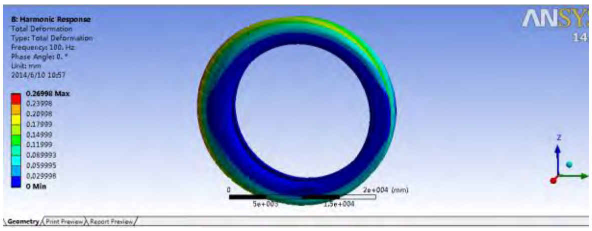


Figure 7. Stress analysis results of car tire

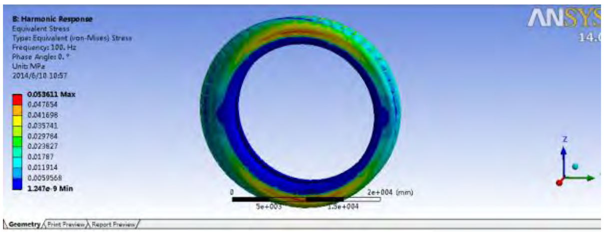


Figure 8. Deformation analysis results of car tire

100 Hz was considered as the Cut-off point of low frequency noise and high-frequency noise, so it was useful to know the actual stress and deformation situation with the help of finite element simulation. Fig .7 and 8 are the stress and deformation at 100 Hz of the car tires, respectively. The stress was mainly concentrated in the tire lateral upper surface, the tire deformation was mainly concentrated in the top and the bottom section, these will caused the larger axle displacement deformation, so vibration and noise are higher. So in the future design of tires, we must find an effective way to reduce the peak stress and deformation and to improve the NVH characteristics of car.

VI. CONCLUSIONS

(1) From the modal analysis results of tire structure, tire had relatively strong local changes, the vibration of the tire acted on the car interior, will make the car interior noise level intensified. Through the modal analysis of tire structure can better grasp the tire vibration frequency and the noise generation mechanism, and provide the basis for the automobile noise prediction.

(2) We can concluded from thee model analysis, the tire did translation motion in the first three order modal frequencies, the vibration excitation force spread to the axle was the largest, was the main cause of road noise. The harmonic response analysis showed that the tire structure prone to resonance at 60 Hz. The stress was mainly concentrated in the tire lateral upper surface, the tire deformation was mainly concentrated in the top and the bottom section. We must find an effective way to reduce the peak stress and deformation and to avoid the resonance phenomenon in the tire design.

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