Impact Fatigue Life Prediction of the Wind Tunnel Balance

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Abstract Impact fatigue damage is the main factor which influenced the life of a wind tunnel balance. It is necessary to predict impact fatigue life of a balance especially in the key points of a balance after static analysis. It is unpractical to implement the impact fatigue experiment in the laboratory while wind tunnel balance is a special transducer which would not be manufactured in batches. Generally, balance designers didn’t do this analysis for its special use. In fact, accidents of this sort which is in the testing are happening with increasing frequency. This paper provided a method to predict impact fatigue life of a balance which based on the finite element analysis. We used finite element analysis tools to modeling the wind tunnel balance, and then we meshed the whole model as fine as possible. After that, stress of the wind tunnel balance under static loading was figured out, as well as the key points of the balance. The fatigue analysis tools were used to estimate the stress of the balance which was bearing the impact loading. These analysis results would much valuable to the wind tunnel testing.
Keywords wind tunnel balance, fatigue damage, finite element analysis

1. Introduction

Wind tunnel balance is used in the wind tunnel widely by the enlargement of the wind tunnel testing, thus the performance of the balance is more attractive to the researchers. These researchers focused on the failure and accident of the wind tunnel balance, because they doubt that the fatigue of the balance is the main factor of these accidents. But what is the fatigue? Maybe this is the first thing which the wind tunnel balance researchers want to know eagerly. Here quote a definition of ASTM E206-72: The process of progressive localized permanent structural change occurring in a material subjected to conditions which produce fluctuating stresses and strains at some point or points and which may culminate in crack or complete fracture after a sufficient number of fluctuations. The actual mechanization of the material fatigue and its scientific describe are not reported at present. Analysis method of fatigue life prediction is the main aspect of fatigue, and this content was concluded throughout of the history of fatigue. For the cost of the fatigue testing is so large that most researchers tend to using finite element analysis to acquire the data of the material which they concerned. Finite element analysis is the most important method for the researcher to develop a new balance for the wind tunnel balance is special research equipment which is unpractical to proceed the fatigue testing.

The purpose of a wind tunnel balance is to measure the aerodynamic forces and moments, which load a model during wind tunnel tests. The balance measures the aerodynamic forces and moments by the wheatstone bridge which consist of strain gauges adhere to the sensitive elements. The sensitive elements suffered pull、torsion、torsion and bend，and even the combination of them. A slot partition a balance into two parts, the axial force elements combined these as a parallelogram. The forces and moments will transfer from model to the balance. The balance used in the airplane was show in figure1.

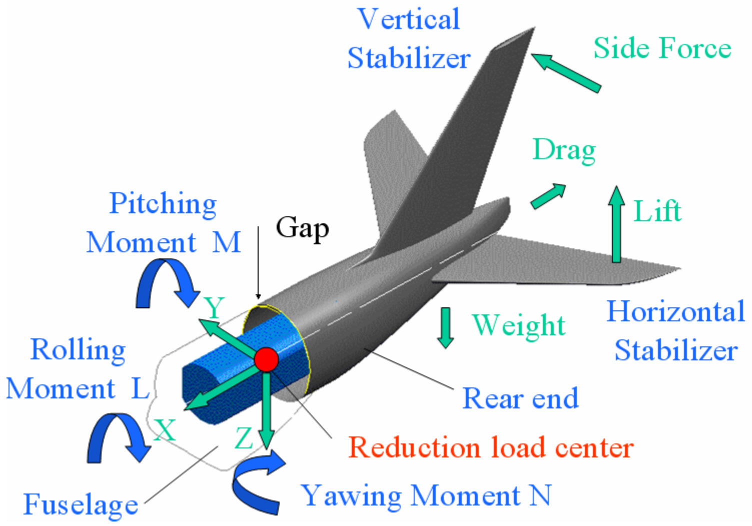

Figure 1. sketch of the six components of wind tunnel balance

Wind tunnel balance is special testing equipment for the wind tunnel testing. They are many rigorous procedures before and after the manufacture of a wind tunnel balance to ensure the balance to be qualified testing equipment. Wind tunnel balance flourishing many years accompany with the new structure and new application domain while the fatigue performance of the balance was ignored by most wind tunnel balance researchers. But this is a question which we could not inevitable, and this is the purpose of this paper also.

2. Fatigue Life Prediction of wind tunnel balance

Fatigue Life Prediction of wind tunnel balance is the responsibility of every balance researcher as other engineering's. Balance users would utilize balance reasonably after fatigue life prediction, and exception handles would also more easier.

Supersonic wind tunnel balance usually bear impact load and steady load and even other complexity situations. Sensitivity of the wind tunnel balance is so excellent that even any relative collection data of the balance would show the trouble of the balance. All of these factors complexes the designing of a wind tunnel balance. Utilizing analysis method to replace the testing method is the goal of the finite element analysis for the balance, and this will decrease the workload and cut down the cost. Utilizing analysis method would get the accurate fatigue life data for the ability of complex geometry processing and anomalous load curse.

Fatigue Life Prediction of wind tunnel balance included several steps. Firstly, we analysis the static stress of the wind tunnel balance, we obtained the dangerous sections or key points of the balance. After that, we take the process of the fatigue analysis until acquire the fatigue life data.

2.1. static stress analysis

The first step of the fatigue life prediction is the static stress analyses, which will also the very important step in the whole curse. Static stress analyzes means that we load the balance by every possible load or rated load. The purpose of static stress analyzes is obtain the dangerous sections by various loading condition. The results of this analysis would play important role to the designing of a wind tunnel balance.

Static stress analyses include several steps: modeling the balance; meshing, loading and solving the problem.

2.2. fatigue analysis

Fatigue analysis should according to the actual working condition, which means every balance designer should find out the actual load curve of the balance. It is useful to predict the true life of a balance by analysis the balance in a real loading condition and real working frequency.

It is more suitable to use the Miner assumption when the curse contains various fatigue stress breadth. Miner on the assumption that: if the cycle stress were a serials breadth denote as S1,S2,S3,….and corresponding destroy life of this material were Nf1,Nf2,Nf3,… then, the life of every stress breadth will be express as the quotient of the actual cycles Ni and life Nfi. We can assumption that the damage cumulate as above method, see Eq. (1)

$$\frac{N_1}{N_{f1}}+\frac{N_2}{N_{f2}}+\frac{N_3}{N_{f3}}...+\frac{N_i}{N_{fi}}=1, \qquad (1)$$

Life will come to the end while the cycles up to the failure times Nfi under a specified stress breadth.

It has many reproaches when we regard the Miner assumption as a effectively designing rule for the testing results are very decentralization. It is widely used in many fields for its simpleness and other strongpoint.

2.3. process of fatigue life prediction

The process of fatigue life prediction listed as follows:

(1) create the frame of fatigue life prediction, define the characteristic of material, set up the parameter of analysis;

(2) define the mode of contact;

(3) using solution combination or specify special stress curve。

(4) solve this problem;

3. example of the fatigue Life Prediction of wind tunnel balance

This section analysis the fatigue life of the B630Q wind tunnel balance which was used in the supersonic wind tunnel.

B630Q wind tunnel balance is a usual balance used for the force and moment measurement. The rated load of this balance listed in the table 1.

Table 1. rated load of B630Q

	My （N.M）	Z （N）	Mz （N.M）	Y （N）	Mx（N.M）	Q（N）
Rated load	50	600	100	2000	30	600

B630Q wind tunnel balance connected with the model by a structure which looked like a cone, which means the contact region is a cone. The finite element model which contains the load equipment showed in the figure 2.

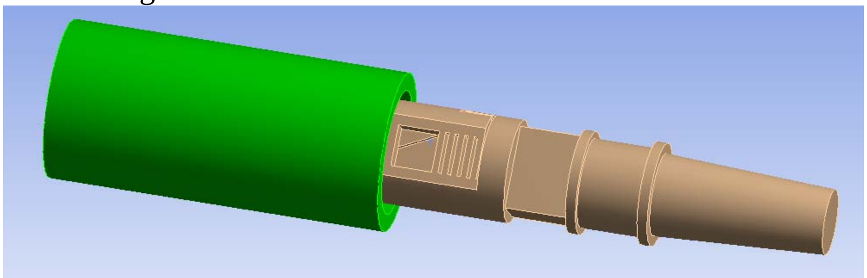

Figure 2. finite element analysis model

3.1. static stress analysis of B630Q balance

This paper analyzed the B630Q wind tunnel balance by finite element analysis. We modeled the balance after the theoretic analysis of this balance. After that, meshing the model was conducted by the software. We can conclude from the meshing contour that the compute node is 172545 and the number of element is 105639. Meshing results of B630Q balanc was showed in figure3. Figure4 showed the contact region of the balance and loading equipment.

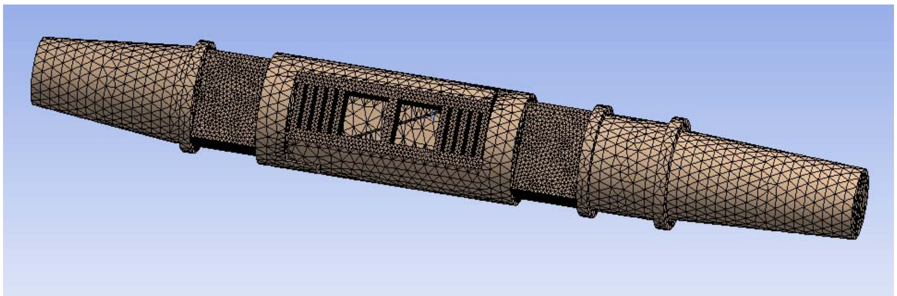

Figure 3. meshing results of the balance

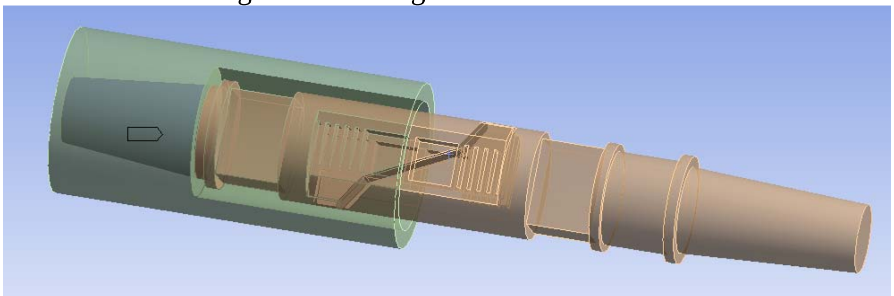

Figure 4. Contact Region

The processing was conducted after the process of meshing the model was completed. The static stress contour and dangerous sections were obtained after six component's load was imposed on the balance and also the integrative load. Figure 5 showed the stress contour of that the six component rated load was loaded integrative. We can conclude that the maximum stress was only 410.7MPa which was lower than the tensile ultimate strength and the location was lie on the root of the supporting beam. Figure 6 showed the each life contour of six components's loading. These figures informed that the dangerous sections were in the root of the supporting beam and the root of the axial force element indeed.

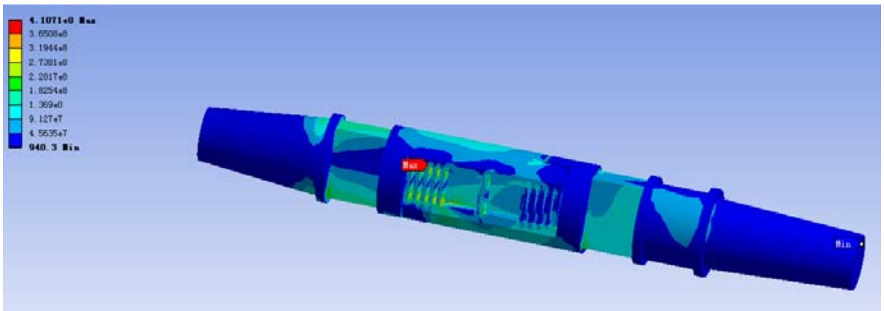

Figure5. Contour of stress

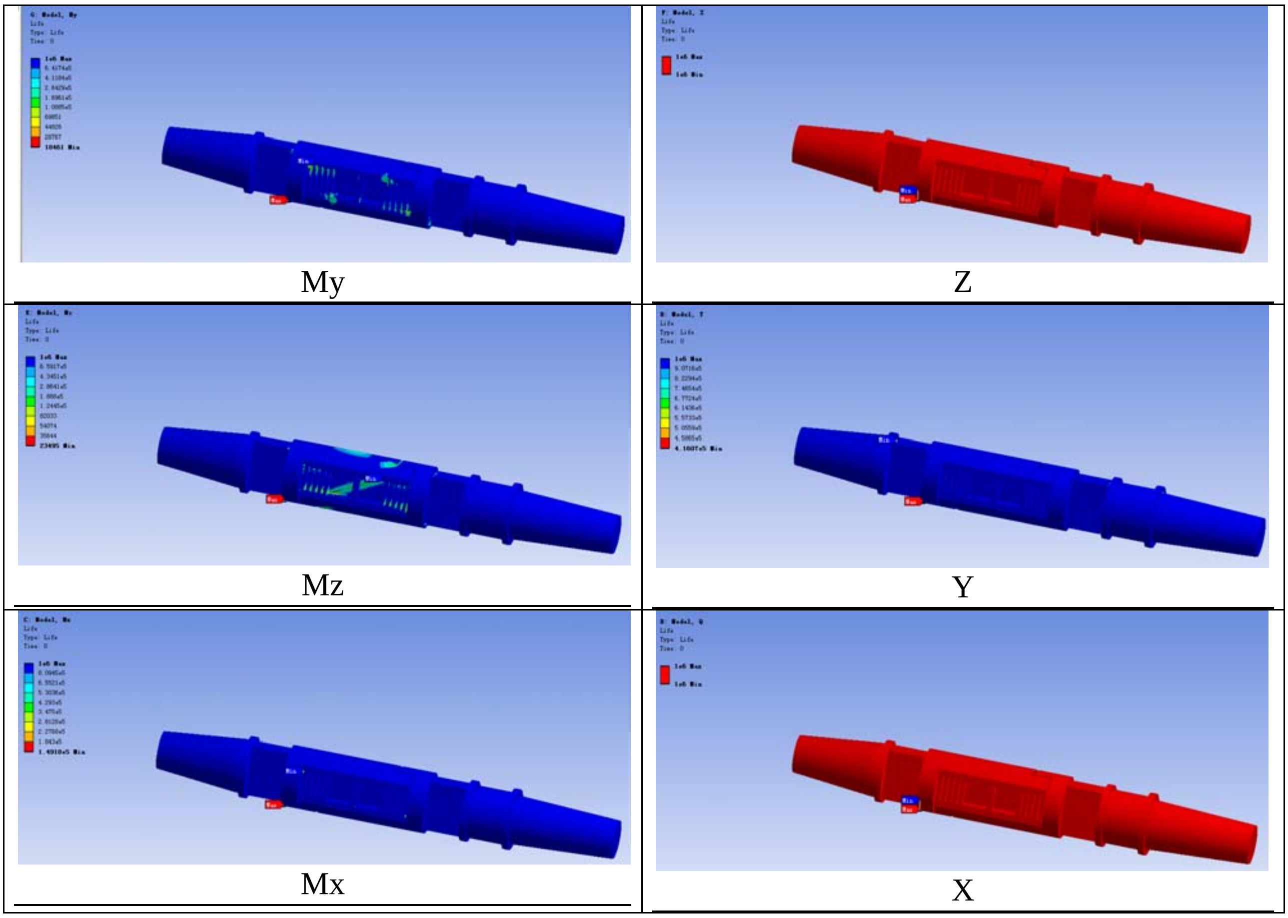

Figure6. Life contour of six component load alone

3.2. fatigue Life Prediction of B630Q balance

We defined the characteristic of the material which was used to manufacture balance. The material was used the structural steel. Detailed parameter were showed subsequently，Poisson’s Ratio is 0.3,Young’s Modulus is 2.0e+011Pa.Tensile Yield Strength is 2.5e+008 Pa, Compressive Yield Strength is 2.5e+008 Pa. Tensile Ultimate Strength is 4.6e+008 Pa, N-S curve showed in the figure 7.

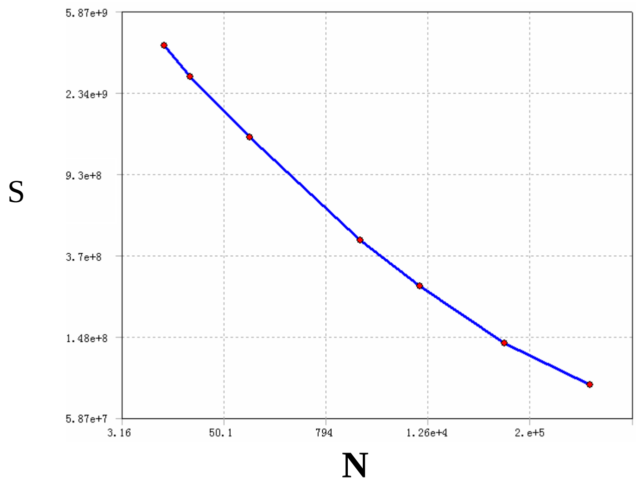

Figure7. N-S curve of structural steel

First, we used history data to simulate the balance. For simplification, the fatigue life prediction curse concerned on the impact on the balance while the wind tunnel startup and steady flow after that and the course of shut down the wind tunnel. We defined the load curve after colligate the above situation. The load curve was showed in figure8.

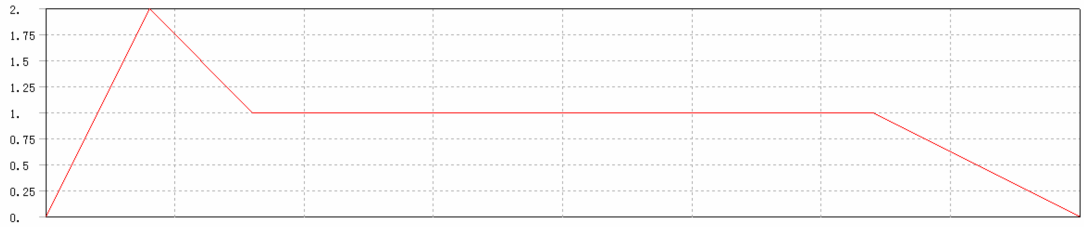

Figure8. load curve of the B630Q balance

Life contour of balance B636Q bearing the combination load was showed in figure 9. We can conclude that the minimum life of balance is 2616 cycles, and the dangerous section was in the root of the supporting beam.

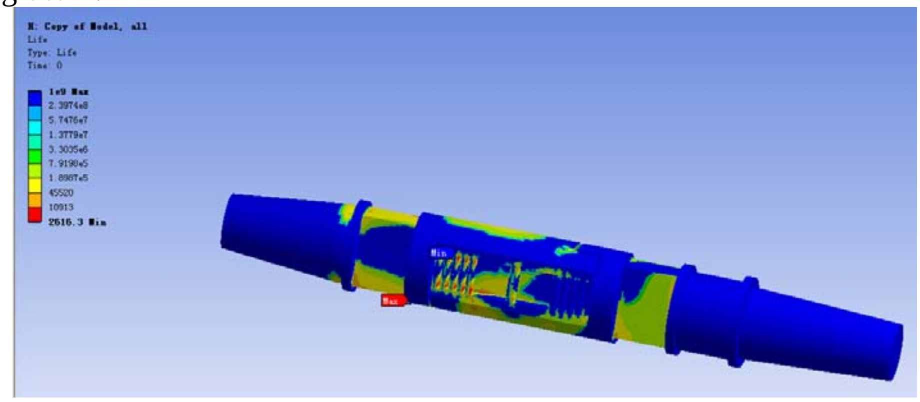

Figure9 Life contour of balance B630Q bearing the combination load

Second, we used solution combination methods to solve this problem. We combined the lift force、pitching moment and axial force according the actual using setting.Life contour of balance B630Q subjected the combination load was showed in figure 10. We can conclude that the minimum life of balance is 15388 cycles, and the dangerous section was not in the root of the axial force element but in the root of the rectangular section. These results maybe arise from the actual load curve didn’t contain the side force and yawing moment.

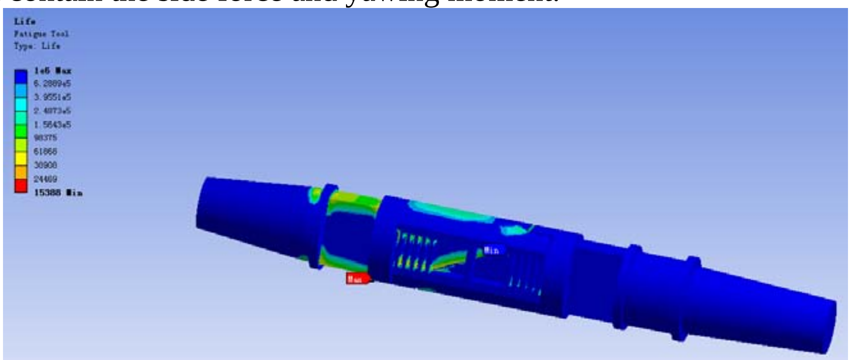

Figure10 Life contour of balance B630Q bearing the combination load

4. conclusions

This paper developed a method to predict the fatigue life of a wind tunnel balance, which was verified by a B630Q balance.

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