Measurement method of flexibility coefficient of large deformation elastic model

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Abstract. The measurement method of flexibility coefficient is to apply load step by step with a quantitative loading system, and measure the flexibility coefficient by "fixed-point loading, multi-point measurement". In the case of deformation, the deformation value of the measured point of the model is measured to calculate the flexibility coefficient. However, when facing the large-scale flexible model, if the model is subjected to large load, the free end of the model will produce large deformation; Using the above loading and measuring methods will cause errors between the actual and target measuring points. The surface density function is constructed according to the measured data, and the actual measured points are extracted by the method of measuring point regression. Based on the coordinates of the undeformed model, the deformation of the actual measuring point and the target measuring point is obtained, and then the region containing all points is constructed according to the actual measuring point and the target measuring point, and the load of the target measuring point is calculated using the node load equivalence principle, and the model flexibility coefficient is finally obtained.

Keywords: Electrostatic precipitator; Cathode frame; Anti bending deformation; Anti slip collapse; high safety and stability.

1. Introduction

Modern advanced wide-body airliners usually adopt composite wings with high aspect ratio, which have large wing aspect ratio, light structural weight, high flight speed and pressure, and high bearing capacity requirements. The elastic deformation after aerodynamic load is significant, resulting in prominent static aeroelasticity problems (Figure 1), which will have a great impact on the cruising economy and operating stability characteristics of the aircraft.

The establishment of a practical wind tunnel test verification technology for large flexibility wing is of great importance to improve the design level of large aircraft, and also has a certain reference role for the design and development of other aircraft. The design and manufacture of structural dynamically-similar static aeroelastic wind tunnel test model is one of the most difficult technical links in the study of static aeroelasticity. In order to check the similarity between the static aeroelastic model and the prototype aircraft, and to comprehensively verify the effectiveness and reliability of the model design method and processing technology, the most direct and effective way is to carry out the ground flexibility test.

Figure 1. Static aeroelastic deformation of B787 wing.

2. Flexibility Test Methods and Data Processing

The basic content of flexibility test is to determine the deformation of the specimen under steady-state load, i.e. structural flexibility, which is usually obtained by the method of point loading and multi-point measurement. The elastic deformation (displacement) of the aircraft structure produced under the action of the load is measured under the condition of load application, and the flexibility matrix is calculated by computing the elastic deformation based on the load and the displacement.

The relationship between the elastic deformation of the aircraft structure and the applied load:

$$c2 = a2 + b2 \tag{1}$$

Then we can obtain from equation (1) that

$$\{P\} = [C^{yy}]^{-1}\{y\} \tag{2}$$

Where $[C^{yy}]$ is the aircraft structure displacement flexibility influence coefficient matrix, the physical meaning of element C_{ij}^{yy} is the deformation (displacement) of the unit force at the j point at the i point, where is the known quantity;

$\{y\}$ is the elastic deformation (displacement) of the aircraft structure under the action of the distributed force $\{P\}$, here is the known quantity;

$\{P\}$ is the load distribution of the aircraft structure producing elastic deformation (displacement) $\{y\}$, where element Pi is the load at point i, where the unknown quantity is required.

$i = 1,2,\dots\dots,N$, $j = 1,2,\dots\dots,N$, N is the number of deformation points and load points.

The flexibility matrix of the measurement model is calculated and the measurement flexibility matrix S'is obtained.

The fully automatic flexibility testing system includes a three coordinate moving machine and a laser displacement sensor (Figure 2). The three coordinate mobile machine consists of three main components: a foundation sliding table, a column, and an extended cantilever. In the static loading deformation measurement experiment of the elastic model, the system uses a quantitative loading system to accurately position and load the fixed model. The laser displacement sensor synchronously measures the deformation online, directly reads the deformation data, and obtains effective data such as the overall stiffness matrix of the model through post-processing calculation as needed.

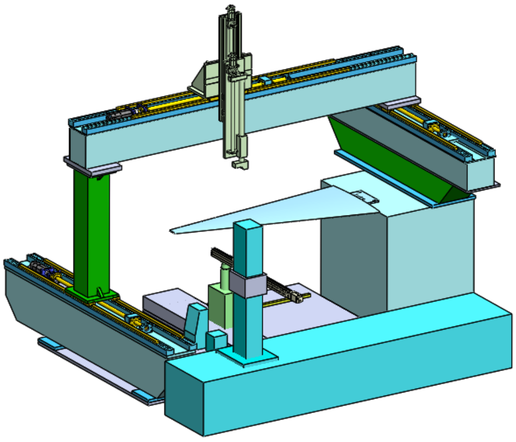

Figure 2. Schematic diagram of the fully automatic flexibility test system

3. Calculation method for flexibility coefficient of elastic model for large deformation

The loading and measurement direction of the fully automatic flexibility test system is always perpendicular to the horizontal plane. When facing a large-scale flexible model, if the model is subjected to a large load, the free end of the model will undergo significant deformation; At this point, using the above loading and measurement methods will cause errors between the actual measurement point and the target measurement point. The main source of these errors is the large deformation of the model, which causes the actual measurement point to deviate from the initial measurement point, resulting in errors.

To solve this problem, this article proposes a method for calculating the flexibility coefficient of a large deformation static elastic model under specific loading measurement methods. The deformation of the target measurement point is calculated by restoring the actual measurement point, and then the equivalent load of the target measurement point is obtained using the node load equivalence principle to correct errors and achieve the calculation of the flexibility coefficient of the target measurement point. This method first constructs a surface density function based on measurement data, and extracts actual measurement points through regression analysis of measurement points. Based on the coordinates of the undeformed model, obtain the deformation of the actual measurement point and the target measurement point, and finally obtain the model flexibility coefficient.

According to the measurement data, based on the fitting data of bicubic rational B-spline surface, the deformed surface is reverse calculated, and the surface expression $f(x,y,z)=0$ is obtained. Based on the reference position, the coordinate of the target measurement point is obtained by continuously seeking the normal vector of the element. Calculate the arc length of the curve corresponding to the measurement point on the surface before the deformation of the model; Take the direction vector of the curve corresponding to the vertical measurement point of the model root positioning block as the initial normal vector $\vec{a}_1=(x_1,y_1,z_1)$; Then search for the first base vector $\vec{a}_2=(x_2,y_2,z_2)$ vertically based on the vector, and the two vectors satisfy the following relationship:

$$\begin{gathered}\vec{a}_1 \bullet \vec{a}_2 = x_1x_2+y_1y_2+z_1z_2=0 \\ f(x_1,y_1,z_1)=0 \\ f(x_2,y_2,z_2)=0\end{gathered} \tag{3}$$

Based on the base vector, search for the normal vector again (both the base vector and the endpoints of the normal vector are on the fitted surface). Repeat this process until the sum of the base vector lengths equals the calculated arc length. The coordinates of the return point are the deformed coordinates of the target measurement point.

4. Verification of Flexibility Coefficient Calculation Method for Model Large Deformation

To verify the effectiveness of the proposed method, a wing like elastic model was used as the test specimen, as shown in Figures 3 and 4. The steel plate root is connected to the support platform through M16 bolts, providing root support constraints. The measurement points are distributed along the span every 170mm as a profile.

For the flexibility coefficient of the wing like elastic model, a fully automatic flexibility test system is used for loading and measurement. The uncorrected measurement data is directly calculated and the above correction method is used for calculation. The calculation results are compared with the theoretical values, as shown in Figure 5. The deformation of the wing root is relatively small, and the results obtained by the two methods are not significantly different. However, due to the large deformation of the model, the flexibility matrix error obtained by directly using the uncorrected calculation method of the data gradually increases, and the maximum error is close to 10%; The modified flexibility matrix is more accurate, with an error maintained within 5%. Therefore, this method can effectively achieve the calculation of flexibility coefficient correction for elastic models under large deformation states.

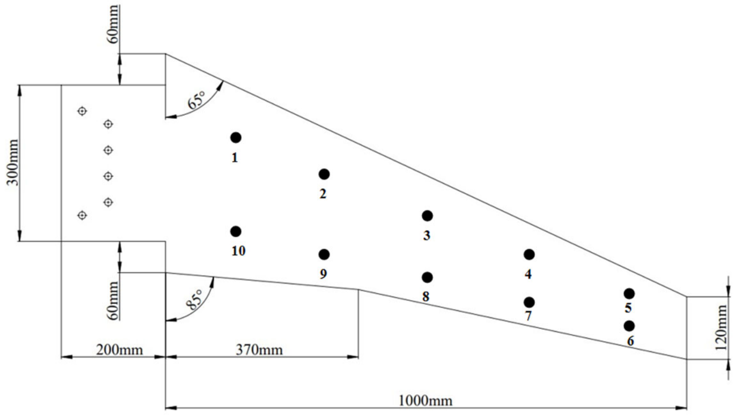

Figure 3. Wing Test Model

Figure 4. Flexibility Test of wing elastic model

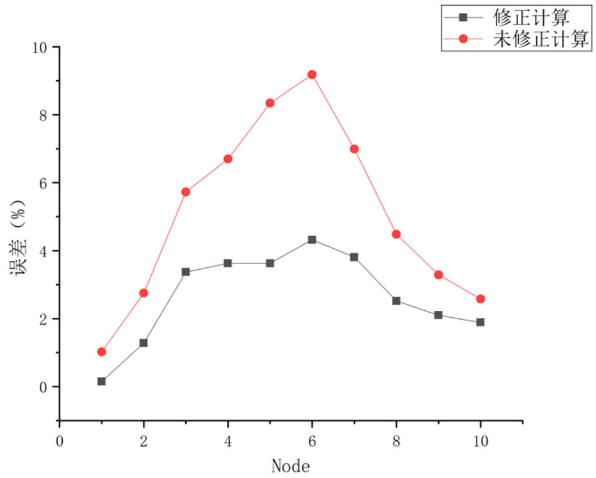

Figure 5. Experimental error under 200N loading force

5. Conclusion

The measurement method for the flexibility coefficient of elastic models facing large deformations can effectively achieve the correction calculation of the flexibility coefficient of elastic models under large deformation states.

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