Advances in Engineering Research (AER), volume 130
5th International Conference on Frontiers of Manufacturing Science and Measuring Technology (FMSMT 2017)

Design and Fabrication of a Three-Component Dynamic Balance Based on Piezoelectric effects

DAI Xing[1, a], TANG Shi-you[2]

[1,2] Mianyang Vocational and Technical College ,Mianyang 621000，China

[a]daixingmy@126.com

Keywords: Bridge Model; Piezoelectric effects; Three-Component Balance; ANSYS

Abstract.
This article introduces a five-beam three-component balance based on lateral piezoelectric effects，which can be used special bridge wind tunnel test ， and was designed used ANSYS software， and homemade quasi-static calibration equipment for balance. The balance quasi-static calibration result indicated that the new type design met the test requirements and the balance had high calibration precision, which used for measuring 1g force accurately and filled up domestic research blank.

Introduction

As the lifeline engineering of traffic engineering, bridge plays an important role in traffic operation. However, with the deterioration of the global climate and environment, a large number of bridges are facing the test of all kinds of natural disasters. The typhoon is one of the most frequent natural disasters, which also brought great destruction to human life and property. In the 40s of last century, under the United States Bridge caused strong wind vibration and damage the influence of the 8 winds caught the bridge designer's attention, thus developing a branch of the edge of the bridge beam wind engineering. In twenty-first Century, a number of large / super large bridge with poised transportation, how to ensure the normal operation of the bridge under various harsh environments, the knowledge of bridge wind engineering is needed to analyze bridge on the main part and the wind field conditions at the bridge site all the various possible connection part simulation, to analyse the response of static effect with the dynamic design and construction of the new bridge to provide solutions [1]. There are three main research methods in bridge wind engineering: theoretical analysis, wind tunnel test and field observation and numerical simulation. The wind tunnel test is to simulate the physical experiment in the wind tunnel simulating the airflow. In the test, the corresponding equipment should be used to measure the three components of the model, such as vibration, wind speed and so on. In order to fill the gaps in China to meet the new test requirements, the bridge model and its measurement equipment are put forward new requirements. In this paper, the three component dynamic balance is used to measure the three component dynamic force in the wind tunnel test. The scale is small, the sensitivity is high, the volume is small, and the technical requirements are special. No similar products at home.

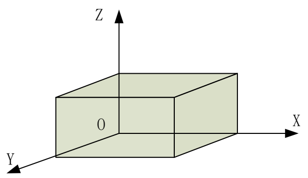
1. Structure design of balance

1.1 The working principle of piezoelectric balance

When the piezoelectric crystal is controlled along a certain direction by external force, the internal polarization phenomenon will happen, which will have opposite in charge of two on the surface at the same time, when the external force is removed, restored to the uncharged state; when the direction changes, the polarity of charge is changed too. When the force is removed, the crystal will have no electricity too. The charge produced by the crystal is proportional to the external force, which is the piezoelectric effect of piezoelectric crystal. Generally speaking, the piezoelectric effect can be divided into longitudinal piezoelectric effect, transverse piezoelectric effect, and tangential piezoelectric effect. This balance is by taking use of the transverse piezoelectric effect of piezoelectric crystal [2], as shown the hexahedron in Figure 1, polarization vector and Z axis parallel to it, when it is subjected to normal stress along the X axis and Y axis direction of the F function, piezoelectric polarization plane respectively generate positive and negative charge, as shown in Figure 2 show. The relationship between charge and force is as follows:

$$Q = \int_{S1} - d_{31}\sigma$$

In the formula, Q is the charge produced by the piezoelectric crystal under the condition of force; S_1 is the surface area of the charge generating surface; d_{31} is the transverse piezoelectric coefficient; the normal stress of the bearing surface is σ. $\sigma = F / S2$, and the area of the stress surface is S2.



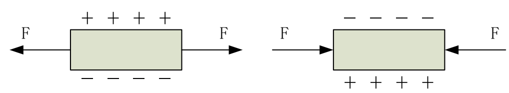


Fig1 Piezoelectric Crystal Fig2 Lateral Piezoelectric Effects

1.2 Bridge wind tunnel test scheme

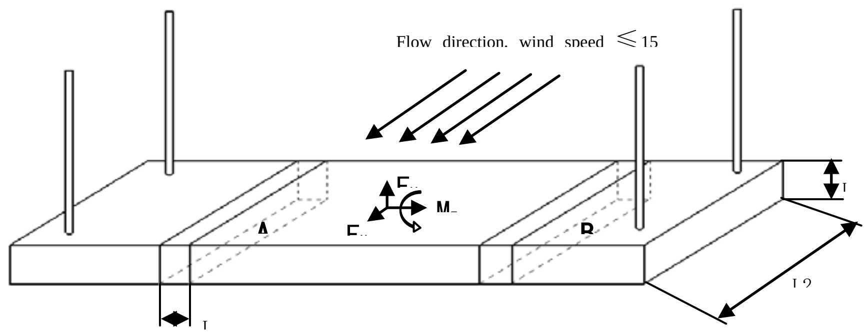


Fig 3 Bridge Tunnel Test Program

Figure 3 is the test scheme of the bridge in the wind tunnel. The bridge model is made of low density and high strength material. The model is used to measure the lift (Fy), lateral force (Fx) and overturning moment (Mz) in the 15m/s direction. Balance is installed on both ends A, B of the bridge, the whole and the signal lead to be covered up, and the length of the balance in L (about 50mm) in the range, the weight should be small with high stiffness.

1.3 Structure design of balance

According to the design requirements of the balance, the five beam structure is adopted. The point is arranged in the center of the cross section of the balance, fixed with the model of the bridge is by bolt, and the base are connected by screw fixation, lift and lateral force is measured by a middle beam, the overturning moment as measurement task by the middle beam around the rest of the four beam, five beam in the whole deformation process, is in S deformation, the deformation has the characteristics of good linearity, high accuracy, which ws as shown in Figure 4. At both ends of the beam is the largest strain, its size can be gotten through the formula: $d\sigma = dM / W$, where dσ is the stress sigma paste piezoelectric crystal at the moment, dM is corresponding to the position of the beam, W is bending modulus.

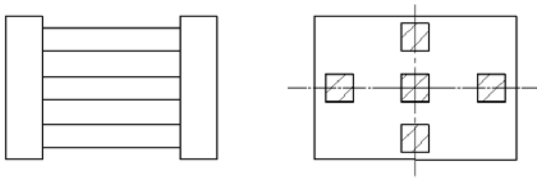


Fig4 S-Shaped Deformation of the Beam Fig5 Balance Structure

In the model, the measurement of the torque is converted into force measurement, the deformation of S shape deformation, in order to reduce the lifting force and lateral force on the measurement of interference, in the selection of piezoelectric crystal, symmetry can be applied should choose consistent performance will be the lowest. Figure 5 shows the balance structure.

2. Finite element analysis of structural model

The design load of the balance is: lift Fy=4N, lateral force Fx=1N, overturning moment Mz=0.3N.m. According to the wind tunnel test conditions, the size of the balance is 50 * 40 * 50mm. In order to reduce the weight of the balance, the balance material is made of aviation aluminum alloy that with high strength and low density.

When the traditional material mechanics is used to design the balance, it is necessary to simplify the calculation model, and there is a big difference between the calculated value and the measured value. In this paper, the finite element analysis software ANSYS is used to design, calculate and analyze.

2.1 Finite element model [3]

The geometric model of the balance is established by creating three-dimensional solid model through the Creo software, transfered into the ANSYE throught IGS format. The element type selects the 8 node three-dimensional entity solid45 to divide the scale model of the balance, and the finite element analysis model is shown in figure 6.

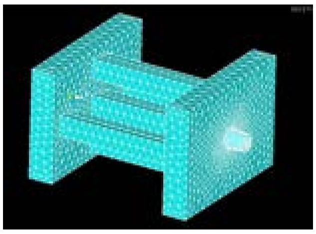


Fig6 Finite Element Model of the Balance

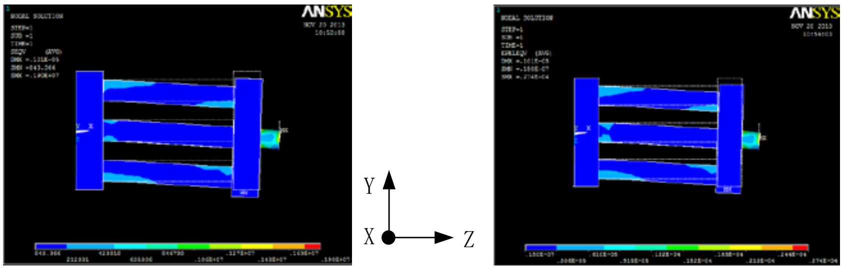
2.2 Boundary conditions and loads

The boundary conditions need to reflect the balance in the working condition of stress and constraint conditions, the balance is fixed by four screw holes and the base, so the constraint for all degrees is freedom constrained circular arc surface mounting hole. In fact, the calibration of the balance is applied to the load of the measuring unit, so the finite element analysis of each measurement unit is needed in the analysis.

(1) Lift analysis

The bridge model is fixed on the balance by the screw, the lifting force generated by the bridge is transferred to the balance through the screw, and the contact surface of the screw is extruded. Through the analysis, we can get the sum of strain at the piezoelectric crystal εFy=13760με. The piezoelectric d31=150PC/N, E=50Mpa, S=0.35×10-4m2, we can calculate the sensitivity of SFy=

balance in the lift direction SFy=（d31*E*εFy*S）/Fy≈903 PC/N.

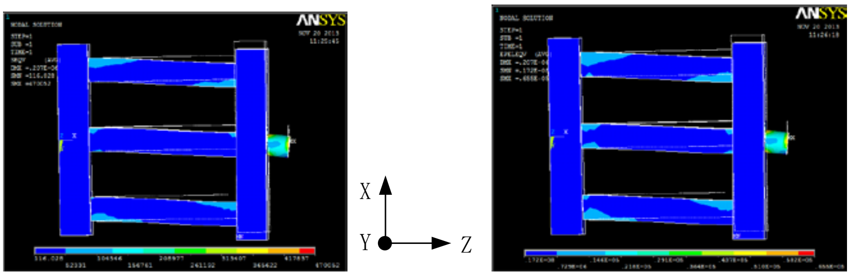


（a）Stress Cloud （b）Strain Cloud

Fig7 Stress and Strain Cloud Chart of Lift Force Analysis

(2) Analysis of lateral force

The lateral force is the same as the lift force, but the direction and size of the load changes. Through analysis, we can get the sum of strain at the piezoelectric crystal εFx=3215με. The performance of the same strain gage, sensitivity of SFx= balance in the direction of the lateral force SFx=（d31*E*εFx*S）/Fx≈844 PC/N.

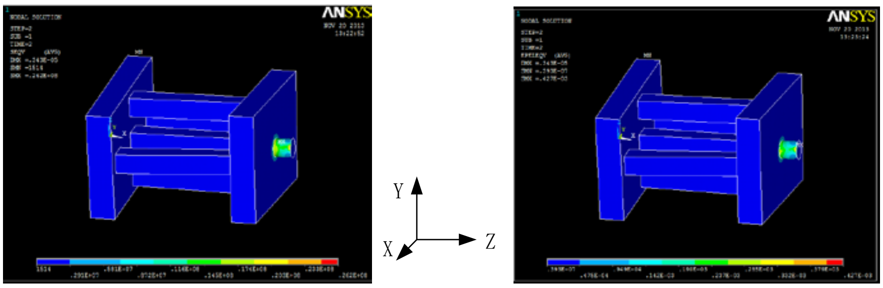


（a）Stress Cloud （b）Strain Cloud

Fig8 Stress and Strain Cloud Chart of Side Force Analysis

(3) Analysis overturning moment

The overturning moment into a force exerted on the stud. Through the analysis, it can reached that the sum of pasted piezoelectric strain is εMz=154600με,, the sensitivity of SMz= (d31*E* e Mz*S) /Mz = 1353 PC/N.cm.



（a）Stress Cloud （b）Strain Cloud

Fig9 Stress and Strain Cloud Chart of Overturning Moment Analysis

3. Quasi-static calibration

The quasi static calibration of the balance uses the calibration device as shown in Figure 10, which is used for single component calibration of the three measuring units. The comparison of calibration data and ANSYS design analysis data is shown in Table 1. It can be seen from the table that the finite element analysis is very consistent with the actual measured values.

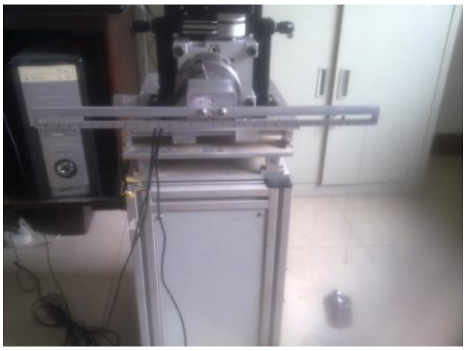


Fig10 Quasi-Static Calibration Equipment

Tab1 Data comparison

Measurement unit	Finite element calculation Sensitivity	Measurement sensitivity
Fy	903PC/N	897PC/N
Fx	844PC/N	821PC/N
Mz	1353PC/N.cm	1313PC/N

4. Conclusion

For a special bridge wind tunnel test, this paper innovatively developed the small five beam volume three component balance of high sensitivit based on the transverse piezoelectric effect, whose size and weight fully meet the test requirements. Balance is of high sensitivity. According to the conversion ratio of 1:1, it can realize the accurate measurement of 1g force, which is the first in the country.

Acknowledgements

Development of dynamic three component wind tunnel balance based on piezoelectric technology.Number: ZRY1204.

Reference

[1] Chen Zhengqing, Bridge wind engineering [M]. Beijing: China Communications Press,.2005;
[2] He Dexin, Wind tunnel balance [M]. Beijing: National Defence Industry Press.2001;
[3]ANSYS Inc. structural analysis ANSYS guide [Z].2004.