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Innovative design of a new CMM structure

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ABSTRACT

This paper presents an innovative structure, called arch-bridge structure, used to mount the Z-axis probe on the Nano-CMM (coordinate measuring machine with nanometer resolution). Compared with the conventional rectangular type of the bridge, this arch-bridge performs less static deflection than the rectangular type under the self-weight and the same spindle load respectively. Analytical solution and finite element analysis are described in detail.

Keywords: *Coordinate Measuring Machine (CMM), arch-bridge, deflection*

1. INTRODUCTION

Coordinate measuring machine (CMM) has already become a mainstream precision measuring instrument. The basic function of a CMM is to allow the x, y, and z positions of a point on the inspected surface to be established. CMMs are indispensable to manufacturers in various industries for the evaluation of product dimensional accuracy and tolerance.

CMMs are available in numerous sizes and types. They vary from desk-top [1] to floor type. A CMM normally consists of several functional components: the worktable, the bridge, the spindle, the touch triggered probe, the motors, the linear scales, the air bearings, and the computer. The Z-motion is normally generated by the spindle; the Y-motion is usually of the spindle head across the bridge; the X-motion can be made by moving the table (the fixed bridge type) or moving the bridge. In the past, researchers have paid many attentions on the probe systems [2, 9, 10], probing paths [3, 4], volumetric errors [5,8], dynamic performance [6], software [7], etc., in order to improve the measurement accuracy and uncertainty. All surround the conventional rectangular bridge type. One important factor has been ignored, i.e. the bridge structure design. The structural balance and the stiffness of the bridge are also critical to the static and external load deflections of the CMM. Only until recently the new shapes of bridge design have been seen in the literatures, such as the triangular bridge [8] and Abbe free structure [9].

This paper presents an innovative structure, called arch-bridge structure, used to mount the Z-axis probe on the Nano-CMM (coordinate measuring machine with nanometer resolution). Compared with the conventional rectangular type of the bridge, this arch-bridge performs less static deflection than the rectangular type under the self-weight and the same spindle load respectively. Analytical solution and finite element analysis are described in detail.

2. DESIGN OF THE ARCH-BRIDGE STRUCTURE

Fixed bridge is always employed in the precision CMM structure, the rectangular-bridge, as the conventional way, used to mount the Z-axis probe, as shown in Fig. 1. The deformation in the center of the bridge, however, is very notable because of the concentrated load from the spindle. The main unit of the new CMM structure developed in our research, as the frame of Nano-CMM, employs a fixed arch-bridge structure, as shown in Fig. 2. The semicircular arch bridge is the novel point in this structure, which forms the flat top that can fix the Z-spindle. This Nano-CMM is designed for the measurement of mesoscale parts to the accuracy of nanometer range. It is of the table top type small CMM. The outer radius is 220mm and the inner is 150mm; the width is 60mm and the dimension of the supporting pad is 70mm×100mm×40mm. The rectangular-bridge used to compare with the arch-bridge has the similar effective dimension.

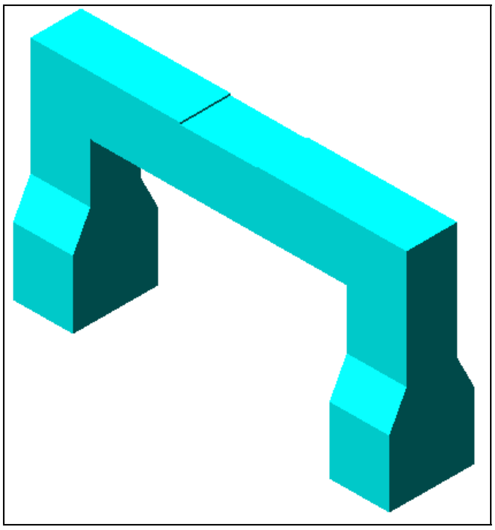


Fig. 1 Rectangular-bridge structure

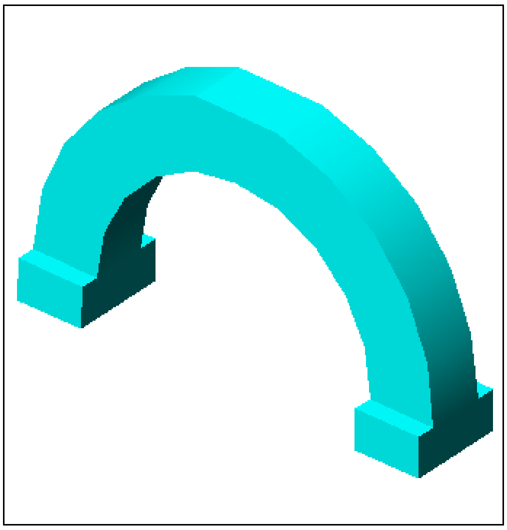


Fig. 2 Arch-bridge structure

3. COMPARISION OF THE ARCH-BRIDGE WITH THE RECTANGULAR-BRIDGE

3.1 Structural Mechanics Analysis

Deflection will happen because of the self-weight and spindle load acting on the bridge, which results to the initial deformation.

3.1.1 Deflection of rectangular-bridge

The deflection mode of the fixed rectangular-bridge is sketched in Fig. 3, which is a statically indeterminate structure. From structural mechanics formula [11] we can use the equation (1) to describe the deflection.

$$\delta_y = \frac{1}{EI}\int_0^R \left(0.3PR - \frac{P}{2}x\right)(-x)dx + \frac{1}{EI}\int_0^R (0.3PR + 0.3Py - PR)(-R)dy \qquad (1)$$

where, P is the spindle load performing on the rectangular-bridge; R is the effective radius referring to the arch structure, E is the Elastic modulus of the material and I is the moment of inertia of the cross section. The maximum deflection at the center of the rectangular-bridge can be described as:

$$\delta_{y\max} = 0.55\frac{PR^3}{EI} \qquad (2)$$

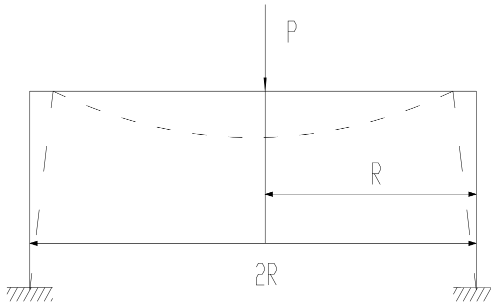


Fig. 3 Deflection of the Rectangular-bridge

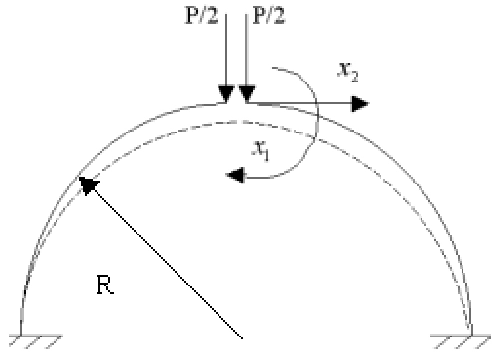


Fig. 4 Deflection of the Arch-bridge

3.1.2 Deflection of arch-bridge

The arch-bridge structure is also a statically indeterminate structure and integral calculation is employed in the structural mechanics analysis. When the spindle load performed on the top flat of the arch-bridge, the deflection of the arch is shown in Fig. 4. Considering the static equilibrium condition, the deflection of any point on the arch-bridge can be achieved by the following equation.

$$\delta_y = \frac{1}{EI}\int_0^{\frac{\pi}{2}} \left(\frac{1}{2\pi}\sin\theta + \frac{\sin\theta - \cos\theta\sin\theta}{3\pi - 8} - \frac{\sin^2\theta}{2}\right) PR^2 R d\theta \tag{3}$$

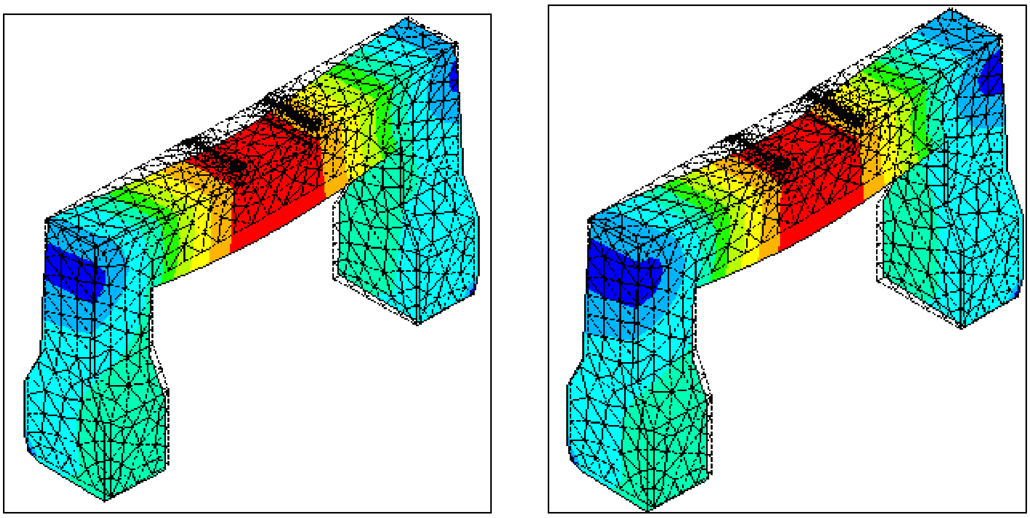
where, R is the mean radius of the arch and P is the spindle load performing on the arch-bridge. When θ is $\pi/2$, the maximum deflection at the arch center can be described as:

$$\delta_{y\max} = 0.24\frac{PR^3}{EI} \tag{4}$$

3.2 Finite Element Analysis (FEA)

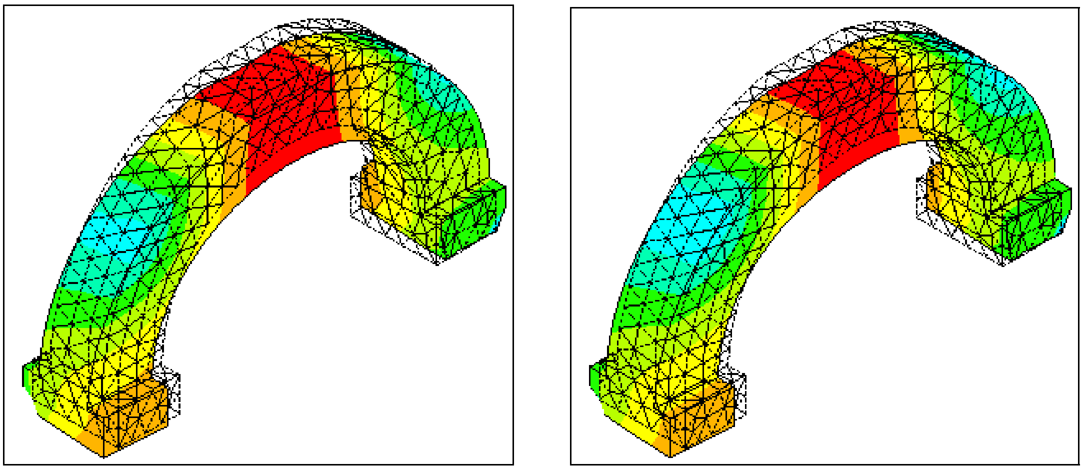
The main unit of the CMM structure is constructed with granite, which has many superior characters to the Al or steel material, including small deformation, fine stability, free-rusting and high flatness.

Extensive Finite Element Analysis (FEA) modeling techniques were used to analyze the configuration and parameters of the rectangular-bridge and the arch-bridge by simulating the deformation. With the AnSYS7.0 analysis procedure, static analysis, including self-weight static analysis and force static analysis, was made for the bridge and the entire unit, shown as Fig. 5 and Fig. 6. Applying the gravity acceleration to the structure in the direction of positive Z-axis, we achieve the bridge deformation with self-weight loading, 0.156 um for rectangular-bridge and 0.113 um for arch-bridge. Applying the load of total 29.4N to the top face, coming from the Z spindle, the deformation is 0.331 um for rectangular-bridge and 0.236 um for arch-bridge. The detailed analysis results are listed in Table. 1.



(1) Self-weight static analysis (2) 29.4N pressure static analysis

Fig. 5 FEM analysis on the rectangular-bridge



(1) Self-weight static analysis (2) 29.4N pressure static analysis

Fig. 6 FEM analysis on the arch-bridge

Table 1: Comparison between Rectangular-bridge and Arch-bridge

Property of Granite				Analytical solution	FEA	
					Self-weight	Spindle load
Density (Kg/ m^3)	Young's Modulus (GPa)	Poisson's ratios	Deflection of Rectangular-bridge	$0.55\frac{PR^3}{EI}$	0.156um	0.331um
2660	60	0.3	Deflection of Arch-bridge	$0.24\frac{PR^3}{EI}$	0.113um	0.236um

From the analysis data in Table 1, the structure advantage of the arch-bridge is obvious. Since the structural mechanics analysis model has chosen the effective dimension as the analyzing parameters and ignored some affecting factors, the calculated result has somewhat error with the data of analysis result in software with ANSYS. The changing trend, however, is proper. Additionally, the FEA results show that the deflection of the central top of arch-bridge is one third less than that of the rectangular one.

4. CONCLUSIONS

In this article, we introduced our new CMM structure “arch-bridge CMM” carried out for the Nano-CMM. We reached the following conclusions:

a) The basic design concept of arch-bridge is introduced in the paper.

b) Structural mechanics analysis method and FEA analysis method have been presented to prove the advantage of the arch-bridge. The deflection of the arch-bridge approximately decreased one third than that of the rectangular-bridge, that is, the rigidity of the new shape has superiority.

c) Ensuring the positioning accuracy of Z-axis with the probe head and being the crucial technique in constructing the Nano-CMM.

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