Structure Optimization and Verification of Portable Intelligent Gauge Calibrator

Hao Chen1,a, XiaoGuang Sun2,b, HuiChen Zhu3,c*
1Shanghai Institute of Metrology and testing technology, Shanghai, China
2Shanghai Institute of Metrology and testing technology, Shanghai, China
3Shanghai Institute of Metrology and testing technology, Shanghai, China
aEmail: chenhao@simt.com.cn, bEmail: 2748862118@qq.com
cEmail: sunxg@simt.com.cn
* Corresponding author: sunxg@simt.com.cn

Abstract: Portable intelligent gauge calibrator is a new type of gauge calibrator to replace the traditional gauge calibrator. It can effectively solve the problems of traditional gauge calibrator, such as unable to carry out on-site measurement, too large volume, low degree of intelligence and so on. In view of the problem that the maximum stress of the connector of the horizontal measuring platform is too large in the trial operation of the portable intelligent gauge calibrator, this paper puts forward a solution combining topology optimization with practical experience. The test shows that the method is effective and feasible.

1. Introduction

The portable intelligent gauge calibrator is a new intelligent product aiming at the disadvantages of the traditional gauge calibrator [1], which is not portable, difficult to carry out on-site detection, and low degree of intelligence. Its overall structure is shown in Figure 1 below.

![Figure 1 General diagram of portable intelligent gauge calibrator](image-url)

Figure 1 General diagram of portable intelligent gauge calibrator
In addition to the gauge, the main part of the verifiable device can be divided into horizontal measuring platform and superelevation measuring platform, as shown in Figure 2 and Figure 3 below.

![Figure 2 Schematic diagram of horizontal measuring platform(left) and Schematic diagram of superelevation measurement platform(right)](image)

(1-horizontal platform leveling motor group; 2-platform guide rail structural parts; 3-two-dimensional electronic level; 4-horizontal platform gauge movable probe clamping slot; 5-grating ruler; 6-platform mobile motor group; 7-horizontal platform main measuring platform; 8-horizontal platform base; 9- superelevation platform track gauge movable probe slot; 10-jack motor group; 11-grating ruler (2); 12-two-dimensional electronic level; 13-superelevation Platform main measuring platform; 14-superelevation platform leveling motor set; 15-superelevation platform base; 16 - superelevation platform gantry)

During the experiment, due to the inconsistency between the actual applied load and the set load on the horizontal measuring platform, the connector is deformed during the operation, which affects the experimental results and accuracy. In this paper, the author optimizes the overall three-dimensional model of the horizontal measurement platform, and carries out static analysis on the new connector through ANSYS simulation software to verify the effectiveness and rationality of structural optimization.

2. Static analysis\(^{[2-3]}\)

The connectors of the horizontal detection platform are shown in Fig. 3 and Fig. 4, which are named as connector 1 and connector 2 respectively. During the operation of the device, because they are fixed by screws and nuts, they are regarded as connectors for simulation.

![Figure 3 Schematic diagram of connection parts of horizontal measuring platform(left) and Figure 4 overall schematic diagram of horizontal measuring platform connector(right)](image)
In order to facilitate the simulation, we simplify the model. The green part of Figure 4 is the connector. The grid model is shown in Figure 5.

![Figure 5 Schematic diagram of grid model of horizontal measurement platform connector](image)

The mesh is divided into tetrahedral meshes with 35432 nodes and 21043 elements. Tetrahedral mesh is used. The material properties of main components are shown in Table 1.

| Part name | Material name | Density (g / cm³) | Poisson's ratio | Elastic modulus (Mpa) |
|-----------|---------------|------------------|-----------------|-----------------------|
| Screw     | 304 stainless steel | 7.93             | 0.31            | 193000                |
| Nut       | 304 stainless steel | 7.93             | 0.31            | 193000                |
| Connector | Al-6061-T6     | 2.703            | 0.33            | 69000                 |

The whole detection process is basically similar to that of the traditional gauge calibrator, and the leveling link of the platform itself is added.

Add the external load according to the actual situation, as shown in Figure 6 below. It can be divided into: The load $F_A$ perpendicular to the front surface of connector 2 is 15N; The simulated thrust load $F_B$ perpendicular to the rear surface of connector 1, where the value of $F_B$ is obtained from the following formula 1 to formula 3:

The speed per minute of stepper motor $V = \frac{\pi \times N \times 60}{360 \times k}$

(1)

The torque $T$ is $3.367\text{N} \cdot \text{M}$ from formula 2.

$T = \frac{9550 \times P}{V}$

(2)

The axial thrust $F_B$ is obtained from Formula 3.

$F_B = \frac{T \times \eta \times 2\pi}{S}$

(3)
The parameters are: step angle \( n = 1.8 \, ^\circ \), subdivision value \( k = 16 \), maximum pulse number per second \( n = 3200 \), screw drive efficiency \( \eta = 90\% \), lead \( s = 1\) mm, motor output power \( P = 5.29\) w.

According to the actual situation, the motor speed range is 60r / min-300r / min, so the value range of \( F_B \) is 38.14N-190.70N.

The positive pressure \( F_C \) applied to the upper surface of connector 1 is 25N; The simulated preload \( F_D, F_E \) applied to the end side of connector 2 is 35N. Finally, after adding the corresponding environment and boundary conditions according to the actual situation, we choose \( F_B = 190.70\) N for static analysis, and the stress and strain nephogram is shown in Figure 7 and Figure 8 below.
It can be seen from Figure 7 and Figure 8 above that the maximum stress and strain appear in the central hollow groove of connector 1, with the stress of 39.644MPa and strain of 0.080mm. According to the data, the compressive yield limit of al-6061 is 55.2MPa, and the safety factor \( n \) is 2, so the allowable stress \( \sigma \) is:

\[
[\sigma] = \frac{\sigma}{n}
\]  

When the \( F_B \) value is the maximum, the stress exceeds the required stress, so it is necessary to optimize the structure of connector 1.

3. Structural optimization
The optimization scheme in this paper combines the practical experience with the topology optimization in ANSYS software \(^4\), as shown in Figure 9 below.

The final optimization scheme is as follows. Firstly, the redundant part of connector 2 is deleted according to the topology optimization scheme. Meanwhile, the redundant material of the shoulder of
the connector 1 is reduced, and the stiffeners are added to deal with the stress concentration of the central groove. The optimized stress-strain nephogram is shown in Figure 10 and Figure 11.

The maximum stress of the optimized connector is 19.627MPa when $F_B = 190.70N$, which is less than the required stress of AL-6061 by 27.6MPa. Since the value of $F_B$ ranges from 38.14N to 190.7N, the comparison of the maximum stress of the integral connector is shown in Table 2:

| Axial thrust $F_B$ | 38.14N | 76.28N | 114.42N | 152.56N | 190.70N |
|-------------------|--------|--------|---------|---------|---------|
| Before structure optimization (MPa) | 8.8059 | 15.968 | 23.858 | 31.751 | 39.644 |
| After structure optimization (MPa)  | 7.1786 | 8.1331 | 11.351 | 15.232 | 19.627 |
It can be concluded that the structural optimization scheme can effectively solve the stress concentration problem of the device, improve the stability of the device structure, and the method used in the text is effective to optimize the connector.

4. Summary
In view of the situation that the stress on the connector of the horizontal measuring platform of portable intelligent gauge calibrator is too concentrated, which is greater than the allowable stress of the material used, a structural optimization scheme is proposed by combining the practical experience with the ANSYS topology optimization scheme. Through data comparison and detection, it is effective and feasible under various conditions of the device operation.

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