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RESEARCH ON 2000 kg MECHANICAL BALANCE WITH THE SENSITIVITY OF 1.3 g

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Abstract: The calibration requirement of the whole more than 500 kg weight is increasing year by year in China, expecially, the class F_1 weight and the weight from the huge deadweight force standard machine and huge torque standard machine. The advantages of measurement more than 500 kg on a new 2000 kg mechanical balance are introduced in the paper. In order to obtain high measurement uncertainty, four vertical forces of two sides of beam is measured and used as reference for adjustment of beam position. Laser displacement sensors to be used in the indication system are more effective for decreasing reading error caused by human vision. The counter weight selecting system is developed for getting any combinations of weights in a limited space. The sensitivity of the new mechanical balance for 2000 kg is better than 1.3 g.

Keywords: Sensitivity; Mechanical Balance; Laser displacement sensor; Repeatability

1. INTRODUCTION

The repeatability and linearity of mass comparator depends on lever constructure, the positon of applied gravity force and the performance of load cells. Lever constructure in mass comparator consisting of pivot and metal beam is used to amplify gravity force during the mass measurment. Meterial and deformation of metal beam are the influence factors of amplifing accuracy. The precision of the amplification on the small mass comparator is better than that on the large mass comparator. The large electronic mass comparator based on lever constructure is difficult to get better repeatability and linearity in the process of mass measurement.

A weight placed on different position of the platform could result in the difference between two adjacent measurements. This is more obvious for a big weight over than 100 kg. For obtaining better repeatability of measurement results, the bottom position of weight on the platform is usually marked. It could ensure the weight to be placed on the same position during the process of measurement.

Due to the characteristic of load cell, the electronic mass comparator with different maximum capacity may be selected when it is used for measuring the masses of weights with the same accuracy and the different nominal value. It is necessary for weights above mentioned to use several electronic mass comparators for performing corresponding measurement [1] [2].

Based on this characteristic, we have developped a new mechanical balance with the maximum capacity of 2000 kg. The sensitivity of mechanical balance for 2000 kg is less than 1.3 g. The repeatability for 2000 kg is less than 0.15 g.

2. CONSTRUCTURE AND OPERATIONAL PRINCIPLE

The mechanical balance is composed of beam system, middle knife, side knives, indicator, counter weights, selecting system, weighing system, motors and controller. Figure 1 is the picture of mechanical balance. The height of the mechanical balance is 2.8 m. The length of balance beam equals to 2 m. The dimension of the maximum rectangle object placed on the weighing platform is 1.2 m (L) × 0.6 m (W) × 0.4 m (H).

Fig.1 The picture of 2000 kg mechanical balance

2.1 Indicators of Mechanical Balance

The display device includes two individual indicators. One is the indicator based on optical principle. Another includes two laser displacement sensors, singal processor and computor. The indicator based on optical principle is used for adjusting another indicator with two laser displacement sensors [3]. The scale of the indicator based on optical principle includes 160 divisions. The interval between divisions of the scale equals to 0.25 mm. The indicator with two laser displacement sensors used as a reading system of the mechanical balance is available for decreasing reading error caused by human vision. Figure 2 shows the position of one laser displacement sensor and the software interface of indicator.

Fig. 2 The position of one sensor and the software interface

2.2 Counter Weight Selecting System

According to the measurement requirement of full range from 100 kg to 2000 kg in a limited space, a counter weight selecting system is designed and produced. The counter weight selecting system shown as figure 3 consists of one stainless steel frame with three layer support, nested counter weights with 1 2 2 5 from in to outside and 3 sets of selecting modules with 9 motors for selecting counter weights. The first selecting module with 4 motors on the top of the counter weight selecting system is used for selecting one weight or one set of weights among 10 kg, 20 kg, 20 kg and 50 kg. The second one is similar as the first layer structure for selecting one weight or one set of weights among 100 kg, 200 kg, 200 kg and 500 kg. There is one weight with 1000 kg and one set of selecting module with 1 motor in the third layer.

Fig. 3 Counter weight selecting system

2.3 Operational Principle

The weighing system is located at the left of the mechanical balance, and the counter weight selecting system is at the right side. When a measurement is stared, the reference weight and the test weight are place on the weighing system of mechanical balance in turn. Meanwhile according to the nominal mass of reference weight, a piece of counter weight or a set of counter weights are selected on the counter weight selecting system. Figure 4 is the general two-dimensional representation of mechanical balance.

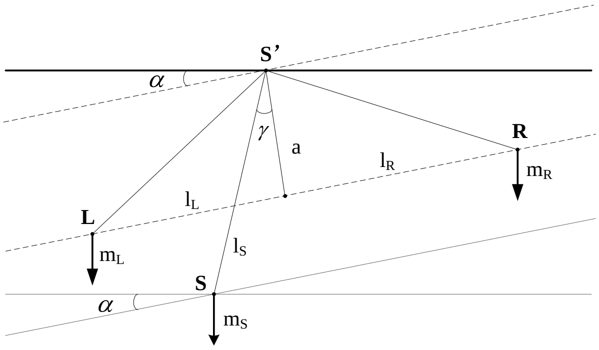

Fig. 4 The general two-dimensional representation

The characteristic quantities of the mechanical balance are shown as figure 7. The point S' is as the beam's pivot. The gravity force of beam mass mS acts at its center of gravity S. The masses mL and mR hang at points L and R. The broken line connecting L and R forms an angle α with the horizon line through point S', and is divided by the perpendicularly through S' with the length a into the sections $l_{\mathrm{L}}$and l_{R}. The lever arm of the balance's center of gravity with a length l_{S}forms an angle γ with a. These torques around point S' are neutralized under the equilibrium condition [4]. With the gravitational accelerations g_{L}, g_{R} and g_{S} in the three gravitational centers of the masses, the following is valid:

$$m_R g_R(l_L\cos\alpha + a\sin\alpha) = m_L g_L(l_L\cos\alpha - a\sin\alpha) + m_S g_S l_S \sin(\gamma - \alpha) \quad (1)$$

It is assumed that $g_L = g_R = g_S = g$, the sensitivity of the mechanical balance is defined according to formula (1) as follows:

$$\frac{\partial\alpha}{\partial m_L} = \frac{l_L\cos\alpha - a\sin\alpha}{m_L(l_L\sin\alpha + a\cos\alpha) + m_R(a\cos\alpha - l_R\sin\alpha) + m_S l_S \cos(\gamma - \alpha)} \quad (2)$$

In the case of $a = 0, l_L = l_R = l, \gamma = 0$ and $\alpha = 0$, formula (1) is changed as follows:

$$m_L = m_R = m \quad (3)$$

The sensitivity of mechanical balance is modified as follows:

$$\frac{\partial\alpha}{\partial m_L} = \frac{l}{m_S l_S} \quad (4)$$

The sensitivity is independent of load, depending only on the mass of beam and the position of the center of gravity.

$\gamma = 0$ means that the mechanical balance is symmetrical. The beam of a symmetrical balance is horizontal only if the masses of ends of beam are equal. $a = 0, \alpha = 0$ means that the pivots are on one level.

Based on the principle above mentioned, the producing and assembling of one long beam with knives and bearing blocks is very important for improving the repeatability and sensitivity of mechanical balance. Three coordinate measuring and adjusting technology is used for adjusting straightness, parallelism and flatness between middle knife and side knives to be mounted on the beam. The parallelism and the flatness between middle knife-edge and side knife-edges are less than 0.02 mm/m.

3. EXPERIMENTS AND UNCERTAINTY EVALUATION

Class E_2 weights 5 g, 10 g and 20 g are used as sensitivity weights from no load to full load. 10 pieces of class E_2 weights 50 kg are used as the reference weight of 500 kg. 100 pieces of class F_1 weights 20 kg are used as the reference weight of 1000 kg or 2000 kg. The sensitivities of no load and full load are shown as table 1.The sensitivity of full load is less than 1.3 g. The standard deviations of no load and full load are shown as table 2 and table 3 respectively.

Table 1. Sensitivity measurements of mechanical balance

Left Side	Right Side	Results (division)	Sensitivity (g)
No load	No load	15.381	0.3
Sensitivityweight 5 g	No load	32.072	
Full load	Full load	18.694	1.3
Sensitivityweight 20 g	Full load	34.130	
No load	No load	15.803	0.3
No load	Sensitivity weight 5 g	-4.177	
Full load	Full load	18.838	1.3
Full load	Sensitivity weight 20 g	3.298	

Table 2. Standard deviation of no load

Results (division)	Sensitivity (g)	Standard Deviation (g)
15.394	0.3	0.04
15.515	0.3	
15.637	0.3	
15.714	0.3	
15.452	0.3	
15.546	0.3	

Table 3. Standard deviation of full load

Results (division)	Sensitivity (g)	Standard Deviation (g)
18.765	1.3	0.13
18.783	1.3	
18.888	1.3	
19.026	1.3	
18.896	1.3	
18.954	1.3	

The uncertainty of mechanical balance is shown as following [5][6]:

$$u^2(E) = s^2(I) + \frac{d_0^2}{12} + \frac{d_L^2}{12} + u^2(L) \quad (5)$$

Where $u(E)$ is the uncertainty of error, $s(I)$ is the repeatability of the mechanical balance corresponding applied load, d_0 is the sensitivity of no load, d_L is the sensitivity at applied load, $u(L)$ is the uncertainty from the reference weight including the air buoyancy correction.The uncertainties of 500 kg, 1000 kg and 2000 kg are shown as table 4.

Table 4. The extended uncertainties on different loads

Load (kg)	Standard uncertainty of the weighing process (g)	Standard uncertainty due to the sensitivity (g)	Standard uncertainty of the reference weight with air buoyancy correction (g)	Combined standard uncertainty (g)	Extended uncertainty(*k*=2) (g)
500	0.072	0.176	0.134	0.232	0.47
1000	0.028	0.236	0.833	0.867	1.8
2000	0.117	0.469	1.667	1.736	3.5

4. CONCLUSIONS

In order to develop the 2000 kg mechanical balance with high accuracy and wide measurement range for measurement of class F_1 weights over than 500 kg, three coordinate measuring and adjusting technology is used to improve the repeatability and sensitivity of the mechanical balance. For the realization of any combinations of counter weights in a limited space, a new construction of counter weight selecting system is designed and accomplished. The counter weight selecting system is developed for getting any combinations of weights in a limited space. The sensitivity of the new 2000 kg mechanical balance is better than 1.3 g.

5. ACKNOWLEDGEMENT

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