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Research on straightness calibration method of straight edge working face based on electronic level

Yi Yang*, Tao Wang, Liwei Dai

Hubei Institute of Measurment and Testing Technology, Wuhan, Hubei, China

Abstract. A straightness calibration method of straight edge working face based on electronic level is proposed. According to the proposed calibration method, the evaluation model of measurement uncertainty is established, and the source of uncertainty is analysed. The expanded uncertainty is less than one third of the maximum allowable error required by the calibration specification, which verifies the feasibility and effectiveness of this calibration method.

1. Introduction

The straight edge is a measuring tool used to measure the straightness and flatness of the workpiece when the working surface is flat [1]. The measuring characteristics of the straight edge mainly include surface roughness, straightness of the working face, parallelism of the upper and lower working faces, etc. Among them, the main measuring instrument for the straightness calibration of the working face is the electronic level. Electronic level is a small angle measuring instrument, which is mainly used to measure the inclination of the relative horizontal plane. It can also be used to measure the parallelism of two parts, the straightness of the guide rail and the flatness of the working surface. Other measuring instruments can also be used to calibrate the straightness of the working surface of the straight edge. In reference [3] the author uses the image level to measure the straightness of the straight edge and evaluate its measurement uncertainty. In reference [4] the author studies the straightness measurement system of the straight edge and its experimental instruments, and proposes a fully automatic straightness measurement method of the straight edge. The common calculation methods of straightness of a straight edge are two-point method, least square method and minimum condition method. In reference [5] the author makes a comparative study on the application of these three methods in straightness calibration of a straight edge. This paper uses the electronic level proposed in JJF 1097-2021[1] to calibrate the straightness of the working surface of the straight edge, processes the measurement data with the minimum condition method, and analyzes the measurement uncertainty. The expanded uncertainty of the measurement results meets the requirements of the calibration specification.

2. Calibration method

The straightness of the working surface of the straight edge is measured by the pitch method with an electronic level. When measuring, fix the electronic level on the bridge slab, then move the bridge slab from one end of the leveling straight edge to the other end, and record the readings of the electronic level in turn. According to the principle of minimum condition evaluation, data processing is carried out through calculation to evaluate the straightness of the working face of the measured straight edge. During measurement, pay attention to supporting the measured leveling straight edge (except bridge type leveling straight edge) at both ends of the leveling straight edge 2l/9 (l is the length of the leveling straight edge) with equal height blocks, and select appropriate bridge slabs according to the length of the leveling straight edge, generally not less than 8 ~ 10 positions, with a span of (50 ~ 500) mm. The schematic diagram of the measurement process is shown in Figure 1.

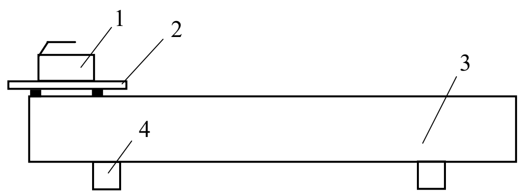

Figure 1. Schematic diagram of straightness calibration of straight edge working face based on electronic level

1 –electronic level; 2 –bridge slab; 3 –straight edge; 4 –block;

* Corresponding author: alex_to@126.com

After obtaining the measurement data of all electronic level instruments, according to the principle of minimum conditions, the straightness of the working surface of the straight edge can be calculated according to the following

$$F = CL\Delta_i \tag{1}$$

$$\begin{aligned} F &= LC\left[\sum_0^k a_i - \frac{k-g}{p-g}\left(\sum_0^p a_i - \sum_0^g a_i\right) - \sum_0^g a_i\right] \\ &= LC\left(\frac{p-k}{p-g}\sum_{i=g+1}^{k} a_i - \frac{k-g}{p-g}\sum_{i=k+1}^{p} a_i\right) \end{aligned} \tag{2}$$

Where F is straightness of the working surface of the straight edge, C is graduation value of electronic level, L is span of bridge slab, Δi is straightness reading conforming to the principle of minimum condition, g and p is sequence number of two low points (or two high points), k is sequence number of high point (or low point) contained in two low points (or two high points), n is the reading number of the electronic level at the pitch of section.

3. Evaluation of measurement uncertainty

3.1 Measurement model

Given

$$F_a = \frac{p-k}{p-g}\sum_{i=g+1}^{k} a_i - \frac{k-g}{p-g}\sum_{i=k+1}^{p} a_i \tag{3}$$

Then the straightness measurement model of the working surface of the straight edge based on the electronic level is

$$F = CLF_a \tag{4}$$

Considering that the uncertainty of a single measurement on each dimension segment is the same, then

$$u^2(a_1) = u^2(a_2) = \cdots = u^2(a_i) = \cdots = u^2(a_n) = u^2(a) \tag{5}$$

$$\begin{aligned} u^2(F_a) &= \left[\left(\frac{p-k}{p-g}\right)^2 (k-g) + \left(\frac{k-g}{p-g}\right)^2 (p-k)\right] u^2(a) \\ &= \frac{(p-k)(k-g)}{p-g} u^2(a) \end{aligned} \tag{6}$$

When g=0, p=n, k=n/2, the u(Fa) is max, then

$$u_{\max}^2(F_a) = \frac{n}{4} u^2(a) \tag{7}$$

$$u_{\max}(F_a) = \frac{\sqrt{n}}{2} u(a) \tag{8}$$

The uncertainty component of the evaluation is composed of the indication error difference of the electronic level, the quantization error of the electronic level, the measurement repeatability, and the influence of the positioning error, then

$$u^2(a) = u_1^2(a) + u_2^2(a) + u_3^2(a) + u_4^2(a) \tag{9}$$

Where u1(a) is the uncertainty introduced by indication error difference of the electronic level, u2(a) is the uncertainty introduced by the quantization error of the electronic level, u3(a) is the uncertainty introduced by the measurement repeatability, u4(a) is the uncertainty introduced by the influence of the positioning error.

3.2 Calculation of standard uncertainty

3.2.1 Calculation of u1(a)

According to the regulation JJG103-2005[2], the indication error shall not exceed (1+A×2%) unit, where A is the change in the number of resolution actually used. When calibrating the level 0 straight edge, the difference between the indicated values of the electronic level from head to tail with the pitch method is not greater than 50 unit. Then the indication error component is

$$A_s = 1 + 50 \times 2\% = 2 \tag{10}$$

It is estimated that the indication error is uniformly distributed in an interval with a half width of 2 unit, then

$$u_1(a) = 2/\sqrt{3} = 1.15 \tag{11}$$

3.2.2 Calculation of u2(a)

Resolution of electronic level is 1 unit (0.001mm/m), which is uniformly distributed, then

$$u_2(a) = \frac{\delta_x}{2\sqrt{3}} = \frac{1}{2\sqrt{3}} = 0.29 \tag{12}$$

3.2.3 Calculation of u3(a)

The standard deviation of measurement repeatability is to install an electronic level with the same span of bridge slab and place it at the same measurement position for 10 times. The reading changes within 1 unit, and the standard deviation is taken as the maximum standard deviation

$$s_x \le 0.5 \tag{13}$$

Taking the maximum value, then

$$u_3(a) = 0.5 \tag{14}$$

Since the uncertainty component introduced by measurement repeatability is larger than that introduced by quantization error, only the uncertainty component u3(a) is taken and u2(a) is omitted.

3.2.4 Calculation of u4(a)

Due to the influence of the straightness of the leveling straight edge, the bridge plate position is required to be connected head to tail during calibration, but there is a positioning error in the actual operation, which causes the change of the indication value of the electronic level. Practice has proved that for the level straight edge of grade 0, the maximum change of the indication value of the electronic level caused by the above operation deviation is not more than 2 unit. The value is equally probability distributed in an interval with a half width of 2 unit, then

$$u_4(a) = 2/\sqrt{3} = 1.15 \tag{15}$$

3.3 Combined standard uncertainty

3.3.1 The calculation results of standard uncertainty

The source of standard uncertainty components of measurement results is shown in Table 1.

Table 1. The source of standard uncertainty components of measurement results

$u(x_i)$	The source of standard uncertainty	coefficient of sensitivity c_i	results of $u(x_i)$
$u_1(a)$	The uncertainty introduced by indication error difference of the electronic level	1	1.15
$u_2(a)$	The uncertainty introduced by the quantization error of the electronic level	1	0.29
$u_3(a)$	The uncertainty introduced by the measurement repeatability	1	0.5
$u_4(a)$	The uncertainty introduced by the influence of the positioning error	1	1.15

3.3.2. The calculation results of combined standard uncertainty

The above standard uncertainty components are not related to each other, so the combined standard uncertainty is

$$u(a) = \sqrt{u_1^2(a) + u_3^2(a) + u_4^2(a)} = 1.7 \tag{16}$$

3.4 Expanded uncertainty

Taking the inclusion factor k = 2, the expanded uncertainty of the straightness measurement of straight edge working face based on electronic level is

$$U = 2u(F) = 2LCu_{\max}(F_a) = 2LC\frac{\sqrt{n}}{2}u(a) = 1.7\sqrt{n}LC \tag{17}$$

According to the provisions of JJF1097-2021[1], different spans L of the bridge slab are selected for measurement. Select the length of 300mm, 1000mm, 2000mm and 3000mm respectively straight edge, the evaluation results are shown in Table 2.

Table 2. The uncertainty of straightness measurement of different length straight edge

length of straight edge (mm)	spans L of the bridge slab (mm)	number of measurement sections	expanded uncertainty U(k=2) (μm)	straightness requirements of grade 00 straight edge[1] (μm)
300	50	6	0.2	1.3
1000	100	10	0.6	3.0
2000	200	10	1.1	5.4
3000	300	10	1.7	7.8

According to the evaluation results in Table 2, the expanded uncertainty of this method is less than one third of the maximum allowable error required by the specification.

4. Conclusion

A straightness calibration method of straight edge based on electronic level is proposed. The evaluation model of measurement uncertainty is established, and the source of uncertainty is analyzed, and the extended uncertainty of straightness calibration of straight edge based on electronic level is obtained. The expanded uncertainty is less than one third of the maximum allowable error required by the calibration specification, which shows that the method in this paper is effective and feasible.

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