MATEC Web of Conferences **35**, 03004 (2015)
DOI: 10.1051/matecconf/20153503004
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Design and application of location error teaching aids in measuring and visualization

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Abstract. As an abstract concept, 'location error' in <Machinery Manufacturing Technology> is considered to be an important element with great difficult to understand and apply. The paper designs and develops an instrument to measure the location error. The location error is affected by different position methods and reference selection. So we choose position element by rotating the disk. The tiny movement transfers by grating ruler and programming by PLC can show the error on text display, which also helps students understand the position principle and related concepts of location error. After comparing measurement results with theoretical calculations and analyzing the measurement accuracy, the paper draws a conclusion that the teaching aid owns reliability and a promotion of high value.

1 Introduction

At present, engineering colleges in China explain related contents to location error analysis and calculation with the assistance of PPT and CAI as teaching aids, lacking of visible location error analysis model. Location error is relatively abstract in practical production, especially when positioned with cylindrical surface, the position reference axis cannot be observed, which is difficult for students to make further understanding about calculation principle of location error. As a result, it is necessary to develop a set of visualized teaching aids of location error for machine manufacturing teaching.

2 Location error analysis

2.1 Concept of location error

Processing error will arise in workpiece location. Under the condition of adjustment method processing, the maximum position variation of process standard in the direction of working size resulted from workpiece positioning is called location error which is signified with Δ_{DW}. The location error includes datum mismatch error Δ_{JB} and datum displacement error Δ_{JW}. The location error resulted from inconformity between position standard and process standard is called datum mismatch error. The location error resulted from subsidiary manufacturing error of position and location error resulted from its fit clearance are called datum displacement error.

2.2 excircle positioning mode and typical location error analysis

There are two kinds of position modes of outside surface: centralized positioning and bearing positioning. The positioning standard of centralized positioning is axial lead of external cylindrical surface with the commonly used positioning device being spring head. The commonly used positioning device of support positioning is V-Block. The thesis adopts different types of position modes, and selects different process standards for finished surfaces of workpiece to make location error analysis and comparison, which can be more comprehensive. The simple instruction about location error calculation will be made with the example of V piece in the following contents.
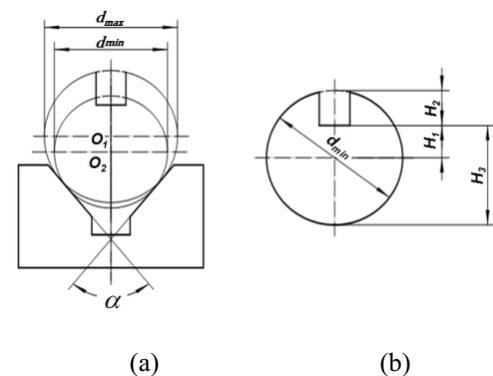

Figure 1. location error analysis of workpiece in V piece

Like in 2-1 picture, mill keyway in workpiece. Take the horizontal plane where central line of workpiece lies as

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the positioning standard, whose standard displacement error being:

$$\Delta_{JW} = \frac{T_d}{2sin\,(\alpha/2)} \qquad (1)$$

Including T_d as diameter tolerance of workpiece

When adopting three kinds of process standards, the corresponding location error calculation is showed in table 1.

Table 1 location error analysis of workpiece in V piece

Process standard	Process size	datum mismatch error Δ_{JW}	Location error Δ_{DW}
Central-line	H_1	0	$T\_d/(2sin(\alpha/2))$
Up-bus	H_2	$T\_d/2$	$T\_d/(2sin(\alpha/2)) + T\_d/2$
Down-bus	H_3	$T\_d/2$	$T\_d/(2sin(\alpha/2)) - T\_d/2$

3 Design scheme of visualized teaching aids of location error

The teaching aids designed in the thesis are aimed to gain location error stated in above contents through measurement. As a result, the teaching aid should possess functions like generation, measurement, and display of location error. The teaching aids designed by the thesis are mainly composed by mechanical part, measuring part and control part, like in figure 2.
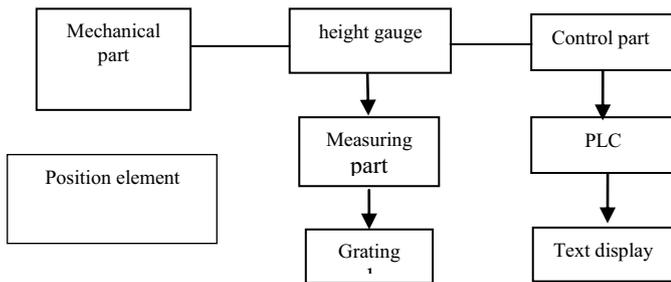
Figure 2. asic composition of teaching aids

4 Mechanical structure design and three-dimensional modeling and simulation of location error teaching aids

## 4.1 Positioning parts and selection of workpiece

When choosing positioning parts, the diversity of location error should be sufficiently considered. So we choose V-Block, 'L' bearing, semicircle sleeve and spring-clip

to show different location mode. In order to observe the tiny change in position error, we design two workpieces of large dimensional tolerances. The diameter of two workpieces are $18mm$ and $20mm$, thus they own a dimensional tolerance of $2mm$.

4.2 switching mechanism design of positioning parts

In order to select different kinds of position element, we refer to indexing plate to design structure. We choose position element by rotating the disk. Then fix the disk to bracket by index pin, to make sure the plate won't move a tiny displacement during the experiment. After that, we fix position element to disk by bolts and locating pin. We also use the compression screw installed on the axle to clamp the workpieces.

The two-dimensional assembling of location error teaching aids designed by the thesis is showed in figure 3.
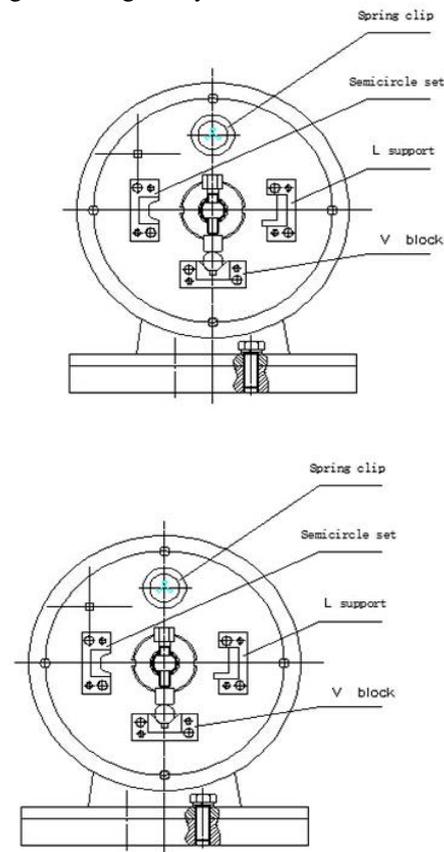
Figure 3.sembling aids picture of location error teaching aids

4.3 measurement mechanism design of location error

We connect height gauge to grading ruler so as to transfer the tiny movement from the location of scriber to grading sensor. By adjusting the location of scriber, we obtain the up-bus, down-bus and the axis position of workpieces.

4.4 Three dimensional modeling and simulation of location error teaching aids

After finishing design of location error analysis, make three-dimensional modeling with SolidWorks software. In addition, motion simulation is made to guarantee the usability of device.

5 Design for measurement and control system and operation interface of location error teaching aid

5.1 function of the location error teaching aid

Function1: Select different kinds of workpieces (we take two different sizes of cylinders for example)
Function2: Switch to various position element (we illustrate how V-block works in the experiment)
   Function3: Process basis selection
Function4: Position Measurement— we get the location error based on up-bus and down-bus of workpieces.
Function5: Data process and display (location error, datum mismatch error, datum displacement error can be visualized on the test display.)

5.2 Design of hardware and software for measurement and control system

5.2.1 Grading ruler selection

Location error teaching aid performs a series of operations by using grading ruler to measure the tiny movement and the text display to show the data. The grading ruler can transmit signal to PLC, utilizing high-speed counter to enumerate. It could give a clear presentation of movement and its accuracy can reach up to $5\mu m$. [5][6]

5.2.2 Test display selection

We choose cost-effective and easy connection test display as HMI to show results. It is of great economical and practical, and the programming is of great convenient.
5.2.3 PLC (programmable logic controller) selection
S7-200PLC has an advantage over rapidity, accuracy and stability. As a result, we take it as the control unit based on economy and well performance of its nuclear-CPU224. [7]
The measurement and control section of teaching aid can be divided into four system unit. Figure 4 shows the transitive relation of data and signal.
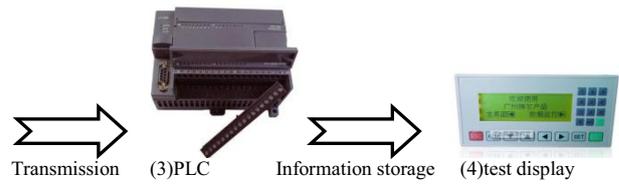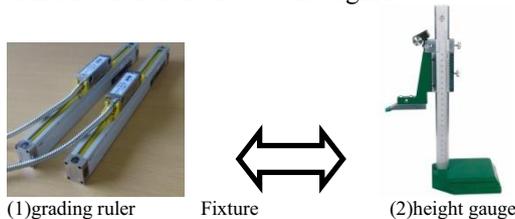

(1)grading ruler   Fixture   (2)height gauge

Transmission   (3)PLC   Information storage   (4)test display

Figure 4.odule components

The grading ruler will transform a tiny movement to an electrical signal, then transmit the signal to PLC when measuring the position of process basis. After simple operation of location error, the system transports the relevant data to the test display. The series make structure clear and simple.

6 Take V-block as a position element to do location error experiments

Figure 5 shows the location error teaching aids we developed. Through joint commissioning of hardware and software, we make the aids operate normally and meet the requirements. We select $\Phi 18mm$ and $\Phi 20mm$ position element to do location error experiment. We compare the measuring actual value Δ_{JB}、 Δ_{JW}、 Δ_{DW} to the theoretical value, in order to verify the feasibility and accuracy of teaching aids.

Figure 5 teaching aid of location error

6.1 Measure the position of process basis

During the experiment of location error, Adjustment Act is regarded as a prerequisite. By selecting different process bases and measure the position of them, we obtain the actual values of location error,
    Table 2 and table 3 show the result of the first set of experiment, table 2 and table 3 show the result of the second set of experiment, the theoretical results are displayed in table 4. Besides, workpiece1 is a cylinder with a diameter of 18 mm, and workpiece1 is a cylinder with a diameter of 20 mm.

Table 2. the first set of experiment of position size

element / Work piece	Display of up-bus by grating/5μm	Display of down-bus by grating /5μm	Display of center by grating/5μm
workpiece1	1176	−2433	−628.5
workpiece2	1665	−2356	−343.5

Table 3 the first set of experiment of measurement error

Process basis position / Type of error	Center /5μm	down-bus /5μm	up-bus /5μm
Δ_{JB}	0	208	208
Δ_{JW}	285	285	285
Δ_{DW}	285	77	493

Table 4 the second set of experiment of position size

element / Work piece	Center /5μm	down-bus /5μm	up-bus /5μm
workpiece1	1456	−2145	−344.5
Workpiece2	1940	−2061	−60.5

Table 5 the second set of experiment of measurement error

Process basis position / Type of error	Center /5μm	down-bus /5μm	up-bus /5μm
Δ_{JB}	0	200	200
Δ_{JW}	284	284	284
Δ_{DW}	284	84	484

Table 6 the theoretical results

center as the process basis/5μm		up-bus as the process basis/5μm		down-bus as the process basis/5μm	
Δ_{JB}	0	Δ_{JB}	200	Δ_{JB}	200
Δ_{JW}	280	Δ_{JW}	280	Δ_{JW}	280
Δ_{DW}	280	Δ_{DW}	80	Δ_{DW}	480

6.2 Processing and analysis of measurement data

Take an average of Δ_{JB}、Δ_{JW}、Δ_{DW} measured in two experiments, table 5 shows the averaged errors.

Table 7 the average of two experiments

center as the process basis/5μm		up-bus as the process basis/5μm		down-bus as the process basis/5μm	
Δ_{JB}	0	Δ_{JB}	204	Δ_{JB}	204
Δ_{JW}	284.5	Δ_{JW}	284.5	Δ_{JW}	284.5
Δ_{DW}	284.5	Δ_{DW}	80.5	Δ_{DW}	488.5

6.3 Comparison and analysis between experimental values and theoretical values of location error

Compare the experimental results with the theoretical result and calculate the absolute difference of location error, results are as follows.

**Table 8** absolute difference of location error

center as the process basis/mm		up-bus as the process basis/mm		down-bus as the process basis /mm	
$\delta_{\Delta_{DW}}$	0.0225	$\delta_{\Delta_{DW}}$	0.0025	$\delta_{\Delta_{DW}}$	0.0425
$\%_{\Delta_{DW}}$	1.6%	$\%_{\Delta_{DW}}$	0.6%	$\%_{\Delta_{DW}}$	1.7%

By comparison, we keep the difference of location error less than 0.05mm, and successfully control the relative error under 2%, which tests and verifies authenticity of the results as well as the ability of experimenting of the teaching aid.

7 Measurement accuracy of location error teaching aid

The cooperative relationship of assembling and the manufacture of dimensional tolerances among each part, will make an impact on the measurement precision of the grading ruler. So it is necessarily to construct dimension-chain analysis of the teaching aid.

A_0 —the closed-loop regarded as the final form of loop during assembling process, the distance from the scriber plane of height gauge to the level.
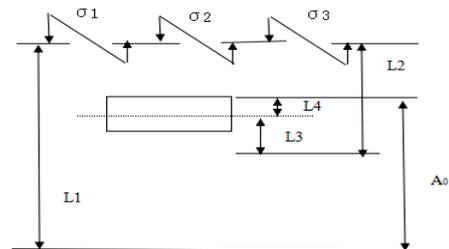
Figure 6. dimension-chain of V-block location error

The definition and accuracy requirements of composing link are as follows:

L_1 —the distance from horizontal plane to the centerline of hole on mounting plate with a dimensional tolerance of 0.1mm.

σ_1 —the deviation from the centerline of disk to the centerline of hole on mounting plate with a concentricity error of 0.1mm.

σ_2 —the deviation from the axis of mandrel to the centerline of disk with a concentricity error of 0.05mm.

σ_3 —the deviation from the centerline of disk to the axis of bearing with a concentricity error of 0.1mm.

L_2 —the distance from the axis of bearing to the bottom of V-block, with a dimensional tolerance of 0.15mm.

L_3 —the distance from the bottom of V-block to the centerline of work piece, with a dimensional tolerance of 0.1mm

L_4 —the radius dimension of the workpiece, with a dimensional tolerance of 0.1mm.

The functional relationship between closed-loop and composing link is

$$A = L_1 - L_2 + L_3 + L_4 - \sigma_1 - \sigma_2 - \sigma_3 \tag{2}$$

After taking total derivative for the equation of dimension-chain, we get

$$dA = \frac{\partial f}{\partial L_1} dL_1 + \frac{\partial f}{\partial L_2} dL_1 + \frac{\partial f}{\partial L_3} dL_1 + \frac{\partial f}{\partial L_{4,6}} dL_1 + \frac{\partial f}{\partial \sigma_1} d\sigma_1 + \frac{\partial f}{\partial \sigma_2} d\sigma_2 + \frac{\partial f}{\partial \sigma_3} d\sigma_3 \tag{3}$$

Plugging the values into the formula, we obtain

$$dA = 0.1 - 0.05 - 0.1 + 0.1 + 0.1 + 0.1 - 2*0.05 - 0.1 = 0.05mm \tag{4}$$

According to the formula of linear closed-loop, we get the dimensional tolerances of 0.05mm. From the experiment, we get the location error of 1.42mm, 0.4mm, 2.44mm, corresponding to the process basis based on up-bus, center and down-bus. The dimensional tolerance of closed-loop is less than 15% of the minimum of the location error. For that case, we can testify the reliability and authenticity of the results.

8 Conclusion

The teaching aid that we invent has simple structure and can be operated conveniently. Besides, with the help of its demonstration and measurement, location errors can be visualized. The aid has following characteristics:

8.1 Visualization of location error

Strong conceptual location errors can be reflected by experiment. A direct demonstration of location error helps students get profound understanding in its principles and knowledge.

8.2 High accuracy

Grating scale as a highly sensitive device can reach the accuracy of 5um. Remarkably enhance the resolution ratio and obtain more reliable measuring results. It proves the reasonableness and accuracy of the teaching aid by comparing the location error between experiments and theory calculation.

8.3 Apply to different kinds of locate modes and procedure sizes

The location error teaching aid use different kinds of locate mode. Not only can measure and show different kinds of location errors with different locate modes, but also analyze location errors of different workpieces in different procedure sizes with the same locate mode. It is a fully functioning device.

In conclusion, the teaching aid fills in the blank of practical observation of location errors. Positive reviews are received from the students after demonstrating the aid in class. This shows that the aid is valuable for application and popularization. It is an ideal aid for location error's teaching in class.

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