Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
July-August 2022 Page No. 920-934
Article History: Received: 30 March 2022, Revised: 8 April 2022, Accepted: 15 April 2022, Publication: 30 April 2022

The Research of Positioning Error Measurement Based on Reinshaw Laser Interferometer XL-80

Wenwen Du*
Anhui Technical College of Mechanical and Electrical Engineering, Wuhu, Anhui, China
*Corresponding Author.

Abstract:

In order to improve the positioning accuracy of CNC machine tools and ensure the size and accuracy requirements of maching parts of CNC machine tools. The THWLBTF-3 machining center is used as the test platform and the Reinshaw laser Interferometer XL-80 is adopted in this paper. The positioning error of X-axis of machining center is measured through non-contact and online measurement, and the test data is measured by software. The results show that the magnitude of pitch error of machining center is one of the important factors affecting the positioning accuracy of machining center.

***Keywords**: Reinshaw laser interferometer XL-80, The THWLBTF-3 machining center, Pitch error compensation.*

I. INTRODUCTION

The factors that affect the positioning accuracy of machining center depend on the precision of the ball screw. In order to improve the positioning accuracy of the machining center, it is necessary to compensate the pitch error of the machining center. The two most commonly methods are respectively the manual measurement and compensation and the automatic measurement and the compensation. The manual compensation method is to use the step gauge and the dial gauge to measure, and then input the measured value into the parameters of the machining center. Automatic measurement is detected and compensated by laser interferometer. The main use of the Renishaw XL-80 laser interferometer for machining center positioning accuracy measurement, through the software to collect the test data, analysis of the test results, finally obtained the GB/T17421.2_2000 triad curve and the GB/T17421.2_2000 analysis curve, from the test results show that the precision of ball screw positioning accuracy has a greater impact on the size of the in this paper.

II. THE BASIS

2.1 The Measuring Principle of Laser Interferometer

The Laser Interferometer is a measurement instrument which is using laser beam as the length datum to make the precise measurement of the positioning accuracy, the repeated positioning accuracy and the

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geometric precision of the machining center. As is shown in Fig 1 is the optical configuration of the Laser Interferometer. The beam from the Reinshaw Laser XL-80 head is divided into two beams after it is entering the linear interferometer. A beam of light is called the reference beam that it is directed to the reflector mounted on the spectroscope, and the another beam is called the measuring beam that it is passes through the spectroscope to the second reflector [1]. Then both beams are reflected back to the spectroscope, at the same time they are reassembled and returned to the laser head, the interference between the two beams is monitored by the inside probe of the laser head.

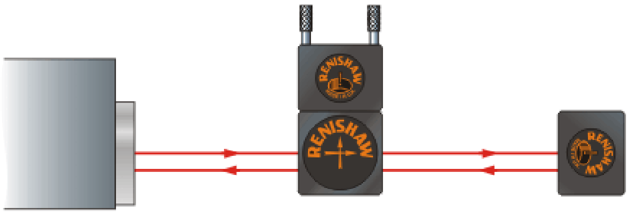

Fig 1: The optical configuration of the Laser Interferometer

One optical component needs to be kept at rest while the other optical component moves along with the measuring axis in the processing of the linear measurement. By monitoring the difference of the light path between the measured beam and the reference beam, the measurement value of the positioning accuracy is generated. The measured value can be compared with the reading value on the machine positioning system, and the accuracy error of the machine can be obtained.

As is shown in Fig 2, it is the measurement principle diagram of the laser interferometer. Usually, the interference mirror is set as the moving optical assembly part, and the reflection mirror is set as the static optical assembly part. The laser interferometer is determines the slight changes of the distance by receiving the changes of the light and the dark stripes of the laser and through the electronic recognition of the system [2-4].

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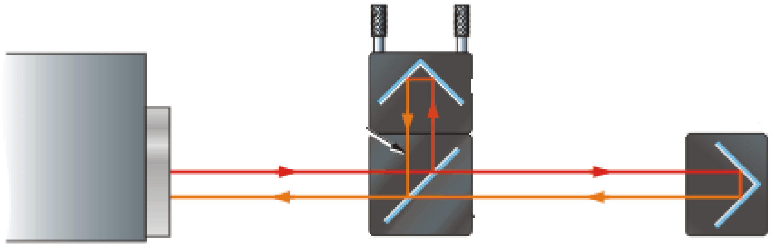

Fig 2: The measurement principle diagram of the laser interferometer

2.2 The Main Measurements and the Calculation Formulas

Pi is supposing as the target position which is the target position that the machine shaft moves according to the numerical control instruction, i is the position point that it is 1... M. Pij is the actual execution location that it is the actual position of the measurement while the servo-shaft of the machine tool is approaching to the target position. I is 1... M, j is 1... M and it is refers to the number of measured times at the i position point.

1) Position Deviation Xij

The difference between the target position and the actual position of the servo-shaft's the movement of the machine tool.

$$Xij=Pij-Pi \tag{1}$$

For the same target position point Pi, the X-axis of the machine tool can be approaching to the position point in both directions. Therefore, the position deviation of the single positive approach to the target position point is denoted as $X_i \uparrow$ and the position deviation of the negative approach to the target position point is denoted as $X_i \downarrow$.

2) One-way mean position deviation $\overline{x}_i \uparrow$ and $\overline{x}_i \downarrow$

The arithmetic mean value of position deviation which is obtained by Pi point that there are the positive and negative one-way of n times approaching to the target position.

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$$\overline{X}_{\mathrm{i}}\uparrow=\frac{1}{n}\sum_{j=1}^{n}X_{ij}\uparrow; \tag{2}$$

$$\overline{X}_{\mathrm{i}}\downarrow=\frac{1}{n}\sum_{j=1}^{n}X_{ij}\downarrow; \tag{3}$$

3) Bidirectional mean position deviation

The arithmetic mean value of the two positive and the negative one-way mean the position deviation of the target position point. It's represented by $x_i\uparrow$ and $x_i\downarrow$.

$$\overline{X}_{\mathrm{i}}=\frac{\overline{X}_i\uparrow+\overline{X}_i\downarrow}{2}; \tag{4}$$

4) Unidirectional position standard uncertainty

The standard deviation of the n-times of the target position which is one-way approaching to the target position.

$$S_{\mathrm{i}}\uparrow=\sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(X_{ij}\uparrow-\overline{X}_i\uparrow)^2}; \tag{5}$$

$$S_{\mathrm{i}}\downarrow=\sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(X_{ij}\downarrow-\overline{X}_i\downarrow)^2}; \tag{6}$$

5) Directional positioning accuracy of the axis

It is the maximum variation of the combination that it is a one-way mean position deviation and the of the difference between the unidirectional mean position deviation and the two-fold standard uncertainty estimate of the unidirectional position, namely the peak valley value.

$$A\uparrow=\max\left[\overline{X}_i\uparrow+2S_i\uparrow\right]-\min\left[\overline{X}_i\uparrow-2S_i\uparrow\right]; \tag{7}$$

$$A\downarrow=\max\left[\overline{X}_i\downarrow+2S_i\downarrow\right]-\min\left[\overline{X}_i\downarrow-2S_i\downarrow\right]; \tag{8}$$

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6) A is the bidirectional positioning accuracy of the axis.

It is estimated by plus or minus 2 times the standard uncertainty of the corresponding one-way position based on two one-way mean position deviations

In the variation range, the maximum variation is peak-valley value (P-V value).

$$A = \max\left[\overline{X_i}\uparrow + 2S_i\uparrow ; \overline{X_i}\downarrow + 2S_i\downarrow\right] - \min\left[\overline{X_i}\uparrow - 2S_i\uparrow ; \overline{X_i}\downarrow - 2S_i\downarrow\right]; \quad (9)$$

7) E↑ or E↓ is the axis one-way positioning deviation.

Refers to the unidirectional mean position deviation Xi or the maximum wave momentum of Xi are obtained by unidirectional approach to the target position Pi along or around the axis, namely, the algebraic difference between its maximum and minimum value.

$$E\uparrow = \max\left[\overline{X_i}\uparrow\right] - \min\left[\overline{X_i}\uparrow\right]; \quad (10)$$

$$E\downarrow = \max\left[\overline{X_i}\downarrow\right] - \min\left[\overline{X_i}\downarrow\right]; \quad (11)$$

8) E is the axis bidirectional positioning system position deviation.

It is represents the algebraic difference between the maximum and the minimum values of the sum of the positive and the negative unidirectional mean the position deviations that approach the target position bidirectionally along or around the axis.

$$E = \max\left[\overline{X_i}\uparrow ; \overline{X_i}\downarrow\right] - \min\left[\overline{X_i}\uparrow ; \overline{X_i}\downarrow\right]; \quad (12)$$

9) M is the Axis bidirectional mean position deviation

It represents the maximum change in the bidirectional mean position deviation of each target position along or around the axis. The quantity is peak-valley value (p-V value).

$$M = \max\left[\overline{X_i}\right] - \min\left[\overline{X_i}\right]; \quad (13)$$

10) B is the axis reverse difference.

For a single target location, its reverse difference is positive and negative travel direction approaching the target. The average deviation of two one-way positions is the difference of sum. Therefore, as a whole, the axis reflection difference B is defined as the maximum value of the absolute value of the reverse difference of each target position on the axis.

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$$B_i = \overline{X}_i \uparrow - \overline{X}_i \downarrow; \quad (14)$$

$$B = \max\left[|B_i|\right]; \quad (15)$$

$\overline{B}$ is the Axis mean reverse difference.

It represents the arithmetic mean of the reverse difference of all the target position points along the axis.

$$\overline{B} = 1/m(\sum_{i=1}^{m} B_i); \quad (16)$$

$R\uparrow$ or $R\downarrow$ is the Axis one-way repeat positioning accuracy.

For any target position point on the spool, the one-way repeated positioning accuracy of the point is 4 times the standard uncertainty of its corresponding position deviation or. I.e. Therefore, for the axis one-way repeated positioning accuracy or, is the maximum value of the one-way repeated positioning accuracy or of each target position point on the axis.

$$R\uparrow = \max\left[R_i \uparrow\right]; \quad (17)$$

$$R\downarrow = \max\left[R_i \downarrow\right]; \quad (18)$$

R is the axis bidirectional repeated positioning accuracy.

For any target position point on the spool, the bidirectional repeated positioning accuracy of the point R_i is:

$$R_i = \max\left[2S_i \uparrow + 2S_i \downarrow + |B_i|; R_i \uparrow; R_i \downarrow\right]; \quad (19)$$

Therefore, R represents the maximum value of bidirectional repeated positioning accuracy at all target position points along the axis which is the Pi.

$$R = \max\left[R_i\right]; \quad (20)$$

From the above calculation formula it can be known that the target position Pi and actual execution position Pij have the most important influence on the calculation of all parameters and indicators. These are used to measuring the accuracy of the actual displacement consistent with the target displacement in

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the axial movement of the machine tool in essencely. Obviously, the displacement measurement error and the accuracy will inevitably introduced the additional displacement position deviation which is relatived to the machine tool for the measurement. Thus it is affecting the evaluation of the displacement movement and the positioning accuracy of the machine tool shaft [5-7]. It can be seen that the displacement and the positioning measurement accuracy are critically.

III. MATERIALS AND METHODOLOGY

3.1 The Principle of the Pitch Error Compensation

The principle of the pitch error compensation of the machining center is that the difference between the instruction value and the actual value measured by the position instruction device of a feeding shaft in the machining center is the positioning error. Then it is to putting the positioning error value into the machining center system for compensation. The pitch error can be compensated by using the Reinshaw laser interferometer XL-80. It is divided into the five parts as following:

3.2 The Preparation Work of THWLBTF-3 Machining Center

(1) Firstly, The THWLBTF-3 machining center should to be levelled, then it should be returned to zero effectively to ensuring the machine tool has no faulty.

(2) The original data of the machine tool should be backed up to preventing the loss of the system data.

(3)The setting of the pitch error compensation is the related parameters.

The installation of laser interferometer

To measuring the position of the tripod by using the gradienter, the tripod should be levelled, and the laser should be installed on the head of the tripod which is fixed. It is should ensuring the laser is placed in the horizontal position. It can be seen from the Fig 3 that it is the installation diagram of the tripod and the laser. Turn on the laser and preheat for 10 minutes.

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Fig 3: The installation diagram of the tripod and the laser

3.3 The Installation and the Collimation of the Linear Optical Lens Group.

1) The installation of the linear optical lens group.

The linear optical group mirrors were respectively interferometer and reflector. The interference mirror is composed of a spectroscope and a reflector. The interference mirror is fixed on the worktable of the measuring axis through the magnetic meter seat. The mirror is absorbed on the main axis of the processing center through the magnetic meter seat as is shown in Fig 4. When measuring, the interference mirror moves with the movement of the worktable, and the mirror is fixed.

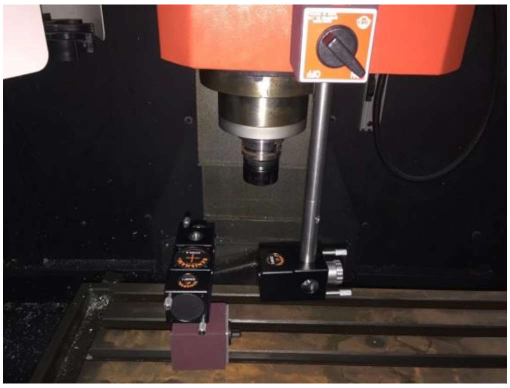

Fig 4: The Installation diagram of linear mirror set

2) The collimation of the mirror groups;

(1) The X-axis of the machine tool should be returning to the origin after starting up the machining center. That is the starting point of the measurement or the measuring axis should be moved to the limit

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position opposite to the origin. That is the end point of the measurement. The reflector should be placed on the magnetic table holder which is attached to the spindle of the processing center. It is should to turning the outlet light of the laser to the outlet position which is focused on the small hole. The target should be placed on the reflector and the white point of the target is upwards. At the same time the outlet light of the laser is already in the target center of the reflector. That is ensuring that the laser is at the same height as the reflector as is shown in Fig 5.

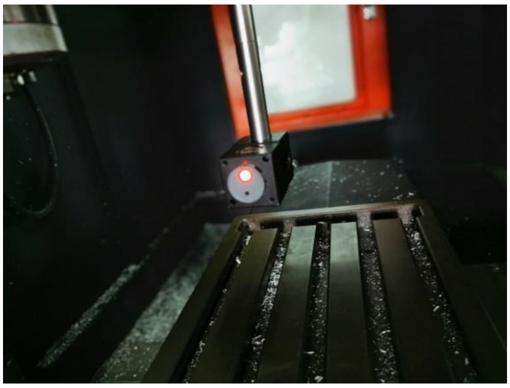

Fig 5: The installation of the Laser and the reflector

(2)The interference mirror was placed on the another magnetic table holder which is attached to the worktable of the measuring axis in the processing center. At this time, the height of the interference mirror should be ensured as the same height as the reflector and the laser head and the two return points of light on the laser head should be coincide into one point as is shown in Fig 6.

Fig 6: The Collimation of the linear mirror sets with laser beams

(3) The front of the laser head should be rotated to making the laser head in the measuring state. At this time, the five indicators of the laser head should be green, as is shown in Fig 7. If only 1 to 4 indicator lights are green or the return points does not coincidence at this time, the position of the interference mirror should be adjusted to making the return point of light on the laser head coincidence, that is, the five green

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indicator lights on the laser head are all on.

Fig 7: The Normal working condition of the laser head

(4)To ensuring the five green indicators on the laser head are all on in the whole measuring process while to moving the measuring axis of the machine center. If, in the process of moving out a green light, the laser should be rotated to the light target down position of the , observe whether the laser head back to the spot to two points, according to the position of light spot back knob to adjust the angle of the laser head, the laser head builds up two back to spot a point, and then adjust the laser head about fine-tuning knob or the tuning knob, make the back light spot is located in the center of the laser head light target, as shown in Fig 8. At this time, rotate the laser head front end to make the laser head in the measurement state, that is, the five green indicator lights on the laser head.

Fig 8: The working state of the laser head during the whole measuring trip

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The principle that should be followed in the adjustment process is the proximal mirror group and distal laser.

3.4 The Basic setting of the measurement software parameters

(1) To selecting the Renishaw Laser XL from the start toolbar and to choosing the software to be executed: the linear length measurement (the positioning measurement), then to entering the window of the linear positioning length measurement software as is shown in Fig 9.

Fig 9: The window diagram of the linear length measurement

(2) To define a new file, select the files in the main menu - > new - > point defined target - > target number: 10 (servo axis movement interval number) - the target: 20 (servo axis movement of interval value) to identify, locate mode: linear positioning - > number: 5 (data analysis) to choose direction: two-way (or one-way) to determine, automatic data collection options: invalid to determine, as shown in figure 10 set figure for linear parameter length measurement and control software.

Click the start button→ confirm→ confirm→ acquisition screen→ confirm processing program, automatic operation program →click data collection in the software →click set benchmark (zero elimination) → space (data collection), as is shown in Fig 11 is the data collection diagram of linear length measurement.

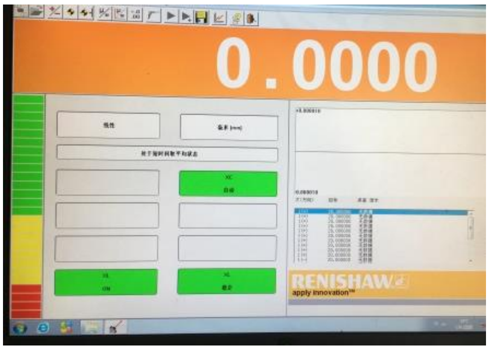

Fig 10: the parameter definition diagram of measurement software

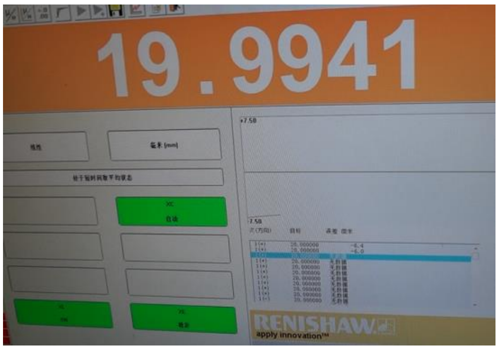

Fig 11: the data acquisition diagram the linear length of linear length measurement

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3.5 The Preparation of Processing Program

Main program;

```
O0001;
G54 G90 X0;
G91 G04 X1;
G00 X2;
G04 X1;
G00 X-2;
G04 X1;
M98 P0002 L10;
G91;
G00 X-2;
G04 X4;
G00 X2;
G04 X4;
M98 P0003 L10;
M30;
```

sub program;

```
O0002;
G91;
G00 X20;
G04 X3;
M99;
```

```
O0003;
G91;
G00 X-20;
G04 X3;
M99;
```

3.6 Data Collection and Result Analysis

(1) Open the above saved file, enter the data analysis or select the Chinese block in the tool column  → select the GB/T17421.2_2000 statistics table, as is shown in Fig 12, to checking the value of positioning accuracy R to compensate the single and the double direction pitch of the machine tool.

Units of error values and calculated statistical values are millimetres

Target Number i	1		2		3		4		5		6		7	
Position (mm)	1.000000		2.000000		3.000000		4.000000		5.000000		6.000000		7.000000	
Approach direction	-	+	-	+	-	+	-	+	-	+	-	+	-	+
Positional Deviation Xij, j= 1	-0.002500	0.036600	-0.001600	-0.001900	-0.003700	-0.003300	-0.003300	-0.005000	-0.003500	-0.003800	-0.002400	0	-0.001000	-0.001900
2	-0.003200	0.037000	-0.001300	-0.001600	-0.002800	-0.004500	-0.004100	-0.003800	-0.004600	-0.004100	-0.001000	-0.000900	-0.001300	-0.001100
3	-0.001400	0.035600	-0.001800	-0.000800	-0.002900	-0.004500	-0.002800	-0.002700	-0.005700	-0.005700	-0.000600	0.000300	-0.001800	-0.001500
4	-0.002300	0.036800	-0.001300	-0.001900	-0.003200	-0.002800	-0.004000	-0.004900	-0.003900	-0.004100	-0.001000	-0.000300	-0.002500	-0.001500
5	-0.001500	0.036300	-0.002000	-0.001000	-0.002900	-0.004200	-0.003600	-0.004600	-0.004300	-0.003500	-0.001600	-0.001100	-0.001200	-0.001100
Mean Deviation	-0.002180	0.036460	-0.001600	-0.001440	-0.003100	-0.003860	-0.003560	-0.004200	-0.004400	-0.004240	-0.001320	-0.000400	-0.001560	-0.001420
Std Uncertainty Si	0.000746	0.000546	0.000308	0.000513	0.000367	0.000770	0.000532	0.000962	0.000837	0.000853	0.000701	0.000592	0.000602	0.000335
2Si	0.001493	0.001092	0.000616	0.001026	0.000735	0.001540	0.001064	0.001924	0.001673	0.001706	0.001403	0.001183	0.001205	0.000669
Mean - 2Si	-0.003673	0.035368	-0.002216	-0.002466	-0.003835	-0.005400	-0.004624	-0.006124	-0.006073	-0.005946	-0.002723	-0.001583	-0.002765	-0.002089
Mean + 2Si	-0.000687	0.037552	-0.000984	-0.000414	-0.002365	-0.002320	-0.002496	-0.002276	-0.002727	-0.002534	0.000083	0.000783	-0.000355	-0.000751
4Si	0.002985	0.002184	0.001233	0.002051	0.001470	0.003080	0.002128	0.003847	0.003347	0.003413	0.002806	0.002366	0.002410	0.001339
Reversal Bi	0.038640		0.000160		-0.000760		-0.000640		0.000160		0.000920		0.000140	
Bidi.Repeat.Ri	0.041224		0.002051		0.003080		0.003847		0.003540		0.003506		0.002410	
Mean Deviation	0.017140		-0.001520		-0.003480		-0.003880		-0.004320		-0.000860		-0.001490	

Statistics

Axis Deviation (millimetres)	Unidirectional (-)	Unidirectional (+)	Bidirectional
Reversal B	Not applicable	Not applicable	0.038640 (at i= 1)
Mean Reversal $\bar{B}$	Not applicable	Not applicable	-0.000002
Mean Dev.M	Not applicable	Not applicable	0.022340
Sys.Dev.E	0.039680	0.041940	0.041940
Repeatability R	0.004190 (at i= 9)	0.005015 (at i= 9)	0.041224 (at i= 1)
Accuracy A	0.042920	0.045539	0.045539

Fig 12(a): The table of statistics from 1 to 7 times

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Units of error values and calculated statistical values are millimetres

Target Number i		8		9		10	
Position (mm)		8.000000		9.000000		10.000000	
Approach direction		-	+	-	+	-	+
Positional Deviation Xij	j= 1	-0.003700	-0.004000	-0.004400	-0.004700	0.034000	-0.003900
	2	-0.004600	-0.004100	-0.004500	-0.005200	0.034400	-0.003600
	3	-0.002600	-0.002600	-0.006600	-0.007700	0.035200	-0.002800
	4	-0.003100	-0.004600	-0.005200	-0.004900	0.035400	-0.002500
	5	-0.004700	-0.004500	-0.003900	-0.004900	0.034800	-0.002700
Mean Deviation		-0.003740	-0.003960	-0.004920	-0.005480	0.034760	-0.003100
Std Uncertainty Si		0.000918	0.000802	0.001047	0.001254	0.000573	0.000612
2Si		0.001836	0.001604	0.002095	0.002508	0.001145	0.001225
Mean - 2Si		-0.005576	-0.005564	-0.007015	-0.007988	0.033615	-0.004325
Mean + 2Si		-0.001904	-0.002356	-0.002825	-0.002972	0.035905	-0.001875
4Si		0.003673	0.003207	0.004190	0.005015	0.002291	0.002449
Reversal Bi		-0.000220		-0.000560		-0.037860	
Bidi.Repeat.Ri		0.003673		0.005162		0.040230	
Mean Deviation		-0.003850		-0.005200		0.015830	

Statistics

Axis Deviation (millimetres)	Unidirectional (-)	Unidirectional (+)	Bidirectional
Reversal B	Not applicable	Not applicable	0.038640 (at i= 1)
Mean Reversal B̄	Not applicable	Not applicable	-0.000002
Mean Dev.M	Not applicable	Not applicable	0.022340
Sys.Dev.E	0.039680	0.041940	0.041940
Repeatability R	0.004190 (at i= 9)	0.005015 (at i= 9)	0.041224 (at i= 1)
Accuracy A	0.042920	0.045539	0.045539

Fig 12(b): The table of statistics from 8 to 10 times

Fig 12: The table of statistics of GB/T17421.2_2000

(2) To entering the data analysis and check the TRIad curve and the analysis curve of GB/T17421.2_2000 to see the size of deviation, the positioning accuracy and the average position error respectively, as is shown in Figure 13 and Fig 14.

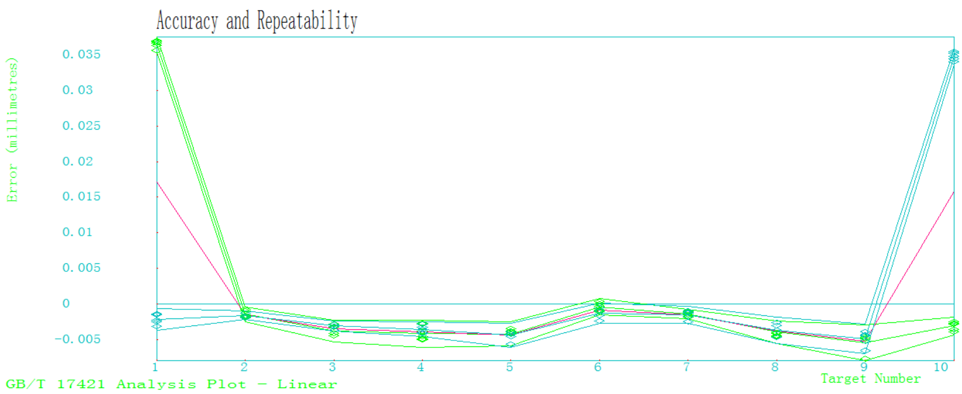

Fig 13: The trigraph of GB/T17421.2_2000

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
July-August 2022 Page No. 920-934
Article History: Received: 30 March 2022, Revised: 8 April 2022, Accepted: 15 April 2022, Publication: 30 April 2022

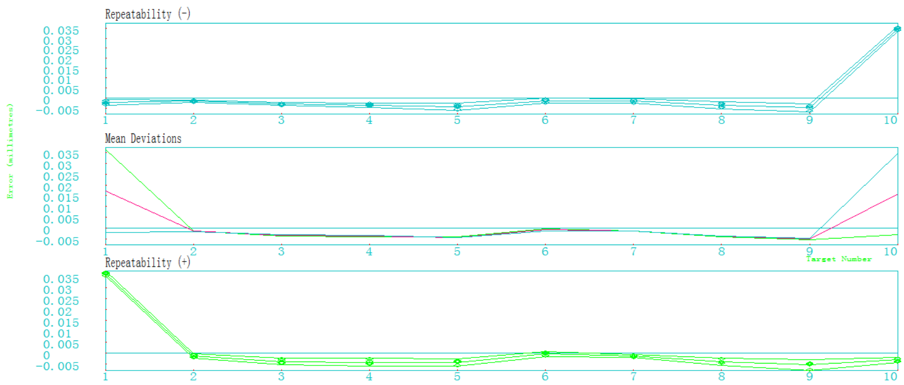

Fig 14: The analysis curve of GB/T17421.2_2000

IV. CONCLUSION

The measuring principle of the Renishaw XL-80 laser interferometer is described. The method and the procedure of the Renishaw laser interferometer to measure the positioning error of the NC machine tool are analyzed. The experimental data show that the reverse clearance is one of the factors affecting the positioning error of the NC machine tools. The screw pitch error compensation of the NC machine tool can be accomplished efficiently by using the laser interferometer. Thus it can improve the positioning accuracy of the NC machine tool. In the process of the work, the attention should be paid to standardize and standardize the operation according to the operating procedures, especially to master the collimation technology of the optical lens group, which requires the continuous summary of the experience in the operation process. The Laser interferometer is an efficient technical means to detect the geometric error of machine tool. The experiment shows that using laser interferometer to detect the screw pitch error and the reverse gap of the machine tool, and input the test result to the numerical control system in the correct way for compensation, the "soft upgrade" of the semi-closed loop control numerical control machine tool can be realized [8-10], and the machining accuracy of the machine tool can be significantly improved.

ACKNOWLEDGEMENTS

This research was supported by Natural Science Research Project of Universities in Anhui Province of China. The project name is Research and development and application of a new vehicle heat balance test bench lifting platform based on KBE. (Grant No. KJ2019A1165).

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Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
July-August 2022 Page No. 920-934
Article History: Received: 30 March 2022, Revised: 8 April 2022, Accepted: 15 April 2022, Publication: 30 April 2022

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