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STRAIGHTNESS MEASUREMENT OF LARGE MACHINE GUIDEWAYS

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Preliminary Note – Prethodno propćenje

This paper shows the guideway types of large machines and describes problems with their straightness measurement. A short description of straightness measurement methods and the results of investigation in straightness of 10 meter long guideways of a CNC machine by means of the XL-10 Renishaw interferometer are also presented.

Key words: machine, straightness measurement, machine guideways

Mjerenje ravnosti dugačkih strojnih vodilica. Rad prikazuje tipove vodilica velikih strojeva i opisuje probleme mjerenja njihove ravnosti. Dat je također i opis metoda mjerenja ravnosti, te rezultati ispitivanja ravnosti 10 metarskih vodilica CNC stroja pomoću XJ-10 Renishawovog interferometra.

Ključne riječi: strojevi, mjerenje ravnosti, strojne vodilice

INTRODUCTION

In case of small machine tools it is simple to machine the base surfaces for the guideways correctly. Although the structure of the body needs to be properly designed, it demands only precise milling and grinding.

In case of large machine tools, with the guideways of a few or more meters long, it is impossible to design and to machine a rigid body with straight slides. The obtained straightness of the slides depends mostly on the accuracy of their assembly.

There are several tools available for machine guides straightness measurement [1]. The common methods are not always suitable for measuring the straightness of long guideways. This is the reason why sometimes customized tooling and programs have to be developed.

GUIDEWAYS OF THE LARGE SCALE MACHINE TOOLS

Two solutions for the body design of the longest axis of large scale machine tools are known:

- monolithic body on which two guideways are placed,
- separated guideways – each guideway is a separate part.

The monolithic bodies are used in gantry machine tools in which a table is placed on the longest slide and in horizontal mobile column machines in which the column with headstock is moving on the longest slide, but the table stays motionless.

Separated guideways are applied in mobile gantry vertical machine tools in which the table is motionless, but the portal moves.

Both the monolithic and the separated guideways can be assembled from individual segments, which enable creating very long slides.

Both kinds of slide design demand rigid foundation and fixing to the ground. They are fixed with special screws, usually arranged every 500 mm, with the possibility to adjust the guideway in 2 directions (horizontally and vertically). The screws are used for leveling as well as for linear setting-up depicts the fixing of the guideway to the foundation (Figure 1).

In case of the separated guideways, besides the precise leveling, it is also required to set them on the same level. Setting them parallel is very important as well.

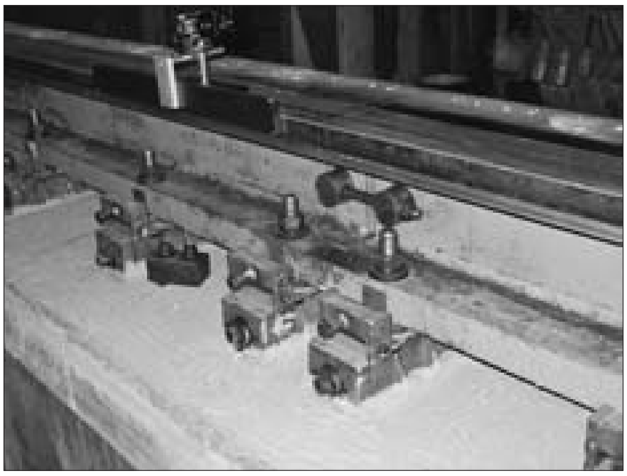

Figure 1 The way of fixing the guideway to the ground and joining two segments

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That could be complicated, when one considers the 7 meter span and lack of suitable measuring instruments.

THE METHODS OF STRAIGHTNESS MEASUREMENT

According to the ISO-230 standard a line located on a plane is considered as straight within given length, if every of its points is enclosed between two lines at distance equals tolerance, parallel to the main direction of the straight [1].

The main direction of the line or the representative line should be taken, so that the straightness error is minimized. It can be determined by means of:

- 2 points selected near the line that is being examined,
- a straight obtained on the basis of the measured chart, e.g. with least squares method.

There are two groups of methods for straightness measurement that base on:

- measuring the length,
- measuring the angle.

In the group based on length measuring there are methods that use:

- precise ruler and gauge,
- string and microscope,
- laser and photosensitive detector,
- laser interferometer with optical set for straightness measuring.

In the second group of methods that base on angle measurement one uses:

- precise level,
- autocollimator,
- laser interferometer with optical set for angle measuring.

The Institute of Mechanical Technology owns a Renishaw laser interferometer XL-10 with optical set for straightness and angular measuring. The optical set for straightness measurement is limited to 4 meters, that's why in the presented investigation the method based on angle measurement was applied.

Measuring the guideway straightness by means of angular measurement is presented in Figure 2. The depicted optical set enables measuring angular displacement in the range +/- 5 ° [1]. In case of the angular reflector rotation, the laser beam A_2 from interferometer to reflector has longer distance than the beam A_1. As a result, a phase difference between A_1 and A_2 is noticed. Considering the known distance of A_2 and A_1, the angular displacement can be calculated.

The basic peripherals for that configuration (Figure 2) are:

- laser interferometer head,
- angular interferometer,
- angular reflector,
- flatness base.

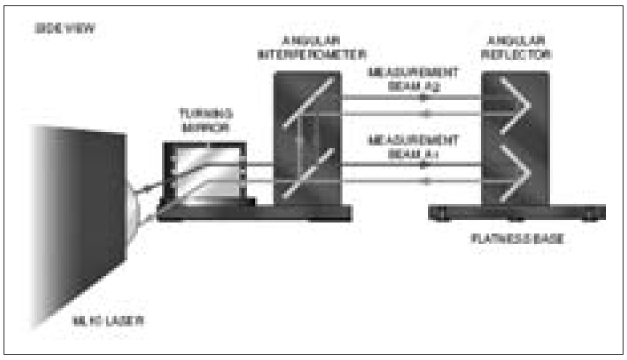

Figure 2 Principle of straightness measurement [2]

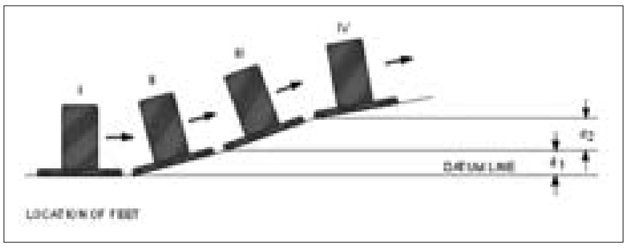

Figure 3 Model for the straightness error calculation [2]

A flatness measurement is carried out by taking a series of incremental height readings as the angular reflector is moved along the measurement path (Figure 3).

On the basis of Figure 3 one can develop a rough equation for the straightness error in a given location:

$$d_n = d_{n-1} + L \cdot \sin \alpha_n \quad (1)$$

where: d_n – straightness error in the n point,
d_{n-1} – straightness error in the previous point,
L – the distance between the measurements,
α_n – the measured deflection error.

Laser interferometer used in our investigation has following main parameters [3]:

- axial range: 0-15 m,
- angular measurement range: ± 175 mm/m (± 10 °),
- angular accuracy: ± 0,1M μm/m (M- measurement distance),
- resolution: 0,1 μm/m (0,01 arc sec).

RESULTS OF THE INVESTIGATION INTO GUIDEWAY STRAIGHTNESS

As the investigated machine tool was a used one, the slide surfaces showed some wear. One could also notice a hard to remove dust layer. Every roughness of the slide surface can influence the investigation results. Setting the straightness of the slide top surface is presented in Figure 4.

The Renishaw XL-10 measuring set includes measuring bases of lengths 50 mm, 100 mm and 150 mm. Considering the fact that the adjusting screws in that particular slide are arranged every 500 mm, a special measuring base of 500 mm was prepared. Thanks to such a long foot it was possible to strongly limit the influence of local roughness on the measurement [4-7]. The foot and the measuring set are presented in Figure 5.

Figure 6 presents the angular displacements for the measured straightness of the slide top surface with the

Figure 4 Setting the straightness of the slide top surface

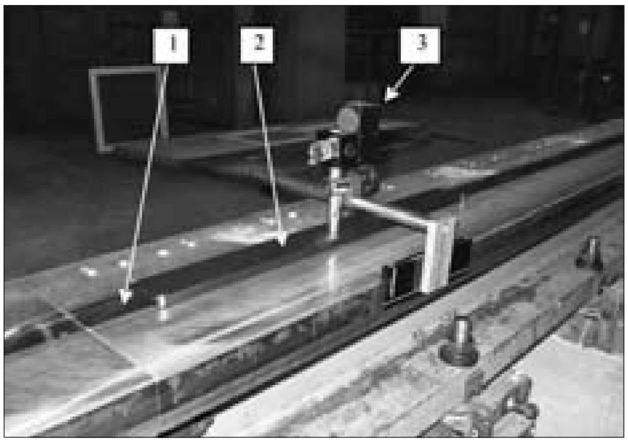

Figure 5 View of the measuring set: 1 – investigated surface (location of the carriage), 2 – prepared 500 mm foot, 3 – measuring optical set

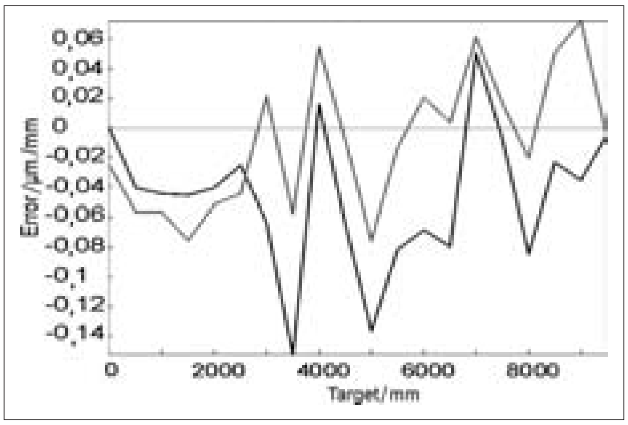

Figure 6 Chart of the obtained angular displacements for the measured straightness of the slide top surface

use of the 500 mm foot. On the basis of that chart and the equation (1) one can calculate the real straightness deviation. To that end a computer program was developed. It calculates the straightness deviation using the data obtained from the measuring system. The program window is presented in Figure 7.

The interferometer does not measure the absolute deflection angle, so the absolute straightness error cannot be obtained. For this reason the graph of the straightness error was compared to a straight line (the curve was rotated so that the start and the end of it were brought to zero). The table deflection calculated according to the described method is presented in the Figure 8.

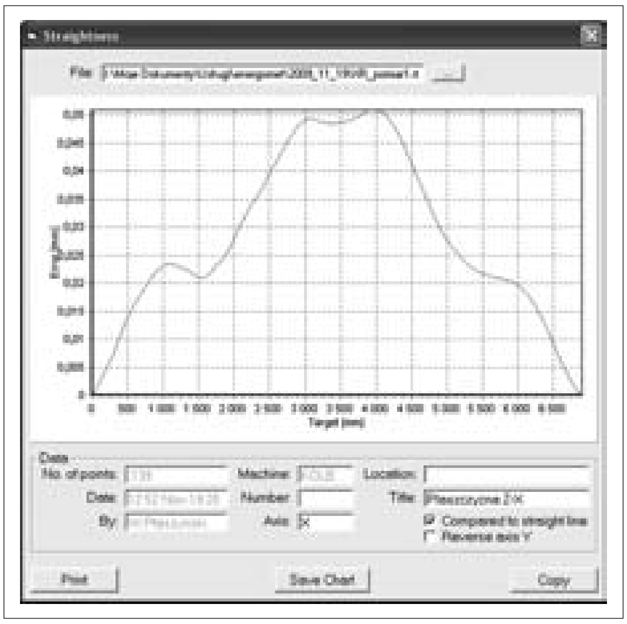

Figure 7 Program for calculating straightness deviation on the basis of angular measurement

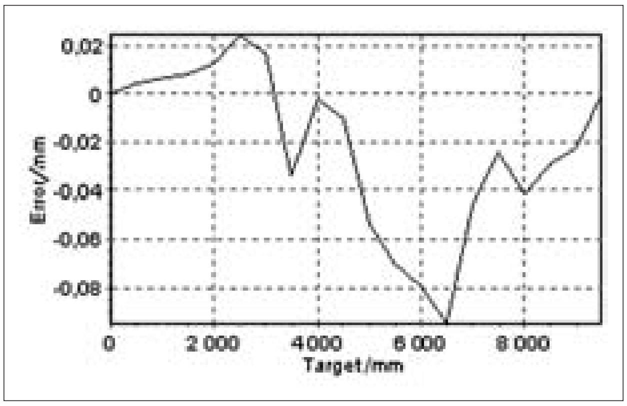

Figure 8 Diagram for the calculated straightness deviation of the top slide surface in relation to the straight line

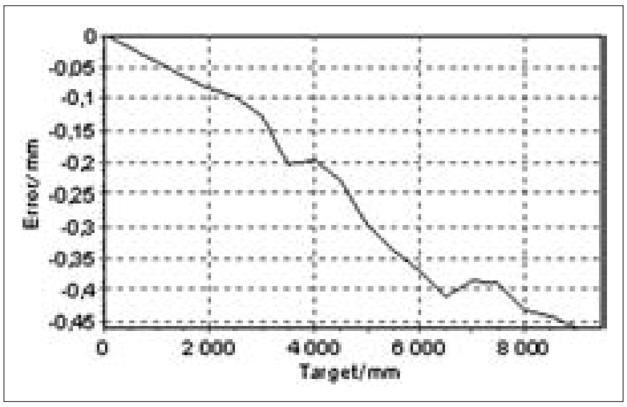

Figure 9 Diagram for the calculated straightness deviation of the top slide surface

The noticeable changes of the straightness, especially in Figure 9, result from the imprecise connection

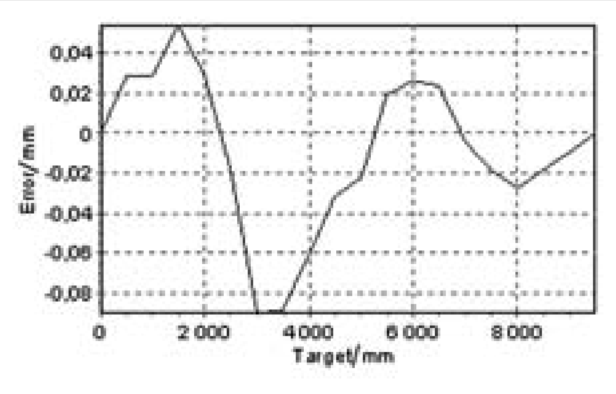

Figure 10 Diagram of the calculated straightness deviation for the side slide surface in relation to the straight line

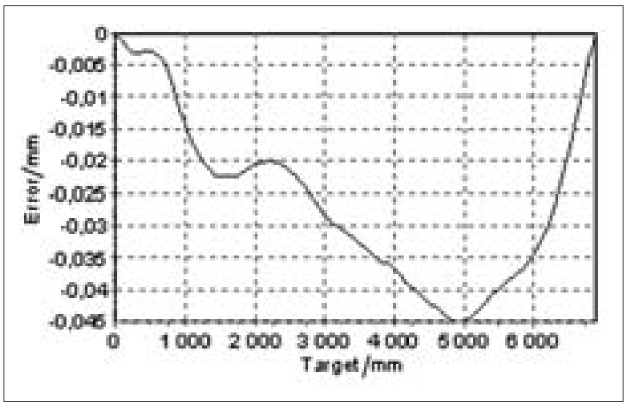

Figure 11 Diagram for the calculated straightness deviation of the portal for motion in the vertical plane

of the slide segments. In that particular machine tool the slides are assembled from 3 m long segments.

For measuring the straightness of the side slide surface an optical set presented in figure 5 was applied. Figure 10 presents a diagram for straightness deviation in relation to the straight line.

RESULTS OF THE INVESTIGATION INTO STRAIGHTNESS OF MOTION

After adjusting guideways and assembling the machine tool an investigation into straightness of motion was carried out. For the investigation the method described in chapter 3 was used, with that difference that the optical system was fixed to the movable part and its angular displacement was measured. The machine tool portal moves on 2 carriages on each side arranged in 2 500 mm distance. The side carriage is made of 4 parts. The straightness error of the slide results in angular deviation of the portal. The Motion straightness investigation was carried out every 50 mm.

Figure 11 presents the calculated straightness deviation in the vertical plane within the whole range of motion – 6 900 mm.

SUMMARY

The accuracy of a machine tool is influenced not only by the accuracy of the measuring system and the servo drives, but also by geometrical accuracy, particularly by guideways' straightness. As already stated the straightness of guideways of small machine tools is quite easy to achieve. However, in case of large machine tools the issue is more complicated. Longer guideways result in lower rigidity of the body. Additionally, the long guideways are assembled from segments that need to be very precisely arranged.

Moreover, since the machine was used, the straightness measurement was influenced by roughness and dust on the slide surfaces.

On the basis of the summarized results one can state that the aim of the study was achieved. For that class and size of machine tools the straightness deviation of 0,045 mm within the whole range of motion is considered as sufficient.

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