New Method of Contactless Measurement and Analysis of CNC Machine Spindle Lopping

Z. Braier, P. Šidlof, V. Čejka and P. Žďárek

Abstract This article is focused and describes a system of a contactless measurement and analysis of a spindle lopping of CNC machines with horizontal axis orientation. The spindle lopping is caused by changes of spindle and headstock deformation during the spindle longitudinal travel and it has a considerable importance for precise CNC machine. The measurement system results from the research and development of a contactless measurement method using a laser source. The laser source is mounted in the CNC machine spindle and rotates together with the spindle. The laser beam goes to the sensor box placed at a specific distance from the spindle. Inside the sensor box, the beam is split into two paths and their traces are recorded by two cameras situated in a position that the beam path total length is different for each camera. The spindle lopping is calculated and analyzed from the camera records using appropriate software equipment. The form and application of the new measurement method is protected by patent CZ305542 (B6).

Keywords Measurement · Contactless method · CNC machine · Spindle lopping · Laser beam

1 Introduction

During extension of a horizontal spindle out of a headstock, the spindle sinks due to the effect of gravity force—i.e. the bending of the spindle and change of deformation of its mounting occurs. These inaccuracies are significant especially in the

Z. Braier (✉) · P. Šidlof · V. Čejka · P. Žďárek
VÚTS, a.s., Measurement, Liberec, Czech Republic
e-mail: zdenek.braier@vuts.cz

P. Šidlof
e-mail: pavel.sidlof@vuts.cz

V. Čejka
e-mail: v.cejka@seznam.cz

P. Žďárek
e-mail: pavel.zdarek@vuts.cz

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case of precise production. At present, the process of lopping is usually measured with respect to a clamping table of a particular machine [1]. However, during that process errors occur, caused by the inaccurate position of the original axis of the spindle with respect to the clamping table, as well as by inaccuracies of the clamping table or its shifting. Another disadvantage is also the fact that the process of lopping of a spindle cannot be measured until the headstock is installed on a particular machine tool and until it is adjusted.

According to new principle, a laser beam source is mounted to the spindle of the CNC machine and laser beam traces are scanned by sensors in the specific position from the spindle end for several spindle extensions. Spindle lopping and angle are evaluated from the differences of point of laser beam incidence. In order to increase accuracy the spindle is rotated during measurement and the center of path transcribed by laser beam is evaluate.

The principle practical realization demands solution a few problems, some of them are: (a) The laser source must be battery powered due to the spindle rotation and the laser beam diameter should be minimized in wide range of distances. It is difficult to realize such requirement, therefore the laser beam is focused in a specific distance and the beam diameter increases out of this point. Therefore the laser beam image is relatively large. (b) Interference stripes are detected due to various factors. (c) The laser beam source outputs polarized light and additional partial polarization happens after reflection at mirrors and semi permeable mirrors in the sensor box. The laser beam intensity is varied during the spindle rotation.

These problems are solving in hardware or software. For example, the laser beam records are filtrate using two dimensional FFT for elimination of the interference stripes and the software evaluation is using many image processing principles. The measurement and evaluation principle is still being improved.

2 Measurement and Evaluation Method

The measurement and evaluation of the spindle lopping is calculated for various spindle extensions and for various weights simulating the spindle mass load at the end. At first the reference measurement is made without weights and fully retracted spindle state. Then, the measurement is repeated for partial or full spindle extension. The same scheme is used for the weight influence measurement. Figure 1 shows fully extended spindle with weights 50 kg, info and details of CNC machine and measurement are described in [2]. Each evaluation of the spindle lopping is compared with the reference measurement without weights.

Schematic illustration of the spindle inclination and lopping measurement principle including dimensions for calculation is shown in Fig. 2. The laser beam, which is skew to the spindle rotation axis in general, transcribes a rotational hyperboloid during the spindle rotation. The cuts of hyperboloid by recording planes have elliptical shape (in Fig. 2 shown in rotated state). The centers of ellipses are evaluated from paths of laser beam at the sensor and changes of their position after

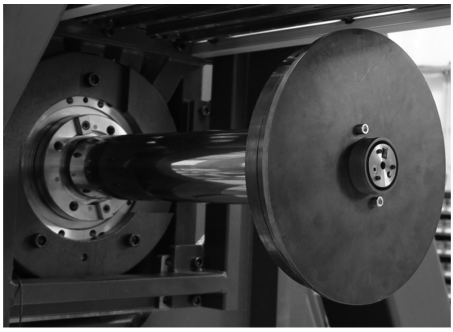

Fig. 1 Photo of extended spindle of CNC machine with weights and laser beam battery source

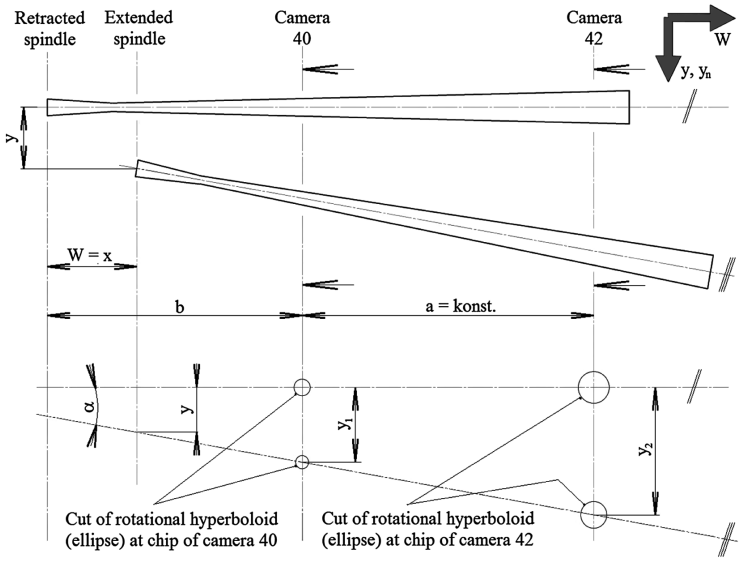

Fig. 2 Schema of measurement principle with scanning of laser beam paths by two cameras (indexes 40, 42)

extension are marked y_1 and y_2. The centers of ellipses are not identical with the intersection of the spindle axis in the recording plane, but errors are maximally in hundredths of µm under given conditions. Therefore the results of the spindle inclination α and spindle lopping y are calculated according to the Eqs. (1) and (2).

$$\tan \alpha = \frac{y_2 - y_1}{a} \tag{1}$$

$$y = y_1 - (b - x) \tan \alpha = y_1 - (b - x) \left(\frac{y_2 - y_1}{a}\right) \tag{2}$$

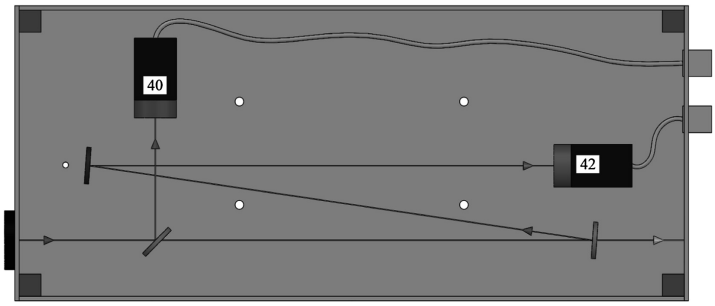

Fig. 3 Schematic figure of sensor box with two cameras (indexes 40, 42) and laser beam trace

The laser beam paths are a little complicated in the real sensor box, which is schematically shown in Fig. 3. Input laser beam is split into two paths in first semipermeable mirror. The first camera (index 40) is situated in nearer optical distance from spindle. Distance of laser beam trace to the second camera (index 42) is extended by using another two mirrors.

Images from both cameras are pre-processed (two dimensional FFT filter, finding the optimal brightness value, image defects elimination, etc.), then the laser beam traces centroid is evaluated by software with focus on threshold parameters and changes of image intensity. Two dimensional matrix of the centroids coordinates is approximated by a general ellipse using SVD method (Singular Value Decomposition) for linear regression. The deviation (diffusion) of points and ellipse parameters (center, the length of semi axis, the angle of main axis) can be extracted from the SVD.

3 Measurement and Evaluation of Results

Measurement, analysis and evaluation were prepared and realized with minimal rpm of the CNC machine spindle. An example of the laser beam traces evaluation of the camera 42 sensor (in retracted and extended states) is shown in Fig. 4. One pixel is 2.2 μm. Measured points, fitted ellipses as well as their major axes indicating the ellipses centers are drawn. Calculation were carried out from 620 points (images of each camera) measured at approximately 5 rpm of spindle. It is evident that a small displacement occurred even in the horizontal direction. The overall spindle lopping evaluation with 50 kg load from 0 to 800 mm extension is displayed in Fig. 5.

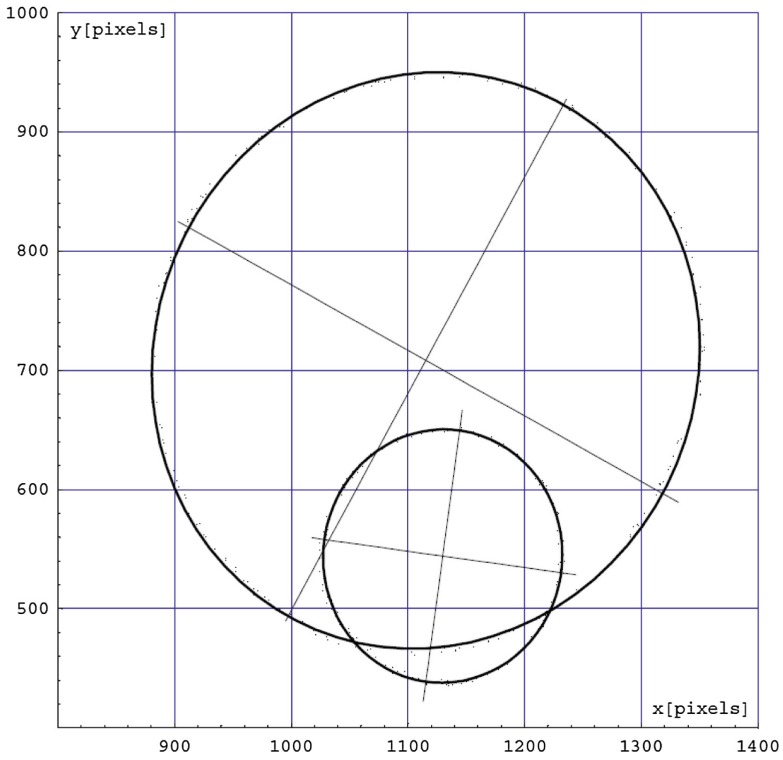

Fig. 4 Example (zoom) of laser beam trace at camera 42 sensor. *Large ellipse* corresponds to retracted state, *small ellipse* corresponds to extended state of spindle. Ellipses major axes are drawn

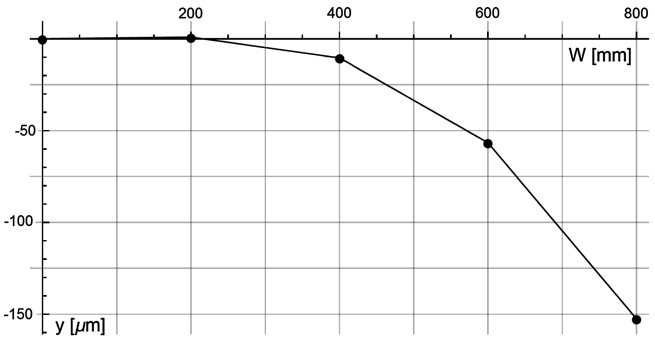

Fig. 5 Spindle lopping versus extension for 50 kg load

4 Conclusions

New method of contactless measurement and analysis of CNC machine spindle lopping was tested on a real machine. Crucial factor for precise and accurate measurement and analysis is sufficient quality of laser beam and necessary quality optics of the sensor box with cameras. It is also important to set the camera exposure time adequately to the spindle extension. It is equally important to eliminate distortions and process of laser beam trace on camera sensor by software, where opportunities for improvement are still open. The described method also allows an inverse way of measurement, e.g. a table machine with attached sensor box is moving (sliding) instead of the spindle. However, the performed measurements and analyses show applicability and usefulness the new methods of measurement and analyses in practice. The form and application of the new measurement method is protected by patent [3].

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