EXPERIMENTAL DEVICE FOR PRACTICING ROUTINES OF MACHINE TOOL PRECISION MEASUREMENT

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ABSTRACT: This article deals with proposal of experimental device for practicing routines of machine tool precision measurement which is currently being developed at Department of Automation and Production Systems, faculty of Mechanical Engineering, University of Zilina. Described device was originally designed exclusively for using with laser interferometer Renishaw XL-80. This article will describe basic construction, principles in controlling mechanism and range of applicability of this device.
KEY WORDS: Experimental device, Precision, Diagnostics, Laser interferometer.

1 .INTRODUCTION

Nowadays manufacturers obeys dictate of consumers' demand for high quality and low prices. Quality of parts produced by machining is closely connected to its accuracy which is closely connected to quality of used machine tool and its individual parts. Technical diagnostic provides methods and tools to obtain not only actual state of machine tool but even its future progress and allows us to estimate probability of faults occurrence. This allows to avoid unnecessary costs due machinery fault, unexpected downtime and production of insufficiently accurate components (Cisar, Novosad, 2013), (Cisar et all, 2013).

Each method of technical diagnostics uses different physical phenomenon, specific devices and detects different types of failures. But, there is two common elements for each of method. First one is the machine tool on which is diagnosing carried out and second one is person who performs diagnostic procedures. It is necessary for such person to have huge amount of knowledge and skills in order to provide diagnostic procedures effectively and reliable. In order to keep these skills fresh it is necessary to train some routines.

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Using machine tool from production for training of machine tool precision measuring can be difficult due workload of production. Keeping machine tool exclusively for such training is waste of resources and also with such machine it is almost impossible to simulate conditions on machines with varying degree of wear. Also these way possibilities of training are limited by specifications of such machine. In small and middle sized production companies is not common to have staff capable of machine tool precision measurement or even necessary devices. Therefor they use services of specialized companies what is usually more cost efficient solution.

One of latest approaches to measure of machine tool precision involves using of specialized laser interferometer capable of measuring lots of geometric properties of machine. Operator has to correctly setup measuring tool, its accessories and machine tool itself in order to perform measurement. Process of measurement preparation requires precise work and ability to predict behaviour of whole system.

For these and other reasons we decided to design special experimental device (Figure 1) which we can use as substitute of actual machine tool. Such device would be more suitable as for training routines as for experimenting with new measurement methods and equipment.

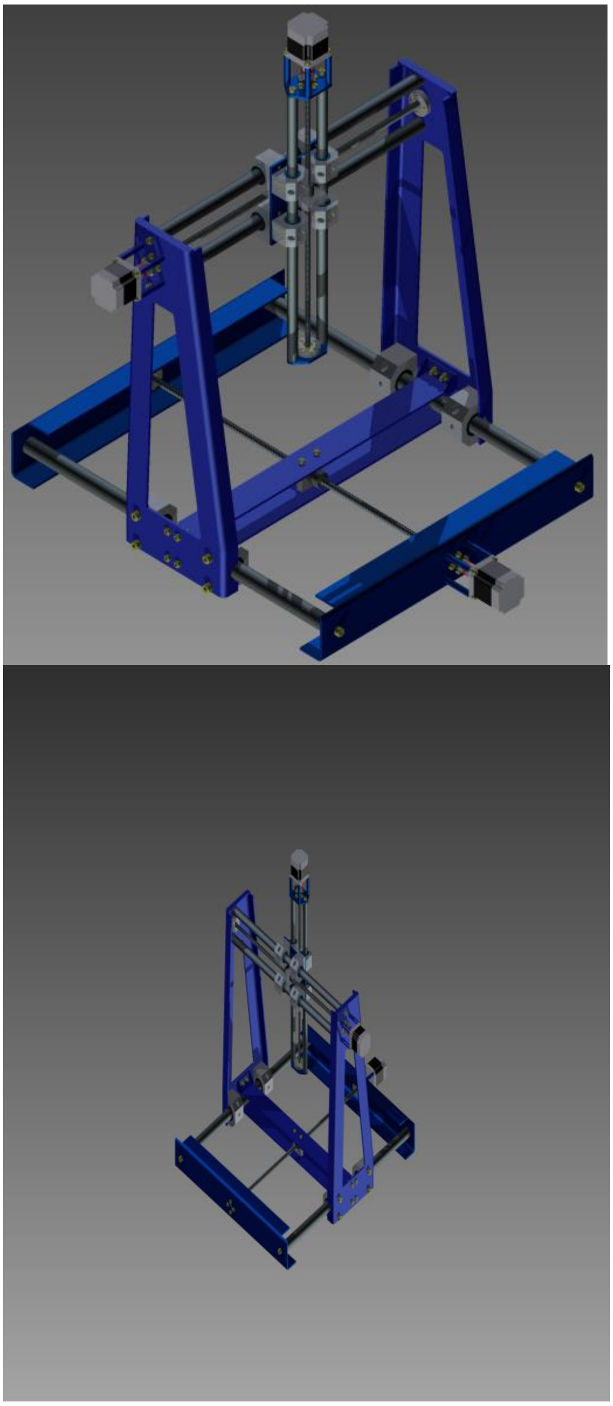

Figure 1. Model of experimental device for practicing routines of machine tool precision measurement

2 . DEVICE CONSTRUCTION

Device construction was designed similar to three axis gantry manipulator. Main parts of device construction are:

- columns,
- gantry,
- slider,
- frame
- T-slot table.

Device was designed to be stiff and light enough to be carried by one man without violating safety rules and limits currently applicable in the territory of the Slovak Republic. This way device can be mobile enough to easily carry out staff training wherever it is necessary.

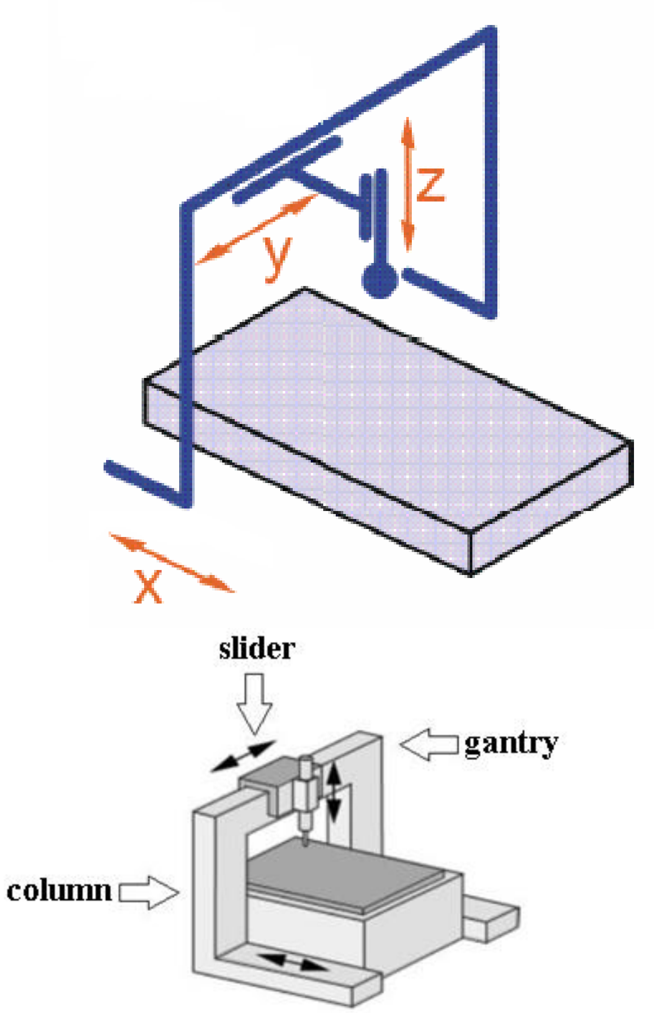

Figure 2. Kinematic scheme of device

Columns are made of steel parts welded together connected to guides at bottom part by screws. Gantry consists of two guide bars connecting columns together by screws. Slider consists of four guides connecting gantry with Z-axis. Unlike actual machine tool described experimental device does not contain spindle as it is not necessary to provide desired functions. Instead of spindle device is equipped with flat steel plate adapted to be used with magnetic blocks.

Bottom frame consists of two beams connected by guide bars. Using guide bars as carrier element significantly reduces weight of construction. Aluminium T-slot table is mounted on top of the bottom frame. Material of worktable was chosen because of weight even though it would not be usable with magnetic blocks. This disadvantage can be easily removed by attaching small steel plate to worktable if necessary.

Guiding of each axis is provided by two inductively hardened guide bars type W with an internal axial thread coupled with linear sets AGC type.

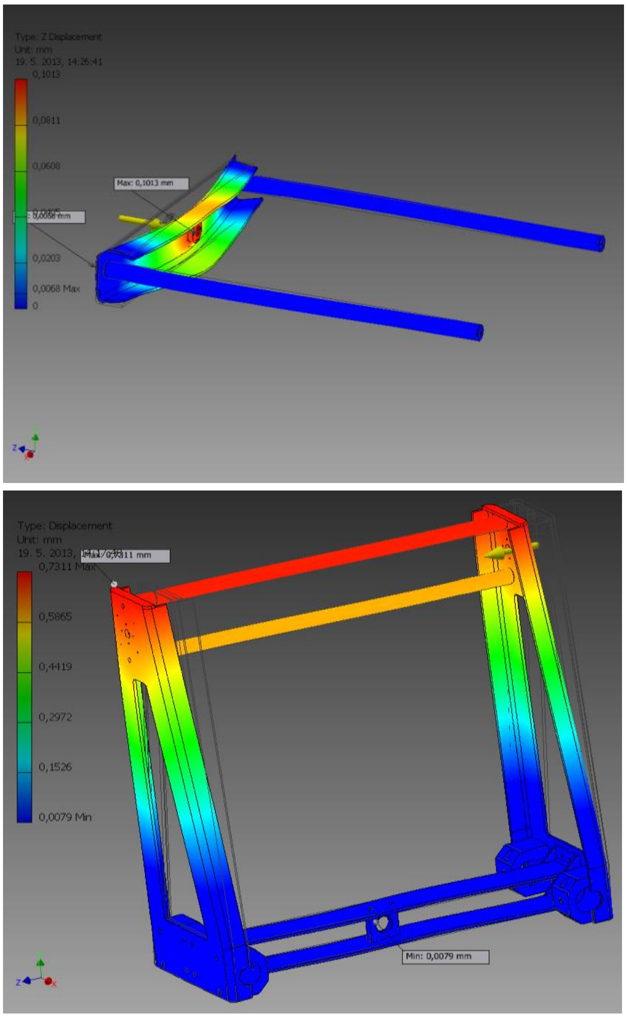

Figure 3. Static analysis of device parts in Autodesk Inventor Profesional 2013

All parts were carefully designed and calculated to withstand the load resulting from the action of drives and weights of individual device parts. Some of parts were too complex to be calculated manually therefor we performed stress analysis in Autodesk

Inventor Professional was also used as environment for designing construction. With correct material parameters and known maximal forces from stepper motors, screws and inertia of mass we were able to determine maximal deformations of individual parts. Maximal overall deformation was less than 0.3mm.

3. DRIVES

For driving of individual axes were chosen common solution - stepper motors combined with ball screws. Motors and ball screws are fixed together by non-flexible clutch that can reduce some radial and axial forces arising from inaccuracies of motor placement. Linear drive of individual axes is provided by ball screw driven by stepper motor placed on end of screw. Each drive is designed to be able to reach velocity $v=100mm \cdot s^{-1}$.

Each axis moves different load. Therefor stepper motor with more power was chosen to drive X axis. This way we can keep maximal electrical current under 5A at 220V.

To ensure security and prevent device from crashing itself due malfunction of control system, each end of each axis will be equipped with end switches which will cut power from motor in case of overrun.

4. CONTROLLING SYSTEM

In order to maximize simplicity of device, we decided to use existing solution Grbl which uses Arduino Mega controller. Grbl is licensed under Gnu GPL license and it is commonly used in lots of different kinds of machines such as 3D printers or milling machines. Control system consists of Arduino controller and stepper motor drivers and computer connected thru serial port or USB. Using ready to use solution allows us to focus on other problems.

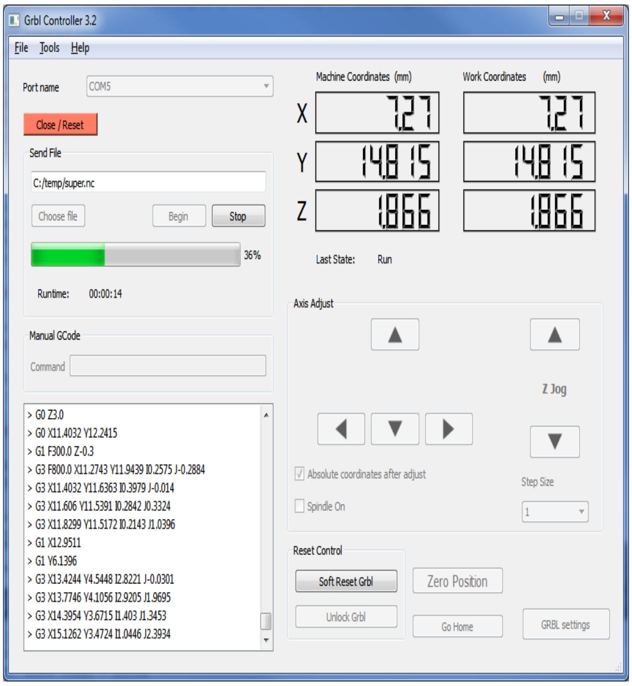

Figure 4. Standard user interface of Grbl controlling software

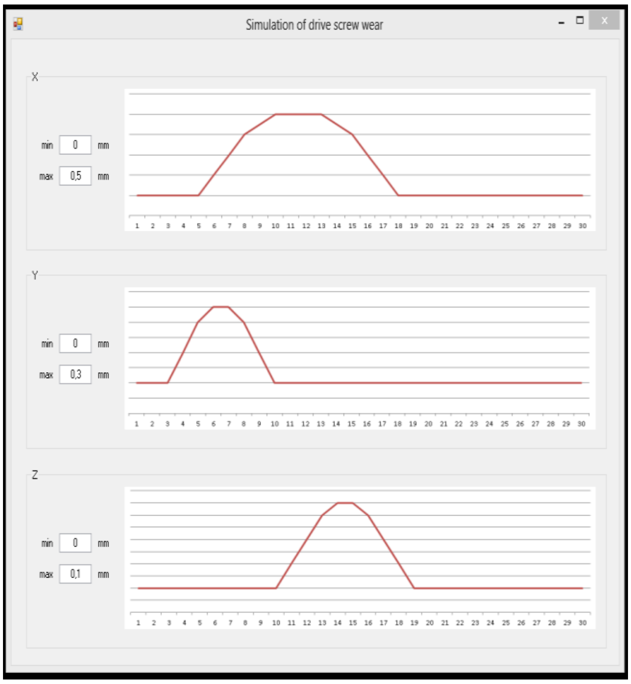

Figure 5. User interface for setting of drive screw wear simulation

User interface in Grbl (Figure 3) is very simple and easy to use or even modify, therefor with little programming it can be used with virtually any USB control panel intended to be used as educational training device as far as it uses standard communication protocols. This way device functions can be upgraded with advanced manual control even more similar to actual machine tool.

Modern machine tools are usually constructed less stiff then it was common in older conventional machines. Higher degree of machine tool precision is achieved by compensating inaccuracies of machine tool construction and deformations due load and lack of construction stiffness (Kovac, 2013).

We can use same principle in different way and simulate all kinds of machine tool faults such as wear of drive screws what can significantly expand usability of described experimental device. This can be realized by adding kind of hysteresis loop to drive control which will be applied during reversing direction. It not just simply add lag in each direction reverse, but it also ads some overrun based on chosen wear size and speed. For this purpose we designed form (Fig. 5) that allow us to set different size of wear for each section of drive screw and individually for each axis.

As we can see, openness of used control system allow us to modify way it interprets so called G codes easily implement simulation of different machine tool faults. Implementation of simulation angular inaccuracies would require more complex modifications. In special cases when simulation such inaccuracies are needed there is still possibility to prepare specially modified for this purpose. Even common CAM software with appropriate postprocessor can be used to generate such code. In such case path of tool have to be precisely planed and programed in NC code.

Construction of device will be equipped with several limit switches in order to avoid collision of moving parts. These switches will also be used as indicators for initial settings such as reference settings. Moreover device each axis will be equipped with security end switches to prevent collision in case of control system malfunction.

Proposed physical solution of control system is characterized by significantly small size and therefor it can be placed in relatively small plastic switchgear box together with fuses breaker, power source and emergency stop button. Device itself will be connected to computer via standard USB cable type B.

5. PARAMETERS OF DEVICE

Described experimental device was designed to reach acceptable level of positioning precision in order to simulate behaviour of machine tool and simulate some common faults and inaccuracies. It is mentioned to serve mainly as aid for teaching some aspects of technical diagnostics with special focus on methods of laser interferometry. Its mobility allows us to arrange workshop virtually anywhere where it is needed.

Also it have significant field of applicability as training device for diagnosticians who are not dealing with precision measurements on daily basis to keep their skills fresh and to try out some new procedures.

Device is fully capable of taking place of machine tool in almost all measurements that laser interferometer Renishaw XL-80 (Figure 6) can be used for such as:

- linear measurement,
- angular measurement,
- flatness,
- straightness,
- squareness,
- dynamic measurement (velocity and acceleration),
- measuring of positional stability,
- feedrate accuracy and stability,
- interpolation accuracy,
- and more.

Described device can be also used with RenishawBallbar QC20-W (Figure 7) to measure all axis and even to perform volumetric analysis, which can measure all planes in single step.

Table 1.

Overall weight:	**34kg**
Maximal feed for one axis:	$v=100mm\cdot s^{-1}$
Power supply:	~230V 5A
Size of work space:	400×400×350mm
Dimensions:	740×650×740mm

6. POSSIBILITIES OF EXPERIMENTAL DEVICE UTILIZATION

Experimental device was originally designed to be used with Renishaw XL-80 laser measurement system and its equipment, but its construction allow to use it with virtually any measurement system focused to measure geometric properties of machine tools such as RenishawBallbar system or even classical ones such as sine bar with micrometer dials.

Device design was focused to stiffness but it still allows us to deform it mechanically by using weights and simulate inaccurate worn or damaged machine on which initial settings and measurement itself are even more challenging than normal. This way we can extend of usability of described device even more and easily perform experiments which would be very difficult, expansive or impossible on actual machine tool.

Mechanical functions of device can be further extended by adding additional rotary axis in form of removable rotary table.

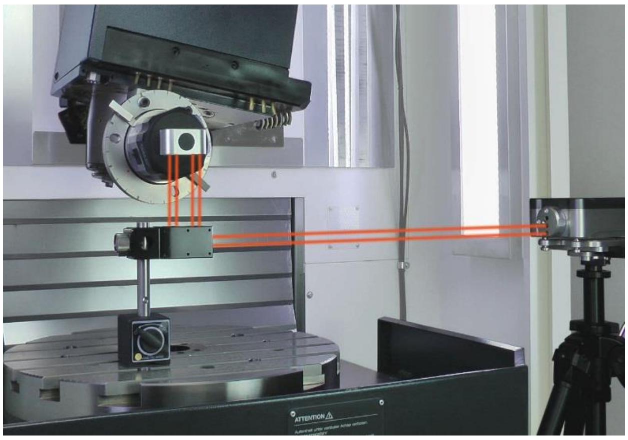

Figure 6. Measuring rotary axis with Renishaw Ballbar XL-80

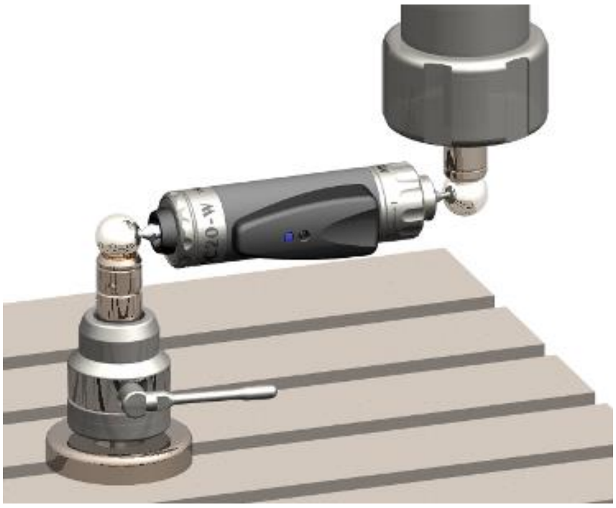

Figure 7. Renishaw Ballbar QC20-W

Applicability of described device as teaching aid can be improved by extending utility software with teaching module in form of expert system which should containing walkthroughs for measurements and describtion of measured

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