MACHINE TOOL ERRORS AND ITS SIMULATION ON EXPERIMENTAL DEVICE

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ABSTRACT: This article deals with machine tool errors and its simulation on proposed experimental device which is currently being developed at Department of Automation and Production Systems, faculty of Mechanical Engineering, University of Zilina. Device is developed as teaching aid for training of machine tool precision measurement as part of technical diagnostics.

KEY WORDS: Diagnostics, machine tool, experimental device, error simulation

1 INTRODUCTION

Overall performance of machine tool as complex mechatronic system is affected by condition of its individual subsystems in terms of production quality and its sustainability. Condition of machine tool is not constant over the time and it is constantly developing according to various factors such as its initial state, occupancy, load level, qualification of operation staff, quality of maintenance and much more. It is clear that maintenance is essential for machine tool to sustain its condition in certain limits allowing reliable production. In order to perform maintenance effectively certain amount of information about machine tool state is necessary, which can come from various sources such as machine tool operators (part of total productive maintenance), monitoring of production parameters or as result of technical diagnostics[1] [3].

Machine tool diagnostics as important part of proper machine tool maintenance is intended to reveal machine tool errors and inaccuracies whether existing or emerging ones. It includes many different procedures based on various physical phenomena and detecting various parameters of overall condition of machine tool [2] [7]. Contemporary methods of machine tool diagnostics commonly use state of the art devices and technologies in order to ensure quality, reliability and informative value of information acquired by diagnostic procedures. In some cases information of same or even higher value can be gained by using multiple diagnostic methods where synergic effect can take place [4] [8]. Usage of multiple diagnostic methods is known as multiparametric diagnostics.

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2 MACHINE TOOL GEOMETRICAL ERRORS

One of most important qualitative parameters of machined parts is accuracy, which is directly connected to precision of machine tool used to produce such part [5] [8]. Therefor examining of machine tool precision is important part of machine tool diagnostics [6] [10].

In ideal world machine tool would be absolute accurate and tools would travel exactly as programmed in control system. However due to various reasons there are lots of inaccuracies that combined affects overall accuracy of tool positioning and product accuracy accordingly [11] [13] [14]. Such errors emerges mainly due to the production tolerances of machine tools parts, wear caused by normal operation, and various damages caused by collisions and extreme loads.

Characteristic geometrical errors of machined parts are included in design as tolerances and took into consideration in production planning because inaccuracies of machine tool directly affects final accuracy of produced part [9] [12]. Process capability analysis introduces process boundary table which defines operations tolerances on dimension and form for holes and planes. These are determined based on statistical regression fits of data (that is a slope and intercept for linear relationships, and exponents and intercepts for nonlinear relationships) based on intuitive analysis, simulation and experimental evidence. Basically, tool position errors for plane generation due to setup or inaccurate measurement of tool length or diameter provide a constant offset or intercept and machining conditions, like metal removal rate, provide a variable input. Tolerances on diameter of holes are estimated similarly [15]. Diagraph shown on Figure 1 shows relations of machined part errors and its sources.

Most important source of geometrical error on finished product are geometrical errors in individual parts of machine tools, errors created by inaccurately assembled machine, and errors caused by usage of machine. Geometrical error manifesting on machine tools can be divided into two basic groups based on motion type of axis related to such error. First group consists of parameters related to linear motion (Figure 2) and parameters related to rotary motion (Figure 3).

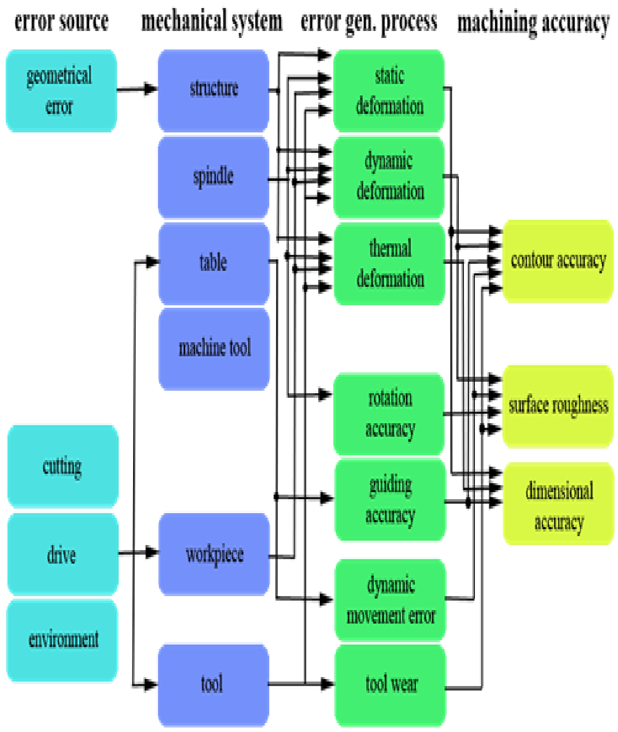

Figure 1. Machining error generation process

Common three-axis machine tool can be characterized by twenty-one geometrical errors as each axis have six degrees of freedom and squareness error as shown on example of X axis on Figure 2. Beside that each rotary axis have six motion errors, two location errors, and two squareness errors. If controlled axis is rotary then it brings in additional six geometric errors as shown on Figure 3. Therefor machines with more complex geometry such have to be characterized by more errors. For example five-axis machine tool can be characterized by total forty-one geometric errors.

Each of mentioned error can be detected, measured, and quantified by various methods. Each method uses characteristic device or devices, provides different level of precision, and take different time necessary to create setup and to perform actual measurement.

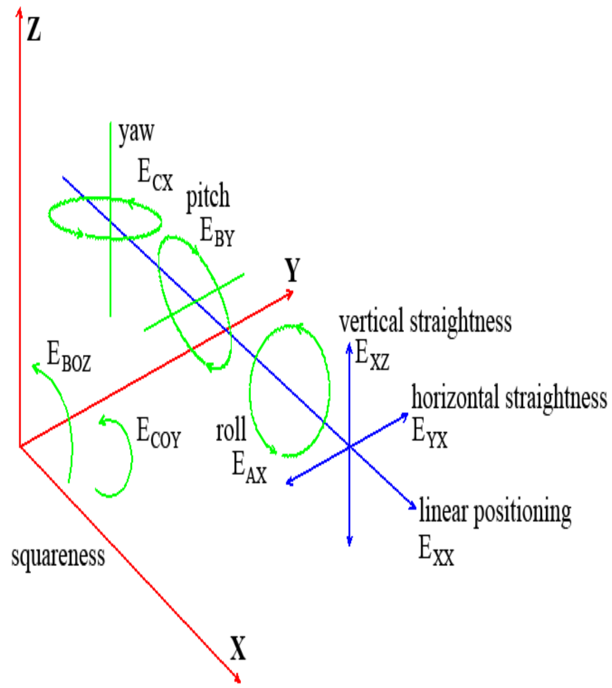

Figure 2. Errors of linear motion

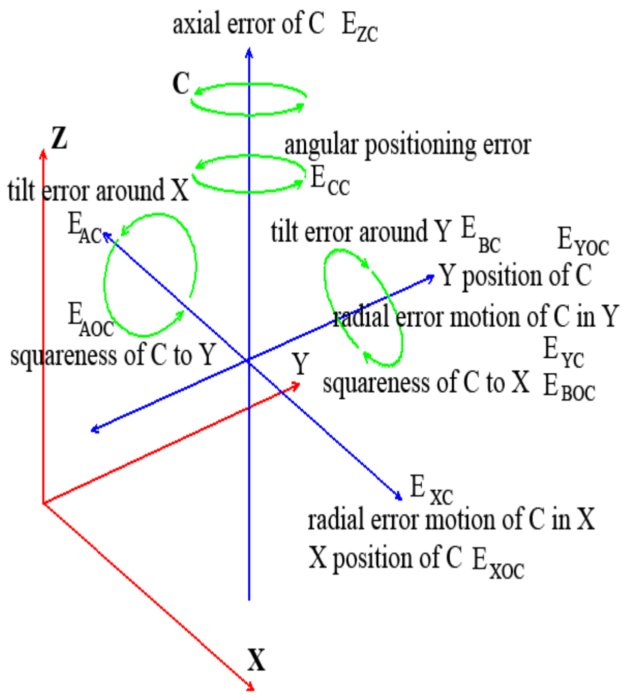

Figure 3. Errors of rotary motion

For example, both a laser interferometer and a granite straight edge can be used to measure the straightness of a linear axis. While the laser interferometer might take longer to setup, the granite straight edge might need to be repositioned multiple times to measure the entire length of the axis.

3. MEASUREMENT OF MACHINE TOOL GEOMETRICAL ERRORS

Measurement of geometrical errors requires decommissioning of the machine tool from production what can have large financial implications for most manufacturers. Time necessary to perform diagnostic tasks is strongly depending on level of skills of diagnostician performing measurement and therefor it should be kept fresh constantly improved thru training if it is possible. Tasks performed during preparation of measurement are slightly different according to machine specific construction and its condition. Generally it is possible to say that machine tool in bad condition requires more time to set up measurement than machine in good condition.

For example if measurement involves laser interferometer it is necessary to properly align optical elements along whole path of measured axis, which is more time consuming or even impossible, if there are large deviations, regardless if deviation is angular or positional, as it require higher skills and more effort to set actual measurement. Each possible error requires slightly different operations during setting up optics.

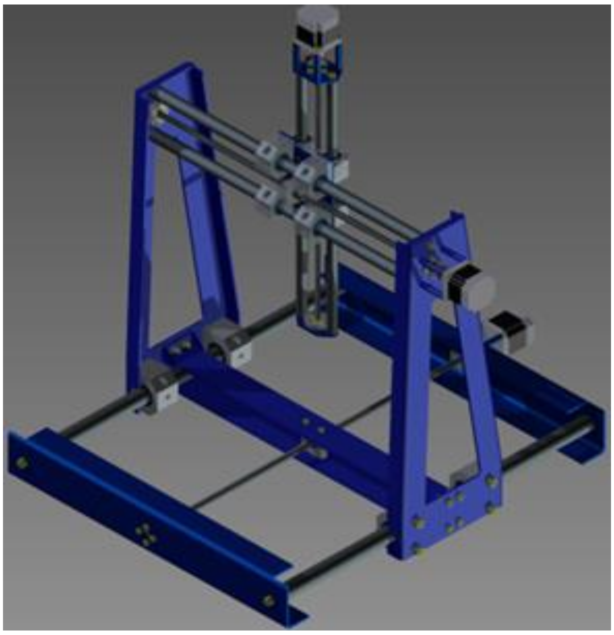

Figure 4. Model of experimental device for practicing routines of machine tool precision measurement

Number of iteration during process of optics aligning and measurement device preparation in the machine tool is proportional to level of skill of operating personnel and condition of examined machine. It is hard to train measurement on machine tools in various condition what have lead us to design device capable of simulating of various condition of machine tool, and to prepare operator to measure in any condition.

Basic requirements for such device was ability to act as machine tool during measurement of positioning precision, ability to simulate various machine tool condition and errors, kinematics should be same or similar as at conventional machine tools, the device should be light and stiff, it should be able to move the tool at similar speed as actual machine tool.

Device is designed to serve mainly as aid for teaching some aspects of machine tool diagnostics with special focus on methods of laser interferometry. High mobility of designed construction allows arranging training workshop virtually anywhere in matter of minutes.

Device is fully capable of taking place of machine tool in almost all measurements that laser interferometer 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.

Construction is similar to three axis gantry manipulator and it is designed with focus on effective weight/stiffness ratio in order to keep weight under certain limit that allows device to be carried by one man without violating of legislative restrictions applicable in Slovak republic.

It would not be much if described device would not be able to simulate some common mechanical errors of machine tool such as wear of drive screws, bent feeds, deviations in feed increments, various nonlinearities and so on.

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. [3] Same principle can be utilized and used in opposite way to simulate such errors. This can be done by modification of algorithms responsible for interpretation of standard NC code used to controlling described experimental device.

Wear of feed drive screw can be simulated relatively easy by implementing hysteresis during change of direction in each axis individually. Backlash is simulated as short stop at change of direction for example during circular interpolation.

Errors in linear positioning can be simulated thru function that calculates as amount of increments necessary to move tool for unit of length in each axis separately. Normally it should be constant but if we want to compensate or create errors in linear positioning then it can be done by simple changing the number of increments along axis. In commercial machines this is done by filling compensation matrix with values measured as deviations between real and programmed position. Control system uses such values to compensate geometrical errors but if matrix is not filled by correct values it can make overall performance worse than it would be without compensation.

Simulation of error in horizontal and vertical straightness is little bit more difficult as it requires movement at least two axes simultaneously accordingly to relative position and desired error. For example during measurement of X axis is position in Y axis and Z axis described as function of X coordinate. Same principle as for simulating of straightness errors can be used for simulating of squareness errors only difference is that the theoretical trajectory after including errors is still straight line so result is angular deviation.

With designed construction it is not possible to simulate jaw, pitch, and roll just by utilization of mechanisms in control system. Such movement would require additional controlled axis for each implemented error, what would make device more similar to five five-axis machine tool and same time it would make more complicated than it is necessary for educational purposes. If situation would ask for training measurement on device with such error it can be done by applying uneven load using weights or clamps to actually deform construction in desired way.

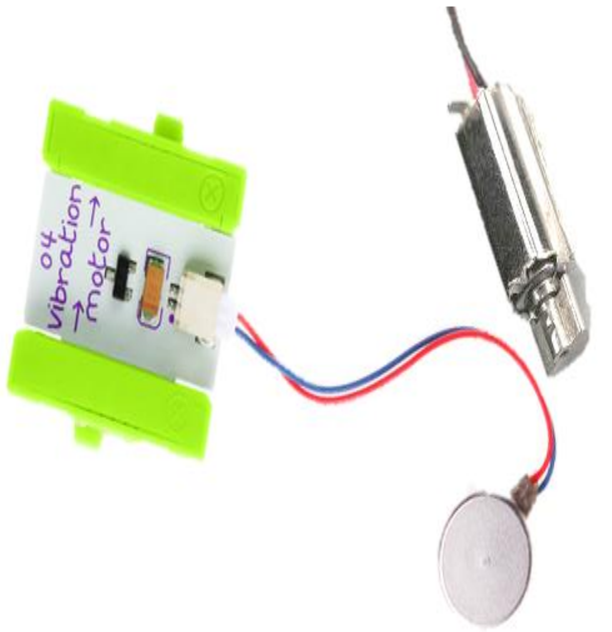

Figure 5. Vibration motors

All errors simulations of which are described above create something similar to space disrupted by gravitational field. This can be done by three dimensional axis of vectors, where position of vector in matrix represents desired (programed) position and vector itself stores deviation of actual position. Actual computing of path can be done either in computer or in control system of described experimental device.

Design of experimental device includes implementation of environmental factors such as vibrations that can be provided by vibration motors (Figure 5) with clamps or magnets that allow us to mount them to construction of experimental device can provide realistic impact of vibrations on precision measurement and machine tool diagnostics. Vibrations should be controlled with standalone controller in order to retain reliable source of vibrations that can simulate normal workshop environment without disrupting of control of positioning.

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