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RETROFITTING A CONVENTIONAL HORIZONTAL MILLING MACHINE TO CNC MACHINE TOOL

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Abstract: The paper presents one example successful retrofitting of conventional horizontal milling machine into full automatic control milling machine. In addition to the new way control of machine also kept the old way with manual control of machine as provided with switch selector. The great accuracy of machine tool is performed using compensation of measuring system errors and sag compensation. Installation of computer numerical control compared to conventional control, significantly is improved efficiency and accuracy of machining and safely handling of milling machine. In paper is presented retrofit of horizontal milling and boring machine W250 HC by manufacturing of Škoda.
Keywords: retrofitting machine tool, computer numerical control, servo drives, servomotors, interpolatory compensation

1. INTRODUCTION

The retrofitting process of the conventional horizontal milling and boring machines into full automatic control milling machine, it consists of two key elements: mechanical and electronics parts. In the mechanical part, a design is made to feed the servo motors via gearbox to the leadscrew or gear rack guideways. In addition for a mechanical transmission system, it is commonly to upgrade a new measurement system for each axis. On the other hand, in the electronics part, implies the implementation of computer numerical control (CNC) and servo drives in order to control the motors movement. In most cases retrofitting is only economically with well preserved and expensive large tool machines. The benefits of retrofitting include a lower costs investment than purchasing a new machine, higher performance and a new level of manufacturing data accessibility in context of Industry 4.0 [1, 2].

In paper is presented retrofit of horizontal milling and boring machine W250 HC by manufacturing of Škoda, with following specifications: X axis horizontal travel (column travel) – 12500 mm, Y axis vertical travel – 4000 mm, Z axis spindle travel – 2000 mm, W axis ram travel – 1600 mm, Z & W axis (spindle & ram) travel – 3600 mm, main spindle speeds – 800 rpm, X, Y axis feeds – 6000 mm/min, Z, W axis feeds – 3000 mm/min, power main drive – 77 kW, total power requirement – 180 kVA, approximate weight of machine – 140 tons.

2. DETAILS OF RETROFITTING A HORIZONTAL MILLING MACHINE

Installation of the 840D sl Sinumerik operate system was performed. In figure 1 is shown a graphical overview a variety of electronic hardware components.

The NCU (Numerical Control Unit) representing main part of the CNC system, interprets NC program, and executes interpolation, position control and error compensation via servo loop. Servo loop is control system with feedback of the measured value of the variable to be controlled. Numerical controls compare constantly the specified value of a NC axis position with the currently reported back actual value and determine from it the necessary control commands for the drive to match (setpoint=actual value) to reach. The output of the position control is sent to the motor drive amplifier system (SINAMICS S120) for speed control and torque control of synchronous servo motors, and finally, the servo motors makes the moving NC axis via the power-transmission devices. The communication between CNC and digital drives S120 is carried out via DriveCLiQ interface.

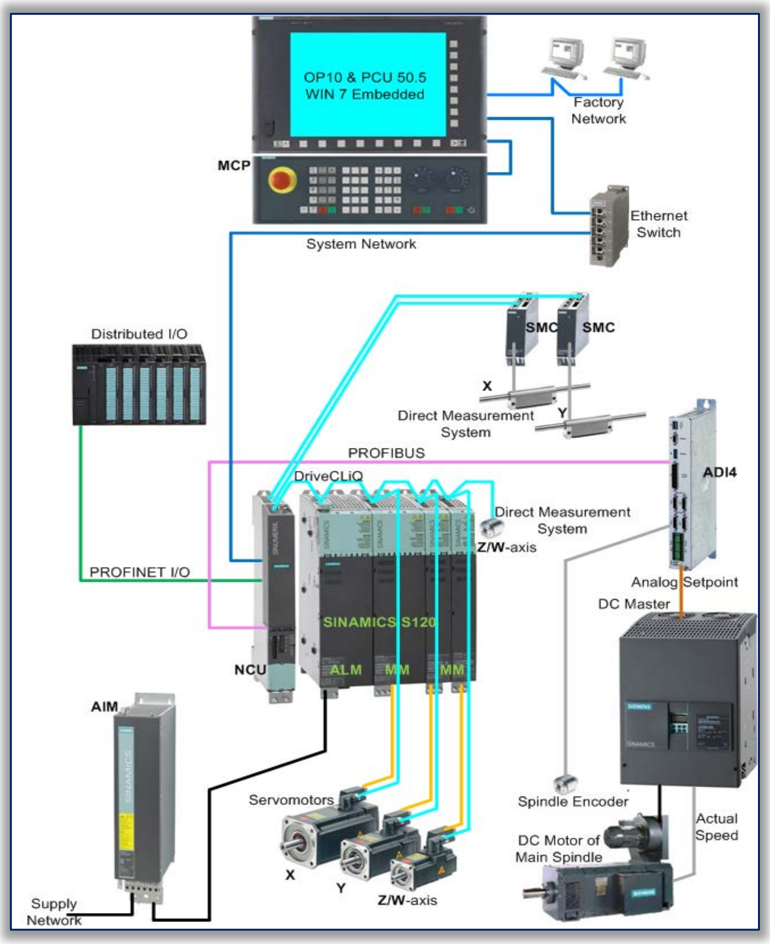

Figure 1. Details of the implementation SINUMERIK 840D sl with PCU 50.5

In our cases we have four linear axes (X, Y, Z/W) and one rotary axis (main spindle S). In addition motor encoder measuring system for each axes are installed direct measuring systems (X, Y – linear encoders, Z/W – rotary encoder). ADI4 (Analog Drive Interface) module is connected in the NCU via PROFIBUS DP port and it's used for analog spindle setpoint, due to using of a DC Master converter for driving DC motor of main spindle. For the purposes of thread cutting function, the spindle encoder is installed. Commissioning a SINUMERIK 840D sl is performed in following basic steps: commissioning of NCU, PLC configuration and creating user program, parameterizing machine data and axis drive data [3].

The 840D sl CNC and S120 drive controller structure contains three cascaded closed loop controllers: current, speed and position. Each controller must be optimized in succession starting with innermost current controller, then the speed controller and finally the position controller. The machine dynamic limits for velocity, acceleration and jerk are set in the interpolator. The speed control loop is always closed via motor encoder while the position control loop can be closed via indirect measuring system (motor encoder) or direct measuring system. The circularity test shown in figure 2 is used to check the interpolation axes that will work together. The tool measures a circle with reference to the motor encoder or direct measuring system. This gives the commissioning engineer the ability to clearly separate controller parameterization issues from mechanical issues.

Due to an easier transition of the operator to the new concept of controlling machine beside to the new way control of machine also kept the old way with manual control of machine as provided with switch selector.

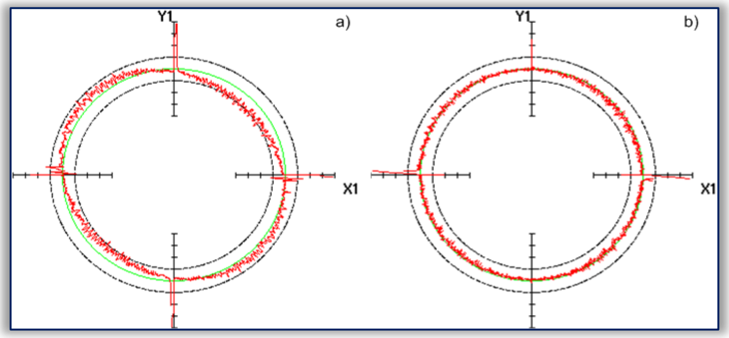

Figure 2. Circularity test a) servo gains mismatched in the CNC b) after correction servo gains for X and Y axis in the CNC

3. INTERPOLATORY COMPENSATIONS

The accuracy of machine tools is impaired as a result of geometric error, thermal error, power-transmission faults and measuring system errors [4]. Some of these deviations can usually be measured during commissioning of machine tools and then compensated for during operation on the basis of values read by the positional actual value. The interpolatory compensation function allows position-related dimensional deviations to be corrected with two following compensation methods:

- compensation of lead screw errors and measuring system errors
- compensation of sag and angularity errors.

The difference between the axis position measured by the position actual-value encoder and required programmed axis position (i.e. axis position of the ideal machine) is called compensation value. The compensation values are measured during commissioning and stored in compensation tables as position-related value. During operation, the corresponding NC axis is compensated between interpolation points through linear interpolation.

— **Compensations of measuring system errors**

The measuring system errors are dimensional deviations caused by the measuring system as well as its mounting on the machine plus any machine-dependent error sources. The principle of this compensation method is to modify the axis-specific position actual value by the assigned compensation value in the interpolation cycle and to apply this value to the machine axis for immediate traversal. The compensation values are derived using laser interferometer measurement system and this measured error curves loaded in the control in form of compensation tables during commissioning of milling machine (see figure 3 and 4).

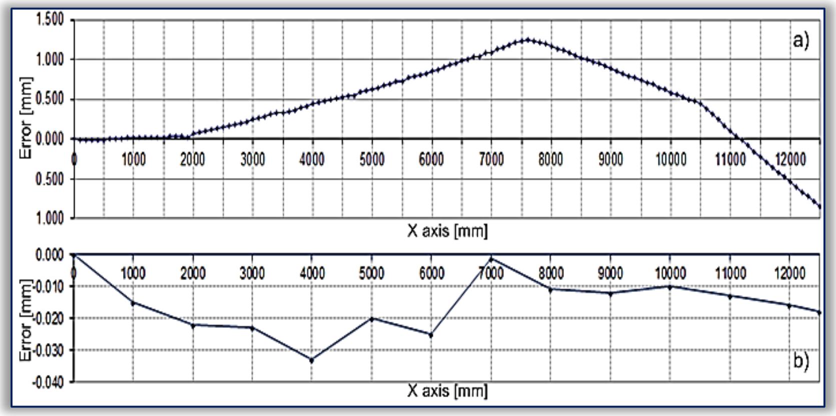

Figure 3. Positioning error for machine axis X a) before compensation
b) after loading compensation values

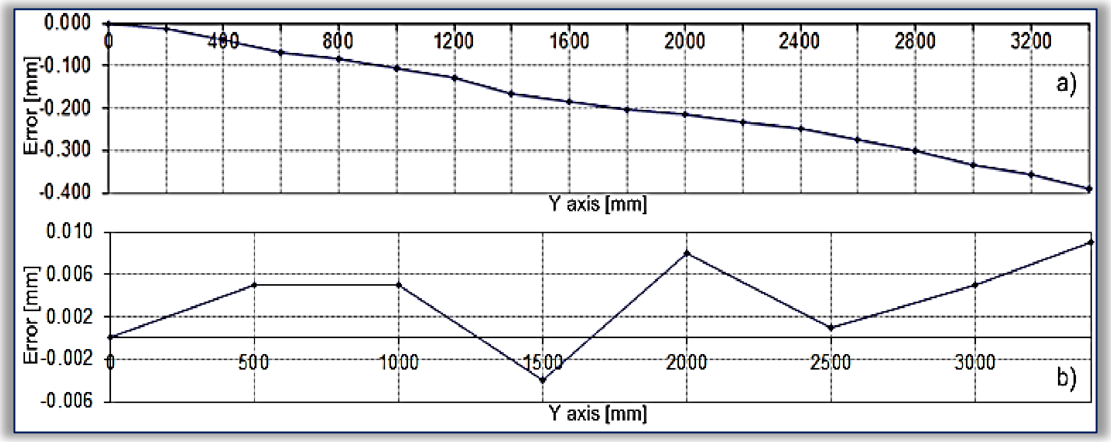

Figure 4. Positioning error for machine axis Y a) before compensation
b) after loading compensation values

Due to imperfect alignment in the mounting of parts of the linear encoders for machine axes X and Y maximum deviations caused by the measuring system are 1.245 mm for X axis and -0.390 mm for Y axis. After loading compensation tables great improvements were obtained and maximum deviations for X and Y axes are -33 μm and 9 μm respectively.

— **Sag compensation**

Weight can result in position-dependent displacement and inclination of moved parts since it can cause machine parts and their guides to sag. In our cases, if we draw out main spindle (Z axis) leads to sag in negative direction of Z axis because of its own weight. In order to compensate for sag Z axis, the absolute position of Y axis must be influenced. The error must be recorded in the form of compensation tables that contains a compensation value for the Y axis for every actual value position in the Z axis. Thus, sag compensation represents an inter-axis compensation (see figure 5).

The maximum Y axis position error before compensation determined by measurement is 1.020 mm. After compensation the maximum Y axis position error is within range ±50 μm. After positioning the W axis it is necessary call the subprogram to activate the corresponding compensation table.

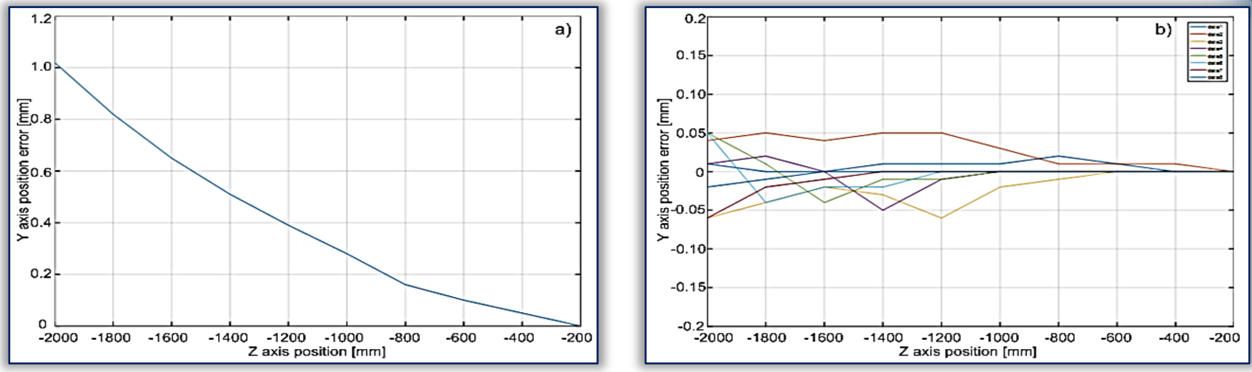

Figure 5. Sag Y(Z) error depending on position W and Z axes a) before compensation and W=-32.069 mm b) after compensation and W=[0 ÷ -1400] mm

4. CONCLUSION

Conversion of a conventional horizontal milling machine from one outdated on a new more powerful control, representing great challenge mostly in connection with the modernization of drives and the measuring systems, as well as the exchange the hardwired controls against a CNC system. The 840D sl controller, together with Sinumerik Operate operator interface is modular CNC controller, designed for a wide range of different complex machine types and technologies. The CNC system can be connected to factory network so that NC data, tool data etc. can load from office computer. The benefit CNC retrofit is reflected in increased productivity and advanced control of machine. Error compensation has been one of the important areas of research and improvement of machine tool accuracy has one of the key roles in the machine-manufacturing field. Experimental results showed that above mentioned compensation functions applied lead to better results in machining.

Note:

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