EAN 2017
55th conference on experimental stress analysis

Rotary Table Machine Accuracy Verification

Aleš Richter[1, a], Pavel Klouček[1,b]

[1]VÚTS, a.s., Svárovská 619, Liberec XI-Růžodol I, 460 01, Czech Republic

[a]ales.richter@vuts.cz, [b]pavel.kloucek@vuts.cz

Keywords: Rotary Table Machine, Accuracy Verification, Measurement.

Abstract. This paper deals with the verification of the operational accuracy of a specially designed rotary table machine.

Introduction

Growing demands on the production efficiency require very fast and precise machines. In our case, a demand for a rotary table machine (Fig. 1.) with an accuracy of 40 μm and a positioning time 0.5 s was set. Diameter of the table is 1000 mm and total moment of inertia is 100 kg.m^2.

The carousel machine serves as a base of a multifunction machine tool. On the carousel plate, 16 beds for clamping workpieces are symmetrically distributed. Within 0.5 s the carousel moves to the exact position (rotation by 22.5°). Then follows a 0.5 s milling period, during which the carousel is stationary. The total cycle of the machine is 1 s. What is important is the positioning accuracy in establishing the plate before machining.

In order to ensure the accuracy of operation and programmable control, a servomotor was chosen [1]. The motor drives the axial cam [2] by a backlash free reduction belt gear. The cam rotates the carousel plate also with a reduction gear (Fig. 1). When the theoretical ideal running, the dependencies of rotation (motor, cam, plate) are as follows: $\varphi_M = 1.25\varphi_C = 40\varphi_P$. Angular velocity is ω, acceleration is α.

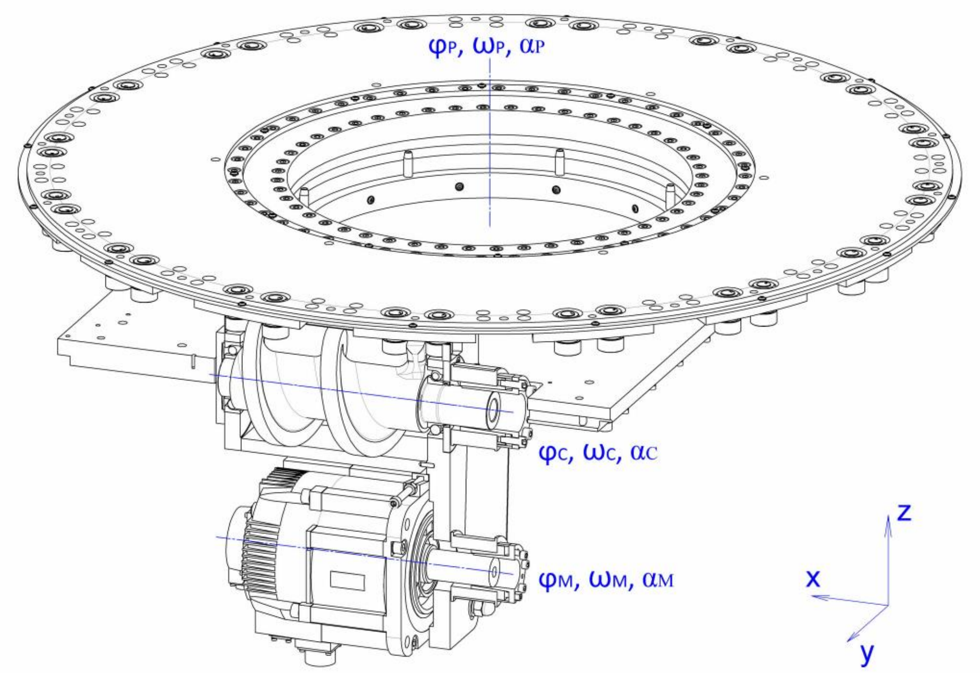

Fig. 1. Model of rotary table machine.

Before carrying out the measurements themselves, it was necessary to develop a mechatronic model of the motor-cam-plate configuration. Furthermore, the selected components were subjected to a stiffness and strength analysis. After many corrections in the calculations and adjustments of the 3D model, a functional sample was made, on which measurements were carried out. [3]

Measurement

The dynamics of the table, repeating accuracy of the position and static backlash in the transmissions were measured.

Measurement conditions: The carousel was positioned on an auxiliary mounting frame loaded with the frame with 16 beds for clamping workpieces. It was driven by a Yaskawa SGMGV-30D3A61 servomotor with an output of 2.9 kW and a nominal torque of 18.6 Nm. Speeds of 60 and 65 steps per minute were tested.

Measurement points: Measurement points are shown in Fig. 2 and 3. Angular velocity and angular position of servomotor, worm shaft and working table were measured.

Encoders: Incremental optical rotational encoders Heidenhain ROD 1020/3600 imp and Heidenhain ROD 880/36000.

Used devices: DMU-PCI plug-in module, A, B, C channels.

Measured quantities were recorded with a Dewetron DEWE-2600 16-channel measurement analyzer equipped with a special DMU-PCI card for precise angular measurements [4]. Evaluation was done using the Weisang FlexPro 9 software.

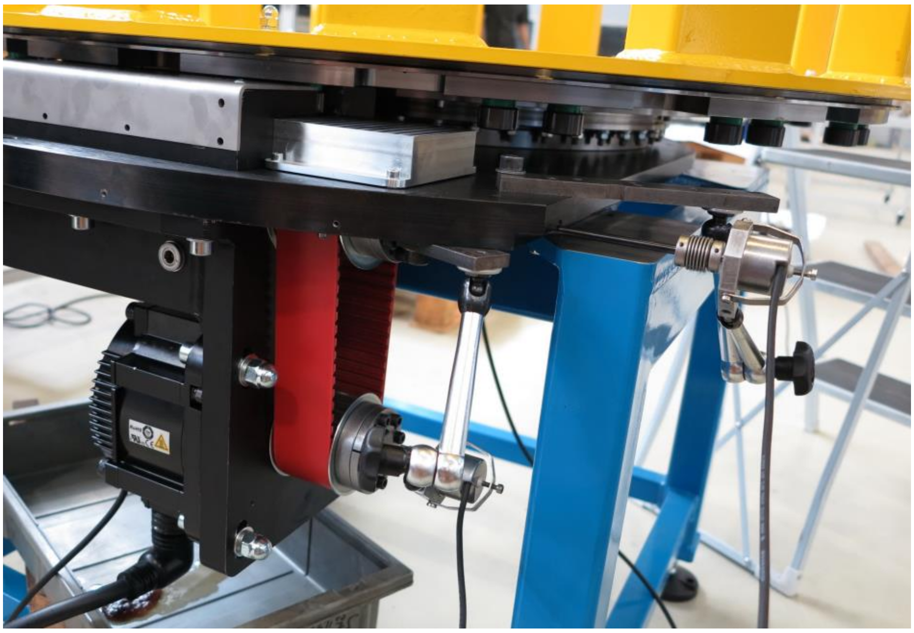

Fig. 2. Incremental encoders mounted on the output shaft of the motor (bottom) and the worm shaft (top).

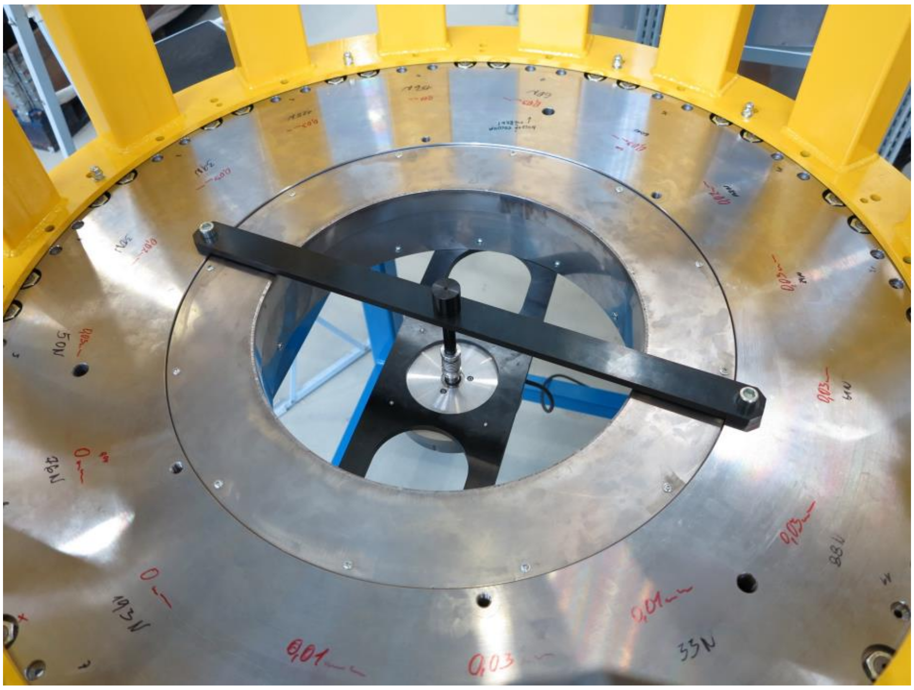

Fig. 3. Incremental encoder mounted to the shaft located in the axis of rotation of the working table.

Method of measurement and evaluation. As a zero position of the table (rotation angle 0°), the position when bed No. 16 is in the engagement of the driving worm was chosen. In order to verify the dynamics of the table and to determine the position repeatability of particular positions, the table was operated in continuous run at a speed of 60 steps per minute. The cycle comprises the working table motion for about 0.5 second, and a stationary working position for 0.5 second. The angular velocity and position of all three shafts were recorded synchronously with a sampling frequency of 50 kHz. For a comparison of the impact of the speed, three positions of the working table were measured also for a speed of 65 steps per minute (in practice, however, the machine will be operated at speed of 60 steps per minute only).

The static backlash of the working table was determined from the difference of the positions when the driving motor performs a rotation by 10° forwards and then backwards. Several positions of the working table in standard mode with two rollers in contact with the driving worm were measured. Additionally, a measurement with the angularly shifted table, when only one driving roller was in the engagement of the driving worm, was performed.

Measurement results

Dynamics of the working table. For measuring the dynamics of the working table using an incremental encoder with high resolution (36000 pulses/rev), it was necessary to choose the correct setting of the angular position range. The DMU-PCI plug-in module is equipped with a 16-bit converter, the angle value is then incremented with each edge of a TTL signal of the incremental encoder. If we choose the range of the measured angle of -10° up to +370° so that we can cover the full range of the angle within one revolution with a slight overlap, the quantization step of the converter is 380/65536 = 0.005798°. Thus, we lose the resolution of the encoder because at 144000 levels of the angle per one revolution, we can achieve a resolution 0.0025°. A usage of the full encoder resolution was achieved by reducing the range of the measured angle to 60°, when two or three working positions of the table were recorded in each measurement (the angular step is 22.5° between two working positions). Fig. 4 shows the typical displacement curves for a change of one position of the working table. The angular position curves of the motor, worm and working table are shown. Fig. 5 then displays the curves of the respective angular velocities.

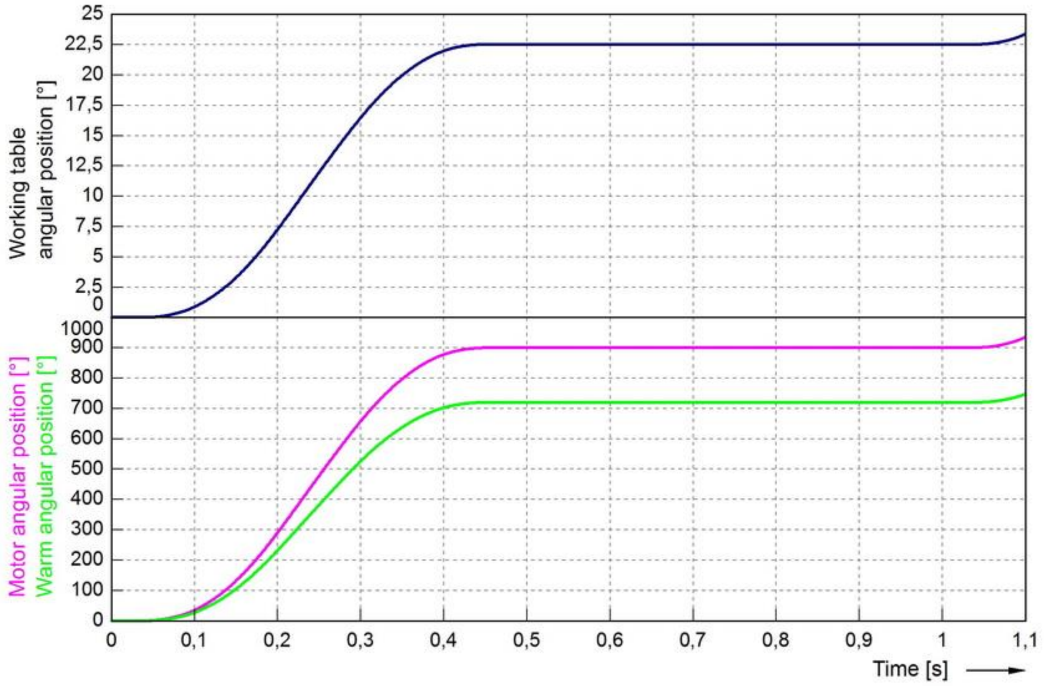

Fig. 4. Displacement/angular position of the working table, driving worm and motor during the transition from position No. 1 to position No. 2, transition and also the dwell part are shown

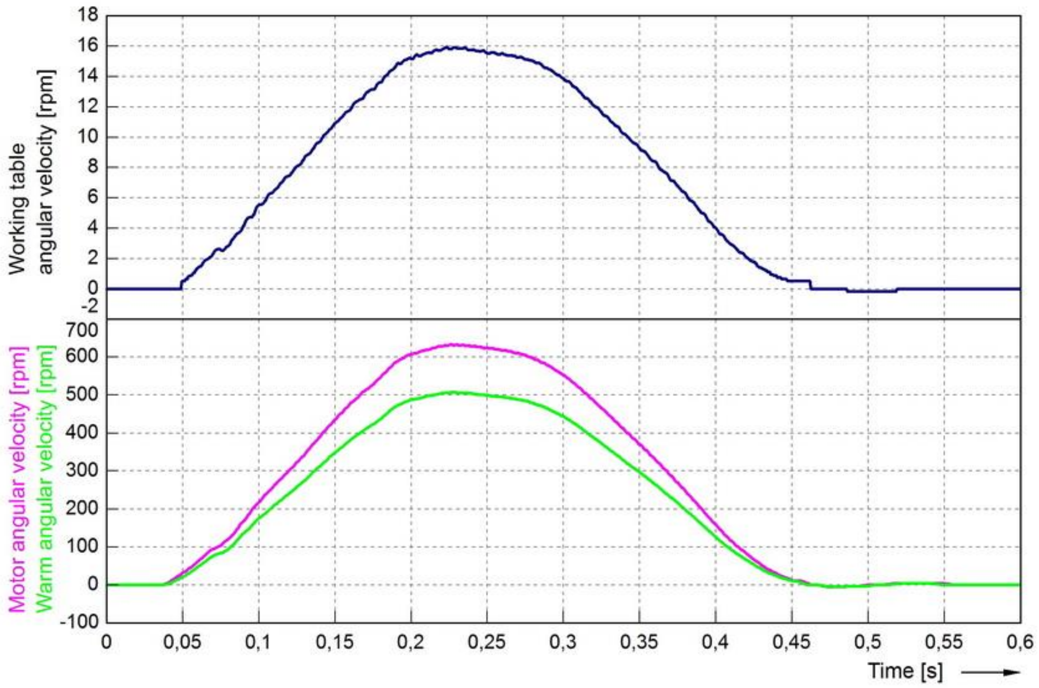

Fig. 5 Angular velocity of the working table, drive worm and motor during the transition from position No. 1 to position No. 2, transition and the beginning of the dwell part are shown

Damping time and overshoot rate of the position are factors affecting the time usable for the actual operation of milling and its accuracy. Therefore, just this segment, when the working table stopped in its new position, was evaluated and compared for all 16 positions of the table. At first, the courses measured by the encoder attached to the working table were assessed. The courses have a stepwise character since the overshoot magnitude is close to couple of quantization steps.. However if we compare the courses with the angular position measured on the driving worm, which can be converted to the motion of the working table with a well-known transmission ratio of 32:1, it can be said that the worm course corresponds to the working table course because backlashes are defined at a unidirectional movement. The incremental encoder on the shaft of the worm has a resolution of 3600 pulses/rev; when converting to the movement of the table and changing the angle size with every edge, it is then 3600 * 32 * 4 = 460800 pulses/rev, i.e. the quantization step of the table movement is 0.00078125°, thus, more than 3 times finer than that from the encoder attached to the table.

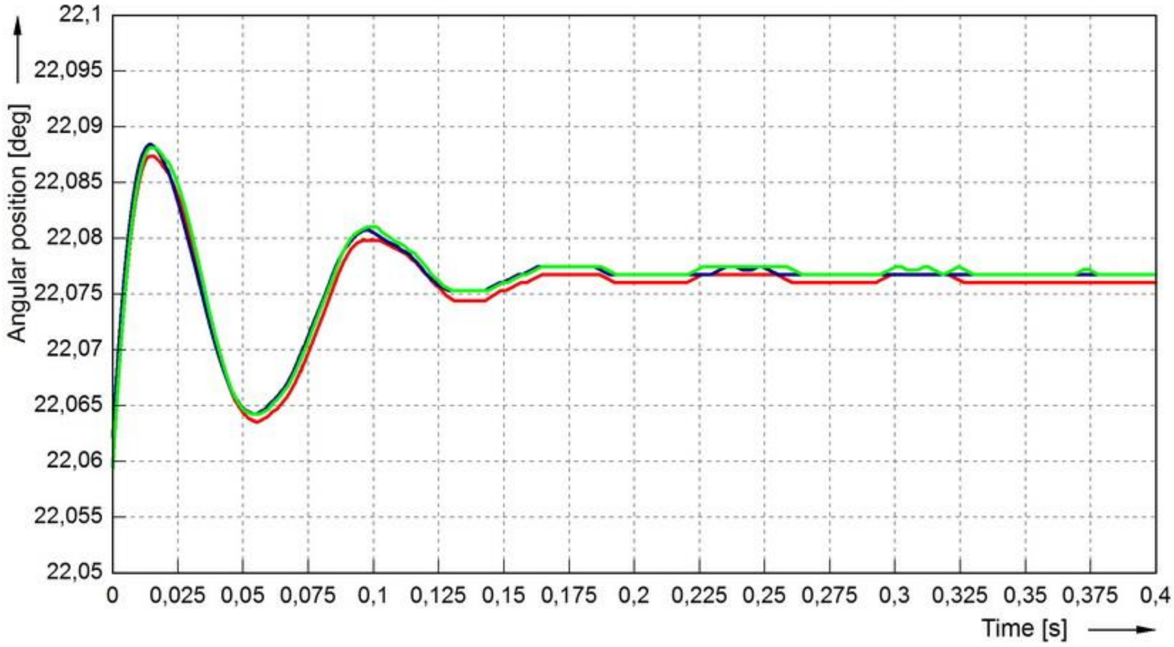

Fig. 6. The course of the angular position of the working table during its stop in the new position when transiting to *position No. 1*. The position measured by the encoder on the shaft of the driving axial cam after conversion by a gear ratio for three consecutive revolutions of the working table (order of the colours: dark blue, red, green).

If we compare the dwell positions in particular positions, , the position repeatability deviation of all positions did never reach a greater value than one quantization step, i.e. ±0.00078125°, during three revolutions of the working table. Should we consider the working table 1 meter in diameter and the maximum position error two quantization steps the maximum peripheral repeatability error is approx. ±13.6 μm. The position error is given by the values conversion, i.e. the output value change will occur only when a specified level is exceeded. It means, the actual value may vary within the full extent of one quantization step and therefore also just under the limit of the following step.. The position overshoot in transition to a new position will reach maximum amplitudes approx. up to 0.015° at a frequency of approx. 14 Hz. Most often, however, a very rapid damping within one or two periods with duration about 0.1 s occurred. After this time segment, the table can be already considered as set in the new position with an accuracy given by the repeatability mentioned above.

For comparison, one measurement of the shifted starting position of the table when only one roller was engaged in the worm at the time of transition to another position was also carried out. Two positions were measured and in both cases, a slight reduction of the overshoot amplitude compared to the operation with two rollers engaged was present. This is surprising as one would expect the contrary.

Static backlashes. For particular working positions of the table, backlashes given by the size of the driving rollers were measured. Further, the maximum value of the position overshoot and the table position in the dwell part of the cycle for three consecutive revolutions of the working table were determined for each position.

To determine the static backlash between the driving rollers of the table and the driving worm, an experiment was conducted in which the driving motor rotated at low speed by ten degrees forward and then by the same angle step back. In such a way, the backlash determination in both directions should happen and the run of the table in the return direction should be shorter for the backlash value than in the theoretical run. The measurement was performed for two positions of the table in the standard setting, i.e. with two rollers engaged and consequently with the table rotated in such way so that only one roller should engage in the driving worm in the measurement point.

The backlash values between the working table and the driving worm were determined and the whole backlash of the mechanisms from the driving motor shaft up to the working table. The backlashes were always related to the angular position of the working table. At positions between the worm and the working table, there is a backlash of approx. 0.002° up to 0.004°, which corresponds to a backlash at the circumference of approx. 0.017 up to 0.035 mm, and it also roughly corresponds to the measurements of the manufacturing tolerances of the rollers and the worm. A backlash in the belt transmission between the motor and the driving worm, which is implemented by the so-called toothed belt “without backlash”, also contributes to the total static backlash,. The backlash found in this transmission is typically 0.001° with its maximum approx. 0.0025°. It corresponds to the peripheral backlash of approx. 0.022 or 0.008 mm. This backlash is given by both the backlash of the belt teeth in the grooves of the toothed wheels and the inherent flexibility of the belt.

Conclusions

The function of the stepping mechanism of the milling machine working table was verified by measurement [5]. Relatively high demands are laid on the angular position accuracy because the peripheral fault is quite high for a relatively large table diameter. The position repeatability for all 16 working positions was examined along with the overshoot rate during the transition to a new position, the static backlash of the table in the selected positions.

The angular position and the angular velocity were measured. The results show that the behavior of the worm and the table during the change of the position can be considered almost identical. The positional repeatability error for all positions of the table was at the limit of the resolution of the encoders. The overshoots when transiting to the standing in the new position did not exceed values of 0.015° at a frequency of approximately 14 Hz. They were very quickly damped so that after the first period of the oscillations, the table can be already considered as established in the new position. Additionally, the determined static backlashes were very small.

Some differences between the selected positions, which are related to the dimension of the appropriate rollers, were detected. On the contrary, the influence of the number of rollers (one or two) in the engagement of the worm was almost not reflected in the static backlash.

The maximum peripheral repeatability error is not greater than 30 μm. The static backlash in the transmissions ranged from 17 up to 35 μm.

References

[1] Souček, P.: Servomechanismy ve výrobních strojích, Vydavatelství ČVUT, ISBN 80-01-02902-6, Praha

[2] Koloc, Z., Václavík, M.: Cam Mechanisms, Elsevier, ISBN 0-444-98664-2, (1993)

[3] Richter A., Ondrášek J.: Rotary Table Machine Input Parameters Optimization. Advances in Mechanism Design II, 2016, pp. 399. ISBN 978-3-319-44086-6

[4] Šidlof P., Svoboda M.: Dynamické vyšetřování mechanismů na základě digitálního měření okamžité úhlové rychlosti, Strojírenství, vol. 34, pp. 267-273, 1984

[5] Klouček P., Braier Z.: Analýza pohybu pracovního stolu frézky, Internal report MER-16/2016, VÚTS, a.s. Liberec