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Rolling screw mechanism in the drilling and milling machine

Tadeusz Sawicki [0000-0002-1797-4464]

APC Presmet Sp. z o.o., ul. Oświęcimska 122H, 45-641 Opole, Poland;
e-mail: presmet@presmet.com.pl

Summary: Machine tools manufactured in the second half of the 20th century, such as drilling and milling machines, are still in use and working today. In terms of machining accuracy they cannot complete with the new machine tool, as the level of technology in the years of their manufacture was for behind that of today state of the technics. At Present, there are many "SKODA" drilling and milling machines manufactured in various years of the 20th century in use in Poland and other countries. In the machining process, important advantages of machine tools are: rigidity and the ability to damp vibrations. Above all, both of these advantages and more are present in the above-mentioned "SKODA" drilling and milling machines, which is why they have been in use for so long.

Improvements in the machining accuracy of these machine tools can be achieved by retrofitting them to a greater or lesser extent. This article presents a partial modernisation of a "SKODA" drilling and milling machine, type WD200B, built in 1972, involving the replacement of Tr90x20/2 trapezoidal thread screw with an 80x10Rx6,5-6 screw and roller mechanism, which serve to move the headstock vertically along the guides.

The material in this article presents a concrete design solution, made and implemented according to the above-mentioned modernisation. The correctness of this application is confirmed by the results of headstock positioning measurements made between 2009 and 2019. The dissemination of such a solution can only take place after the machine tools has been in operation for an appropriate numbers of years, as has been demonstrated.

Key words: screw, rolling screw mechanism, nut, positioning, drill-milling machine

1. Introduction

Screw-rotary mechanism is used for precise positioning of workpiece carriers and for converting rotary motion into longitudinal motion or vice versa. Rolling screw mechanism is used as the driving element for linear motion. Rolling screw mechanism is also popularly known as a ball screw. The basic components of rolling-screw mechanisms are the screw and nut. The screw is the conductor of movement and the nut that encases it converts rotary movement into linear movement. These components are usually made from high quality, high strength and wear-resistant steel. The rolling screw mechanisms are manufactured with a high degree of precision, which ensures their high reliability and efficiency, making them widely used in many industries. [5]

There are two types of rolling screw mechanisms:

– rolling screw mechanisms, using balls as rolling elements, which ensure high precision, efficiency and low friction,
– planetary mechanisms for heavy-duty applications using shafts with near-metric threads instead of balls.

In the machinery industry, ball screw mechanisms are most commonly used. The material contained in this article presents the use of a ball screw mechanism in a boring-milling machine, which is a machine tool used for machining mostly heavy and bulky workpieces. The machining of such workpieces are based on the principle that the workpieces is stationary and the working movements of the cutting tool are obtained by moving the machine with the tool. The cutting tools are primarily milling heads.

As a machine tool, the boring and milling machine is designed so that the cutting tool can carry out its working movements according to the three main axes, namely "X", "Y" and "Z". Most often, the tool performs working movements in the horizontal and vertical planes. Horizontal movements is achieved with a pinion and toothed bar and vertical movement is usually achieved with a tralling threaded symmetrical screw and nut. For heavy loads, a rack-and-pinion drive is also used for vertical movement. Precise machining of workpieces depends primarily on accurate positioning of the machine tool, and thus of the tool over the entire machining range. Significantly better positioning accuracies, compared to trapezoidal threaded screws are achieved by using a rolling screw mechanism.

The material in this article presents a design solution for replacing a screw with a trapezoidal thread for a screw-rolling mechanism and shows a comparison of the positioning accuracy of the two cases. The vertical rolling screw mechanism replaced the traditional trapezoidal thread screw in the "SKODA" type WD200B drilling and milling machine, construction year 1972. Both the trapezoidal threaded screw and the rolling screw mechanism are used to move vertically up or down on the headstock column guides with the cutting tool. The advantage of the rolling screw mechanism over the conventional trapezoidal threaded screw is that it is subjected to rolling friction during movement, while the screw is subjected to sliding friction, which causes greater resistance to motion and reduces the efficiency of the entire drive.

In view of the above, the following hypothesis should be put forward:

– the use of rolling screw mechanism instead of a trapezoidal threaded screw is expedient,
– this replacement is intended to demonstrate, on the basis of a comparison of positioning accuracy measurement results, the advisability of this application.

The replacement of this mechanisms did not take place directly, but required a certain design solution, which had little effect on the introduction of the above into the aforementioned drilling and milling machine. The material in this article presents a solution to all the problems associated with replacing these mechanisms, as well as discussing the advantages and disadvantages of this solution.

2. The headstock of the drilling and milling machine of the trapezoidal threaded screw

As machine tolls produced in the second half of the 20th century, drilling and milling machines for moving the headstock along vertical column guides were primarily equipped with a trapezoidal threaded symmetrical screw and nut type mechanism. The mechanism was structured as follows: a trapezoidal screw stationary, fixed and fixed to the column, a nut driven and movable. This is illustrated in Figures 1 and 2.

Drawings no. 1 and 2 were taken from the technical and operational documentation of the drilling and milling machine type WD200B.

Figure 1 shows how a Tr90x20/2 trapezoidal threaded screw is permanently attached to the column of a drilling and milling machine, as well as illustrating the main components of this machine tool.

Figure number 2 illustrates the nut rotation drive mechanism on a Tr90x20/2 screw.

Rotation of nut position 2 is carried out by means of a toothed wheel position 5, which is fixed on this nut.

A nut located on the screw is connected to the headstock. [4] The rotation of the nut causes a vertical, rectilinear movement of the nut and thus of the entire headstock along the screw upwards or downwards.

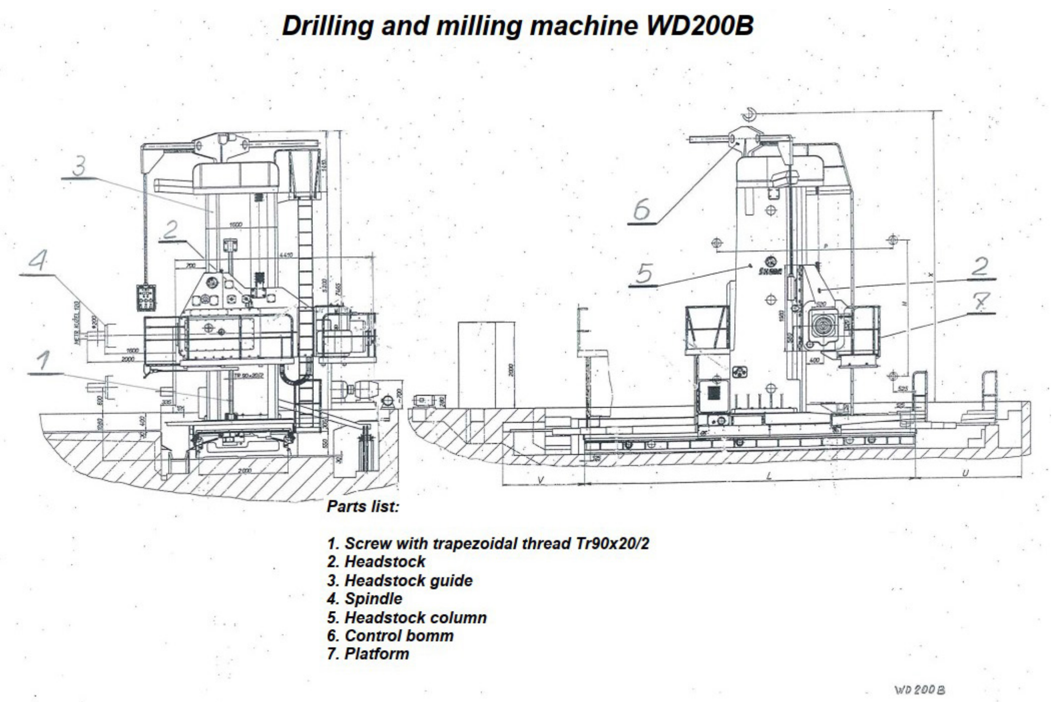

Fig. 1. View of screw with trapezoidal thread on column of drilling and milling machine (own study)

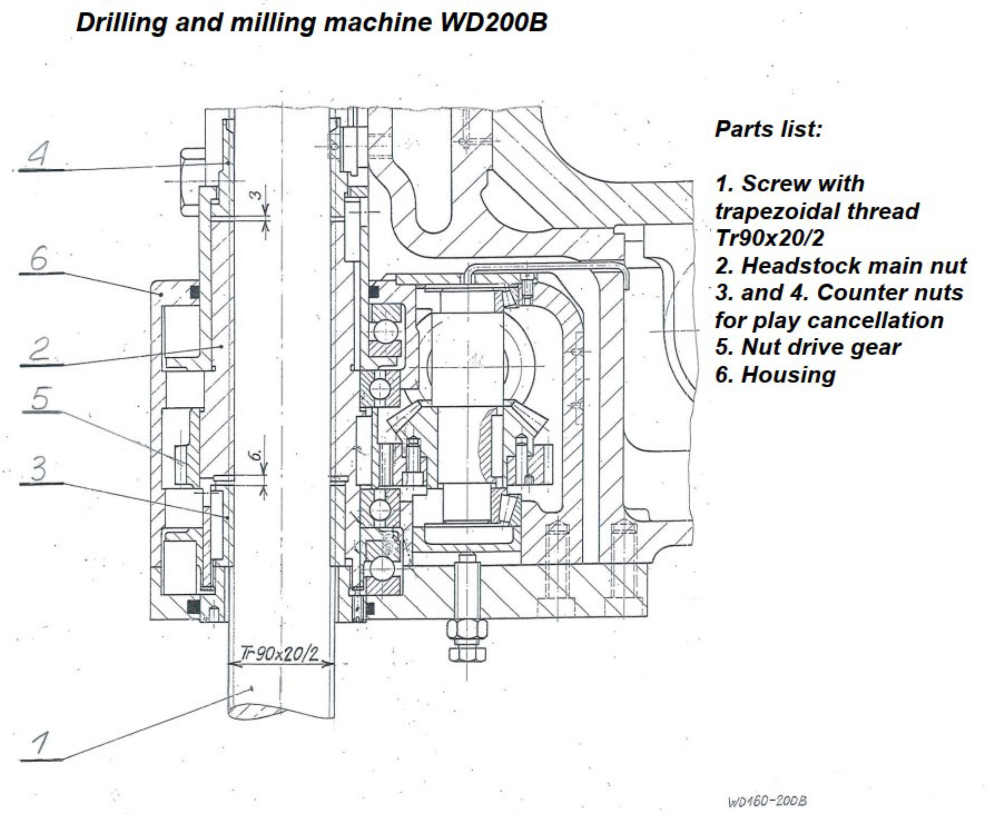

Fig. 2. Drive mechanism trapezoidal thread screw and nut (own study)

The company in which the above-mentioned drilling and milling machine operates specialises in unit production and thus manufactures products with varying degrees of difficulty and precision.

The requirements, particularly with regard to accuracy, were the reason for the modernisation of the above-mentioned machine. Firstly the computer control of the drill-mill was installed. The positioning of the headstock was then measured over the entire working range, i.e. 3000 mm.

This was measured using a Renishaw ML-10 laser interforometer, based of the parameters:

– measuring resolution of 0.01 µm,
– measuring accuracy of 0.1 µm.

The result of this positioning measurement is show in Figure 3.

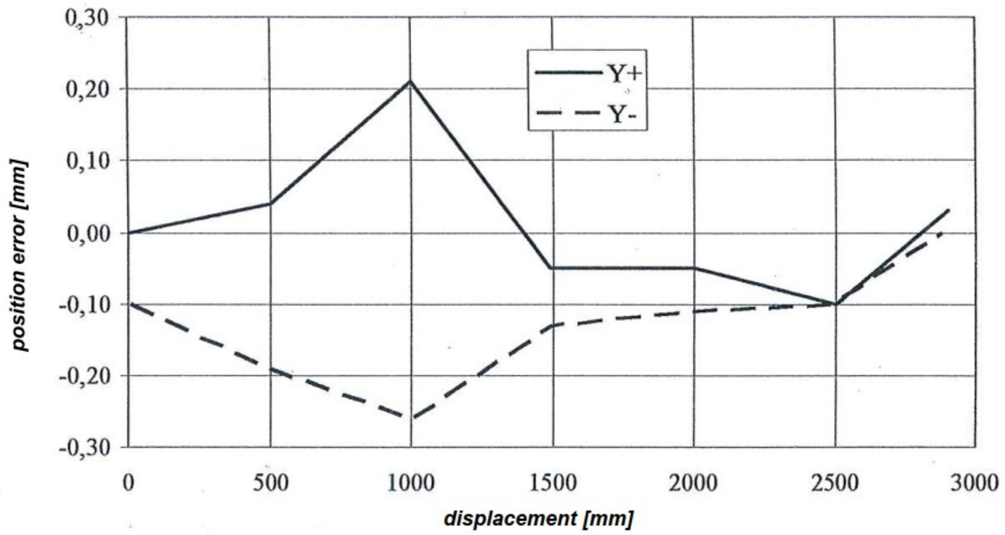

Fig. 3. Graph of the indication errors of the vertical Y-axis measuring system of the headstock with a trapezoidal screw (own study)

The Y+measurement was taken during the upward movement of the headstock over the entire machining range from 0 to 3000 mm in 500 mm steps. The Y-measurement was taken similarly during the return movement, i.e. from 3000 mm to 0.

The measurement point was a fixed point designated on the headstock.

The measurement was made as follows: the displacement on the trapezoidal thread screw by 500 mm was computer-defined. After completing this pass, the headstock stopped and the actual displacement was measured with the interferometer. Then, a further 500 mm displacement was requested and the actual measurement was repeated. This is how the headstock displacement was measured over the entire range on the screw with a trapezoidal thread i.e. from 0 to 3000 mm. The actual measurement was taken after each given displacement every 500 mm.

The interferometer recorded the deviations and transmitted them to a connected computer, which plotted a graph of the deviation errors.

The total positioning error is between -0.2 mm and 0.2 mm, i.e. a maximum of approximately 0.4 mm.

At the same time, this measurement showed different degrees of wear on the trapezoidal screw due to the fact that the headstock operates at different times, over different working ranges, not always over the entire range.

The demonstrated positioning error proved to be too large and did not allow accurate machining to be performed. For example, it will not be possible to turn a ø500H7 hole while maintaining the standard tolerance of +0.063 mm.

The positioning measurement of the aforementioned screw with trapezoidal thread was carried out on 01.03.2007, after it had been in operation for several years.

APC Presmet Sp. z o.o. purchased the WD200B drilling and milling machine in 2004 as a second-hand machine after a complete overhaul.

Starting in 2007 the machine tool was modernized starting with computer control.

This was followed by the fabrication and installation of an additional 1000mm long section, increasing the height of the vertical column, which extended the working range of the headstock from 3000 to 3800 mm.

The next stage of the upgrade was the replacement of the trapezoidal threaded screw with a screw-and-roll mechanism.

3. The headstock of the drilling and milling machine of the rolling screw mechanism

The demand to increase the machining field range of the machine tool, as well as to improve the positioning accuracy, necessitated further stages of modernization.

After increasing the vertical of the headstock travel column by 1000 mm, the trapezoidal threaded screw was replaced by a rolling screw mechanism.

The result of this replacement was the replacement of the Tr90x20/2 symmetrical trapezoidal threaded screw with an 80x10Rx6.5-6 screw/roller mechanism.

Characteristic sizes of screw Tr90x20/2:

- double thread,
- thread direction right,
- 68 mm core diameter,
- screw core area 3632 mm2.

Characteristic sizes for the 80x10Rx6.5-6 rolling screw mechanism:

- diameter 80 mm,
- pitch 10 mm, right-hand thread,
- screw core diameter 73.3 mm,
- screw core area 4219 mm2,
- class T5 (0.023/300) – roller screw.

Characteristic sizes of the mechanism nut:

- flanged double,
- number of rounds of balls, i = 6,
- standard seal,
- pre-lubricated,
- preload 7%.

A comparison of the core area of two solutions shows an increase of 16% in favor of the screw-roller mechanism, which should be considered as an advantage.

Increasing the vertical column required special development and design of this mechanism.

Ensuring the correct operation of the aforementioned mechanism required the directions of the working movements, i.e. the reverse of the trapezoidal screw.

In a rolling screw mechanism, the working motion is performed by screw and the nut is stationary.

The reason for this arrangement of movement was that the nut, which was made and fitted to the screw by the manufacturer, could not be removed to fit a rotating component on it (e.g. a gear wheel). The following issues need to be addressed in the design of the screw-roller mechanism:

– ensure the active thread length of the screw to achieve the required machining size,
– the fastening of the screw ends so that they can rotate (bearing), [1]
– enable the nut to be flanged to the headstock body (fixed),
– fitting of folding guards on screw sides of the screw to protect it from contamination.

A screw an roller mechanism that meets the above requirements is shown in Figure 4.

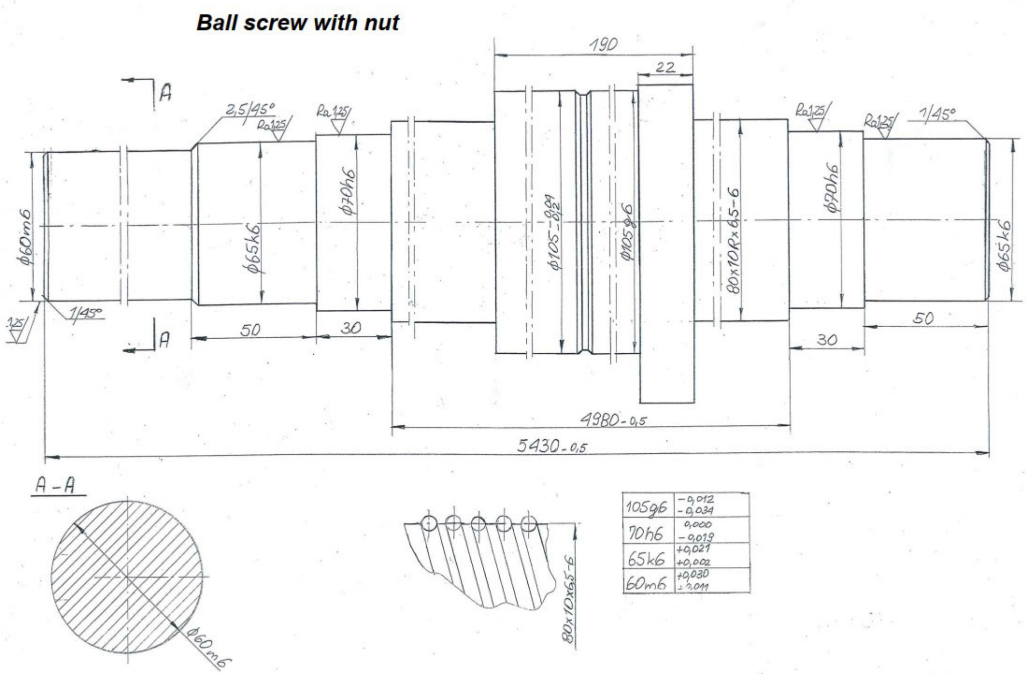

Fig. 4. Rolling screw mechanism (own study)

The active working length of the thread is 4980 mm.

The rolling screw mechanism in Figure 4 was made by the German Company REXROTH at a cost of around 3000 Euro, which was not a large sum.

Both ends of the ball screw have been bearing-mounted and built into the special housings shown in Figure 5.

Due to the considerable length of the ball screw it had to be protected against buckling.

This effect can be achieved by carefully balancing the headstock so that the ball screw is not encumbered by its weight, which is considerable and can amount to several thousand kilograms. The entire weight of the headstock can be adjusted with a counterweight, which is located in the hole of the vertical column and moves with it hanging from a chain.

The active surfaces of the ball circulation in the recirculating screw mechanism are protected from contamination by the use of accordion covers.

In addition to this, these areas need to be lubricated, preferably with a drip. [2]

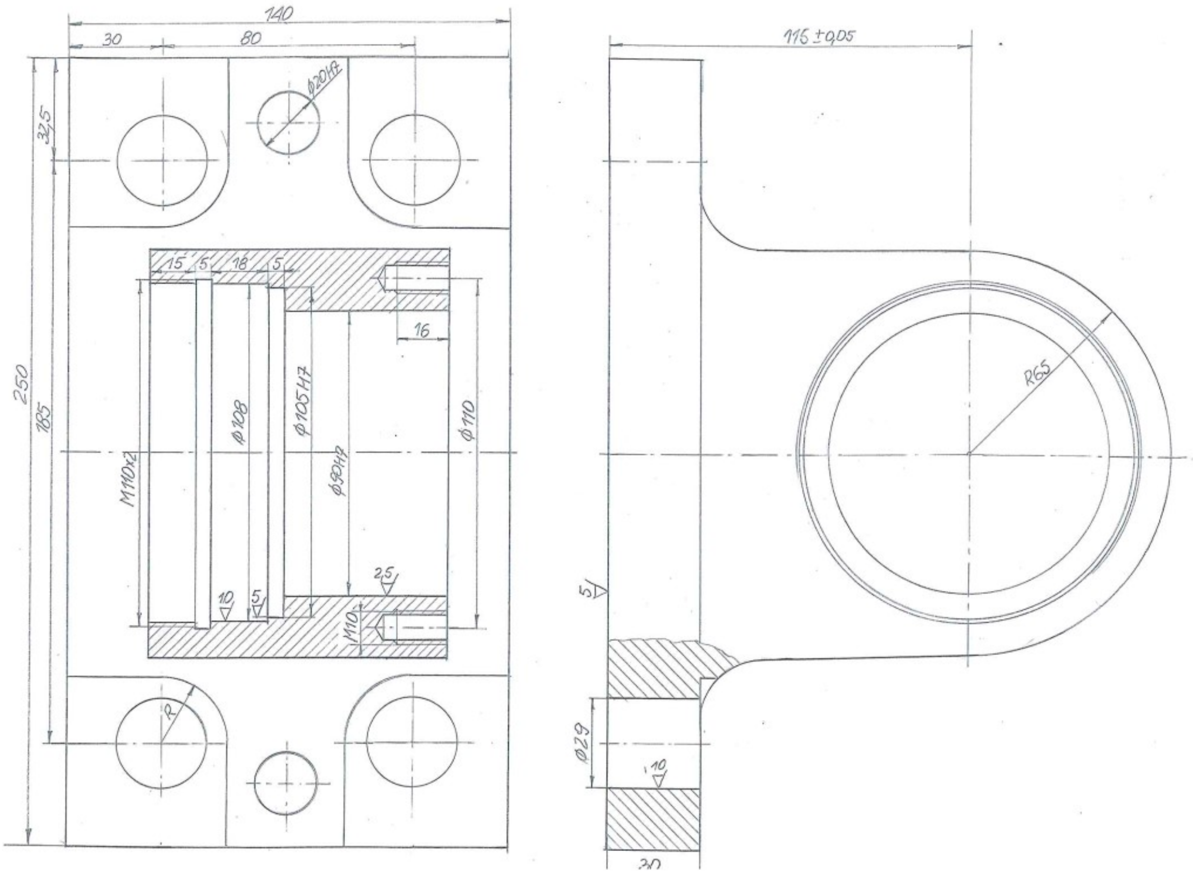

Fig. 5. Bearing housing upper and lower ball screw (own study)

In a rolling screw mechanism, the rotary motion is performed by a ball screw and must therefore be driven.

The ball screw could only be turned in both directions by connecting the drive mechanism, i.e. motor and gearbox, to the upper end of the screw.

The location and attachment of the drive mechanism for the ball screw rotation was made on the final, upper vertical plane of the column. [3]

On the basis of the know power consumption of the previous drive and the ratio, the following ball screw drive mechanism was selected, namely a servo motor with an absolute encoder and a bevel, bevel gearbox, with parameters:

- rated motor speed 3000 min^{-1},
- output speed 203 min^{-1},
- rated motor power 6.79 kW,
- rated motor current 20A,
- rated output memento 407.7 Nm,
- overall gearing 14.05,
- permissible continuous rotation 1900 min^{-1},
- rated motor torque 29 Nm,
- working position EL4.

Fixing the drive to the top of the vertical column involved designing a special body.

In addition, the connection of the ball screw tip to the gearbox was made by means of an additional shaft, which is shown in Figure 6.

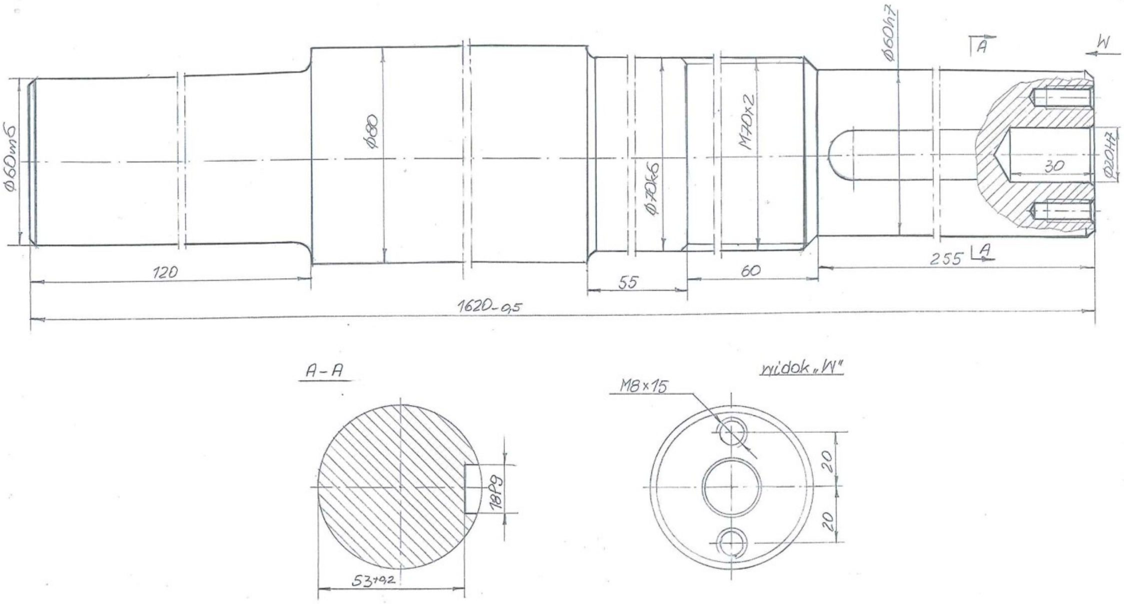

Fig. 6. Ball screw drive shaft (own study)

The mounting body for the ball screw drive, i.e. the gearbox mounting body, has a flanged connection with holes ø14, for M12 screws and is shown in Figure 7.

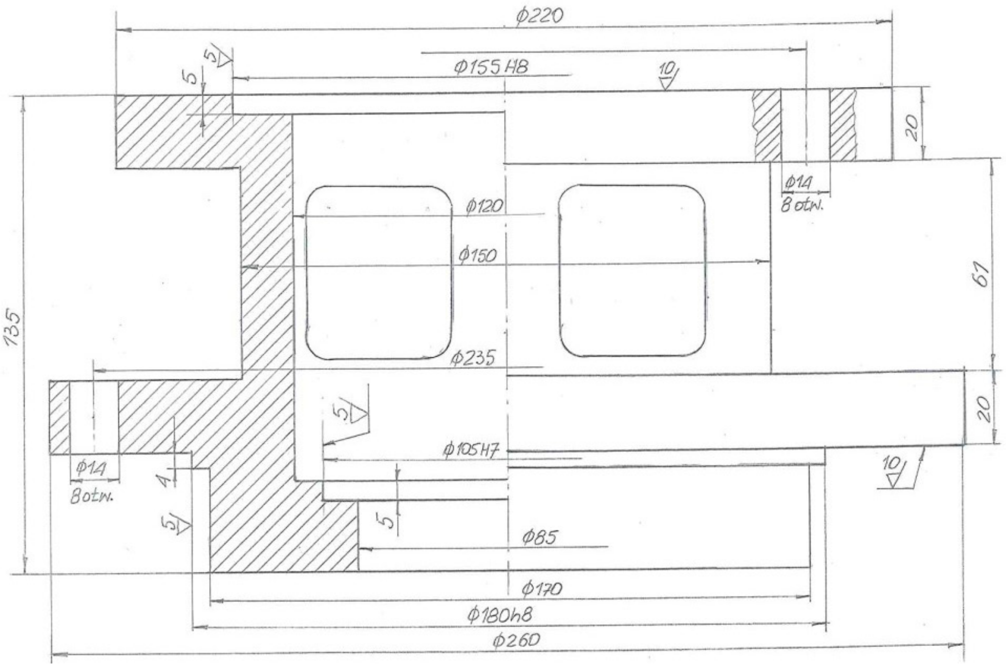

Fig. 7. Drive attachment body (own study)

Figure 8 shows the entire screw and roller mechanism in the "SKODA" drill-milling machine type WD200B.

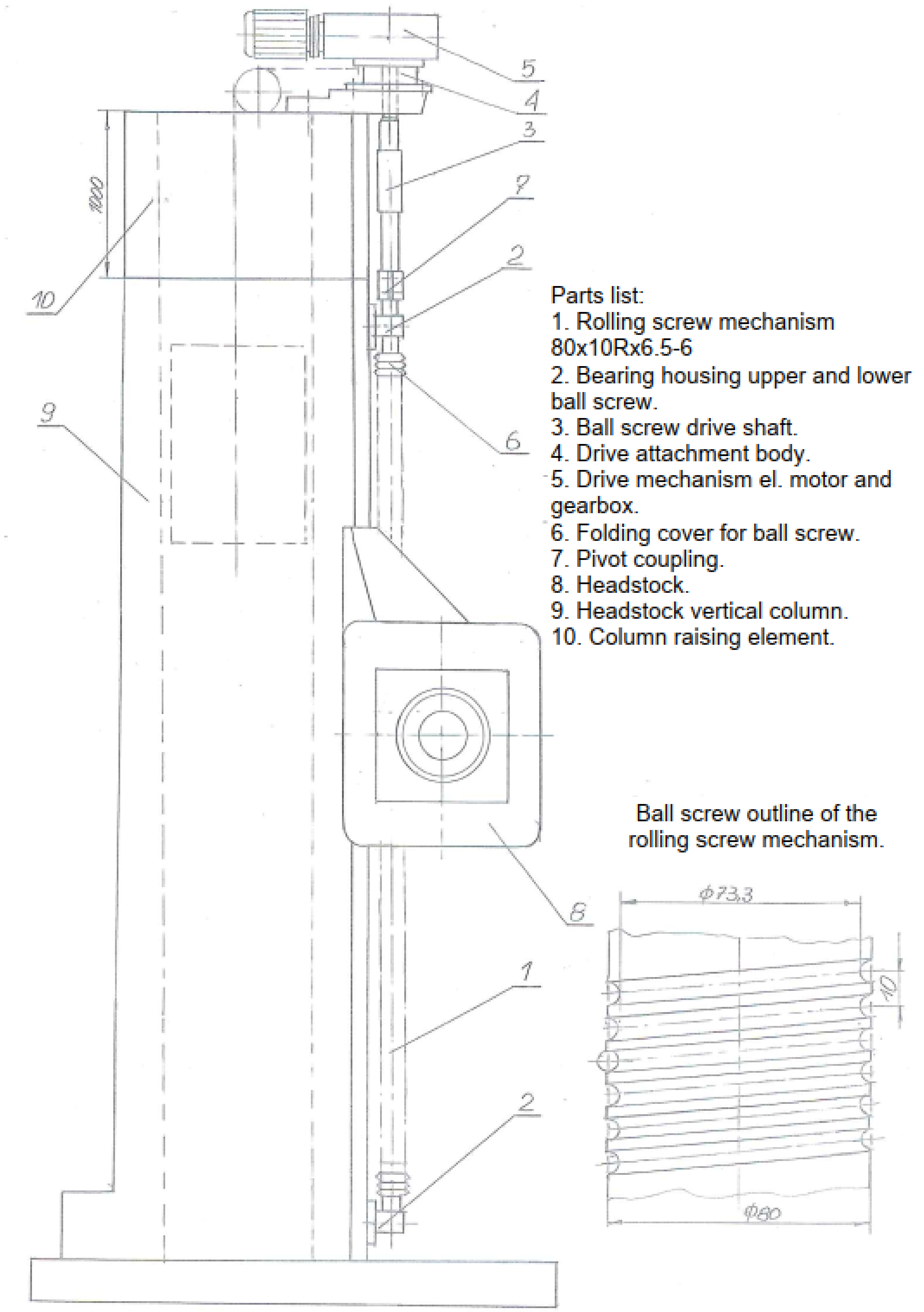

Fig. 8. The rolling screw mechanism in the drilling and milling machine (own study)

In place of the trapezoidal screw its associated metals, a reciprocating screw mechanism was installed, which did not interfere with the factory spindle rotation and quill extension drives, which should also be considered a plus.

4. Measurements and results

The installation of a rolling screw mechanism in the drilling and milling machine was the reason for measuring the positioning of the headstock on the vertical column over the entire travel range, i.e. from 0 to 3800 mm.

The positioning measurements were taken in each case with the same measuring instrument, a Renishaw ML-10 laser interferometer, and by the same hired company.

The measurement parameters of the interferometer are:

– measuring resolution 0.01 µm,
– measuring accuracy 0.1 µm.

Below in the figures are computer diagrams made from the positioning measurements obtained. Positioning was measured in both (+, -) directions with 200mm steps. The final results of the positioning deviations were given after compensating the measuring systems.

In the positioning deviation diagrams, the vertical measurement axis is indicated as "Y".

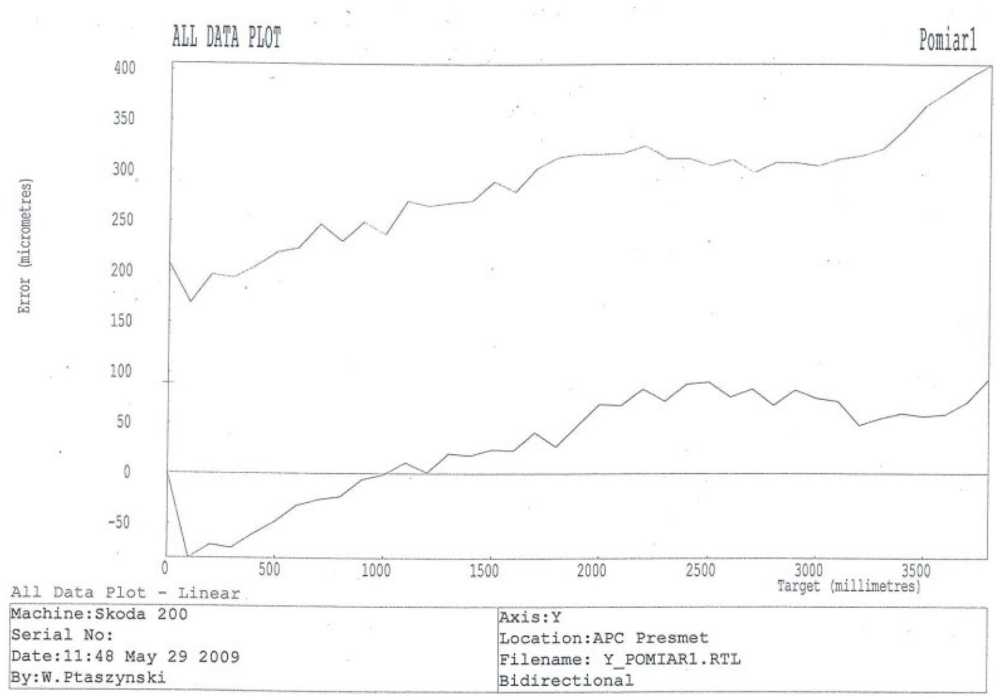

Fig. 9. Graph o Y-axis positioning deviations before compensation made on 29th May 2009 (own study)

This graph shows the result from the first measurement of the positioning deviations after the installation of the screw-roller mechanism. The positioning deviations shown on the chart range from -0.08 to +0.08 [mm]. After compensation of the measuring system, the bi-directional deviation of the Y-axis positioning is +/- 0.04 mm (Fig. 9).

Another positioning measurement was taken on 20.06.2011 (Fig. 10).

The positioning deviations shown in the diagram are within +/- 0.05 mm and the same positioning results are given after compensating the measuring system.

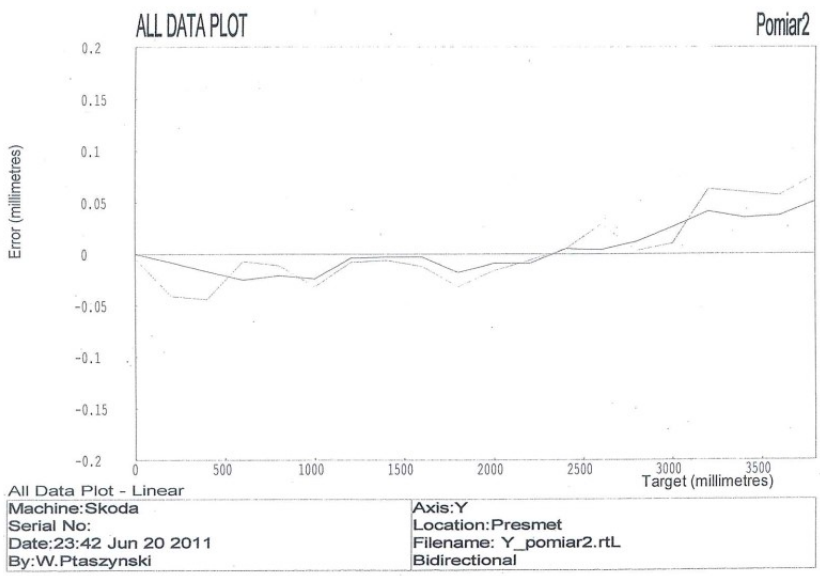

Fig. 10. Diagram of deviations and positioning of axis Y before compensation made on 20.06.2011 (own study)

The next positioning measurement was taken on 18.12.2019 (Fig. 11).

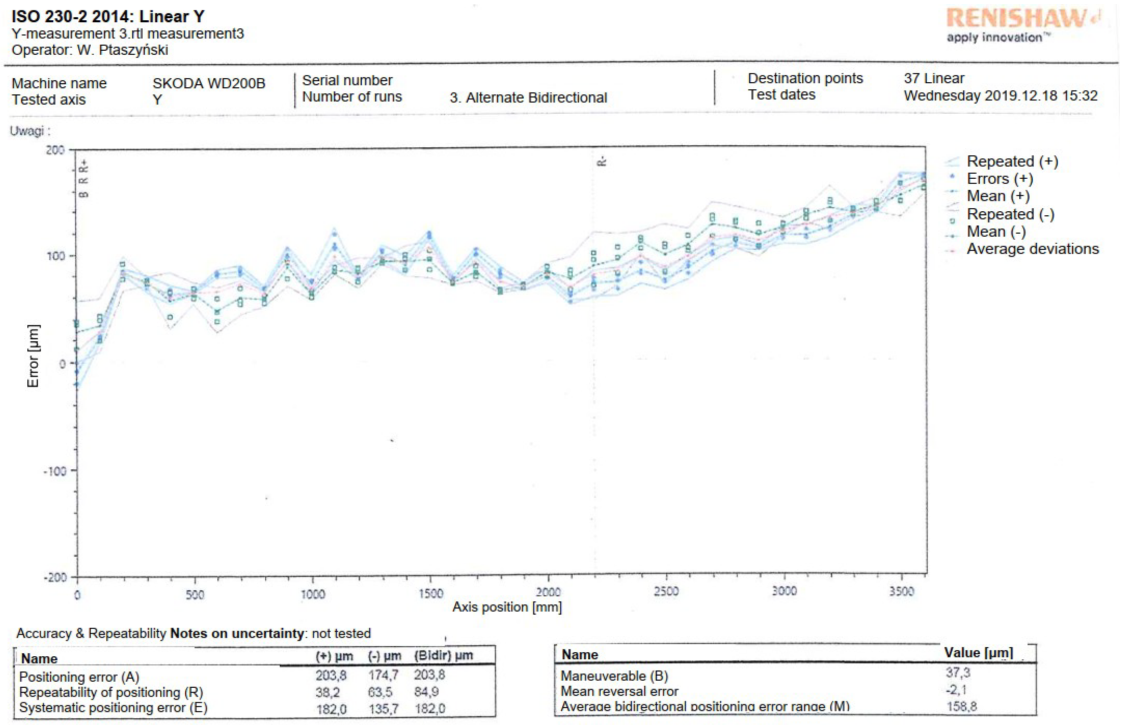

Fig. 11. Graph of Y-axis positioning deviations after compensation made on 18.12.2019 in accordance with ISO-2303 (own study)

Measurement of the positioning accuracy of the Y-axis was carried out in accordance with ISO-230 over a distance of 3600 mm, within the range of movement of the axis in the machine system from Y = 100 mm to Y = 3700 mm with a step of 100 mm, with three measurements in the positive and negative directions.

The key positioning results obtained are:

- bi-directional positioning accuracy A = 204 μm,
- bi-directional positioning repeatability R = 85 μm,
- B axis backlash B = 37 μm.

The number of measurements taken, three in each direction, was based on ISO-230.

5. Conclusions

Drilling and milling machine "SKODA" type WD200B originally equipes with a Tr90x20/2 trapezoidal threaded screw or after the installation of a 80x10Rx6.5-6 screw-rotor mechanism, works continuously in a minimum of two shifts.

Measurements of the positioning deviations of the headstock head were performed on both of the above-mentioned mechanisms.

The table below shows a summary of positioning measurement deviations.

	Type of mechanism			
	Trapezoidal thread screw	Rolling screw mechanism		
Positioning deviation [mm]	0,4	0,04	0,05	0,204
Date of measurement	09.03.2007	29.05.2005	20.06.2011	18.12.2019

The deviations shown were too large, so the gauge measured them in tenths of a mm.

As indicated in the chart, the deviations ranged from ±0.2mm, to a maximum of 0.4mm.

The first measurement of the positioning deviation of the headstock after installation of the rolling screw mechanism was carried out on 29.05.2009.

As the deviations were correspondingly small, they were measured in hundredths of a mm.

The post-compensation measurement on the gauge measured in both directions showed deviations ±0.04 mm.

The next positioning deviation measurement taken on 20.06.2011 was within ±0.05 mm.

A further measurement of the positioning deviations was made on 18.12.2019. This measurement showed a bidirectional positioning accuracy of 204 μm. This measurement showed greater positioning deviations than the previous ones, which arose as a normal phenomenon resulting from wear and tear on the mating parts over the years of use. Even so, these deviations are definitely smaller than those shown by the measurement on the trapezoidal threaded screw.

The results of the positioning measurements after the installation of the rolling screw mechanism showed that there was a significant improvement in the machining accuracy of the above machine tool.

The modernization has proved desirable and fulfilled expectations and is therefore eligible for dissemination, as machine tools manufactured in the 1970s can be upgraded in this way.

Modernization still has the advantage of not being too expensive compared to the price of new machine tools. The demonstrated improvement of the above-mentioned machine tool in terms of positioning can complete with the corresponding performance of new machine tools, which also the aim of this design solution.

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