SYSTEMS FOR THE ADJUSTMENT OF THE MAIN KINEMATIC CHAIN OF THE VERTICAL TURNING LATHES

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Abstract: This paperwork presents some systems for the adjustment of the main kinematic chains of the Vertical Turning Lathes that have been used within the last 20 years. There are presented adjustment systems used when having the machine equipped with older type motors, with only one speed, and also modern systems for which A.C. motors with the speed adjustable by frequency variation are needed. It insists on the present role of the “gearboxes” as torque multipliers and not as speed reducer.

Keywords: vertical turning lathes, gearboxes, adjustment mechanisms.

1. Introduction

The Vertical Turning Lathes are Heavy Machine Tools and initially they were intended for cutting circular workpieces for which the ratio between length and diameter is less than 1, between 0.5 and 0.9. At the beginning they were able to perform only turning. Then, drilling, milling, grinding and gear cutting became possible, especially after the implementation of the CNC equipment on the Vertical Turning and Boring Machines. Because of the vertical position of the main spindle, these machines have rigid kinematic chains that allow heavy machining with a high accuracy and efficiency [1].

The main characteristic of the Vertical Lathes is the diameter of the table or workpiece. Usually, the table diameter is between 1000 mm and 6000 mm. However, there are Vertical Lathes with the table up two 20000 mm [2]. If the Vertical Lathe is for turning only, then the main kinematic chain ensures exclusively the table rotation. If millings, drillings are needed, then the table is driven mostly by the main kinematic chain or by a circular feed kinematic chain [3].

2. Electric motors used for driving the main kinematic chains of the Vertical Lathes

The asynchronous motors were the first motors used for driving the main kinematic chains of the Vertical Lathes [2]. The characteristic curve of the asynchronous motors is shown in Figure 1. The figure indicates: A – motor idle running starting point, B – motor idle running starting point, when connected to the main kinematic chain, C – maximum torque and speed point. Useful are can be defined as BCED.

For these motors the adjustment mode of the speed results from the following relation:

\[ n = \frac{60 \cdot f}{p} \cdot (1 - s) \quad [\text{rpm}] \]  

(1)

The notation in the relation (1) represents: \( n \) – speed [rpm]; \( f \) – frequency of the mains [Hz]; \( p \) – number of pole pairs of the stator coil [-]; \( s \) – slip [-]. The speed adjustment by slip variation [2] implies unwanted speed variations and poor efficiency.

The number of pole pairs is usually \( p = 1 \) or \( p = 2 \), and thus, it can be considered practically that the motor has two speeds. Usually, the power corresponding to the upper speed is by 20% smaller than the one corresponding to the lower speed.

This method does not satisfy the operational requirements, imposing complicated gearboxes as shown further. Initially, the speed adjustment by frequency variation (using frequency converters) represented a complicated and very expensive solution.
The reasons presented above have led to the driving by using DC motors. That had been the solution preferred by the manufacturers until 90’s. Meanwhile, the development of the frequency converters and the decrease of their price have brought back the attention on asynchronous electric motors, this time with electronic adjustment of the speed by actuating continuously the frequency. The characteristic curves of the DC motors and asynchronous motor with frequency adjustments look like those in Figure 2.

An adjustment at constant maximum torque is made until reaching the rated speed \([3]\), then, above this value, the adjustment is made at constant power. For the Vertical Lathes, especially for rough machining, the machining at constant torque is usually preferred, i.e. with speeds smaller than the rated speed. For fine cutting and depending on each machine type, machining at constant power is possible.

Between the rated torque \(M_{\text{NOM}}\), rated speed \(n_{\text{NOM}}\) and rated power \(P_{\text{NOM}}\) there is the following relation:

\[
M_{\text{NOM}} = 9550 \cdot \frac{P_{\text{NOM}}}{n_{\text{NOM}}} \quad \text{[Nm]}
\]  \(\text{(2)}\)

For machining on a Vertical Lathe, the kinematic chain must ensure at its output an established speed and sufficient torque for the required cutting. Usually, the rated speed and the maximum speed are much higher then the required value and the required torque is much bigger than the one developed by the motor. This is the reason of using the gearboxes. In the beginning they were used just for reducing the speed mechanically. After the development of the adjustment with speed converters, the gearboxes have been used as torque multipliers, after having been modified and simplified by the technical evolution.

3. Mechanical systems for the adjustment of the speed and torque on Heavy Vertical Lathes

These systems that are usually named gearboxes vary on machine-tool size and field of application and on the manufacturer, as well. They can have horizontal or vertical shafts. The horizontal shafts gearboxes are older and simpler solutions which do not affect the working
area. Because of the horizontal shafts, a group of bevel gears is needed for driving the main spindle and that induces uncontrollable backlashes and specific noise.

The gearboxes with vertical shafts are more complicated and imply the usage of some systems for securing the vertical sliding gears, and they are close to the working area. However, they do not need bevel gears and therefore the backlash and the noise are removed.

Figure 3 represents the kinematic diagram of an older Vertical Lathe, with horizontal gearbox. The electric AC motor EM has a single speed. For the adjustment the gearbox has a sliding gear with three positions and two sliding gears with two positions, ensuring seven speed steps. The kinematic chain includes a belt reducer (235/385) and the final mechanism – pinion crown gear (18/113), as well. There are five shafts in the gearbox.

Figure 4 represents the kinematic diagram of the gearbox of a Vertical Lathe with 6000-mm table diameter, manufactured before 1960.

![Fig. 3. EM – driving electric motor, T_M, \( n_M \) – motor torque and speed, T_MS, \( n_{MS} \) – main spindle torque and speed](image1)

![Fig. 4. EM – driving electric motor, T_M, \( n_M \) – motor torque and speed, T_MS, \( n_{MS} \) – main spindle torque and speed](image2)

The electric motor is mounted vertically, without belt transmission. The gearbox has four steps ensured by means of two double clutches, to the shafts II-III and IV-V. The solution with clutches is simpler from constructive point of view.

For larger size machine-tools, with table diameter over 6000 mm, some manufacturers of Vertical lathes use two motors – each with its own gearbox – to develop the required power. The synchronization of the motion is made electronically. Figure 5 shows the kinematic diagram of a vertical gearbox manufactured at present by an European company.

The electric motor is an AC motor with frequency converter, rated power 100 kW, rated torque 636 Nm at a rated speed of 1500 rpm. Maximum speed is 4500 rpm. The speeds ensured at the main spindle are \( n_{MS} = 0.27 -33.65 \) rpm, while those for the adjustment of the motor are \( n_M = 50 – 1500 \) rpm. These are adjustments in the range of constant torque. In the range of constant power \( n_{MS} = 100 \) rpm can be reached. This machine has milling capabilities as well, the main kinematic chain becoming a circular feed kinematic chain [4]. The Vertical Lathes with table diameter within 1200 mm – 4000 mm made in Romania for the last 20 years have been equipped very often with gearboxes with three speed ranges (1:1, 1:3 and 1:9). The related kinematic diagram is presented in Figure 6. It shows the variant used for SC 17, with a pinion – crown gear mechanism with the transmission ratio 20:217. It is a compact box, with only three shafts, out of which two are coaxial.
The actuation of the 3-position sliding gear is hydraulically achieved. The motor is connected directly to the gearbox, the output being on the same direction. The 21-tooth bevel pinion transmits the motion to crown gear pinion through a shaft named secondary shaft.

The gearbox and the secondary shaft just above equip at present Conventional and CNC Vertical Lathes. They are characterized by a high reliability on condition of rational exploitation. Some of the disadvantages are: specific noise – especially when operating in the speed range 1:3 and high backlashes. Because of the backlash, it cannot be used within the circular feed kinematic chains required by the machines provided with milling head. Such cases require a separate kinematic chain [4].

A modern solution for the brand new or refabricated Vertical Lathes is represented by two-step gearboxes made by specialized companies for machine-tools [5], [6]. They have the following advantages: reduced backlashes allowing their usage on Vertical Lathes able to perform milling, eliminating the circular feed kinematic chain; separate lubrication line, which reduces heat transmission to the main spindle; connection to the main spindle through belt transmission, preventing vibration; reduced noise; simple and compact design with direct connection to the main driving motor; high efficiency, over 95%; speed change is made through a device integrated in the gearbox, electrically, pneumatically or hydraulically actuated.

The kinematic diagram of such gearbox, with the transmission ratio 1-1 and 1-4 is shown in Figure 7. The electric motor 1 – EM is connected directly to the gearbox 2 – GB. The motor shaft drives the gear 3. If the sliding clutch 4 is put on step I, through the holes a, the motion reaches the planetary gears 6 and then the output shaft 7. The gear 9 is locked. This is the step that ensures the ratio 1-4 [6]. If the sliding clutch is on position II, in holes b, the planetary gears 6 and the gear 9 ensures the ratio 1-1. 5 and 8 are bearings systems. The motion from the gearbox output shaft is transferred to the main spindle trough pinion-crown gear or belt mechanisms. This solution removes heat transfer and vibration. Because of their design, these gearboxes look like an extension of the electric motors. They could operate in any position provided that the lubrication is ensured according to the gearbox manufacturer recommendation.
These gearboxes have reduced noise and backlash and as a consequence they can be incorporated within the feed kinematic chains. There have been manufactured Vertical Lathes with two-speed gearboxes instead of three-speed gearboxes as those presented in Figures 7-10. For the same main driving motor, asynchronous with frequency converter, there is no difference with respect to speed adjustment; however the two-speed gearbox is to be preferred. Problems can occur regarding the developed torque: the maximum reducing ratio is 1:4 for the two-speed gearbox, while for the three-speed gearbox is 1:9.

For example, it is considered the driving by a motor with the following parameters: \( n_{\text{NOM}} = 1500 \) rpm, \( P_{\text{NOM}} = 37 \) KW, \( T_{\text{NOM}} = 236 \) Nm [7]. The characteristics in Figure 8 are obtained at the output of the three-speed gearbox. The maximum torque developed is 2124 Nm up to a speed of 166.6 rpm, 708 Nm up to 500 rpm and 236 Nm up to 1500 rpm. When using a two-speed gearbox for the same motor, the characteristic curve in Figure 9 is obtained. The maximum developed torque is only 944 Nm for a speed up to 375 rpm and 236 Nm for a speed up to 1500 rpm.

Depending on the machine-tool kinematic features and machining needs, the following variants result: developed torque is sufficient (no rough machining on hard materials); other reducing mechanisms are incorporated [4]; selection of a more powerful motor (bigger torque) [6].

Two-speed gearboxes have become a commonly used solution for the Vertical Lathes SC14 and SC17, when keeping the secondary shaft – see the kinematic diagram in Figure 10.

The electric motor is mounted vertically, on the same axis with the gearbox. A special timing belt (usually made of carbon fiber) takes the motion from the gearbox and transfers it to the secondary shaft, without needing bevel transmission. Only the pinion driving the crown gear is kept from the secondary shaft. The motion transferred from the electric motor to the secondary shaft is backlash free, but the classic pinion-crown gear mechanism presents backlash values that are not acceptable for the feed kinematic chain. If the machine performs milling operation, then pinions with backlash compensation [4] or a kinematic diagram as the one in Figure 11 can be used.
4. Conclusions

The development of the electronic adjustment systems with frequency converters has mechanically simplified the mechanisms and adjustment systems in the main kinematic chains of the Vertical Lathes.

The adjustment of the main kinematic chain is made for technological processing reason: speed and cutting torque, as well. The gearboxes are theoretically no longer necessary for the adjustment of the speed. However, if the gearboxes were not be used, then the driving motors would be oversized and very expensive.

Technically and economically, the two-speed gearboxes, with electric shifting of the speed range, made by specialized companies, represent an advantageous solution for the manufacturing or refabrication of the Heavy Vertical Lathes, mostly for the CNC ones.

References