

Modernization of CNC Milling Machines

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Received January 20, 2026; revised March 18, 2026; accepted May 5, 2026

Abstract—This article describes the features of modernization of CNC milling machines by replacing the main drive motor, which significantly simplifies the machine configuration, makes the machine more accurate, and greatly simplifies assembly and operation.

Keywords: CNC milling machine modernization features, main drive, machine configuration

DOI: 10.3103/S0967091226701457

INTRODUCTION

This vertical, normal-precision cantilever machine is designed for multi-operation machining of complexly shaped parts made of steel, cast iron, non-ferrous, and light alloys in a closed, semi-automated cycle. In addition to milling operations, the machine can also perform drilling, countersinking, reaming,

and boring of precision holes connected by coordinates, as well as thread cutting. This machine can be used in both custom and serial production. A general view of machine is shown in Fig. 1.

The cantilever machine' layout with a vertically movable, a slider moving according to the program and a longitudinally and transversely movable table is shown in Fig. 2.

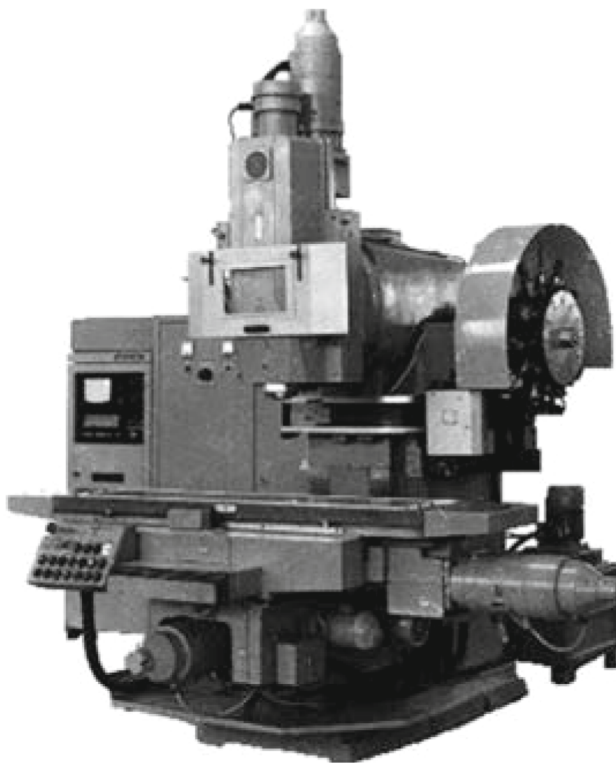


Fig. 1. General view of machine model GF2171S5.

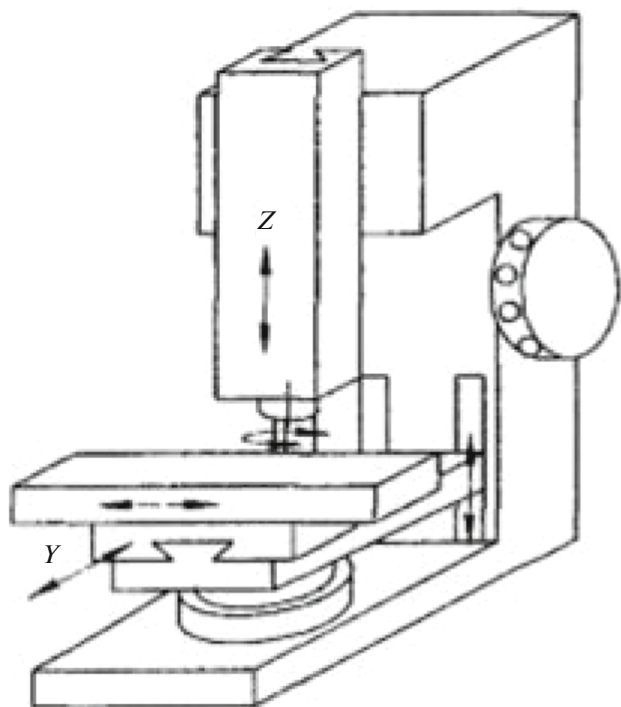


Fig. 2. Layout of the machine model GF2171S5.

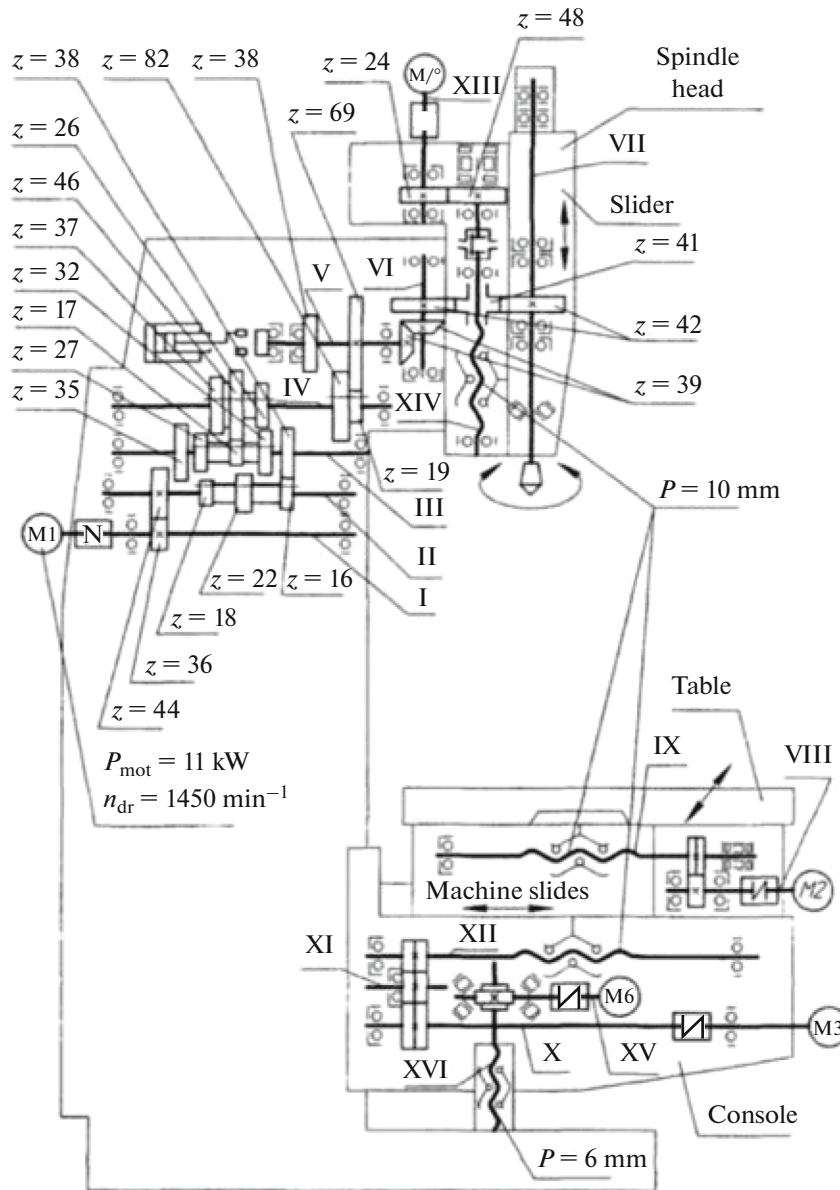


Fig. 3. Kinematic diagram of machine model GF2171S5.

MATERIALS AND METHODS

The main drive is driven by an M1 asynchronous electric motor through a gearbox providing 18 spindle speeds. The feed drives are driven by high-torque M2, M3, and M4 electric motors (Fig. 3). The vertical (setting) movement of the console is driven by an M5 electric motor.

Additional machine features:

- Manual control of coordinate movement from a remote handwheel;
- Connection of a SONDI 3D measuring probe;
- Ability to input process programs from FD 3.5 floppy disks;

— Storage of process programs on a hard disk with a capacity of 5 to 20 GB.

GF2171S5 machine technical specifications are listed in Table 1.

In the CNC machine modernization plan, a variable-speed motor has been proposed instead of an asynchronous motor. On CNC milling machines, both those close to machining centers and those actually machining, the two- and three-speed asynchronous motors are used as the main drive. When combined with a gearbox with electromagnetic clutches, they provide the required spindle speeds. The disadvantage of such drives is the gearbox' large size, its complexity, and low reliability. Furthermore, the

Table 1. Technical characteristics of the machine model GF2171S5

Accuracy class according to GOST 8–82	H
CNC device model	2S45-65
Number of controlled coordinates	3/2
The number of simultaneously controlled coordinates during linear/circular interpolation	2
Minimum and maximum distance from the spindle nose to the table, mm	500
Distance from the spindle axis to the vertical guides of the bed (reach), mm	850 × 250 × 380
Maximum dimensions of processed surfaces (length × width × height), mm	400
Dimensions of the table working surface (length × width), mm	1600 × 400
Number of T-slots, dimensions of T-slots	3
Maximum longitudinal movement of table (<i>X</i>), mm	1010
Maximum transverse movement of table (<i>Y</i>), mm	400
Maximum vertical movement of table (installation) (<i>Z</i>), mm	250
Maximum travel of slider (<i>Z</i>), mm	260
Limit of working feeds of table and slider, mm/min	3–6000
Rapid travel speed of table (<i>X</i> , <i>Y</i>)/slider (<i>Z</i>), mm/min	7000
Permissible feed force along the <i>X</i> and <i>Y</i> coordinates, N	15690
Permissible feed force along the <i>Z</i> coordinate, N	9806
Positioning accuracy, mm	0.015
Spindle speed, rpm (number of stages)	18
Number of spindle speeds	0.615
Maximum torque, kN m	50
Spindle output speed series coefficient	1.26
Tool magazine capacity	12
Tool change time, s	20
Maximum diameter of face mill, mm	125
Maximum diameter of end mill, mm	40
Maximum drill diameter, mm	30
Maximum tool weight, kg	15
Tool reach from spindle nose, mm, no more than	250
Main drive electric motor, kW (rpm)	7.5 (1450)
Feed drive electric motors HG-112B, HG-112C (<i>X</i> , <i>Y</i> axes), N m	17
Electric motors for the HG-112C slider feed drive (<i>Z</i> axis), N m	23
Electric motor for adjusting console movement, kW (rpm)	2.2 (1450)
Electric motor of the hydraulic station, kW (rpm)	2.2 (1450)
Lubrication pump electric motor, kW (rpm)	0.27 (1500)
Electric coolant pump, power, kW	0.12 (2800)
Coolant pump capacity, L/min	8
Type of hydroelectric power station	5AG48-22N
Machine dimensions (length, width, height), mm	3680 × 4170 × 3150
Machine weight, kg	6580

number of rotational speeds does not meet the optimal cutting speed requirements for machining centers and CNC milling machines. Of the wide variety of main drive methods used for machining centers, the following are used: gear shifting using sliding gears and their blocks; a mixed shifting scheme using sliding and replaceable gears; shifting using electromagnetic clutches; varying the spindle speed using multi-speed motors and electromagnetic clutch switching; stepless control of AC motors by varying the supply frequency; stepless control of DC motors and gear unit switching; a combined system consisting of a DC motor, gear units, and toothed belt transmission. To meet all the requirements for main drives, it is necessary to use a thyristor-controlled speed control method using a DC motor and gear unit switching in a gearbox. A combined machine drive combines a stepped gearbox and a variable-speed motor with thyristor or frequency control. The most common drives consist of a stepped gearbox and a DC motor with thyristor control [1–3].

Drive adjustment range [1]:

$$R_{dr} = R_{mot} \cdot R_{box},$$

where R_{mot} is the motor control range; R_{box} is the gearbox control range.

It follows from this that the motor is the main group, and the gearbox is the first overhaul group, for which the denominator of the series is $\phi_{box} = R_{mot} \cdot \phi$ [1–3].

We determine the maximum spindle speed [1–3]:

$$n_{spind(max)} = R_{mot} \cdot n_{spind(min)},$$

where $R_{dr} = 90$ is the drive control range; $n_{spind(min)} = 40 \text{ min}^{-1}$ is the minimum spindle speed.

Then:

$$n_{spind(max)} = 90 \times 40 = 3600 \text{ min}^{-1}.$$

We determine the motor power [1–4]:

$$P_{mot} = \frac{P_{eff}}{\eta},$$

where $P_{eff} = 8 \text{ kW}$ is the effective cutting power (according to the task); η is the drive efficiency.

To calculate the motor power, we roughly take the drive efficiency to be equal to $\eta = 0.80\text{--}0.85$ [1–4], we take $\eta = 0.80$.

Therefore,

$$P_{mot} = \frac{8}{0.80} = 10 \text{ kW}.$$

An engine of the 2PN200L type is selected [2], for which $P_{mot} = 11 \text{ kW}$; $n_{mot(max)} = 3000 \text{ min}^{-1}$ is the maximum engine speed at constant power; $n_{mot(nom)} = 750 \text{ min}^{-1}$ is the nominal engine speed at constant power; $d_{1mot} = 48 \text{ mm}$ is the motor shaft output end' diameter [2].

We determine the motor' regulating range at constant power [1–5]:

$$R_{mot(reg)} = \frac{n_{mot(max)}}{n_{mot(nom)}},$$

$$R_{mot(reg)} = \frac{3000}{750} = 4.$$

We determine the gearbox control range [1–5]:

$$R_{box} = \frac{R_{dr}}{R_{mot(reg)}},$$

$$R_{box} = \frac{90}{4} = 22.5.$$

We determine the number of gearbox speeds [1–3]:

$$z = \frac{\log R_{dr}}{\log R_{mot(reg)}},$$

$$z = \frac{\log 90}{\log 4} = 3.25.$$

We accept $z = 3$.

To select the denominator of series ϕ , you can use the following recommendations [1]: for lathes and screw-cutting lathes $\phi = 1.26$; for turret lathes, depending on the processing diameter $\phi = 1.41$ and $\phi = 1.58$; for drilling machines of all types with a drilling diameter of more than 18 mm $\phi = 1.41$; for milling machines of all types $\phi = 1.26$; for multi-operation machines $\phi = 1.26$ and $\phi = 1.41$.

We accept $\phi = 1.26$.

We determine the value of c [1–3]:

$$c = \frac{\log R_{mot(reg)}}{\log \phi}, \quad c = \frac{\log 4}{\log 1.26} = 5.99.$$

We accept $c = 6$.

We determine the number of intervals $\log \phi$ that intersect the rays depicting the last group' gears on the rotation frequency graph [3]:

$$K_m = \frac{\log R_m}{\log \phi} = \frac{\log R_g}{\log \phi},$$

where R_m , R_g is the range of regulating of gear groups.

Since the box has one group, then according to [3]:

$$K_m = \frac{\log R_{box}}{\log \phi}, \quad K_m = \frac{\log 22.5}{\log 1.26} = 13.52.$$

Round up to $K_m = 14$.

However, when $\phi = 1.26$, the number of intervals $\log \phi$ that intersect the rays representing the gears of group on the rotation frequency graph cannot exceed 9 [3]. Therefore, we adopt $K_m = 9$. The remaining 5 intervals can be obtained by regulating the engine in the constant torque zone.

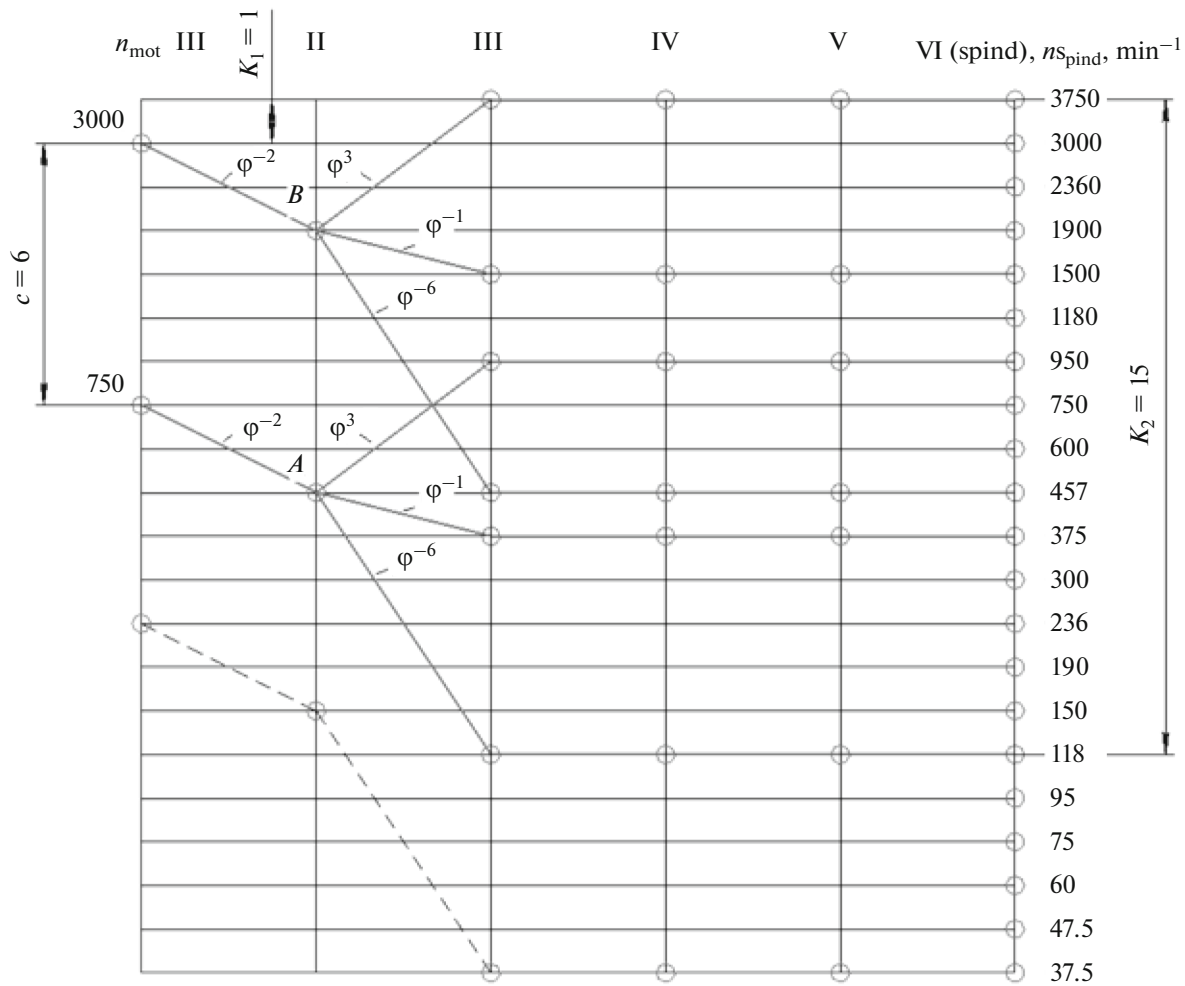


Fig. 4. Spindle speed graph.

We determine the actual control ranges of the gearbox and the drive as a whole [4–7]:

$$R_{\text{box(actual)}} = R_j \cdot \varphi^{K_m}, \quad R_j = R_a R_b \dots R_{m-1} = R_N^\varepsilon,$$

where R_j is the adjustment range on the last shaft,

$$\varepsilon = (p_a - 1)x_a + (p_b - 1)x_b + \dots + (p_{m-1} - 1)x_{m-1},$$

$$R_{\text{dr(actual)}} = R_{\text{mot(reg)}} \cdot R_{\text{box(actual)}}.$$

The actual control range of the box $R_{k(\text{actual})} = R_a \varphi^{K_m}$; in our case $R_a = 1$, $\varphi = 1.26$, $K_m = 9$, therefore,

$$R_{\text{box(actual)}} = 1\varphi^9 = 1 \times 1.26^9 = 8 \text{ [3]}.$$

Then, the drive control range can be determined as follows:

$$R_{\text{dr(actual)}} = 4 \times 8 = 32.$$

We determine the number K_1 of intervals between the maximum spindle speed and the maximum engine speed, as well as the number K_2 of intervals between the maximum and minimum spindle speeds [3]:

$$K_1 = \frac{\log(n_{\text{mot(max)}}/n_{\text{mot(max)}})}{\log \varphi}, \quad K_2 = \frac{\log R_{\text{dr(actual)}}}{\log \varphi}.$$

The calculated values K_1 and K_2 are rounded to the nearest higher integer [3].

Hence,

$$K_1 = \frac{\log(3000/3600)}{\log 1.26} = 0.83,$$

we accept $K_1 = 1$.

$$K_2 = \frac{\log 32}{\log 1.26} = 14.996,$$

we accept $K_2 = 15$.

We determine the total number of intervals [1–3]:

$$K_{\text{total}} = K_2, \quad K_{\text{total}} = 15.$$

Therefore, the spindle speed graph should have 16 horizontal lines, with an interval equal to $\log 1.26$, for the motor operating range at constant power.

To ensure that the spindle speed is regulated at constant power throughout the entire range, it is necessary to ensure, when plotting the speed graph, that the control range in the next group is always smaller than on the previous shaft [5–8].

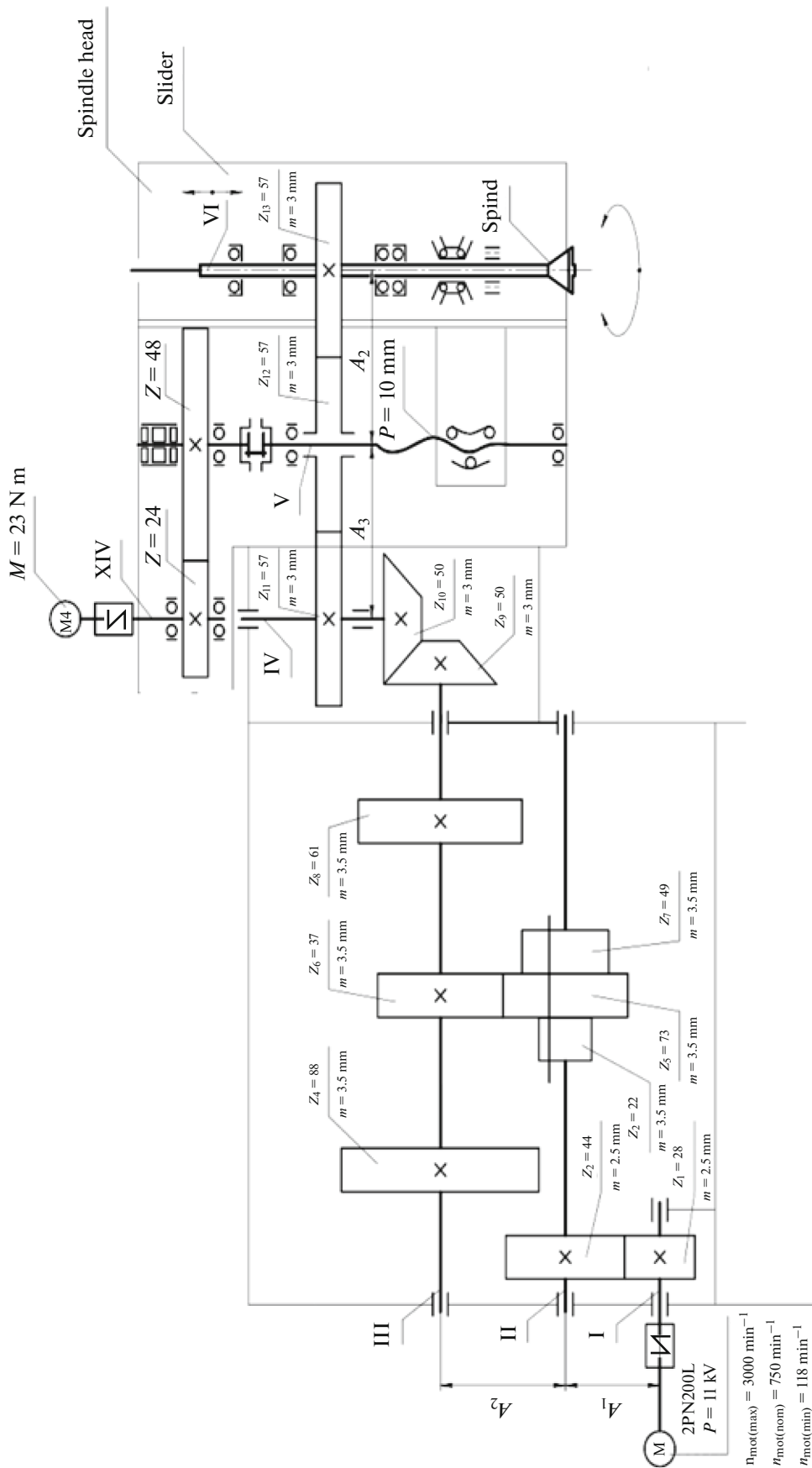


Fig. 5. Kinematic diagram of machine' main movement drive.

In accordance with [1, 4], we select a series of spindle speeds for the GF2171S5 machine in the following range: 3750; 3000; 2360; 1900; 1500; 1180; 950; 750; 600; 475; 375; 300; 236; 190; 150; 118 and plot the speed graph (Fig. 4) in the following order.

On the vertical scale, we mark the point of maximum spindle speed $n_{\text{spind}(\max)} = 3750 \text{ min}^{-1}$ and count $K_2 = 15$, determining the point $n_{\text{spind}} = 118 \text{ min}^{-1}$.

From this point, draw a line 6 intervals up the shaft II to point *A* (point $n_{\text{spind}} = 475 \text{ min}^{-1}$). There are nine intervals in total corresponding to the group's adjustment range. Therefore, from point *A*, we draw a line three ($9 - 6 = 3$) intervals up to the point corresponding to the spindle speed $n_{\text{spind}} = 950 \text{ min}^{-1}$. Next, the group's adjustment range is divided in half (in our case, four and five intervals), i.e., we draw a line from point *A* to point $n_{\text{spind}} = 375 \text{ min}^{-1}$. Then, from point *A*, we plot $c = 6$ intervals up along line II, and obtaining point *B*. From point *B*, we draw rays parallel to the rays drawn from point *A*.

Then, we connect points *A* and *B* with the points corresponding to the maximum and nominal engine speeds, and finally, from the nominal engine speed point, we plot two intervals, drawing lines parallel to the lines and rays exiting from point *A*. This defines the drive's operating zone for constant-torque control:

$$\begin{aligned} n_{\text{spind}} &= 95 \text{ min}^{-1}, \quad n_{\text{spind}} = 75 \text{ min}^{-1} \\ n_{\text{spind}} &= 60 \text{ min}^{-1}, \quad n_{\text{spind}} = 47.5 \text{ min}^{-1}, \\ n_{\text{spind}} &= 37.5 \text{ min}^{-1}. \end{aligned}$$

Figure 5 shows the kinematic diagram of the main drive of machine tool of the basic model GF2171S5 (z is the number of teeth on the wheels).

CONCLUSIONS

Multi-purpose CNC machine' modernization proposed significantly simplified the gearbox, making the machine more precise, reliable, and significantly easier to assemble and operate.

FUNDING

This work was supported by ongoing institutional funding. No additional grants to carry out or direct this particular research were obtained.

CONFLICT OF INTEREST

The author of this work declares that he has no conflicts of interest.

REFERENCES

1. GOST (State Standard) 8–82: *Metal-Cutting Machine Tools*, 1983.
2. Skryabin, V.A. and Pavlova, Zh.V., Modernization of a portable machine for grinding and lapping the sealing surfaces of gate valves in pipeline fittings, *Remont. Vostanovlenie. Modernizatsiya*, 2015, no. 2, pp. 8–13.
3. Skryabin, V.A., Sorokina, N.V., and Vikhoreva, A.S., Features of modernizing multi-purpose CNC machines, *Steel Transl.*, 2026, vol. 56, no. 3, p. 237. <https://doi.org/10.3103/S0967091226700816>
4. Skhirtladze, A.G., Skryabin, V.A., and Boriskin, V.P., *Tekhnologicheskoe oborudovanie mashinostroitel'nykh proizvodstv* (Process Equipment for Machinery Manufacturing Plants), Stary Oskol, Belgorod oblast: TNT, 2013.
5. Skhirtladze, A.G., Skryabin, V.A., and Boriskin, V.P., *Remont tekhnologicheskikh mashin i oborudovaniya* (Repair of Process Machinery and Equipment), Stary Oskol, Belgorod oblast: TNT, 2011.
6. Starodubov, V.S., Improving the accuracy of metal-cutting tools with numerical control, *Russ. Eng. Res.*, 2000, vol. 20, no. 5, pp. 27–32.
7. *Proektirovanie avtomatizirovannykh stankov i kompleksov. Uchebnik v 2 t.* (Design of Automated Machine Tools and Systems: A Textbook in 2 Volumes T. 2), Chernyanskii, P.M., Ed., Moscow: Moskovskii Gosudarstvennyi Tekhnicheskii Universitet im. N.E. Bauman, 2012.
8. Skhirtladze, A.G. and Skryabin, V.A., *Remont tekhnologicheskogo oborudovaniya. Uchebnik* (Repair of Process Equipment: A Textbook), Moscow: Infra-M, 2018.

Translated by V. Selikhanovich

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