

RE-DESIGNING THE KINEMATIC CHAINS OF THE MACHINE - TOOLS FROM THE PERSPECTIVE OF THE SUSTAINABLE DEVELOPMENT. MAIN KINEMATIC CHAIN

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In cadrul lucrării se prezintă construcția și metodologia de calcul a lanțului cinematic principal de la mașinile-unelte moderne, abordate din perspectiva dezvoltării durabile. În conceperea și proiectarea noilor serii de mașini trebuie să se ia în considerare cu prioritate consumul de materiale. Acest tip de lanțuri cinematice se bazează pe două componente: motorul electric de turație reglabilă și cutia de viteze cu mecanism planetar. Soluția prezentată poate fi folosită la mașinile noi, dar și în cazul refabricării mașinilor-unelte vechi.

The paper presents the construction and the calculation methodology of the main kinematic chain of modern machine-tools, approached from the perspective of sustainable development. When contriving and designing new series of machine-tools one should consider among priorities the consumption of materials. This kind of kinematic chain is based on two components: the electric motor with variable speed and the planetary gearbox. The technical solution presented herein can be applied to new machines and also when refabricating old machine-tools.

Keywords: sustainable development, machine-tools, re-designing

1. Introduction

Sustainable development, viable and sustained ecologically, is that development that meets the needs of the present time without altering the capability of the next generation to satisfy its own needs. Sustainable development is the necessity of integrating economic objectives with the ecological and environment protecting ones [1].

If, until now, the machine-tools have been thought and manufactured as means of production accelerating the progress and the civilization, without taking

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into consideration the impact with the environment, this practice is no longer possible without risks for the next stages of their development.

The present stage of environment degradation and the perspective of its aggravation impose reconsidering the contriving and exploitation conditions for these products and also analyzing their impact with the environment.

Under these circumstances, the impact with the natural environment should be included among the main factors to be considered when designing, manufacturing and exploiting the machine-tools and machineries.

Although there are no methods of quantifying the impact with the environment through material consumption, the result of reducing the material consumption over the global costs is relevant.

Therefore, the minimization of material consumption is one of the trends of the eco-design. This trend is known among the present researches as dematerialization action.

The number of the mechanical components within the structure of a machine determines substantially its total weight and consequently, the consumption of material. The kinematic chains reflect this the most.

A way to reduce material consumption is to obtain the same movements of the tool or of the work-piece by using kinematic chains with the less possible number of components that transmit, adjust and transform the motions required for generating the surfaces.

Using specific driving motors has allowed to a great extent the removal of the mechanical mechanism used for the adjustment of the kinematic chains (gearboxes and feedboxes) [2].

The mechanical mechanisms for the discreet adjustment of the cutting speed, even for the case of a reduced number of steps, increase the weight and size of the machines without ensuring optimal values for the cutting parameters.

Speed losses, low energetic efficiency and high consumption of material for the manufacturing of the gearboxes are the main reasons that have determined reconsidering the way of adjusting the kinematic chains.

There have been designed and put into operation machine-tools having the driving motor directly connected with the main shaft, so that the traditional kinematic chain used for taking over the motion from its origin, transmitting and adjusting it, has been reduced to a minimum number of components.

The disadvantage of such kind of driving solution is the reduced value of the developed torque. For heavy machine tools intended for high efficiency machining, a high torque developed by the kinematic chain is compulsory, therefore the need of keeping mechanisms such as the gearbox.

The modernization of the machine tools should be orientated towards new directions that ensure the impact of their manufacturing and exploitation with the environment.

Under these circumstances, not only the economic criteria should be followed when modernizing, but also should be completed by the ecological one.

Modernization should be benefic not only from economical point of view, but also considering the impact with the environment.

2. Main kinematic chain

Technological cutting speed is determined based on cutting theory criteria, under economical conditions, and that is why it is generally expressed by the formula:

$$v_a = \frac{C_v}{T^m \cdot t^{x_v} \cdot s^{y_v}} \quad [\text{m/min}] \quad (1)$$

where C_v , x_v and y_v are experimental constants for different materials and T [min] is tool durability, t [mm] - cutting depth and s [mm/rot] - feed.

The real cutting speed is accomplished on the cutting motion path during the cutting process. No matter what is the machining type, the real cutting speed is the resultant of adding up the speeds of the motions on the paths of whose combination determines the directory path, or of adding up these motions and the feed motion. The main component of the real speed is the main cutting speed.

The main kinematic chain is the generating kinematic chain which ensures - on the directory path or on one of its components – the main cutting speed, the biggest component of the real cutting speed [3].

For the most machine-tools the main function of the main kinematic chain is the function of ADJUSTMENT, so that the real cutting speed to have a value as close as possible to the technological cutting speed.

3. Adjusting mechanisms for the main kinematic chains

The adjusting systems used the most for the main kinematic chains are the gearboxes and electronic controllers. Usually, the gearboxes ensure demultiplying the input speed and amplifying the output torque.

If considering the transmission ratio of the gearbox CV, for a certain adjustment, as i ($i < 1$), than:

$$n_{CV} = n_{ME} \cdot i \quad (2)$$

$$M_{CV} = M_{ME} \cdot i^{-1} \quad (3)$$

where: n_{CV} [rpm] - gearbox output speed, n_{ME} [rpm] – electric motor speed, M_{CV} [Nm] – available torque at gearbox output, M_{ME} [Nm] – electric motor torque.

The classic gearboxes include specific mechanisms: sliding gears, clutches, shafts, bearings, etc.

Additionally to these elements there are the adjusting mechanisms: levers, actuators, cams, linear hydraulic motors and their related driving systems.

In most cases the housing is a specific component, made of cast iron and then accurately machined.

Therefore one can notice that gearboxes are complex parts, being for many times some of the most expensive components of the machine-tools.

The classic gearboxes can transmit heat or vibrations to the main shaft affecting the precision of the machine-tool.

4. Construction of two-speed gearboxes with electric shifting

The two-speed gearboxes for machine-tools, made by specialized companies represent a modern solution applicable to new or refabricated machine-tools.

The advantages of these two-speed gearboxes are the following:

- a lubrication line separate from the rest of the machine, which reduces the heat transfer towards the main shaft;
- a connection to the main shaft by means of toothed belts, preventing the transmission of vibrations;
- low level of noise;
- simple and compact construction, with direct connection to the driving motor;
- high rate of efficiency, over 95%;
- minimum backlash;
- speed range shifting made through a device incorporated in the gearbox and electrically driven.

The kinematic diagram for such a gearbox, with transmission ratios of 1/1 and 1/4 is shown in figure 1.

The electric motor 1-ME is directly connected to the gearbox 2-CV. The motor shaft drives the gear 3.

If the selector shaft 4 is coupled on Ist step, through ports a, the motion reaches the planets 6 and then the output shaft 7. The gear with internal tooth 9 is locked. It is the step that ensures the ratio of 1/4.

If the selector shaft is on the IInd position, on ports b, the planets 6 and gear 9 ensure the ratio 1/1. 5 and 8 are the bearing systems.

Usually, belt transmissions transfer the motion from the gearbox output shaft to the main spindle.

This solution removes heat and vibration transfer towards the main spindle.

Due to their design these gearboxes look like an extension of the electric motors.

These constructions can operate in any position provided that the lubrication is ensured in accordance with the recommendations of the manufacturer [4].

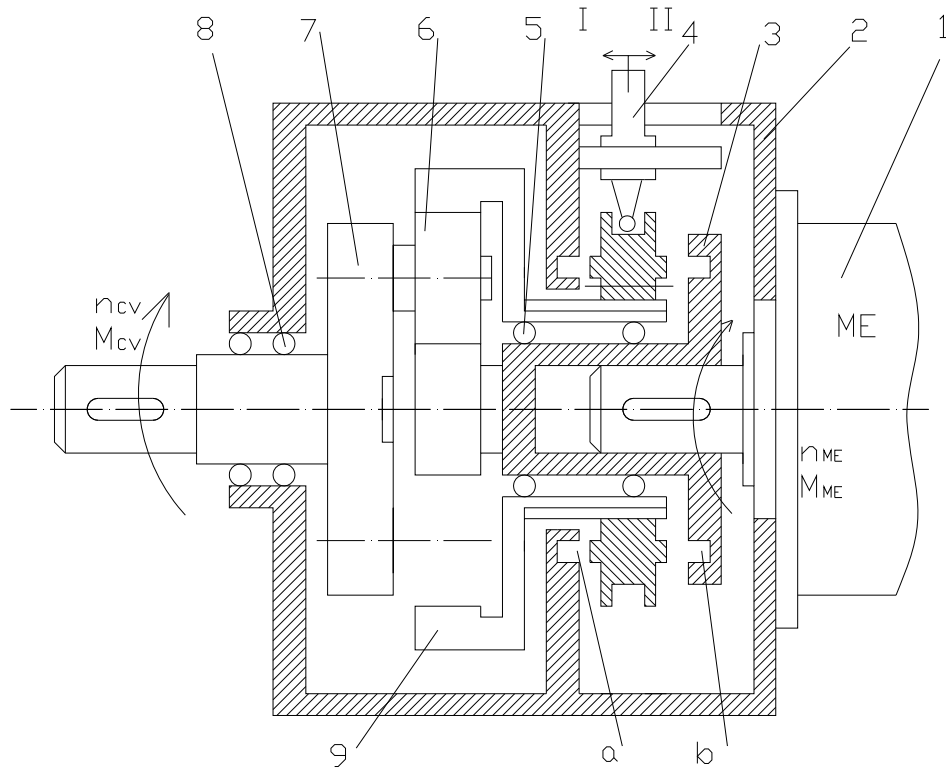


Fig. 1. Two-speed gearbox.

5. Gearbox characteristics

An electric motor is defined by the following: P_{ME} [kW] - power, M_{ME} [Nm] – rated torque, n_{nom} [rpm] - rated speed, n_{max} [rpm] – maximum speed.

If selecting a gearbox with the ratios $1/4$ and $1/1$ and considering the efficiency rate of 100%, then the adjustment characteristics at constant torque and constant power, respectively, in figure 2, are obtained.

Cutting at constant torque is preferred for turning, milling, boring operations performed by heavy machine-tools.

The modern motors intended for main kinematic chains are AC motors with the speed adjustable through frequency variators.

Usually, the rated speed is 1500-2000 rpm. Maximum speeds can reach 5000-8000 rpm.

It is considered a motor with $P_{ME} = 40$ kW, $M_{ME} = 254$ Nm, $n_{nom} = 1500$ rpm, $n_{max} = 6500$ rpm, coupled with a gearbox with $i_1 = 1/4$ and $i_2 = 1/1$.

Torque and power characteristics at gearbox output shaft are presented in figures 3 and 4.

This system can ensure speeds within 0 - 6500 rpm, a constant torque of 1016 Nm from 0 to 375 rpm or 254 Nm from 0 to 1500 rpm.

From 375 rpm to 1500 rpm, one can perform machining with constant power of 40 kW with a decreasing torque, and then, also with a decreasing torque but at the same constant power, up to 6500 rpm.

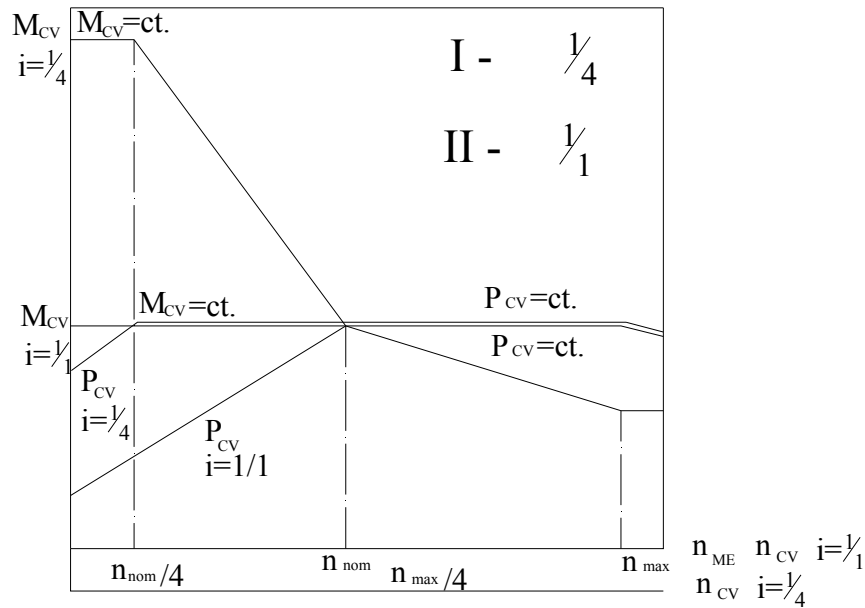


Fig. 2. Adjustment characteristics at constant torque and constant power.

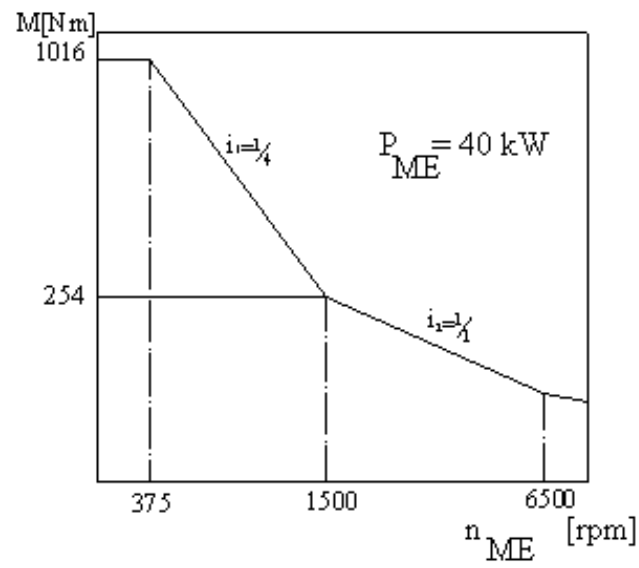


Fig. 3. Torque characteristic.

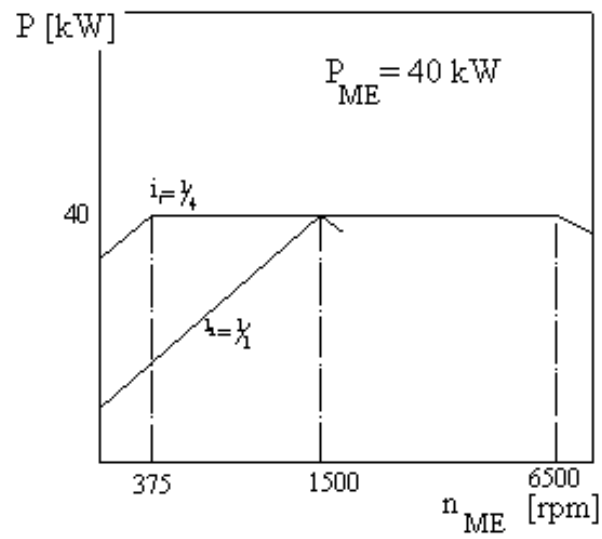


Fig. 4. Power characteristic.

6. Machine-tools with two-speed and electric shifting gearboxes

These gearboxes are successfully applied on Horizontal Boring Mills (AF and AFP), but also on Vertical Turning Lathes within SC 14 – SC 33 CNC range [5].

The gearboxes of the Vertical Turning Lathes operate in vertical position and continuous oil lubrication is recommended.

Figure 5 presents the lubrication diagram for a Vertical Lathe with CNC.

A double pump P23 ensure the lubrication of the mechanisms of the main kinematic chain and other elements of the machine-tool.

The lubrication of the gearbox is ensured by the second pump P3. The maximum pressure is adjusted with the pressure valve 1Sp2.

The filters 1F3, 1F5 and 1F5.1 clean the oil needed for lubricating the mechanisms inside the gearbox.

The pressure gauge 2M1 displays the lubrication pressure, when actuating the directional control valve 4RM.

The throttle valves 4Dr1 and Dr help adjusting the flows for the gearbox and its bearing.

The rest of the components in the diagram are provided for the lubrication of the main spindle bearings and the pinion-crown gear mechanism – a mechanism specific to Vertical Turning Lathes [6].

For maintaining the temperature of the oil a COOLER – a thermostated cooling system - was used.

The machine was re-built within a refabrication program that included another 8 machines of this type.

The first machines with this type of transmission were manufactured in 2004 and they have been working since then, without requiring any intervention on the main kinematic chain.

Conclusions

The two-speed gearboxes with electrical shifting of the speed range, manufactured by specialized companies, represent a very advantageous solution – technically and economically – when manufacturing or refabricating heavy machine-tool in general and CNC machine-tool in particular.

Such solution has been applied on Horizontal Boring Mills (AF and AFP type) and on Vertical Turning and Boring Mills.

Among the advantages, one can mention:

- simplicity and reliability;
- adjustment – usually - within 1/1 or 1/4 (3);

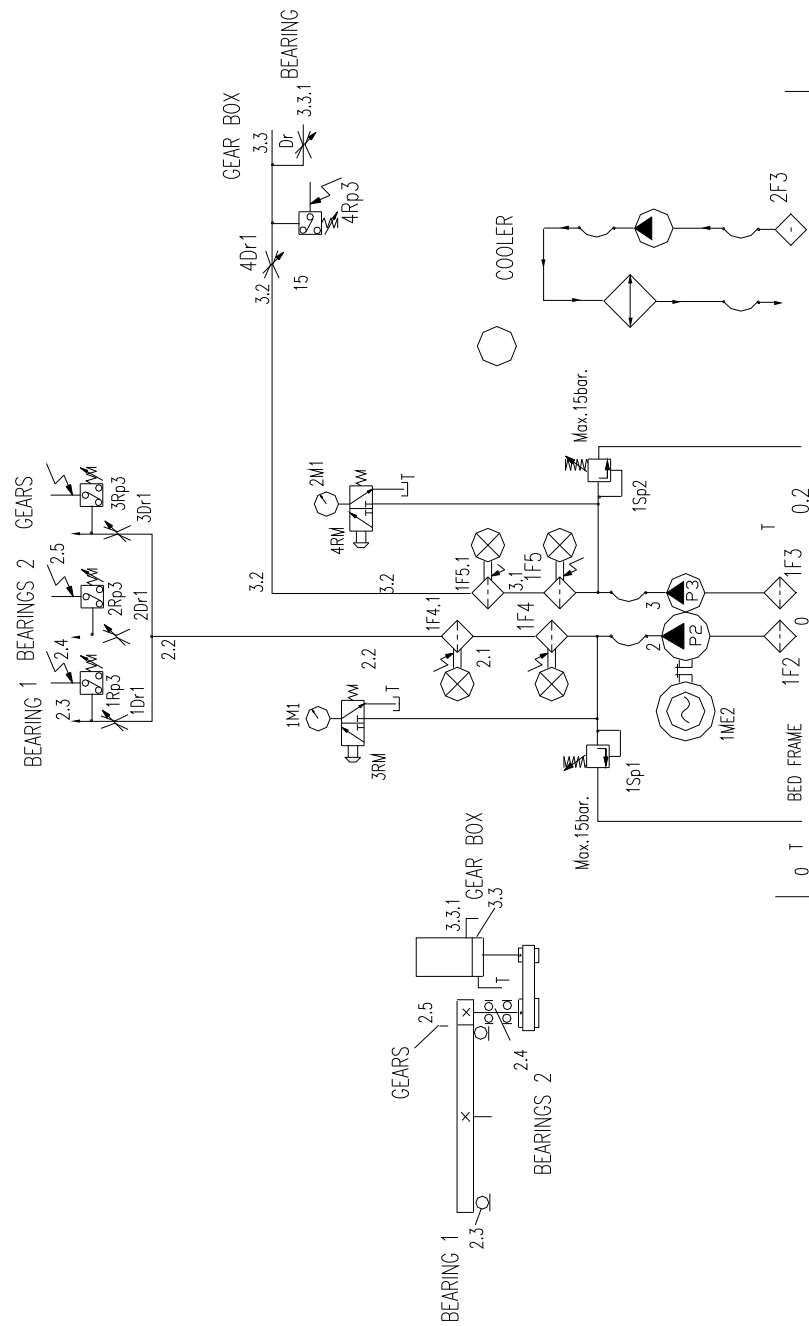


Fig. 5. Gearbox lubrication diagram.

- no special maintenance required;
- efficiency rate higher than 95%;
- low level of noise;
- diminished functional backlashes;
- no accurate machining – boring, grinding, etc. – required.

For accomplishing the final transmission, toothed belt transmission is recommended between the gearbox and the main spindle.

This transmission removes vibration and heat transfer and ensures the possibility to correlate the feed motion with the spindle rotation, which is very useful for the CNC Vertical Turning and Boring Mills.

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