A method for determining the constant DC/AC motor power range and main technological spindle unit parameters

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Abstract. The article offers an original method for determining the constant DC/AC motor power range and basic technological parameters of the main spindle unit for multifunctional machine tools at the design stage. The method allows them to be determined, both in terms of the strength characteristics of the gearbox (or the strength characteristics of the system “machine-equipment-tool-work piece”) and in order to obtain the maximum spindle torque needed to ensure maximum machine productivity. The graphical interpretation of the method can be used both for designing new and for operating existing machines.

1. Introduction

Modern CNC machine tools (MT) are characterized by a higher level of energy costs than universal MT [1-5]. Moreover, the spare higher capacity lead to kinematic changes, increasing the mass of the machine, and hence increasing the operating costs and decreasing the wear-resistance of the machine as a whole.

On the other hand, it is known from many studies, the full power of the machines often is not used. In many other examples, some of main parameters (maximum spindle torque, maximum cutting power, etc.) are insufficient, which limits the cutting modes. Therefore, the choice of the input power and core technical parameters of the main spindle unit of the machine tools must be a production necessity and not a consequence of the market conjuncture. In the modern CNC machine tools are used stepless DC or AC motors.

That means that the correct calculation of the input power and basic technical characteristics of the machine must be carried out at the design stage. For the strength dimensioning of machine parts and units, it is necessary to determine the nominal or maximum load, as well as the calculation mode, which can be expressed by torque, load force, power or rotational speed [5,6].

In most cases the basic parameters of a newly designed machine tool are determined from the designer by analogy to other machines. Then they are complemented in the design process. In design, the basic parameters of the machine tools must be determined by analysing the family of parts for which the machine is designed.

The rated power output of the main motor and other technical parameters - the speed range, torque, the range of part’s diameters, cutting speeds, etc., determine the production and economic capabilities of the machine. The correct and accurate determination of these parameters at the design stage should
be based on the analysis of the physic-mechanical properties and geometric parameters of the parts family, blanks and tools related to the realization of particular technological process/processes. In this analysis, group technology methods are used, with the family of details divided into groups and a detail-type representative (complex work-piece/phantom detail) is synthesized for each group.

In the modern machine tools stepless DC or AC motors are used. The diagrams of the torque (M) and the power (P), depending on the spindle frequency n are shown in figure 1.

![Figure 1. (M_sp – n_sp) Diagram](image)

This paper presents an original method for determining the constant power range of the main DC/AC motor and the basic technological parameters of the main spindle unit for multifunctional machine tools at the design stage. In principle, the suggested method can be used to design of servo MT’s drives/transmissions.

2. Methodology and research results

The function \((M_{sp} – n_{sp})\) (figure 1), expressed by the spindle power \((P_{sp})\) in the double logarithmic coordinate system \((\lg n_{sp} – \lg M_{sp})\) is a straight line equation (1). The angle between it and the abscissa is \(45^0\) (figure 2).

\[
\frac{\lg M_{sp}}{\lg \left(\frac{1020.30 P_{sp}}{\pi}\right)} + \frac{\lg n_{sp}}{\lg \left(\frac{1020.30 P_{sp}}{\pi}\right)} = 1
\]

(1)

For the different cutting power values, a family of straight lines is produced. On an axis perpendicular to them, the corresponding bands can be seen (figure 2).

For the purpose of the study, the spindle power diagrams \((P_{sp})\) and spindle torque \((M_{sp})\), depending on the rotational spindle speed \((n)\) from figure 1 can be represented as shown in figure 2.
From the merging of the diagrams of figure 1 and figure 2, the diagram shown in figure 3 is obtained, from which both the momentary and the power values of the spindle can be taken into account.

From figure 3, the equivalent power equation \((R_e)\) can be written. It is considered as a random probability interval within the range \((P_{\min} - P_{\max})\). This interval corresponds to the interval \((n_{\min} - n_{\max})\) and is equal to the mathematical expectation:

\[
P_e = \lim_{n \to \infty} \sum_{i=1}^{n} P_i P_i^*,
\]

where \(n\) are the cutting passes (the size of the spindle speed variation range); \(P_i\) - the equally probable random magnitude of the power \(n = n_{\min} + n_c\) within the probability range \(P_i^*\).

For \(P_i\) and \(P_i^*\) can be written:
\[ P_i = \frac{n_i}{n_c} P_{\text{max}} , \] (3)

\[ P_{i}^{*} = \frac{n_{i+1} - n_i}{n_c - n_{\text{min}}} = \frac{\Delta n}{n_c - n_{\text{min}}} . \] (4)

After substitution of (3) and (4) in (2) for the equivalent power, the equation is obtained:

\[ P_e = \int_{n_{\text{min}}}^{n_c} \frac{P_{\text{max}}}{n_c(n_c - n_{\text{min}})} ndn = \frac{P_{\text{max}}(n_c + n_{\text{min}})}{2n_c} . \] (5)

Equivalent power \( P_{e}^{*} \) can also be calculated from the cutting conditions of the details set that are intended to be machined or using the group technology of the cutting conditions of the complex workpiece using the equation:

\[ P_{e}^{*} = \sqrt{\sum_{i=1}^{m} \frac{P_i^{2} t_i}{t_i}} , \] (6)

where \( t_i \) is the time for processing the \( i^{th} \) pass; \( P_{\text{max}} \) - the maximum value of the cutting power required.

After substitution of (6) into (5) for the value of the calculation frequency \( (n_c) \) is obtained the following equation:

\[ n_c = \frac{n_{\text{min}} P_{\text{max}}}{2P_{e}^{*} \lambda - P_{\text{max}}} , \] (7)

where \( \lambda \) is the gearbox's efficiency.

The calculation frequency \( (n_c) \) is using for strength calculating the components of the gearbox and spindle unit. Depending on the required power for different details sets \( (P_{e}^{*}) \) the point \( n_c \) is approaching or moving away from \( n_{\text{min}} \). Thus it limits the torque \( M_{\text{sp}} \) and creates prerequisites for optimizing the strength dimensioning of the transmission.

For the rated output of the motor is obtained the following equation:

\[ P_m = \frac{P_{e}^{*}}{\lambda} k , \] (8)

where \( k \) is a reliability factor.

After applying \( P_{e}^{*} \) for \( P_m \) the diagram shown in figure 4 is obtained.
3. Example

From the calculation of the cutting conditions for the processing of details set to be processed, it is obtained (figure 5):

Spindle speeds range \((n_{\text{min}} - n_{\text{max}})\): 45-3980 min\(^{-1}\); \(t_i = 0,2 \div 2,0\) min; \(\lambda = 0,82\); \(P_{\text{sp, max}} = 14,5\) kW; \(P_{\text{sp, min}} = 2,1\) kW.

From (6) follows \(P_{e}^* = 11,6\) kW; or (8) \(P_m = 14,1\) kW. Choose from a catalog is selecting \(P_m = 14,5\) kW, where \(n_{m, max, p} = 4000\) min\(^{-1}\), \(n_{m, min, p} = 1150\) min\(^{-1}\), \(M_{m, max} = 120\) Nm).

From (7) is obtained for \(n_c = 144\) min\(^{-1}\).
4. Conclusion

1) An original method for determining the constant DC/AC motor power range and main technical parameters of the main spindle unit for multifunctional machine tools at the design stage is proposed.

2) The method to be determined allows, both in terms of the strength characteristics of the gearbox (or the strength characteristics of the system “machine-equipment-tool-work piece”) and in order to obtain the maximum spindle torque needed to ensure maximum machine productivity.

3) The method allows the determination of the basic technological parameters in order to obtain the maximum necessary spindle torque. This approach must be basic in order to obtain the maximum spindle torque needed to ensure maximum machine productivity.

4) The diagram of the type shown in figure 4 can be used both for designing new machines and for operating existing ones to quickly check for the ability and efficiency of using a particular machine to process certain details.

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References

[1] Defilippi A, Ippolito R and Micheletti G F 1981 NC machine tools as electric users, CIRP Annals - Manufacturing Technology 30(1) pp 323-326

[2] Dimitrov K, Dzhedzhev K and Mitsev T 2018 Enhancing Smart-home Environments Using Infrared Arrays, 9th National Conference with International Participation, ELECTRONICA–Proceedings 8439575

[3] Nikolova N and Nikolov E 2006. Energy saving algorithms and control system, IFAC Proceedings Volumes, International IFAC Workshop on Energy Saving Control in Plants and Buildings ESC 2006 Bansko Bulgaria 2-5 October 2006 Code 85982, Vol. 1, Issue PART 1, pp 141-146

[4] Holkup T, Vyroubal J and Smolik J 2013 Improving energy efficiency of machine tools, G. Seliger (Ed.), Proceedings of the 11th Global Conference on Sustainable Manufacturing - Innovative Solutions ISBN 978-3-7983-2609-5 Universitätsverlag der TU Berlin, pp 125-130

[5] Skoczynski W, Maczka J, Wasiak Z, Roszkowski A and Pres P 2013 Assessment of Energy Consumption by Machine Tools, Acta Technica Corvinensis – Bulletin of Engineering Tome VI, ISSN 2067-3809, pp 103-108

[6] R. Crowder R 2006 Electric Drives and Electromechanical Systems, Butterworth-Heinemann is an imprint of Elsevier Linacre House Jordan Hill Oxford OX2 8DP UK ISBN–13: 978-0-7506-6740-1 p. 292