

The technique of designing high-power CNC lathes for enterprises of the heavy engineering industry

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Abstract. Proposed is the method of heavy machine tools constructions' structural-parametric synthesis based on their components processing parameters statistical study. The process of designing high-power metal cutting equipment that most completely meets the customer's essential requirements consists in developing its technological structure in the form of a functional-structural model with the main technological parameters (accuracy class, size of working space, necessary power parameters, cutting modes) substantiation.

1. Introduction

Enterprises of the heavy machine-building industry are specific with a wide range of products, those unique products sizes, and weight, a long cycle of parts manufacturing, the unique and small-scale nature of manufacturing, technological process arranged to base on the principle of operations concentration. The necessity to process various pieces predetermines this wide equipment versatility. Manufacturing parts weighing tens and hundreds of tons requires the use of different machines, which represent a characteristic feature of this machine building branch. That equipment nomenclature and quantitative composition should ensure the ability to carry out tasks in conditions of continuously changing production facilities. In this connection, acute is a need to increase the production of the following character at a given output volume.

In this case, the specificity of parts machining with heavy machine tools is not sufficiently considered, due to the scale factor (Figure 1) (machined parts up to 24000 mm in diameter and up to 5000 mm in diameter, weighing up to 250 tons), tool design, large dispersion of processing parameters, increased probability of tool destruction (up to 45%), and the need to consider tool reliability in the processing of extensive and costly parts.



Figure 1. Large rolling shaft

Developed is the knowledge base on massive metal cutting equipment operation. Analysis of high-load CNC lathes operation showed that often technological saturation with these machines does not correspond to the structural and technological characteristics of the parts. The machine tools working space size sometimes significantly exceed the overall dimensions of parts, the number of shaping movements and tools in the store are also superfluous. This leads to an increased material and energy intensity of machine tools, and produced pieces' overpriced production cost.

It was evident that the development of justified requirements for high-load machine tools with adaptive control is possible only with generalization and investigation of a particular set of characteristics specific to parts manufactured by heavy engineering enterprises. The application of computer numerical control (CNC) in the processing at the lathe is shown in the following papers [1-6] and in other processing is shown in the paper [7].

2. The technique of structural-parametric synthesis of heavy lathes

Established is that the technological basis for designing CNC machines can refer to parts grouping. Developed and in practice tested are several features and criteria for selecting parts in groups. Based on the cluster analysis of the overall dimensions and the number of necessary form-forming motions, the processed parts are analyzed for the conditions of heavy machine-building enterprises [8-17].

Each piece is characterized by a set of features:

$$D=\{P_1,...,P_i,...,P_n\} \quad (1)$$

where P_i – i-th feature of the piece;

n – features a total number.

The CNC machines' parameters are characterized by the set:

$$Y=(y_1,..., y_i) \quad (2)$$

The set of classification features $X=(x_1,..., x_i)$.

Multivalued representation of CNC lathe's parameters set Y within classification features set X :

$$\begin{aligned} v: B \rightarrow A \\ v(b_i) = \{A_i\} \in A \\ Un \in Nv(b_i) = \{a_i/3n(n \in N) \wedge a_i \in v(b_i)\} \end{aligned} \quad (3)$$

where N – set of elements' (b_1, \dots, b_i) images is B when elements of the set N .

Total set of classification features X :

$$A=\{(Un \in Nv\{b_i\} \in A)\} \in A_{ki} \quad (4)$$

Classification features values region:

$$\begin{aligned} Ako &= \{ ako \} \\ Ak1 &= \{ ak11, ak12, ..., ak1j \} \\ Aki &= \{ aki1, aki2, ..., akij \} \end{aligned} \quad (5)$$

where $\{ako, \dots, akij\}$ is Ak – set of classification features values representing areas of structural features' names values Ako, \dots, Aki .

Developed is the algorithm of classification kinds reduction in compliance to the pieces' grouping process. That process consists of transforming the hierarchic structure of graph Lg using the graph grabbing operation. The practical realization of convolutional operation for graph Lg consists of combining the classification features $Akij$, for which processing required is the same composition and number of shape-forming coordinates Fk . A functional model of the primary process as to the metal-cutting equipment functional-structural model construction has been developed, that made it possible to establish all processes entering the primary process, their interrelation, incoming and outgoing information. Mathematical models have been developed that allow us to establish the functional dependencies between the processed parts complexity, equipment functions and the functional units they realize. Machine functions:

$$r: S \times T \rightarrow F \quad (6)$$

where r is the set mapping; $S = \{Si\}$ is the set of the complex detail representative of the complexity Si ; $T = \{Te\}$ is the basic set of technological operations realized by the machine system; $F = \{Fi\}$ is the set of machine system functions.

$$r(Si \times Te) = \{Fi: (U \cdot Si \times Te) \cdot (Si \times Te; Fi) \in r\} \quad (7)$$

Functional units determining:

$$B \in x \{B_i : i \in I\} \quad (8)$$

where B is the machine system in the form of a set of functional units; \times the symbol of the Cartesian product; $B_i : i$ is the i -th functional unit; I set of functional units.

$$In \in B_1 \times B_2 \times \dots \times B_n \quad (9)$$

Displaying a set of machine functions in a set of functional units

$$d: F \rightarrow B \quad (10)$$

Functional units B_i , providing the given function:

$$d(Fi) - (\{B_i\} : (\exists Fi) (Fi; B_i) \in d) \quad (11)$$

The finite subset of functional units $\{B_i\}$, required to implement the whole machine tool functional model:

$$U d(Fi) - \{B_i / \exists (m \in M) \wedge B_i \in d(Fi)\} \quad (12)$$

where M – functions' images set $(Fb \dots, Fi) \in F$ when representation d ; m – an element of set M .

Unified composition of functional units for the needed machine tools creation:

$$B_i = [U \cdot (Ud(Fi)) \in B \forall (Fi) \in F] \quad (13)$$

Correlation between different levels functions sets:

$$F = \{F_0\} \times \{F_{1i}\} \times \{f_{ij}\} \quad (14)$$

Units possible composition:

| | |
|--|------|
| $A \parallel B \parallel \dots \parallel f_{ij} \parallel$ | (15) |
|--|------|

where a_{ij} – matrix elements; $i = 1, n, j = 1, n$ – number of auxiliary functions and units.

Proposed are dependencies for determining the unified composition of functional blocks for the entirely new equipment spectrum construction on a single element base. A general view of the CNC machine functional-structural model is shown in Figure 2.

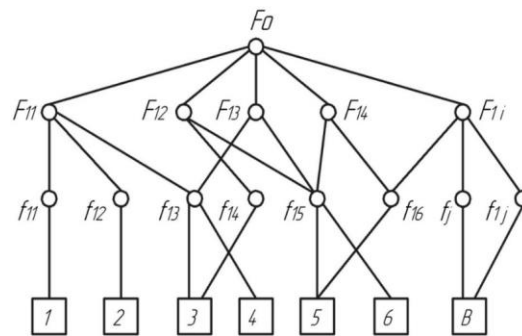


Figure 2. CNC lathe functional-structural model general scheme

F_0 - system-wide function; $F_{11} \dots F_{1j}$ main functions;

$f_{11} \dots f_{1j}$ auxiliary functions; B - the functional units of the machine.

The principal, essential, and auxiliary functions of the machine are formulated, and its generalized functional model is developed. As the basic machine functions, its shape-forming coordinates are taken, which composition determines the equipment efficiency. Developed is the machine functional-structural model is developed, which coordinates functions with functional blocks. Formulas for the evaluation of the new machine tool functions significance are proposed, and the functionally justified expenses for their implementation are determined. Building the functional-structural model allows us to establish a set of necessary and sufficient (optimal) functions implemented by the machine tool, and the executive mechanisms that provide them (assemblies, units, etc.).

3. High-load CNC machines operation in substantial engineering enterprises: results of the analysis

The data bank on the operation of heavy machines has been analyzed, that served to establish that the most probable lengths of parts lie in the range from 3 to 9 m, they slightly increase with increasing D_0 over 1,250 mm and remain constant. With the growth of D_0 from 1250 to 5000 mm, the maximum lengths of the details decrease from 24-27 m to 12-15 m. The most probable weight of parts with a change in D_0 from 1250 to 3200 mm rises from 0-10 tons to 25-50 tons and remains with a further growth D_0 approximately constant. The maximum weight of parts increases from 50-75 to 200-250 tons. Since on machines, $D_0=5000$ and 6300 mm mainly welded parts are processed, it is recommended to provide their load capacity of not more than 200 tons. For machines with $D_0=1250$, 1600 and 2000 mm, having L_0 25 m, and $D_0=2500$ mm with $L_0=20$ m, it is recommended to complete lengths of the front and two tailstocks for fuller use of the bed length.

It is established that a screw for tapping is necessary on the machine $D_0=1250$ mm, and on machines $D_0=1600-2000$ mm, the possibility of mounting the screw should be provided. Also, it is required to provide the possibility of increasing the thread pitch to be cut. Obtained are data on the applicability of

processed and tool materials. Over 80% of all machining is carried out with a carbide tool. The average cutting depth for roughing operations with carbide cutters on machines $D_0=1250-3200$ mm was 20 mm and on machines $D_0=4000-5000$ mm - 25 mm. The maximum cutting depths are up to 45 mm. The feed at roughing with a carbide tool did not go beyond the limits 0.6-2.0 mm/rev. The average feed rate on the machines $D_0=1250-1600$ mm was 1.1 mm/rev, on the machines $D_0=2000-3200$ mm - 1.2 mm/rev and on the machines $D_0=4000-5000$ mm - 1.5 mm/rev. At finishing operations, the feed rates were in the range of 0.05 mm/rev to 40 mm/rev.

It is established that in the overwhelming majority of cases, the cutting force vertical component does not exceed 80-90 kN. The most likely forces are about 30 kN. Taking into account the increase in cut cross section due to the growth of feeds in the future, the calculated force values for machine tools of different models are determined. It is established that with increasing D_0 up to 2000 mm, the most significant actual value of M_{cr} increases sharply, but does not exceed 700 Nm. The most probable value of M_{cr} does not exceed 100 Nm.

The average coefficient of machine used by power with an increase in D_0 from 1250 to 5000 mm decreases from 0.8-0.45 to 0.05-0.1; the smaller values refer mainly to finishing machines. The maximum values of this coefficient on most large machines do not exceed 0.8-0.5; at the same time, many roughing machines with $D = 1250$ mm have a power factor of more than -1.0. The average cutting power with an increase in D_0 to 2000-2500 mm increases for finishing machines to 12 kW and roughing machines to 19 kW, and then decreases. By the same law, the cutting power maximum value will change. The average power consumed by the machine does not exceed 90 kW, and the maximum 150 kW. Based on reference sources' data mathematical processing concerning machines of different producers, power-law dependences of several machine parameters (Q_0 , n_{max} , n_{min} , M_{cr} , N , etc.) on D were obtained. A method for analyzing the machines use in time was developed and tested based on their state data at each moment. This method allows many times to reduce the time required to determine the average data on the equipment used. A statistical survey of the multi-purpose equipment use and analysis of machined parts requiring its application show that no unified solutions can be found here. It is established that due to the wide variety of factors influencing the expediency of using multi-purpose/ universal equipment on heavy lathes, the vast majority of equipment should be supplied only on a particular order. These types of equipment include open, closed, and semi-closed lunettes of all sizes, milling, drilling, boring, and grinding devices.

5. Conclusion

As a result of the conducted research, the actual scientific and technical problem of key importance industrial significance has been stated that consists in the need to develop scientific bases for designing of machine tools aimed to process pieces at heavy machine building industry. The technological bases of designing new metal-cutting equipment with NC control, specializing in the manufacture of commonly used components for the production of economically feasible complexity with an operative selection of rational equipment from the existing type machine tools range for certain production conditions have been elaborated and developed. The stated problem solution allowed to increase productivity by 30-45%, 3-4 times augmenting accuracy and rendering the substantial machinery parts manufacturing reliability more certain by 20-25%.

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