Study dynamics machining centre SF68VF4

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S u m m a r y. Procedure of the calculation forms for vibration of the carrier system machining centre milling-drill-bore types in condition low frequencies is realized. The organized categorization of main nodes and their presentation in the manner of rods and masses. 3D-model spindle's node is built in system KOMPAS-3D. Main nodes "spindle-instrument" and "table-workpiece", exert most influence upon dynamic quality tool is exposure. Accounting scheme of the springy system tool is built and is offered mathematical description of the tasks dynamics with provision for characteristic of the process by cutting. They are determined transmission functions of the equivalent springy system tool and is designed its structured scheme.

K e y w o r d s: machining centre, dynamic characteristics, form of vibration, carrier system, spindle.

INTRODUCTION

The Modern machine-building production puts before tool industries problems of increasing to accuracy and capacity metalcuting tool, as well as requirements on minimization of their cost [1, 19, 2]. This brings about need of searching for new and improvements existing design tool, to need of the use scientifically motivated methods of the designing, founded on mathematical modeling of the different processes, occurring in tool, providing possibility of the estimation to accuracy tool and influences upon it separate nodes on initial stages of the designing already. Using of such methods accelerates the process of the development of the project, provides the possibility to optimization to designs and brings about significant reduction of the expenses on creation and complete of the pilot models.

Increasing of the requirements to quality milling tool, their technological complex in connection with the general increasing of accuracy in machine building, fabrication of the details from machining material, rational use high effective cutting instrument, compels to search for the way of the improvement main form creative nodes, ", exert most influence upon capacity and accuracy of the processing. These are a main technological features metal cutting equipment are limited, as a rule, their vibration resistance, for estimation which necessary knowledge of the dynamic features milling tool and its main element.

Besides, increase to efficiency of the processes realized on modern technological complex on the base multioperation equipment is connected with increasing of dynamic stability of the main nodes metal cutting tool. The analysis of the balance to softness and the forms of the frequencies form creative nodes multioperation tool milling-drill-bore type has shown that the most intensive frequencies are characterized such form creative nodes, as "spindle - mandrel - instrument" and "table - workpiece".

Such operations with interrupt by cutting as milling are characterized by big range power influence, appearing in process of the processing, including probabilistic forming in the manner of collections of the dynamic harmonicas.

PUBLICATION AND METHOD ANALYSIS

In background labour on dynamic tool [15] is for the first time entered system of the factors dynamic quality tool (the spare and degree to stability, speed and deflection dynamic system parameter under external influence) and is given general methods theoretical and experimental analysis and estimations tool on this factor. The position is entered about closed loop of the dynamic system tool, which is defined interaction element springy system "tool-instrumental-equipment-detail" with workers process: cuttings, friction and in drive. Together with that, author limits the variety a quotient particularities of the dynamic phenomena's in tool, linearization system. These restrictions are justified by possibility of the analysis of the much of machine exhibits with sufficient for practical by accuracy result. The analysis of the particularities of the dynamic system tool enabled to enter the new notion "equivalent springy system" (ESS) metal cutting tool. It is directly connected with division of the zones, where run the worker processes element of the springy system. Such approach turned out to be efficient at decision of the following problems:

1. The problems connected with choice of the drive or its calculation, when as equivalent is considered element "mechanical system", including processes of the cutting and friction with their relationship.

2. The problems of the analysis of the conditions of friction in directing or bearing of the nodes tool. Here, the equivalent element unites the springy system and processes in engine.

3. The problems of the calculation of the conditions of the cutting, where as equivalent element are considered springy system tool and processes in engine and friction.

The approach offered prof. V.A. Kudinov turned out to be productive in different exhibits tool building to branches. So in work [17] is considered dynamics mechanism auxiliary motion, in particular mechanism of the periodic turning of the nodes (the geneva, cam-teat, toothed-arm and slotted link mechanisms). It besides is in detail considered dynamics clamping and load mechanism, including intended for automatic change the instrument.

In work [18] is conducted study ESS special diamond-bore tool and are defined frequency features boring bar diamond-bore of the heads and for improvement dynamic quality are offered designs of the dumper vibration of the frequencies. For these design is built model, on the base which are built amplitude-phase-frequency characteristics springy system "spindle-console" with damper of the frequency. On the base result, got in work [15] are determined dynamic characteristics of the process fine bore, moreover determination of constant time chip formation T_r and specific power of the cutting K_r is realized on base built nomograph that relieves the calculations of the features of the process of the cutting.

Together with that got in work [15, 18] dynamic characteristic of the process of the cutting, got as a result direct experiment, needs for revision. For event overflow chip formation revision is connected with presentation of the process to deforming the chip, moving on cutter as on beam on soft base [8]. On the grounds of found dependencies of the length of the contact of the chip and instrument are received transmission functions, characterizing change the length of the contact when change the thickness of the cut. Comparing got results with available experimental given possible to note their qualitative coincidence [8].

At a rate of configuration designing is offered as criterion of the comparison of the arrangements to use not generalized criterion, but factor dynamic quality on limiting operation [9, 4]. On the base experiment on lathes is shown, [9] that under firm cutting level frequency in zone of the cutting the most intensive in low frequency of the area, corresponding to own frequency of the vibration of the carrier system (CS) tool. In this case dynamic characteristic CS computable under chosen accounting condition, will characterize the quality of the arrangement with position to not only stability of the process, but also influences of the vibration on accuracy of the processing. The similar approach is used for comparison of the arrangements multi-objective tool milling-drill-bore type [4, 10]. The organized collation of the dynamic characteristic CS different arrangements, differing mutual location stationary and moving block, in particular, location tool magazine and spindle head on column. As criterion for comparison was used factor to dynamic softness. Volume of dynamic softness is calculated for different technological operation on the first and second own frequency under different design spindle head. On this base is made choice to rational design element carrier systems.

Final element method is broadly used at study dynamic multi-objective tool. So in work [11, 5] is presented complex approach to problem of the multiversion analysis of the dynamic characteristics of the springy systems tool, resting in their schematizing by means of super element, uniting between itself in border node point final-element grid. The certain balance to dynamic softness multi-objective tool with crusade table [11, 12]. For detail of the influence constructive parameter on its dynamic characteristic is used procedure of the energy analysis of the vibration spring system on determined mode of the vibration on frequency 41 and 66 Hz. The results of the analysis have allowed to give the recommendations on change design element spring system tool in purpose of the improvement its dynamic characteristic.

The influence upon dynamic quality multi-objective tool with use hydraulic motor drive is considered in work [21, 22].

The analysis dynamic quality tool for speediest processing (the parameter specific speed $n \cdot d = (2…3)\ 10^6$ mm/min) is connected with monitoring spindle's nodes on characteristic of the displacement and vibration [1]. For checking and forecasting of the nature and values vibration in process of the processing are created special programs, taking into account condition spindle's nodes and instrument, material of the workpiece, stiffness of its fastening and other characteristics.

OBJECTS AND PROBLEMS

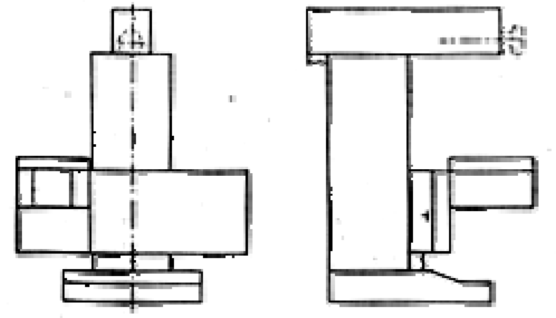
The purpose of the work is an improvement of the process of the designing main form creative nodes machining centre on the base of the procedures of the study dynamic and shaping rational design these tool on criterion vibration resistant

THE MAIN SECTION

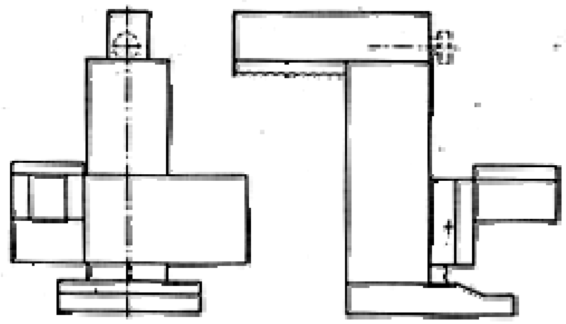
Considering design multi operation tool, as closed-loop dynamic system [15, 18, 17], most often resort to schematizing, got in work V.A. Kudinov [15].

In general event equivalent springy system tool (ESS) tool milling-drill-bore type can be presented in the manner of linear system with many degrees of freedom. The system includes certain amount concentrated and portioned element, possessing corresponding to inertia, springy and dissipation characteristics.

During preliminary experiment on base model tool SF68VF4, constructed and made on Lugansk tool building plant, are received: moving the instrument and workpiece, installed on rotary table under the action of weight of the elements and power $P_{x,y,z}$. Herewith, the most disadvantage scheme of the location for elements of the carrier system tool was taken into account (Fig.1) – a spindle in the most extreme position; the table with workpiece in the most lower position.



a



b

Fig. 1. The Schemes of the location of the elements tool: a – a scheme I, b – a scheme II

For estimation of the influence parameter form created elements on level of dynamic softness necessary building forms of the vibration on that own frequency, which are characterized comparatively high level of the fluctuations of the instrument and stocking up. The Analysis experimental amplitude-frequency characteristics have shown that most interest presents the low frequency of the vibration fi (Hz):

$$fi = \{ 16{,}5;\ 20{,}2;\ 24{,}6;\ 28{,}6;\ 44{,}2 \}.$$

On specified above frequency were calculated forms of the vibration of the carrier system tool, and the numerical values of the displacement their element. On Fig.2 graphic are presented forms of the vibration on frequency f = 20,2 Hz, which are characterized intensive displacement spindle head in planes XOZ and table with workpiece in planes YOZ. Herewith springy deformation were fixed under the most disadvantage scheme of the location of the elements tool (Fig.1, scheme 1) and following variant load: P_{z1}= -1000 H; P_{y1}=P_{x1}= 1000 H (are attached on the end of the spindle).

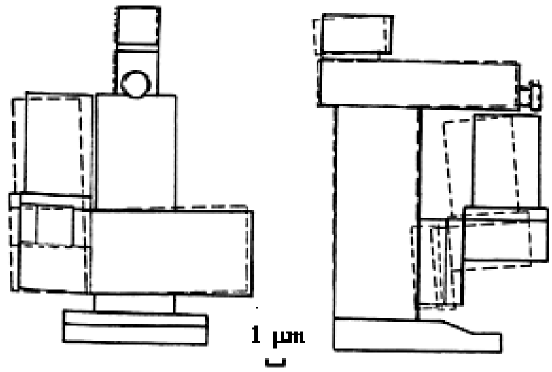


Fig. 2. Form of the vibration tool on frequency f = 20,2 Hz

On base of the picture of the displacement point springy system tool is organized categorization its main elements: arrays and rods (the springy beams). The pertain to array – instrument, table rotary, workpiece and drives of the presenting and the main of the motion (Tabl.1).

Table 1. Categorization for main elements of tool

Indication (number of the node)	Node tool
Concentrated masses (arrays)	
1	Instrument
9	Drives main motion
14	Drive of feed (on axis У)
16	Table rotary
17	Workpiece
Rods	
2-3-4	Spindle's node
5-6-7-8	Splinde's head
10-11-12	Column
14-13-15	Carriage
Joint	
2-5, 3-6	Support of spindle's node
7-9, 8-9	Support of engine
7-10	Splinde's head - column
11-13	Column - carriage
14-16	Carriage - vertical table
16-17	Table rotary - detail
Supports	
12-0	Base- foundation

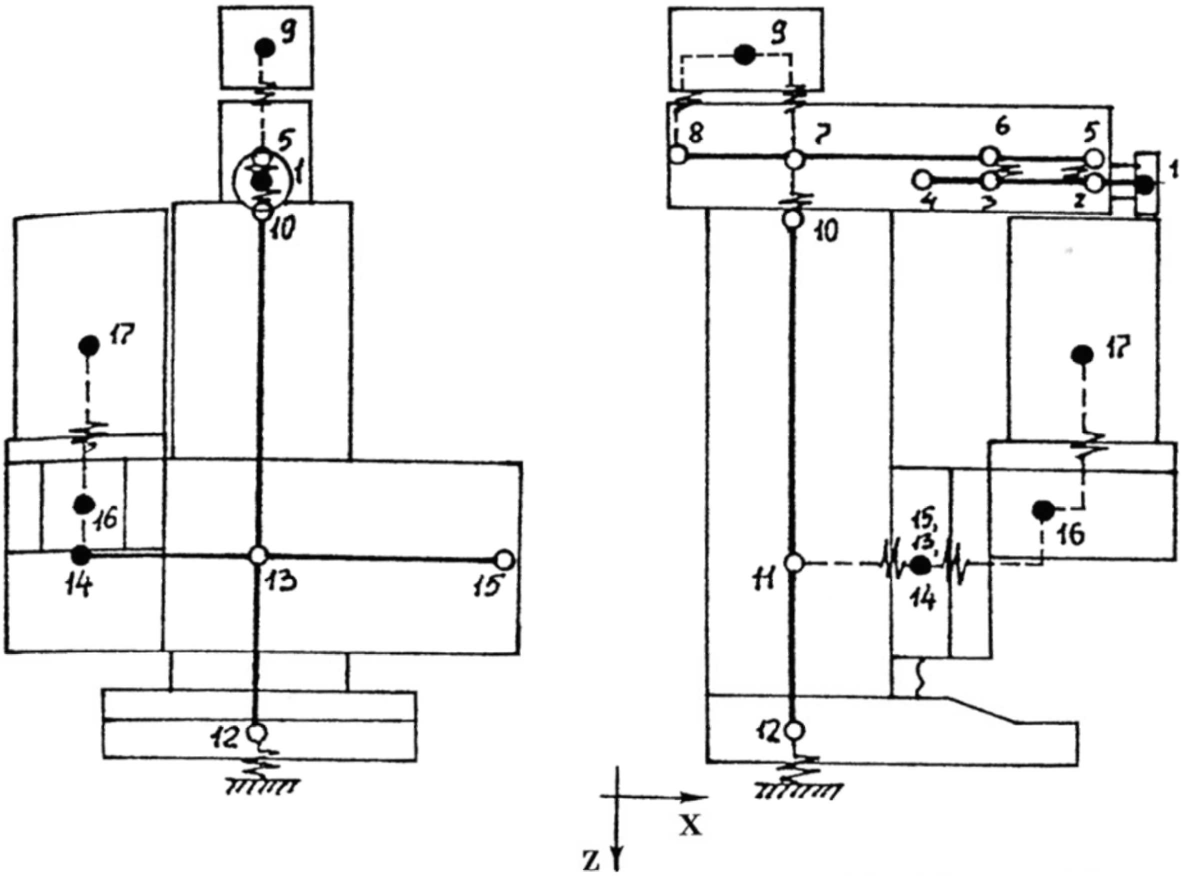
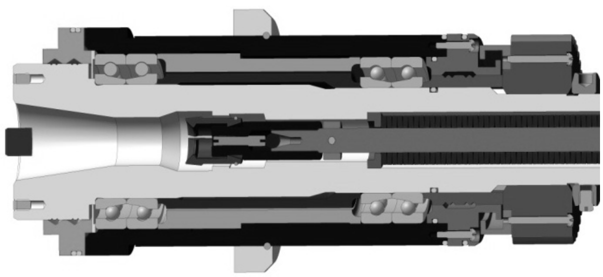


Fig. 3. Accounting scheme tool

As is well known, under array are understood such elements tool, own deformation which possible neglect in contrast with contact deformation in their butting with the other element that affords ground present them in the manner of concentrated masses (Fig.3) [5].In joint "table rotary- detail" will be taken into account only angular softness in plane YOZ and YOX.

The spindle tool, which 3D-model is designed in CAD KOMPAS-3D [13, 14, 3] (Fig.4) is submitted for accounting scheme in the manner of weightless springy beam with three concentrated masses on two elasticity damper supports. Instrument it if its own deformation possible to neglect (stiffness boring bar, milling cutter) introduces the array.

Thereby, real springy system tool is replaced by accounting scheme i.e. system with final number of the degrees of freedom in the manner of 5 concentrated masses, united springy and dissipation (diffusing energy of the vibration) element, with linear characteristics usually.



a

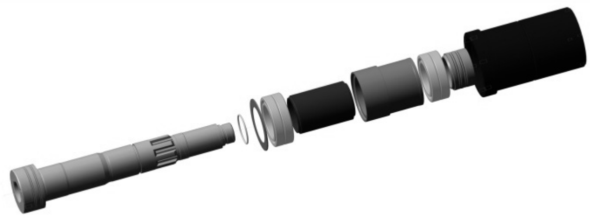


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Fig. 4. Spindle’s node: a – assembly, b – mating parts

Each mass in general event can have six degrees of freedom and its motion must be described six times by differential equations of the second order.

The reduction to working hours of the exact calculation of the system is connected with highlighting of the main elements, rendering most influence upon level of the factors dynamic quality. The concrete variant of the highlighting depends from delivered tasks in turn. So in task of the analysis and estimations to accuracy designed tool in process of the operation (form creative surfaces of the details) solving importance renders spindle's element [20]. This is confirmed by broughted studies with using the spectral analysis, which have shown that in roundnessgramm of the surfaces of the processed details are present only frequencies typical of vibration spindle's element i.e. frequency spectrum of the vibration to paths to axis of the spindle is wholly copied on detail.

Together with that other form creative element tool on the base SF68F4 in the general picture deformation conditions greatly influences upon quality produced to product:

- on frequency of the vibration f =16,5 Hz exist the intensive fluctuations of the table rotary and carriage toward axises X and Y, that brings about torsion of the body carriage and deformation in joint "column- carriage ", " carriage -table",
- on frequency f = 20,2 Hz occur the rocking vibration carriage with table for column in planes YOZ, which are defined by angular stiffness of the joint guideway column with carriage in planes YOZ with total mass of the workpiece the table and carriage (Fig. 2),
- on frequency f=28,6 Hz also exist the intensive vibration an spindle's head and table rotary in planes YOZ.

Though springy systems tool with NC type SF68VF4 present itself multimass connectivity system, breach of the form and quality processed surfaces depends, first of all, from such main and form creative elements as "Spindle-instrument" (S-I) and "Table-workpiece"(T-V). Thence possible draw a conclusion that considered springy system tool with satisfactory approach possible to consider as two mass. This is confirmed and constancy of the amplitude of the springy moment under undermost form of the vibration.

The relative small size of the amplitudes of the vibration (Fig. 1), presence preload springy system, created power of the cutting and weight of its element and applicability of the principle superposition (within the range of acting indignations) allows to consider this system linear, described by system of the common differential equations of the second order.

For machine centre to models SF68F4 accounting scheme of the equivalent springy system (the Fig. 5) includes two concentrated masses m_1 (the subsystem "S-I") and m_2 (the subsystem "T-W"), having linear characteristics to stiffness K_1 and K_2 and damping h_1 and h_2.

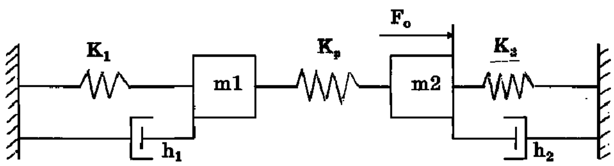

Fig. 5. Accounting scheme of the equivalent springy system: m_1 – a concentrated mass of the subsystem S-I, m_2 – a concentrated mass of the subsystem T-W, h_1 and h_2 – damping factor

The Mutual influence of the masses m_1 and m_2 occurs in process of the cutting with stiffness factor of the cutting Kr [15]. Under such statement of the problem instrument and workpiece are bound with each other by process of the cutting.

The Mutual influence of the masses m1 and m2 occurs in process of the cutting with stiffness factor of the cutting k. Such two mass system can be described by system of the differential equations of the second order with practically constant factor i.e. vibration section:

$$\begin{aligned} m_1\ddot{y}_1 + h_1\dot{y}_1 + k_1 y_1 - k(y_2 - y_1) &= 0; \\ m_2\ddot{y}_2 + h_2\dot{y}_2 + k_2 y_2 - k(y_2 - y_1) &= F_0. \end{aligned} \quad (1)$$

where: y_1 – a moving the subsystem S-I, y_2 – a moving the subsystem T-W,

F_0 – outraging power, appearing in consequence of instability of the spindle and mandrels, as well as unevenness allowance.

For account dynamic property necessary to take into account the dynamic characteristic of the process of the cutting [15]; as inertia link first-order:

$$T_p \dot{F}_p + F_p = K_p y, \qquad (2)$$

where: $K_p = K_3$ b=(1,3…1,5) $\sigma_B \cdot b$ – stiffness of the cutting,

K_3 – specific power of the cutting, N/mm,

b – width of the chip, mm,

σ_B – a temporary resistance of the processed material, MPa,

F_p – power of the cutting (brought about normal coordinate), N.

Constant time chipcreating T_r is defined by dependency:

$$T_p = \frac{\alpha a \xi}{V},$$

where: α – a factor to proportions,

a – thickness of the chip, mm,

V – a velocity, m/s,

ξ – factor of the chip contraction.

Considering expression for averaged stiffness S-I and equation (1) to account of the expression (2) is realized building of the system integral-differential equations:

$$\begin{gathered} m_1 \ddot{y}_1 + h_1 \dot{y}_1 + k_1 y_1 - F_p = 0, \\ m_2 \ddot{y}_2 + h_2 \dot{y}_2 + k_2 y_2 + F_p = F_0, \\ T_p \dot{F}_p + F_p = K_p (y_2 - y_1). \end{gathered} \qquad (3)$$

The presentation (3) correct for event, when velocities of the longitude feeds presenting comparatively small in contrast with value of the transverse vibration S-I.

In operation form (using transformations Laplas: p = d/dt , system (3) possible present in the manner of:

$$\begin{gathered} (m_1 p^2 + h_1 p + k_1) y_1 - \frac{K_p}{T_p p + 1}(y_2 - y_1) = 0, \\ (m_2 p^2 + h_2 p + k_2) y_2 - \frac{K_p}{T_p p + 1}(y_2 - y_1) = F_0(p). \end{gathered}$$

(4)

After transformations we shall get the transmission function W(p) on outraging influence $F_0(p)$:

$$W(p) = \frac{Z(p)}{F_0(p)} = \frac{A(p)(T_p p + 1)}{K_p[A(p) + B(p)] + (T_p p + 1) A(p) B(p)} \qquad (5)$$

where: Z(p) - an output parameter of the system:

$$\begin{gathered} Z(p) = y_2(p) - y_1(p), \\ A(p) = m_1 p^2 + h_1 p + k_1, \\ B(p) = m_2 p^2 + h_2 p + k_2. \end{gathered}$$

Relative moving the masses "S-I" and "T-W" is an algebraic amount: $Z = y_2 - y_1$ moreover moving the detail y_2 includes two forming:

y_2' – is caused influence outraging power F_0,

y_2'' – is caused influence springy link "S-I".

On base of the foregoing interpretation structured scheme dynamic system tool can be presented in the manner of:

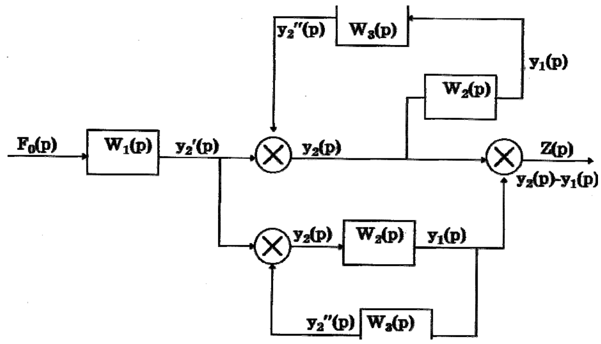

Fig. 6. Structured scheme of the dynamic system tool

On fig. 6 are presented transmission functions $W_1(p)$, $W_2(p)$ and $W_3(p)$, reflecting transformations: outraging power F_0 in forming moving the spindle $W_1(p)$, resulting moving the workpiece in displacement звена "S-I" $W_2(p)$, expressing influence of the process of the cutting and resulting displacement springy link "S-I" in the second forming moving the workpiece $W_3(p)$ reflecting speaker звена "T-W".

Transmission function in operating form for tool as a whole can be presented as:

$$W(p) = \frac{W_1(p)[1 - W_2(p)]}{1 - W_1(p)W_2(p)},$$

CONCLUSIONS

1. In given article is presented procedure of the study dynamic machining centre with table rotary.

2. The experimental analysis amplitude-frequency characteristics of the equivalent springy system (ESS) tool to models SF68VF4 that has allowed to reveal the spectrum an low frequency, under which exists the high level a vibration instrument and workpiece is carry out.

3. The calculated form of the vibration of the carrier system tool, on base which is organized categorization of the main elements and presentation them in the manner of rods and array.

4. 3D-models of the separate details and assemblies spindle's element in CAD KOMPAS-3D is built. This is a base of the further modeling.

5. Information ESS is restore to two mass vibration system on the base two the most affecting vibration link: "table-workpiece" and "spindle-instrument".

6. Accounting scheme ESS is built and is offered description in the manner of systems of the differential equations two order with constant coefficients.

7. Transmission functions ESS tool SF68VF4 are received in operation form and is designed structured scheme of the dynamic system tool.

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ИССЛЕДОВАНИЕ ДИНАМИКИ МНОГООПЕРАЦИОННОГО СТАНКА СФ68ВФ4

Олег Кроль, Максим Бельков

Аннотация. Рассчитаны и построены формы колебаний несущей системы обрабатывающего центра фрезерно-сверлильно-расточного типа в условиях низкочастотных вибраций. Проведена классификация основных узлов и их представления в виде стержней и масс. Построена 3D-модель шпиндельного узла в системе КОМПАС-3D. Выявлены основные узлы"шпиндель-инструмент" и "стол-заготовка", которые оказывают наибольшее влияние на динамическое качества станка.
Построена расчетная схема упругой системы станка и предложено математическое описание задачи динамики с учетом динамической характеристики процесса резания. Определены передаточные функции эквивалентной упругой системы и разработана структурная схема станка.
Ключевые слова: Обрабатывающий центр, динамическая характеристика, формы колебаний, несущая система, шпиндель.