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THE DYNAMIC BEHAVIOR OF A MULTI-DISKS CUTTING MACHINE

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Abstract: The paper presents the basic parameters of the machining process to cut wooden materials by multi-cutting machines, the kinematic and constructive structure of a horizontal shaft cutting machine. As an example, the value of the average machining tangent force in case of a cutting employing a 10 cutter machine was determined for conditions in which a power supply of about 50 kW is available. The results of the measurements on the dynamic behavior of the machine are presented. In view of that the data base supplied by accelerometres and acquisition plate in LabVIEW medium were used. The measurements show the vibration spectrum, the acceleration characteristics, the transfer function and Nyguist characteristics for various operations of the machine and materials to be machined. The frequencies specific to the idle running of the machine and during the process of cutting various wooden materials were determined. Also the kinematic leading chain, the exhaustion system, were considered to be, or not, in service.

1. INTRODUCTION

The identification and solving of numerous aspects related to the dynamic behavior of the machines are required both in the design phase and fabrication, but specially during their operation. The importance of knowing the dynamic phenomena which may occur in the cutting process is determining the diversity and extension of the methods and measurement instruments [3, 4]. So, the machine is maintained within its operational parameters, the accuracy imposed to the machining is obtained, cutting tools are used within their durability limits, vibrations and noise which may occur during the machine operation, are reduced. The cutting process, the dynamic and acoustic behavior [5] of the machine are determined by the parameters of the cutting regime, by the shape, arrangement and condition of the cutting tool edges, by the type and uniformity degree of the material to be machined, by the balance of the moving parts (slide carriage, cutting tools, electric rotors, couplings, devices, etc.) and by the satisfaction of the operation instructions. Of an equal importance are also the uniformity of the generating movements, of the shaft and bearing stiffness, of other organic elements strongly subjected to variable cutting forces/moments, of the correct fastening of the machine onto the foundation and the proper operation of its associated systems. The experimental researches allow for rapidly determining the influence of such parameters, for assessing the ways to improve the dynamic behavior by the modification of the process parameter values and by constructive modifications, by the proper selection of the cutting tools, of the shape and position of their cutting edges, by the balance and stiff fastening of the tools on the main shaft, by the improvement of the machine rotating and gliding coupling stiffness and by the efficiency of the fastening systems, etc.

2. OPERATION PARAMETERS

The multi-disk cutting machine is aimed to cut wooden materials of a uniform thickness and 2000 to 4000 mm length in a single - pass milling.

The analyzed machine (Fig. 1) consists of a horizontal main shaft and a part for clamping and driving the disk miller type cutting tools (*S*), which is at the free end of the main shaft (*AP*).

Fig. 1. View of the cutting machine

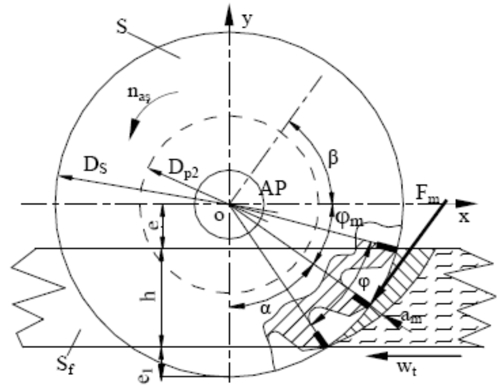


Fig. 2. Geometrical and technological parameters of the disk miller cutting

The semifabricated item, S_f, is travelling on horizontal plane in a feeding longitudinal motion, driven by an electromagnetic carrier type system, T_r, having the guiding items in contact and travelling on the flat horizontal guiding of the mount, B_t. The cutting feed is continuously adjusting by a mechanical speed variator.

2.1. Milling speed, force and power

The parameters of the cutting regime , selected or determined by calculations, are determining the magnitude of the cutting forces and moments, the power of each electric motor that is driving the two technological kinematic chains: the main and the feeding one.

The cutting speed is set in function of the kind of the wooden material [8], the material of the cutting tool edge and the actual durability of it, the position of cutting versus the material fibre, the cutting scheme (Fig. 2), the durability and diameter of the cutting tool and the quality of the machined surface. For this cutting speed parameter of the milling regime, values ranging between D_{vas}: 35…80 m/s are recommended.

The tangent milling force is varying with the thickness of the chip (Fig. 2). The average value of that force is determined by the relation:

$$F_{\text{med}} = K_{as} \times t_l \times \frac{u_z \times h \times 360}{\pi \times D_s \times \varphi} \times z_{as} \times m_s \text{, daN} \tag{1}$$

in which : K_{as} is the specific milling strength; t_l is the milling width (the width of each disk miller) in mm ; u_z is the pitch feed in mm/tooth; h - thickness of material to be cut, in mm; D_s is the miller diameter , in mm ; φ_m is the contact angle, in degrees; z_{as} is the number of tool teeth simultaneously in contact with the milling surface; m_s is the number of millers which are simultaneously developing the milling process.

The average milling power is determined by the relation :

$$P_{as\text{med}} = \frac{F_{\text{med}} \times v_{as}}{102} \text{, kW} \tag{2}$$

in which: v_{as} is the main milling speed, in m/s.

Further herein, the numerical results of an application experimentally verified on the machine, are presented. The numerical data of the parameters [1], as per the markings on fig. 2 and relations (1) and (2) above, are the followings: K_{as} = 13.426; t_l = 3.5 mm; u_z = 0.07 mm/tooth; D_s = 350 mm; h = 100 mm; e = 60 mm; m_s = 10 millers; φ = 46 degrees;

φ_m = 39 degrees; F_{med} = 70.2 daN; tangent force on one edge F_{td} = 2.30 daN/tooth; v_{as} = 71.5 m/s (n_{as} = 3900 rpm). The longitudinal cutting feed of the wooden material: $w_L = n_{as} \times u_z \times z_s = 3900 \times 0.07 \times 32 = 8736$ mm/min (z_s = number of miller teeth).

The milling power resulted from the calculations is 49.2 kW.

Since the power of the main electric motor is 55 kW, by calculations and experiments, it was proved that for the process parameter values indicated above, the machining process was developed in normal conditions.

2.2. Kinematic and constructive structure

The main kinematic chain [1] of the machine is driven by an asynchronous electric motor (M_E) of P_n = 55 kW rated power, n_0 = 2910 rpm rated speed and 430 kg weight. The output of the main kinematic chain is considered η_{lcp} = 0.87. The motion from the electric motor to the main shaft *AP* (Fig. 3) is conveyed by belt gearing. The gear diameters are D_{p1}= 240 mm and D_{p2} = 180 mm respectively, the shape of the 6 belts is trapeze (SPA narrow type) and the center-to-center distance is 669.5 mm.

The main shaft is supported on bearings in the vertical slide box, *SV*, which is sliding on the machine stand guiding for to be positioned. The bearings of the main shaft include two types of balls, namely [1]: in the main "B" bearing – a radial ball bearing (6214) and in "A" bearing - a taper double-row ball bearing (NN 3015 KTN/ SPW33). At one end the main shaft–bearing assembly is subject to milling forces, F_{med} and at the other end, the assembly is subject to the driving force generated by the belt gearing. The diameter of the main shaft between the bearings is 75 mm and the diameter of the main shaft at the cylindrical shaped end is 65 mm and provided with a keygroove and thread (M 40 x 2).

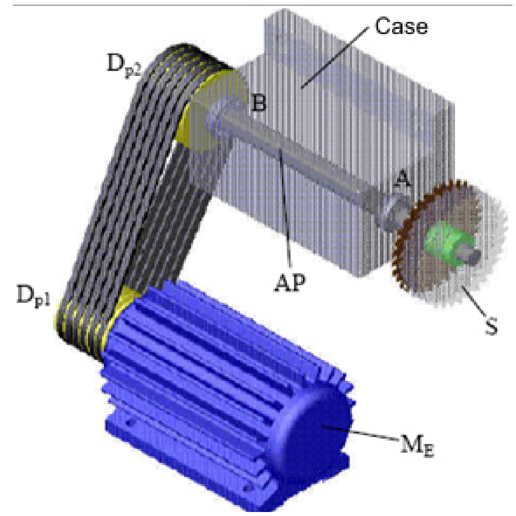


Fig. 3. The structure of the main kinematic chain

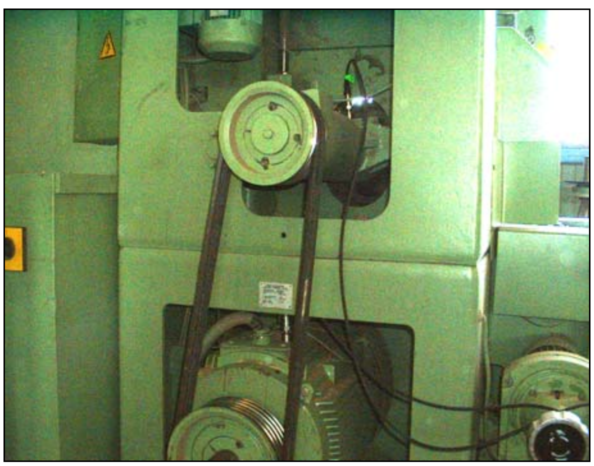
Fastening the cutting tools on a mandrel is made through the long parallel key and their axial positioning is accomplished by spacers. The set of tools is nut screwed.

The kinematic feeding chain is electro-mechanically driven and consists of an asynchronous electric motor, a mechanical speed variator, a cylindrical gear and a hinged carrier which is moved by a driving wheel. The hinged parts are provided with guiding surfaces which come into contact with the flat horizontal supporting surfaces of the mount. All the mechanisms that make-up the kinematic feeding and guiding chain are so made to provide the required smoothness of the feed motion. Moreover, all such mechanisms need to take over the components of the resulted milling force, the semi-fabricate item weight and the friction forces.

3. COMPUTER-AID EXPERIMENTAL RESEARCH

The experimental researches were mainly aimed to determine the function of transfer between the main electric motor and the vertical slide. In view of that, two accelerometers located on the assemblies have been used (Fig. 4). The electric motor was considered a source of vibrations. Consequently, the vibrations generated by the tools were also conveyed to the slide in which the main shaft-bearings assembly is housed. So, the main components of the vibrating system were gathered. By the application of Fourier's fast transform of the ratio between the slide vibrations and the electric motor vibrations, the way in which the vibrations are conveyed from the motor and other tools to the vertical slide assembly. The determinations have been done for various values of the process parameters and materials to be machined. Also, Fourier spectrum of the electric motor, of the vertical slide and of the transfer function between them was determined [6]. Evidencing Fourier vibration spectrum of the transfer function means the determination of the frequencies which might influence the quality of the machined surface, the durability of the tools and the level of noise during the machining process.

The experimental research consisted in the measurement of the vibrations in two important points of the cutting machine for wooden materials, one located on the main electric motor and the other one located on the housing of the main shaft - bearings - tools assembly. The machine, under study, is operating in variable load regime determined by many parameters among which: the material non-homogeneity, the non-uniform wearing of the milling tool edges, the improper selection of the work parameters, etc. The dynamic behavior was studied during the process of machining two types of wooden materials: hard wood and soft wood materials in the same values of the work parameters. Moreover, the dynamic behavior of the machine in cases when the kinematic feeding chain and/or the exhaustion installation were not in service, were also analyzed.



a.

b.

Fig. 4. Experimental stand: a - ***accelerometers location;*** b - ***data acquisition system***

Fig. 5. Arrangement of disk millers on the main shaft

The experimental stand consists of the following components (Fig. 5): cutting machine, two accelerometers (601A01, SN 30710 type) from IMI, an electronic amplifier for accelerometers, CB - 68LP type connector and 6024E type acquisition plate from "National Instruments" [7, 9], a PC and LabVIEW VI program to determine the Fourier's transform.

Some experimental results obtained with the data acquisition are presented in figures 6 to 13.

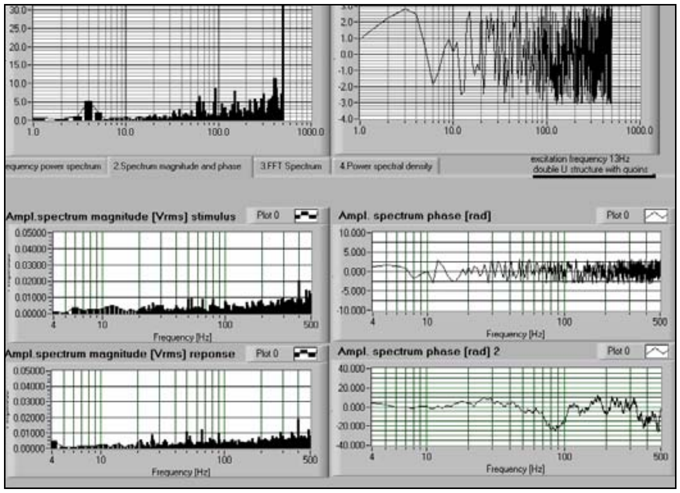


Fig. 6. Fourier's spectrum of the electric motor and of vertical slide transfer function when the machine is in service without feeding motion and exhaustion system

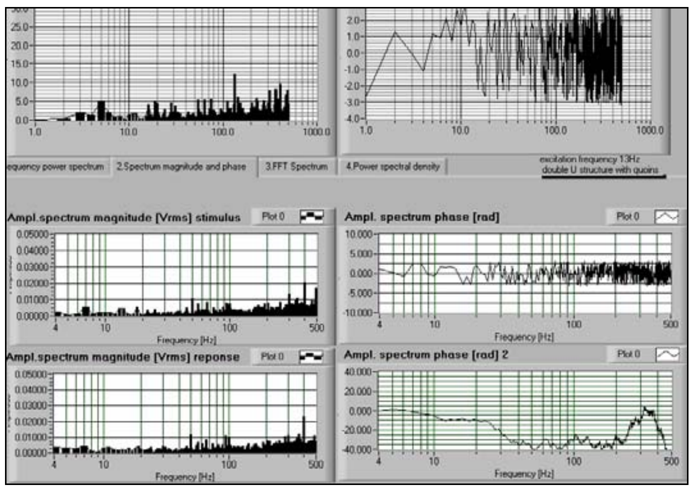


Fig. 7. Fourier's spectrum of the electric motor and of vertical slide transfer function when the machine is in service with feeding motion and exhaustion system

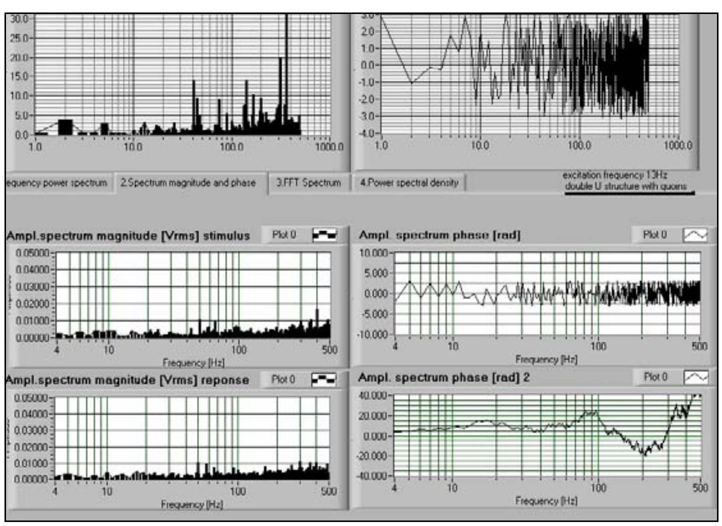


Fig. 8. Fourier's spectrum of the electric motor and of vertical slide transfer function when the machine is in service with feeding motion and exhaustion system during the process of cutting a 40 mm thick beech plate

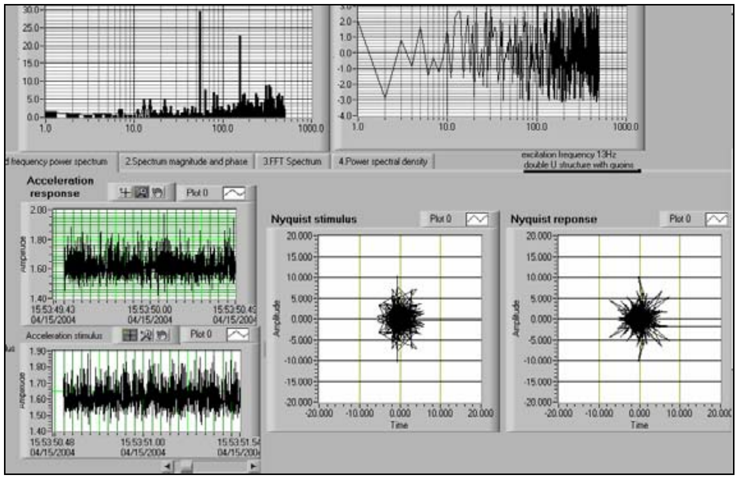


Fig. 9. The characteristics of the electric motor and vertical slide accelerations, Fourier's spectrum for the transfer function and Nyquist characteristics with the machine in idle regime

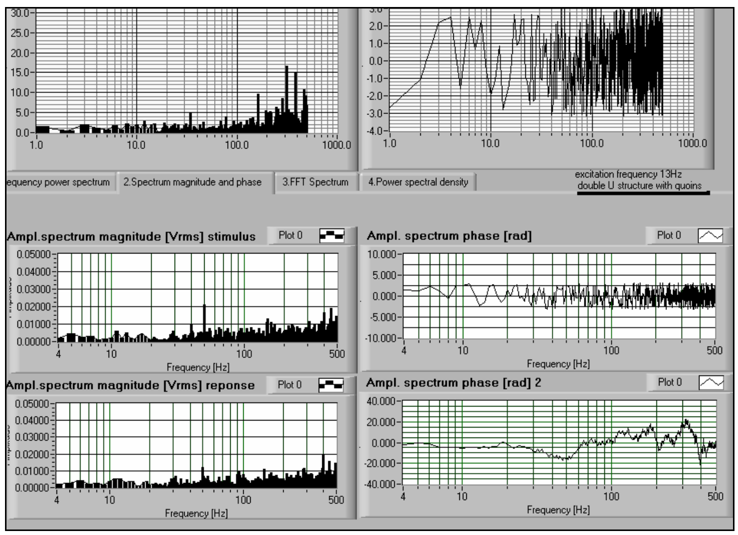


Fig. 10. Fourier's spectrum of the electric motor and vertical slide transfer function with feeding motion and exhaustion system during the process of cutting a 35 mm thick oak plate

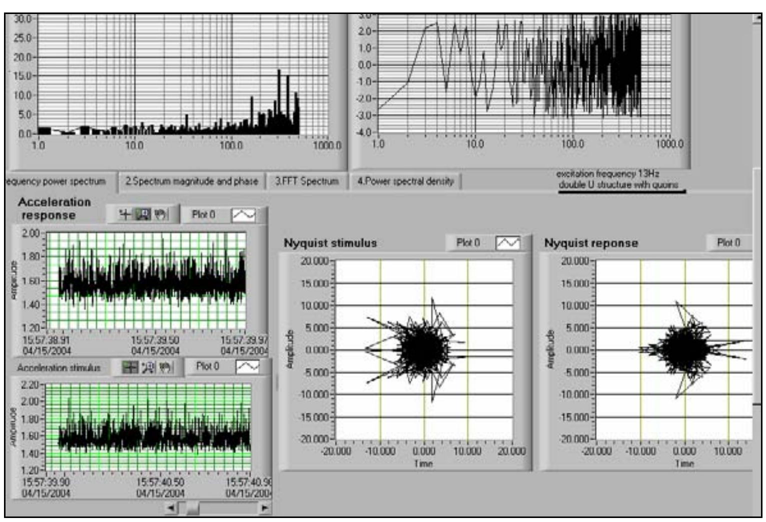


Fig. 11. Acceleration characteristics, the transfer function and Nyquist characteristics in the process of milling a 35 mm thick beech plate

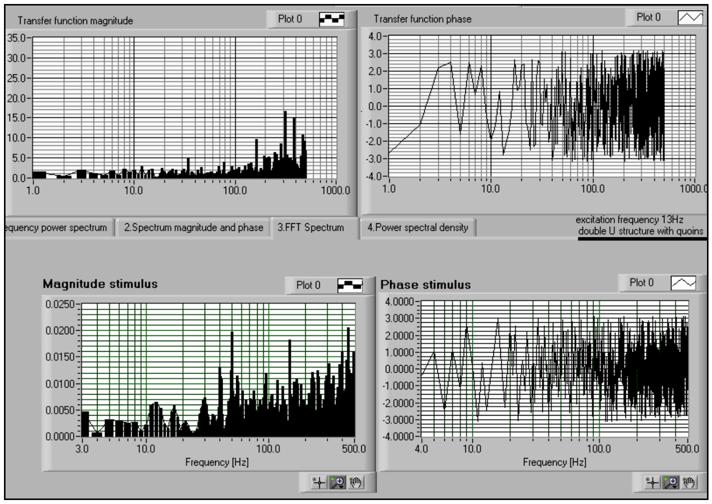


Fig. 12. Fourier's rapid transform of the impulse and the transfer function for the operation without the cutting process

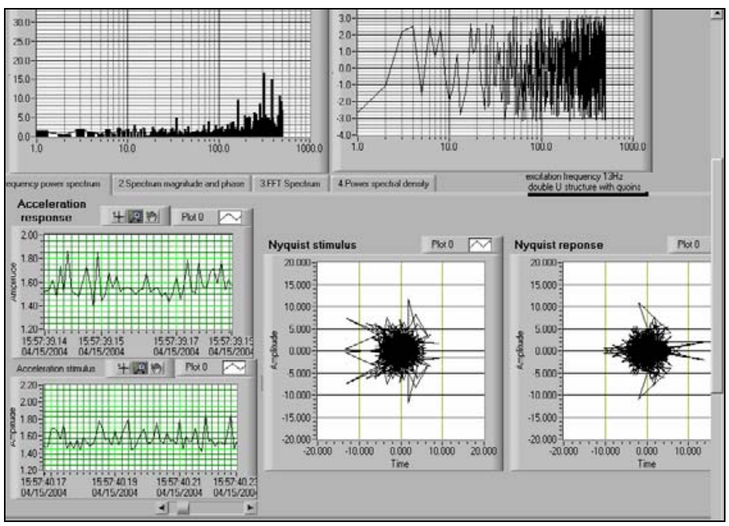


Fig. 13. Zoom of the acceleration, transfer function and Nyquist characteristic in the process of cutting a 35 mm thick oak plate

Following to the analysis of the experimental results the findings are shown below: the milling process introduces a set of resonance frequencies determined by the essence of the machined material, by the geometry of the tools and the arrangement. So, in case of oak tree wood, the frequencies are low (i.e. 1,3,6,8,10,15,20,25,35,70 Hz and others) (Fig. 10) and in case of beech tree wood, the frequencies are 2, 5, 10, 12, 14, 25, 40, 42, 46, 80 Hz and others (Fig. 8).

The frequencies specific of the idle running without feeding motion and exhaustion system are 4, 5, 40, 50, 60, 75, 90 Hz, and others (fig. 6 and 12), the frequencies without machining but with the function feeding kinematic chain and exhaustion system are 3, 4, 5, 6, 15, 20, 25, 30, 35, 40 Hz, and others (Fig. 7).

Analyzing the Nyquist characteristics (Fig. 9, 11 and 13) the followings were highlighted: the dynamic system of the machine is unbalanced (unsteady), the amplitude of the vibrations is exceeding the coordination limit (-1.0) both in idle running (Fig. 9) and during the milling process (Fig. 11 and 13); the amplitude of the vibrations during on-load operation (Fig. 11 and 13) is exceeding by about 80 -100% the amplitude of the vibrations during idle running (Fig. 9).

4. CONCLUSIONS

The frequencies specific of the main milling system are: 4, 5, 40, 50, 60, 70, 90 Hz; of the feeding and exhaustion systems are: 3, 6, 15, 20, 25, 30, 35 Hz and the frequencies typical to oak material machining are: 1, 8, 10, 70 Hz and to beech material machining are : 2, 12, 14, 40, 42, 46, 80 Hz.

The analysis of such values leads to the following remarks: by its structure , the feeding kinematic chain has a bigger influence on the vibration response spectrum and thus, it influences more the dynamic behavior of the machine than the main kinematic chain (frequencies 6, 15, 20, 25, 30, 35 Hz occur only with the feeding kinematic chain); the exhaustion system is less influencing the dynamic behavior and influencing more the level of the sound intensity.

The data acquisition program may be supplemented with the possibility to display all the frequencies in Fourier spectrum on basis of which a more accurate interpretation of the data on each case may be developed and practical measures can be stated to reduce such influences. One of the proposed measures is a different angular arrangement of the tools on the main shaft. So the 10 disk millers, each having 32 teeth, need to be one degree-angle interposed. By the numerical simulation of the milling process , such an arrangement proved to lead to a reduction of the vibration amplitudes and noise by about 20%.

Nyquist characteristics point out a certain unbalance (unsteadiness) of the machine dynamic system both during its idle running and cutting process. That is caused by the lack of balance among the moving masses (motors, couplings, tools), of the improper fastening of the semi-fabricated part and specially of its non-uniformity as well as due to the operation of the other auxiliary systems of the machine (exhaustion system, protection systems).

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