UDC 621.91.01 DOI: https://doi.org/10.32782/1995-0519.2022.1.23

# THEORETICAL STUDY OF DAMPING PROPERTIES INFLUENCE OF SPECIAL TOOLHOLDER WITH AN ORIENTED CENTER OF RIGIDITY ON VIBRATION RESISTANCE WHILE TURNING

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The article presents the results of a theoretical study with using a mathematical model of a potentially unstable dynamic system tool holder-carriage-workpiece and the cutting process, at the influence of the tool holder subsystems damping parameters on the relative value of the vibration resistance level. Known ways to increase the vibration resistance of turning is to reduce the negative impact of the "coordinate links" between the elastic displacement of cutter and machined workpiece during cutting process through the use of an additional tool holder with an oriented position of the center of rigidity or a tool holder with increased damping characteristics. It is relevant to study the feasibility of a simultaneous combination of these two directions for increasing vibration resistance in one tool holder design. Based on the results of simulation modeling of the cutting process and evaluation of its constancy according to the Nyquist criteria, it was found that a relative increase in the damping parameter in the design of a tool holder with an oriented center of rigidity leads to a decrease in the relative level of the amplitude of fluctuations in the distance between the cutter and the workpiece and a simultaneous decrease in the vibration resistance of the machining process. Therefore, in the case of high-performance machining at the upper-limiting cutting conditions on a lathe, in order to counteract the occurrence and increase in self-oscillations due to deficiencies in the elastic characteristics of the carriage construction, it is effective to create special vibrations of the cutter directed in a certain way through the use of special toolholders with a subsequent decrease in self-excitation energy. An increase in the damping parameter in construction of such a special tool holder through the use of plastic materials leads to a decrease in the effectiveness of its useful vibrational effect on the cutting process.

**Key words:** vibration, vibrostability, tool holder, lathe work, the dynamics of machines, center of rigidity.

PROBLEM STATEMENT. The task of increasing the processing productivity of lathes with a given machining accuracy is directly related to the issue of improving the dynamic quality of machine tools, especially their carriage system. The dynamic quality of the machine tools system to a greater extent characterizes the stability of the movements of its working parts during cutting. Insufficiently high dynamic stability worsens the technical and economic performance of the machine tools, it leads to a decrease in the quality of the machined surface and increases the cutting tool wear.

Known studies of the dynamics cutting process confirm the significant influence of the vibration level during processing on the cutting tool stability. The results of experimental studies indicate that with an increase in the amplitude of self-oscillations, the wear of cutting tools increases, and the frequency of oscillations of the dominant machine tools dynamic sub-system also affects tool wear. It was found that vibrations at low frequencies affect wear at relatively large amplitudes, however, with an increase in frequency, the intensity of the destructive effect on the tool increases. Therefore, when turning parts under special conditions of cutting conditions, when the cutting force is significantly increased, which ensures high productivity, for example, for large machine tools, it is necessary to ensure the conditions for the inadmissibility of self-oscillations during cutting because this leads to a significant decrease in cutter stability and possible undermining of the cutter, deterioration in the quality of the machined surface, as well as increased wear on the machine tools rail.

A difficult and urgent task is to choose the optimum in terms of the dynamic quality of lathe carriage construction. Solving the problem of the dynamic stability of a machine tool during cutting process requires a deep understanding of the essence of dynamic processes during cutting, taking into account the multifactorial dependencies with multilevel correlations of system parameters. Because of this inherent complexity of the dynamic system of research, questions about the dynamics of lathes are generally problematic.

Theoretical and design developments to address the issue of improving the dynamic quality of a potentially unstable machine tool carriage system during cutting process require the identification and subsequent consideration of the necessary optimal ratios of the elastic system parameters, elastic and dynamic parameters of the dominant dynamic subsystem. An effective solution to increase the vibration resistance of the machining process can be the use of a machine carriage construction structure with a stable optimal orientation of the rigidity axes or using special equipment like the toolholder with an oriented position center of rigidity [1; 2].

Consequently, the productivity and accuracy of the machine tool is largely determined by the quality of the dynamic processes that take place in the "carriage-workpiece" system during cutting. These processes are very complex and not fully understood, but they are not indirectly related to the overall problem of system stability. There is a known method [3] for correcting the dynamic characteristics of a lathe with minimizing the dynamic error during cutting due to a specially introduced elastic element into the elastic system of the machine, implemented in a special design of the cutters. This element redistributes the elastic deformations of the cutter with compensation for processing deviations in the cross section of workpiece.

MATERIAL AND RESULTS. Analyze of the damping parameters influence of tool holder with an oriented center of rigidity on the turning vibration resistance in articles, the structure [4] and differential equations [5] of the developed mathematical model of the dynamic system of the machine tool are given, in which the elastic and dynamic properties of this tool holder are taken into account.

Since high-performance turning with increased cutting forces, for example, at roughing stages of processing, as well as for heavy lathes, is limited by insufficient vibration resistance, therefore, rigidity and geometric accuracy are not a significant factor in the use of such tool holder equipment. Therefore, the use of tool holders with an oriented position of center of rigidity will have the greatest efficiency and economic feasibility for processing parts of especially large diameters (up to 2500 mm) on heavy lathes of models 1A670, 1M665, 1K670F3, 1A665F3, 1K675 in the manufacture of bladed hydraulic turbines.

The vibration resistance increase and productivity of metal-cutting machine tools can be achieved by increasing their rigidity or, with even greater success, by increasing their damping capacity. The damping ability of the tool or tool holder can be

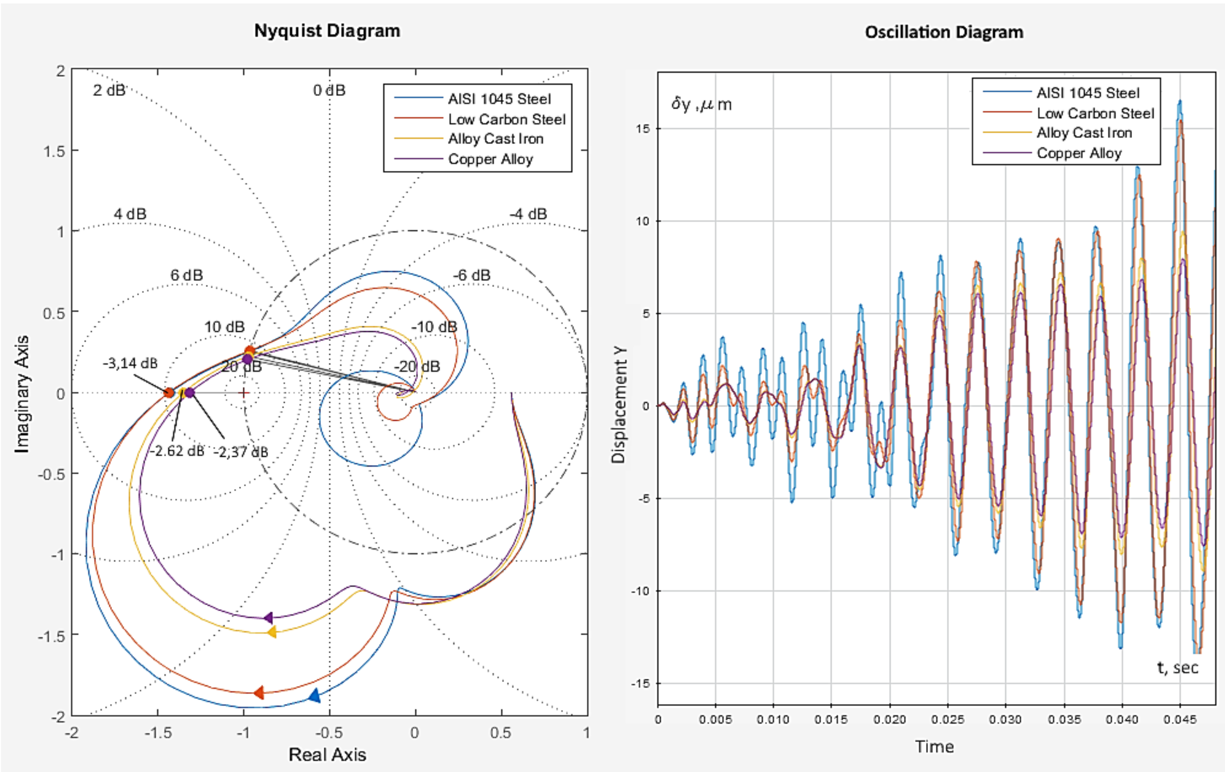


Figure 1 – The Nyquist and Oscillation Diagram of an unstable lathe dynamic system using ordinary tool holder during cutting process

increased by constructive damping, that means, by increasing the resistance at the joints, at the junctions of the cutting tool inserts with the cutting block and the block with the tool holder, as well as active damping, that also knowns as introducing vibration damping devices into the design of special tools or tool holders. One of the options for such cutter designs, where damping resistance at the joints is used, are special “glue fixed cutters”. These cutters consist of a universal holder in which various cutting blocks are mechanically attached (depending on the transition). A hard-alloy plate of cutter is glued into the seat of the cutting block with a special heat-resistant adhesive glue. Heat-resistant adhesives glue VK9, VK20, etc. are used. Vibration damping occurs both in the flat joints of the cutting block with the tool holder, and in the adhesive layer that fills the gaps between the carbide plate and the cutting block over the entire contact surface; at the same time, metal contact between the hard-alloy cutter plate and the block is also possible in separate small areas. Experiment testing and industrial use that glue fixed cutters have shown that such cutters are much more resistant to vibration than standard cutters with soldered inserts and cutters with mechanically fastened hard-alloy plate inserts. Glue builders typically have a self-oscillation amplitude of approximately two to three times less than mechanically held cutters and standard brazed blade cutters, resulting in a significant increase in tool life.

The theoretical analysis of the influence of damping characteristics of tool holder with an oriented center of rigidity on vibration resistance at a point was carried out using the materials of the publication [5], which shows the structure and system of differential equations of the mathematical model of the dynamic system of a lathe, where taking into account the elastic and dynamic properties of the equipment.

Implementation of a theoretical study by modeling the turning process and determining the indicators of vibration resistance of the movement of the cutter and the part is reduced to solving systems of differential equations through numerical integration. In this case, this is argued by the impossibility of using methods for the analytical solution of systems of differential equations or using root methods for determining the stability of motion. However, carrying out numerical calculations using mathematical packages has a disadvantage, since as a result we obtain only partial solutions. Anyway, the implementation of the simulation allows you to determine the impact in a wide range of changes for the elastic, damping and inertial parameters of the dynamic subsystem of the toolholder on the overall vibration resistance of high-performance machining.

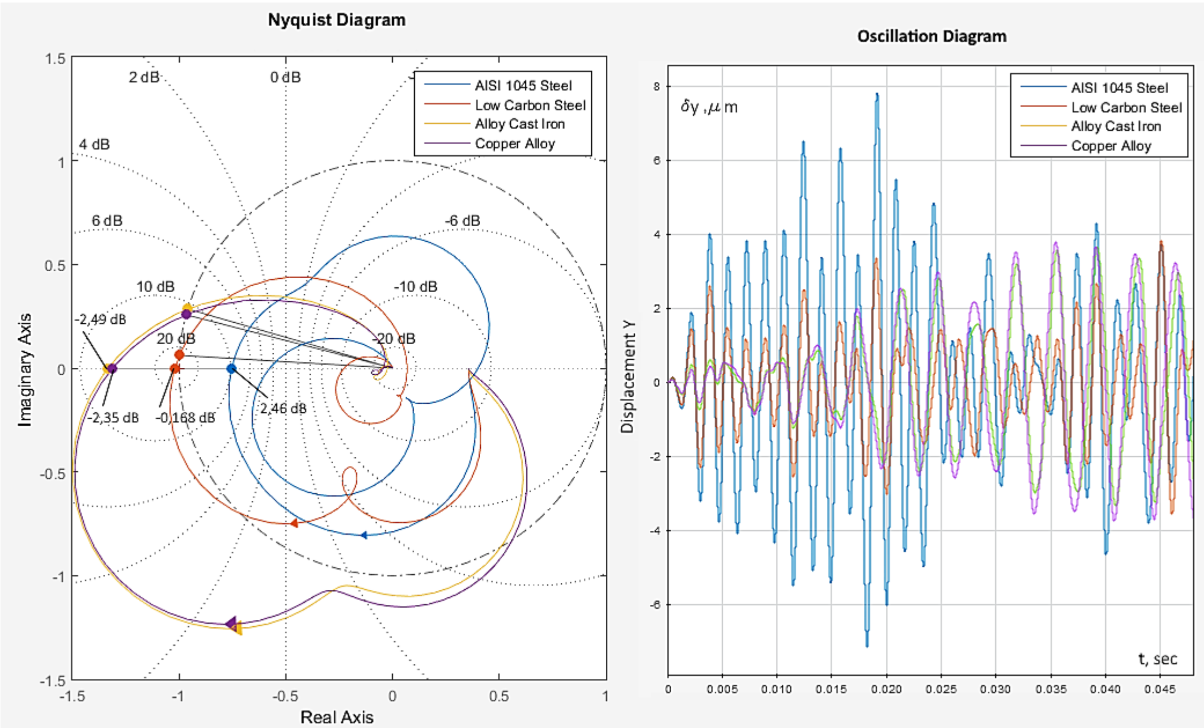


Figure 2 – The Nyquist and Oscillation Diagram of a potentially unstable lathe dynamic system using special tool holder with oriented center of rigidity during cutting process

The elastic and dynamic characteristics, reduced to the cutting point, of the equivalent elastic subsystems of carriage and workpiece for most lathes are determined by theoretical calculations of their elastically deformed state using the finite element method, taking into account contact deformations in movable joints.

The systems of differential equations used for research are linear, therefore, the implementation of a mathematical model in the Simulink (Matlab) software package using state variables $x_1(t), x_2(t), \dots x_n(t)$ is proposed, taking into account the initial conditions and external influences.

For simulation using the proposed dynamic model, needs to experimentally or theoretically determine the necessary elastic and damping parameters of the dynamic system of machine tools. The elastic stiffness parameters of the carriage system reduced to the cutting point are taken in the following combinations $c5_{max} = 80$ kN/μm and $c6_{min} = 47$ kN/μm with the ratio of the stiffness of carriage system $c_{min}/c_{max} = 0.58$, which approximately reflects the elastic properties of the lathe model 1K62 as research machine tools. The values of the reduced mass parameter for the elastic system of carriage are obtained through calculations using the formula $f = \frac{1}{2\pi}\sqrt{\frac{C}{m}}$, where $f$ is the oscillation frequency during deformations in the directions of the reduced maximum and minimum stiffness.

The values of the damping coefficients and the coefficient of viscous friction are closely related to the vibration damping coefficient $\zeta = 0.31$. The value of this coefficient is taken for all parts of the elastic system of the machine tools equal to the attenuation coefficient for transverse vibrations of the steel rod. The damping coefficient is calculated using the formula $h = 2\zeta\sqrt{mc}$, where m is the mass value and $c$ is the stiffness value.

To study the impact on the vibration resistance of machining from the side of the tool holder of a pronounced directional stiffness and the choice of its orientation relative to the direction of the cutting force action vector and the directions of orientation of carriage rigidity axes, the following ratio between the maximum and minimum reduced stiffness of the tool holder was adopted in a wide selection range. The maximum reduced stiffness of the tool holder is taken as $c1_{max} = 20$ kN/μm, and the minimum is taken from the following values $c2_{min} = 5$ kN/μm with the stiffness ratio $c_{min}/c_{max} = 0.25$. Implementation of the reduced elastic properties of the tool holder and changing the orientation angle of maximum rigidity is possible by shifting the relative position of the center of rigidity of the elastic system by adjusting or changing its design.

The elastic and dissipative parameters of the workpiece equivalent elastic system are taken from the results of an experimental study and we do not consider it appropriate to expand their range in modeling, since the dynamic effect of the tool holder with an oriented center of rigidity on the vibrations of the part is insignificant and is carried out through the force cutting process. The parameters of the reduced stiffness of the workpiece elastic system are assumed to be the same $c3_{max} = c4_{min} = 20$ kN/μm.

Studies have been carried out on the influence of the damping properties of a tool holder with an oriented center of rigidity on the level of vibration resistance $L$ dB of a closed dynamic system of a machine tool (Figure 1, figure 2). The vibration damping coefficient is artificially changed in the range $\zeta = 0.3$–14.1 due to the use of metal materials with increased vibration absorption capacity in the tool holder design.

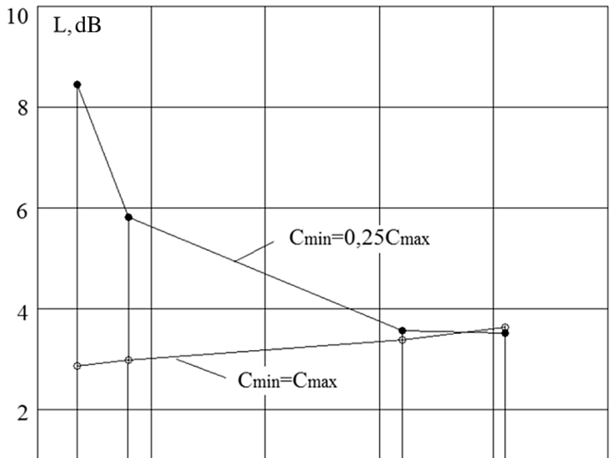


Figure 3 – The results of the numerical study of the influence of vibration-absorbing materials use in the design of a tool holder with an oriented center of rigidity on the vibration resistance level

According to reference books determined experimentally [6], with transverse vibrations of steel rods (AISI 1045 Steel) ($E = 2.03 \cdot 10^4$ kg/mm$^2$), the attenuation coefficient $\zeta = 0.31$; for Low Carbon Steel (Gost St3) ($E = 2 \cdot 10^4$ kg/mm$^2$) – $\zeta = 0.8$; for Alloy Cast Iron ($E = 1.9 \cdot 10^4$ kg/mm$^2$) – $\zeta = 3.2$; for Copper Alloy ($E = 1.15 \cdot 10^4$ kg/mm$^2$) – $\zeta = 4.1$.

The results of the study are shown in comparative graphs (Figure 3) for a tool holder with an oriented center of rigidity with reduced elastic parameters $c1_{max} = 20$ kN/μm, $c2_{min} = 2.5$ N/μm and ordinary base tool holder with the same rigidity $c1_{max} = c2_{min} = 20$ kN/μm at the same boundary conditions of cutting ($t = 15$ mm, $P = 9.5$ kN) for an elastic carriage system with parameters $c5_{max} = 80$ kN/μm, $c6_{min} = 47$ kN/μm and a negative angle of orientation of the stiffness axes $\delta = –60°$. An increase in the damping coefficient for a tool post with the same rigidity leads to a gradual increase in the level of cutting stability L = 2.8–3.6 dB, however, for a spacial tool holder with an oriented center of rigidity, this leads to a sharp decrease in the level $L = 8.4–3.5$ dB.

CONCLUSIONS. According to the results of the study, it can be argued that the damping properties of the equivalent elastic system of a tool holder with an oriented center of rigidity are related to its ability to dynamically influence the vibration processes of the carriage during turning. An increase in the parameters of internal friction in the design elements of the tool holder due to the use of plastic materials or the use of an additional external friction damper only leads to a decrease in the efficiency of using such tool holders.

A characteristic feature of the carriage group systems of the lathe is a large number of fixed joints that have a large damping effect. In order to evaluate the effect of the carriage's elements, the stiffness was changed in individual joints and the effect of this change on stability was checked. Experiments with carriage of universal machine tools during turning "press down to carriage" do not show a noticeable effect of the vibration stability. But as soon as the traditional design and loading pattern changes, the carriage begins to affect the vibration stability. The lowest vibration resistance in lathes is observed when turning with wide cutters with small plan angles, in particular, when cutting and slotting. On universal machines, processing is practiced with reverse rotation of the workpiece and turning "to tear carriage off rails". In this case, the direction of the cutting force and the loading conditions of carriage change, and the stability increases. It is known, for example, that careful fitting of carriage parts can sometimes reduce stability, while on carriage with loose wedges or on worn carriage or rails, stability is higher. The high vibration resistance of carriage can be explained by increased damping in the fixed joints. At the same time, if the carriage has a large mass and, accordingly, a low frequency of natural oscillations, then the vibration resistance of such machine tools may be lower than that of machines with light carriage.

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# ТЕОРЕТИЧНІ ДОСЛІДЖЕННЯ ВПЛИВУ ДЕМПФІРУЮЧИХ ВЛАСТИВОСТЕЙ СПЕЦІАЛЬНОГО РІЗЦЕТРИМАЧА З ОРІЄНТОВАНИМ ЦЕНТРОМ ЖОРСТКОСТІ НА ВІБРОСТІЙКІСТЬ ПРИ ТОЧІННІ

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У статті наведено результати теоретичного дослідження з використанням математичної моделі потенційно нестійкої динамічної системи різцетримач-супорт-деталь та процес різання, та вплив параметрів демфірування підсистеми різцетримача на відносне значення рівня вібростійкості. Відомими напрямками підвищення вібростійкості токарної обробки є зменшення негативного впливу координатного зв'язку між вібраційним переміщенням різця та процесом різання, через використання додаткового різцетримача з орієнтованим положенням центра жорсткості або різцетримача з підвищеними демпфіруючими характеристиками. Актуальним є дослідження доцільності одночасного поєднання цих двох напрямків підвищення вібростійкості в одній конструкції різцетримача. За наведеними результатами імітаційного моделювання процесу різання та оцінки його сталості за критеріями Найквіста встановлено, що відносне підвищення показників параметра демпфірування в конструкції різцетримача з орієнтованим центром жорсткості призводить до зменшення відносного рівня амплітуди коливань відстані між різцем та деталлю та одночасним зменшенням вібростійкості процесу обробки. Отже у випадку високопродуктивної обробки на граничних режимах різання на токарному верстаті для протидії виникненню та збільшенню автоколивань через недоліки пружних характеристик конструкції супорта, ефективним є саме створення направлених певним чином вібраційних коливань різця через використання спеціальних різцетримачів із подальшим зменшенням енергії самозбудження. Збільшення параметру демпфірування в конструкції такого спеціального різцетримача через використання пластичних матеріалів призводить до зменшення ефективності його корисної вібраційної дії на процес різання.

**Ключові слова:** вібрації, вібростійкість, різцетримач, токарна обробка, динаміка машин, центр жорсткості.

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*Стаття надійшла 03.03.2022*