УДК 621.9.06-752

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RESEARCH OF THE POSSIBILITY OF SELF-EXCITED VIBRATIONS AMPLITUDE REDUCING WHEN TURNING BY THE VARIATION OF THE CUTTING SPEED

В статті приведені результати експериментальних досліджень можливості пригнічення автоколивань при точінні через модулюванння швидкістю різання. Описаний експериментальний підхід щодо здійснення варіативного керування приводом головного руху токарного верстата. Досліджені можливості приводу головного руху роботи в режимі постійного варіювання швидкістю обертання
Ключові слова: точіння, пригнічення автоколивань, модулюванння швидкістю різання

В статье приведены результаты исследования возможности подавления автоколебаний при точении модулированием скоростью резания. Описан экспериментальный подход осуществления вариативного управления приводом главного движения токарного станка. Исследованы возможности привода главного движения работы в режиме постоянного варьирования скоростью вращения.
Ключевые слова: точение, подавления автоколебаний, модулирование скоростью резания

In this paper the results of research of the possibilities of self-excited vibrations suppression in turning by the cutting speed modulation are presented. The experimental approach to conduct the variative control of lathe main drive is described. The possibilities of main drive working in continuous rotation speed mode are researched.
Keywords: turning, suppression of self-excited vibrations, cutting speed modulation

The problem of appearance of self-excited vibrations in turning remains relevant to this day. The excess of the allowable values of the vibration amplitude of tool or blank leads to degradation of the machined surface quality, quick tool wear and breakage, and also to damaging the elements of machine.

For now different approaches of the vibration suppression at machining are applied:

- using the active damper devices;
- tightening the elements of machine – device – tool – detail (MDTD) system;
- choosing the optimal cutting conditions;
- the modeling for prediction and nursing from self-excited vibrations (to the prejudice of performance).

Self-excited vibrations are the ones that appeared and supported by internal features of the working system at the presence of constant external energy source. They appear in turning as a consequence of the elastic deformation of the elements of MDTD system at the influence of the external exciting cutting force.

Self-excited vibration is the main obstacle towards increasing the machining performance, because they are very hard-suppressed and highly stable.

One of the modern methods of chatter suppression at machining is cutting with constantly-varying the main motion speed [1, 2, 3, 4]. This approach is based on reducing of the influence of the regenerative exciting by destruction of stable phase shift $\psi = 180°$ on the cutting surface between the trail, that is left from the previous tool path (revolution of workpiece), and current vibration trajectory.

The purpose of this article is determination of the efficiency of described method of chatter suppression when turning. The 16K20T1 lathe with 2P22 numeric control (NC) system was used for this. The external device – *modulator* – was used for enable to vary the main motion speed that is built-in main drive control system (Fig. 1), which is controlled by the NC through the converter C1 that governs the motor M1. The last one transfers the rotation to spindle with chuck through the belting and gearbox.

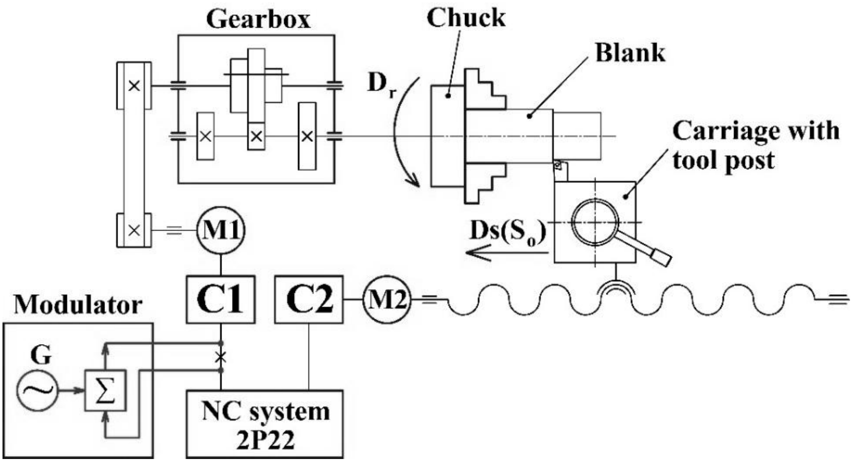

Figure 1 – The machine movements control scheme:
M1, M2 – the motors of main drive and feed drive; C1, C2 – drives converters; ∑ – adder;
G – generator; Dr – main motion (the rotation of spindle);
Ds – feed motion (the longitudinal displacement of carriage)

Modulator is a digital device that is based on single-chip computer, and represents the sinusoidal signal generator G and adder ∑, which adds the control signal from the NC system and generator signal. As a result, the modulated signal transfers to the converter C1, which controls the spindle speed n_{sp}.

By changing the waveform of generator signal G, the various law of spindle speed n_{sp} changing can be set. In this research the harmonic waveform was used with the feature of varying it frequency and amplitude during the machining. In this paper the term *modulation* is used for describing this drive mode.

As a cutting tool the device of researching the self-excited vibrations at turning [5] was used. The construction of it allows to record tool displacements in horizontal and vertical directions. The cutter has reduced stiffness that allows conducting the researching in the best conditions in terms of chatter studying.

The cylindrical blank (L = 130 mm; D = 100 mm, material – AISI-1045 steel, hardness HB170) is used for the experiments. The encoder sensor (HTR-5B-100-3-5V) was used for measuring of the actual spindle speed. The half-coupling was installed on his axis, which got the rotation from the end of blank through the rubber gasket.

Thus, the test bench (Fig. 2) was created for researching the influence of the *modulation* of the cutting speed, which allows performing the longitudinal turning and record next cutting process parameters:

- elastic displacements of tool in horizontal and vertical directions;
- actual spindle speed n_{sp}.

The received signal was processed for measurement of these parameters by one of this software: MatLAB, Octave. The method of processing is described by authors in references [6, 7].

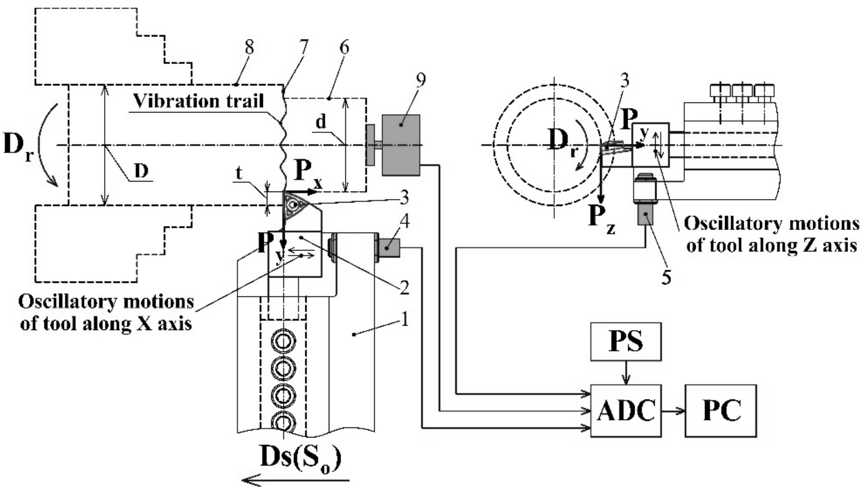

Figure 2 – The test bench scheme of the measurement of the tool vibrations when turning: 1 – body of device; 2 – elastic element; 3 – insert; 4 – horizontal tool displacement sensor; 5 – vertical tool displacement sensor; 6 – machined surface; 7 – cutting surface; 8 – machining surface; 9 – encoder; Dr – main motion; Ds(So) – feed motion; ADC – analog-digital converter; PC – personal computer; PS – Power supply

The spindle speed *modulation* is characterized by next parameters:

- frequency of *modulation* Fn – determines the amount of periodic change of the n_{sp} value per second;

- depth of *modulation* An – maximal deviation of the actual spindle speed n_{sp} from the average value.

Seeing, that the elements of machine have the inertial properties, the actual spindle speed n_{sp} can be differing from it set by the NC system and the *modulator* depending on the Fn and An parameters. The tests with setting of different values of the depth and frequency of the *modulation* were conducted to determine the capabilities of the main drive. The measuring of actual rotation speed was carried out by encoder.

Tests were conducted:

- without cutting – in the absence of external load;

- when cutting by the rigid cutter (PDJNR 2525 M11, insert: DNMG 441PF r = 1,2 mm, material T15K6) at t = 2 mm; So = 0,15 mm/rev; n_{sp} = 403 rev/min; D = 94,8 mm.

Following the comparison of the specified *modulation* parameters with recorded by encoder signal, the main drive chart (Fig. 3) was obtained, which describes the capabilities of implementation of *modulation* in current working conditions depending on setting values of Fn and An. The cutting force at the frequency of *modulation* Fn ≥ 3 Hz doesn't effect on the spindle speed. Herewith, when cutting the depth of *modulation* practically doesn't depend on the value that is set on the *modulator*, because the reaction of drive in loading conditions depends on characteristics of the machine motor M1. However, the actual depth of cut reduces at the frequency Fn increase, since the inertial properties of the elements of main drive appears largely.

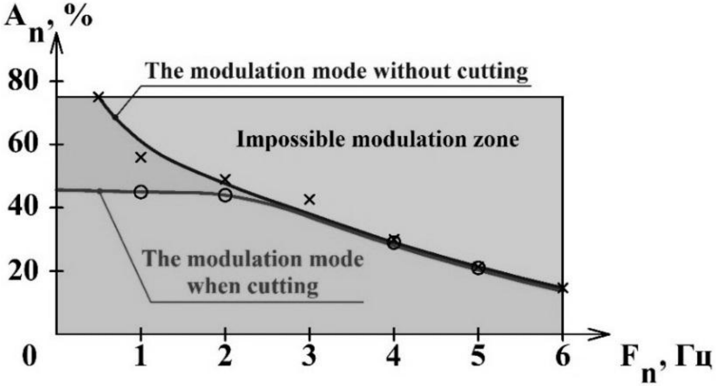

Figure 3 – Main drive chart

Further experiments with modulator working were conducted while cutting at self-excited vibrations occurring. The oscillogram of the tool vertical displacements and chart of changing the spindle speed are presented on Fig. 4. The turning was performed at the following conditions: t = 1,2 mm; So = 0,15 mm/rev; n_{sp} = 347 rev/min; D = 91,9 mm; V = 100 m/min; Fn = 0,5 Hz. The cutting was conducted by tool with next parameters: rake γ = -8º, flake α = 8º, major cutting edge angle φ = 90º, minor cutting edge angle φ_1 = 7º, nose radius r = 0,2 mm, flake wear fz = 0,2 mm, material of insert T5K10.

In this experiment 2 region of detail (10 mm longitude of each), successively turned: with and without the *modulation* respectively. In the first case the vibration amplitude was 321 μm. At the turning on the varying of the rotation spindle speed by *modulation*, the average value of Az became 212 μm. Although the oscillogram of displacement has periodically changing form, the overall vibration level decreases.

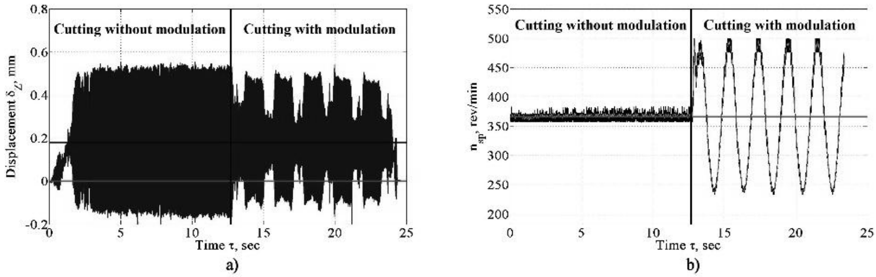

Figure 4 – Turning with the *modulation* at Fn = 0,5 Hz:
a) vertical tool displacements oscillogram; b) the spindle speed n_{sp} changing chart

Further research of the capabilities of the chatter suppression was passed by changing the modulation parameters. Since the depth An is strongly limited by the capabilities of main drive and weakly depend on set value by *modulator*, the influence of the modulation frequency Fn was investigated. Longitudinal turning of the blank (D = 89,3 mm) was conducted by changing the *modulation* frequency in range Fn = 0…10 Hz with step 1 Hz (turning 10 mm per each value). The cutting was performed in a single pass at next conditions: n_{sp} = 357 rev/min; V = 100 m/min; So = 0,15 mm/rev; t = 1,5 mm. As a result, the dependence of the vibration amplitude in vertical direction *Az* from the modulation frequency Fn was obtained (Fig. 5).

The chart shows that turning on the *modulation* at the cutting process straight reduces the vibration amplitude. However, further increasing of the frequency Fn doesn't lead to significant vibration level reducing.

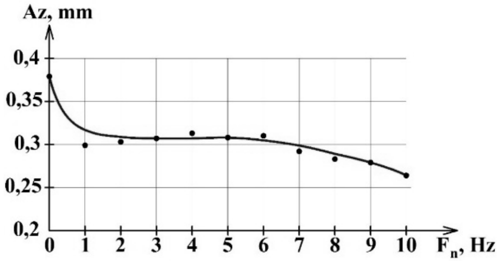

Figure 5 – The dependence of tool vibration amplitude Az from modulation frequency Fn

Inasmuch as the changing of the actual rotation speed occurs on the periodic law, the system customizes on this machining conditions so that the tool vibration level also changes periodically (Fig. 4a). The obtained results confirm the conclusions of the Afonina's work [8] that the modulation by a harmonic law is ineffective, because the reduction of the vibration amplitude is insignificantly (about 20%). In that work it is also said, that for the best chatter suppression when turning the conditions of the cutting speed varying with random changing of the modulation parameters must be used. To verify this fact in this research the turning with stochastic modulation frequency changing Fn was conducted at next conditions: t = 1,5 mm; So = 0,15 mm/rev; n_{sp} = 403 rev/min; D = 94,9 mm; V = 120 m/min. The turning was performed in single pass at Fn = 1 Hz with next random frequency changing law to Fn = 2 Hz (Fig. 6).

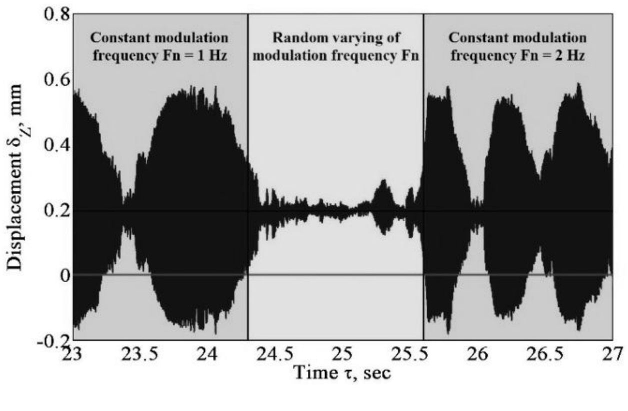

Figure 6 – Tool displacement oscillogram in vertical direction with random changing of the *modulation* frequency Fn

The experiment showed that random modulation frequency changing leads to significant reduction of the self-excited vibration level that also confirms the conclusions of the Afonina's work [8].

Thereby, at turning in the varying of the main motion speed conditions the reduction of the vibration level is observed. However, in view of the features of self-organization of self-excited vibrations it is necessary to conduct the further researches to find out the *modulation* conditions that allow suppressing chatter when turning as efficiently as possible.

Summary:

1. The cutting in continuous variation of the main motion speed conditions leads to reduction of self-excited vibration amplitude.
2. The cutting speed *modulation* with constant parameters Fn and An doesn't lead to significant decreasing of vibration level.
3. Stochastic spindle speed modulation mode is the most effective for chatter suppression in turning.
4. The further research is needed to find out the conditions that allow to reduce maximally the self-excited vibration in turning.

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