Identification of the self-oscillating mode in metal-cutting machines in the production of agricultural machinery

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Abstract. The production of modern agricultural machinery includes various technological chains machining workshops, consisting mostly of turning and milling machining centers. The influence of self-oscillations on the dynamic characteristics of mechanisms for various purposes is due to the increased requirements for the quality and reliability of products of modern machines and units. Timely detection and reduction of the impact of oscillatory processes makes it possible to qualitatively optimize the design of mechanisms. A special role in the process of operation is exerted by self-oscillations on metal-cutting machines in the processing of materials. The consequence of the self-oscillatory process is a violation of the performance of a metal-cutting machine, expressed in a parametric (accuracy) failure. In this paper, the possibility of using parametric spectral analysis for the early identification of a self-oscillating process in hexapod machine tools was evaluated, for which the objective function was determined, i.e. the value of the damping coefficient of the dynamic system.

1 Introduction

The issue of self-oscillations in machine tools has been and remains one of the most important and most discussed in scientific circles [1-4]. Self-oscillations in machine tools are most appropriately described in the book by I. Tlustoy “Self-oscillations in machine tools” [5]. Namely: “During machining, under certain conditions, intense vibrations arise, the amplitude of which increases rapidly, and in the case of less intense vibrations, it can be observed that the amplitude is quickly established, reaching a certain value. In most cases, the vibrations are so intense that cutting has to be stopped, and therefore the amplitude never reaches a steady value.” As practice shows, the frequency of such oscillations is usually close to one (sometimes several) of the natural frequencies of the elastic system of the machine.

In Russian and foreign literature the issue of identifying the mode of self-oscillations in machine tools remains open [6-8], and therefore, it seems promising to use the procedure of

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parametric spectral analysis (PSA) for this purpose. It should be noted that the Prony method was used in [9] to identify the mode of self-oscillations (flutter) of the blades; in particular, the fact of a change in the sign and magnitude of damping means a change in the role of this mode of non-stationary oscillation.

Estimating the parameters of a non-stationary (exponential) signal is one of the most common tasks in various fields of technology. This is because the response of a linear system to an impulsive action is the sum of just such signals, i.e. by estimating the parameters of the signals at the output of the system, it is possible to solve the problem of identifying the system and its state. The use of the Fourier transform for this purpose does not always give good results, since this transformation was originally intended to estimate the signal spectrum, and not the frequency, and in the classical version is not statistically stable.

In contrast to the Fourier spectral analysis, the Prony spectral analysis as a PSA method allows [10,11]:

- to perform spectral estimation of segments of time series without side effects in time windows of limited duration;
- to use a non-stationary time series model (for example, increasing or decreasing in the time window);
- to determine the intrinsic frequency spectrum and the spectrum of modal damping of the modes of the system manifested in this segment of the time series.
- to get the analytical Fourier spectrum of the signal, i.e. without using FFT.

The Prony method [10,11] lacks several limitations inherent in the Fourier transform, for example, as a result of the Fourier transform of time series representing damped sinusoids of the form

$$Ae^{-\delta t} \times cos(\,2\pi ft + \varphi) \tag{1}$$

get estimates of three parameters:

- $\frac{A}{\delta^{\frac{1}{2}}}$- Fourier amplitude;
- φ - phase;
- f - frequency (considering dissipative properties), the accuracy of which depends on the quantity δ.

And in the Prony method, the decomposition of time series segments is used, as a result of which for time dependences of the form

$$Ae^{-\delta t} \times cos(\,2\pi ft + \varphi) \tag{2}$$

estimates of all four independent parameters are determined: A, φ, δ, f.

The Prony method allows a sequence of complex data to be approximated by a model $y_i$consisting of m damped complex exponents$\tilde{y}_i$:

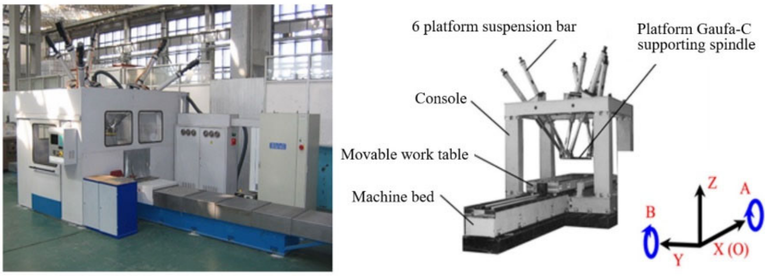
$$\tilde{y}_n = \sum_{k=1}^{m}[A_k\, exp(j2\pi f_k \Delta tn + j\phi_k)\, exp(-\delta_k \Delta tn)],\, n = \overline{1, N} \tag{3}$$

where: A_k- amplitude; f_k- frequency; φ_k- initial phase; δ_k- attenuation coefficient; Δt - signal sampling period; n - reference number; N - number of signal samples.

In [12], the author analyzed the non-stationary process filmed on the headstock of the SU40 lathe and described by I. Tlusty in his monograph [5] on pp. 70-71. The conclusion is made about the possibility of using ASA to identify self-oscillatory processes in metal-cutting machines, the objective function is determined - the value of the damping coefficient of the AIDS system (the established tendency of the system damping to zero).

2 Results and discussion

As an example of using the capabilities of PSA to identify the mode of self-oscillations in machine tools, a non-stationary process was chosen, filmed during full-scale studies of the machine - the Hexamech-1 hexapod (Figure 1), [13, 14]. As studies of static rigidity have shown, the Hexamech-1 machine has insufficient rigidity and the presence of mutual influence, i.e. when a force is applied to the spindle body, deformations (displacements) are observed in a direction perpendicular to the direction of the force. A similar picture is observed in the study of the dynamic compliance of the Hexameh-1 machine tool.



(a) machine (b) "mechanical part" of the machine

Fig. 1. General view of the machine.

To evaluate the operation of the machine in 5 coordinates (X, Y, Z, A, B), a sample made of aluminum alloy D16T was processed. Stable self-oscillations were observed during the processing of the "ribs" of the sample. The processing of the "ribs" of the sample was carried out under the following cutting conditions: Tool: end mill Sandvik R216.42-16030-AK26A H10F (Ø16, R8, Z=2), working dyne of the cutting part Lcut = 26 mm, total length L = 126 .72 mm. Machining parameters: spindle speed - S = 18000 min-^{1}, minute feed - F = 2000 mm/min. Allowance - 2 mm.

During processing, increased noise and vibration were observed, the roughness of the machined surface was increased, which indicates the transition of the machine to a self-oscillating mode of operation. Figure 2 shows the oscillatory process taken during the processing of the "ribs" of the sample. The oscillatory process graph was processed in the SAProny program. Figure 3 shows the modal decomposition of the signal without regard to scale. Figure 4 shows the modal decomposition of the signal, considering the scale.

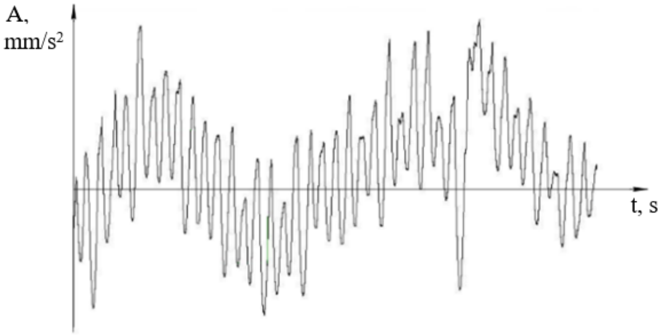


Fig. 2. Oscillatory process, "filmed" on the machine "Geksameh-1".

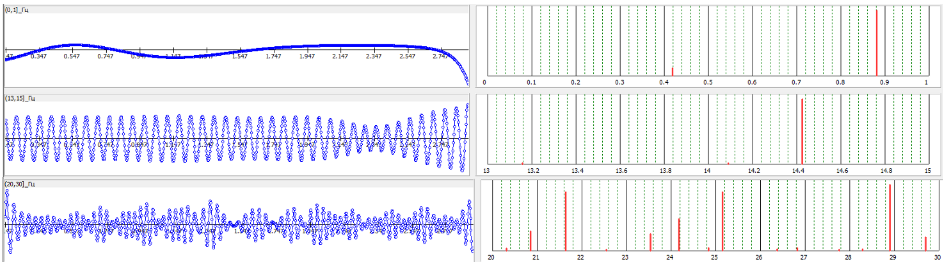


Fig. 3. Modal signal decomposition without scale.

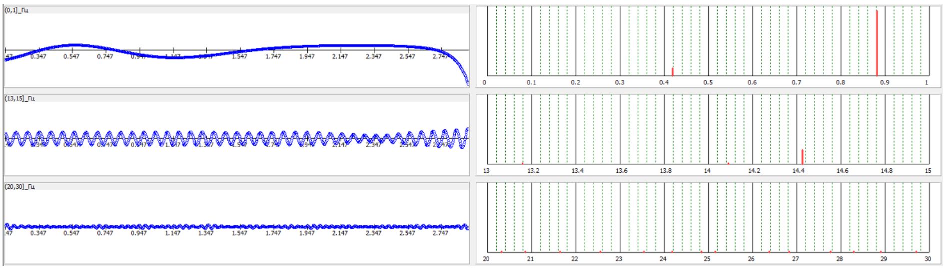


Fig. 4. Modal signal decomposition with scale.

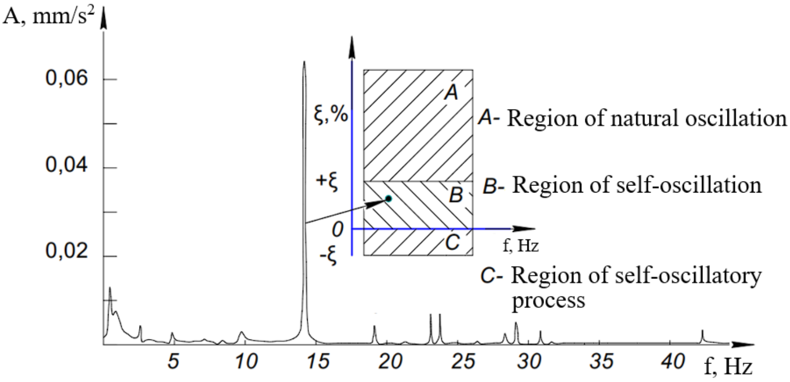


Fig. 5. Prony-Fourier spectrum obtained as a result of processing the experimental signal taken on the Hexameh-1 machine.

The oscillatory process graph was digitized and processed in the SAProny program. Figure 5 shows the Prony-Fourier spectrum obtained as a result of processing the experimental signal. From the presented results the oscillation frequency is 14.32 Hz and it is close to the 1st natural frequency of the NS of the machine (15 Hz). This mode has a damping coefficient tending to 0 (0.016), which indicates the transition of the system to a self-oscillating mode.

3 Conclusion

PSA can be effectively used to identify the process of self-oscillations in hexapod machines. A similar result cannot be obtained using the technology of classical spectral analysis based on the fast Fourier transform.

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