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Evaluation of the Dynamic Properties of Tillage Process with Toothed Operating Tools

Zoja Shanina, Iryna Kylymnyk, Anton Fasoliak and Olena Syvachuk
National University "Zaporizhzhia Polytechnic", Zhukovskoho 64, Zaporizhzhia, 60063
0000-0002-7640-2589, 0000-0001-5554-6498, 0000-0002-5874-1368, 0000-0002-9747-0070

Abstract: In the process of tillage (crushing) of soils, including agricultural ones, a complex dynamic process of interaction between the tool and the solid soil and its crushed parts takes place. The analysis of oscillograms shows that in the vast majority of cases, the grinding process is a stationary random process. The spectral analysis of oscillatory processes of different toothed tools while tilling was carried out and a correlation evaluation of the obtained models has been proposed.

Keywords: soil tillage, soil crushing, toothed operating tools, dynamics of the tillage process, probabilistic processes, dispersion, correlation function, frequency, spectral density.

Statement of the problem

The oscillograms of controlled quantities represent the initial material for studying the operation of a tillage operating tool in real conditions. In the stable mode of operation of toothed operating tools, the recordings on oscillograms can be characterised as stationary random processes [1, 2]. Statistical methods of processing these records allow obtaining a number of dynamic properties of the object which are later used when analysing the work of tillage machines operating tools in real production conditions.

The general provision for the choice of realization length depending on the required accuracy of estimates of probabilistic characteristics is based on the fact that mathematical statistics allows obtaining a quantitative measure of the dependence of estimates on the realization length. However, the specificity of random processes observed during the operation of toothed operating tools, as well as other tillage tools, does not allow for an unlimited increase in the length of the realization. As the length of the realization increases, the probability of obtaining the realization of a non-stationary process increases. This means that both the mathematical expectation and the dispersion of the process may change.

Analysis of recent studies

Studying and testing agricultural mobile units [1, 3, 4], when analysing process oscillograms, is limited to calculating the average values of parameters and their standard deviations m_e. However, it is known that assessment of processes characteristics only by these values is not sufficient. The most complete static characteristic of a random process is its correlation function $R_x(t_1, t_2)$, which characterises the degree of dependence between the values of random function $x(t)$ at a given time t_1 and t_2. For stationary processes, an essential static characteristic is the spectral density $s_x(\omega)$, which describes the frequency composition of the correlation function of a random process.

Statement of the problem

The aim of this paper is to determine the correlation function that characterises the random process of soil crushing by toothed operating tools and the spectral density of this function.

Presenting the main material

The analysis of the processes occurring during the operation of agricultural units has shown that in the vast majority of cases they are stationary in a broad sense, i.e. the mathematical expectation and dispersion are constant, while the correlation function depends only on the difference in time points $t_2 - t_1 = t$.

$$R_x\ (t_1 - t_2) = R(t_2 - t_1) = R(\tau) \qquad (1)$$

In the first approximation, random processes in the operation of tillage machines in stable modes of operation can be classified as stationary with ergodic properties. Thus, one realization (oscillogram) of the random process *x(t)* obtained over a sufficiently long period of time *T* can serve as the starting material for calculating the correlation function $R_x(\tau)$ and the spectral density $s_x(\omega)$.

When determining the required number n of measurements for a sufficiently reliable calculation of the mathematical expectation and correlation function, it is recommended to proceed from the condition that at least 10 points of the studied random function are located in an interval of one period of the highest quality harmonic. In this case, the most permissible number (the number that determines the magnitude of the shift along the abscissa axis) should not exceed a quarter of number *n*, and the recording interval *T* should be large enough for the correlation function to be calculated by formula (2) and be close to zero for all *m* close to ¼ *n*. It is recommended to take the realization duration depending on the number m_{max}. The number of points of the correlation function curve can be determined by formula (3)

$$m_{\max} = \frac{\tau_{\max}}{\Delta t} \tag{2}$$

Where Δt isthequantization step

Leading scientists recommend taking the realization duration *T* within [3] and [4], respectively

$$T = 10\tau_{\max} \tag{3}$$

$$T = 4\tau_{\max} \tag{4}$$

When determining the minimum permissible realization duration *T*, condition (4) can be used; if it is necessary to determine the characteristics of the random function more accurately, condition (3) should be used.

The correlation function $R_x(\omega)$ of a stationary random process is the mathematical expectation of the set of ordinates of a random function at a time point($t+\tau$), i.e.

$$R_x(\tau) = M[x(t) - x(t+\tau)] \tag{5}$$

Defining $R_x(\tau)$ as the average at time *T*, we have

$$R_x(\tau) = \lim \frac{1}{2T}\int_{-T}^{T} x(t)x(t+\tau)dt \tag{6}$$

Where *T* is the duration of the realization record

Since the experiment is carried out within a limited period of time *T*, the initial approximate formula for calculating $R_x(\tau)$ is

$$R_x(\tau) = \lim \frac{1}{T}\int_{0}^{T} x(t)x(t+\tau)dt \tag{7}$$

The connection between the spectral density and the correlation function is accomplished by the Fourier cosine transform

$$s(\omega) = \frac{\pi}{2}\int_{0}^{\infty} R(\tau)\cos\omega\tau d\tau \tag{8}$$

The oscillograms obtained during strain gauging show that the process of changing the traction resistance of the toothed operating tools has the form of continuous random oscillations relative to the average value, i.e. oscillations of different frequencies. The frequency and range of oscillations depend on the soil condition and the nature of the interaction of the operating tool with it.

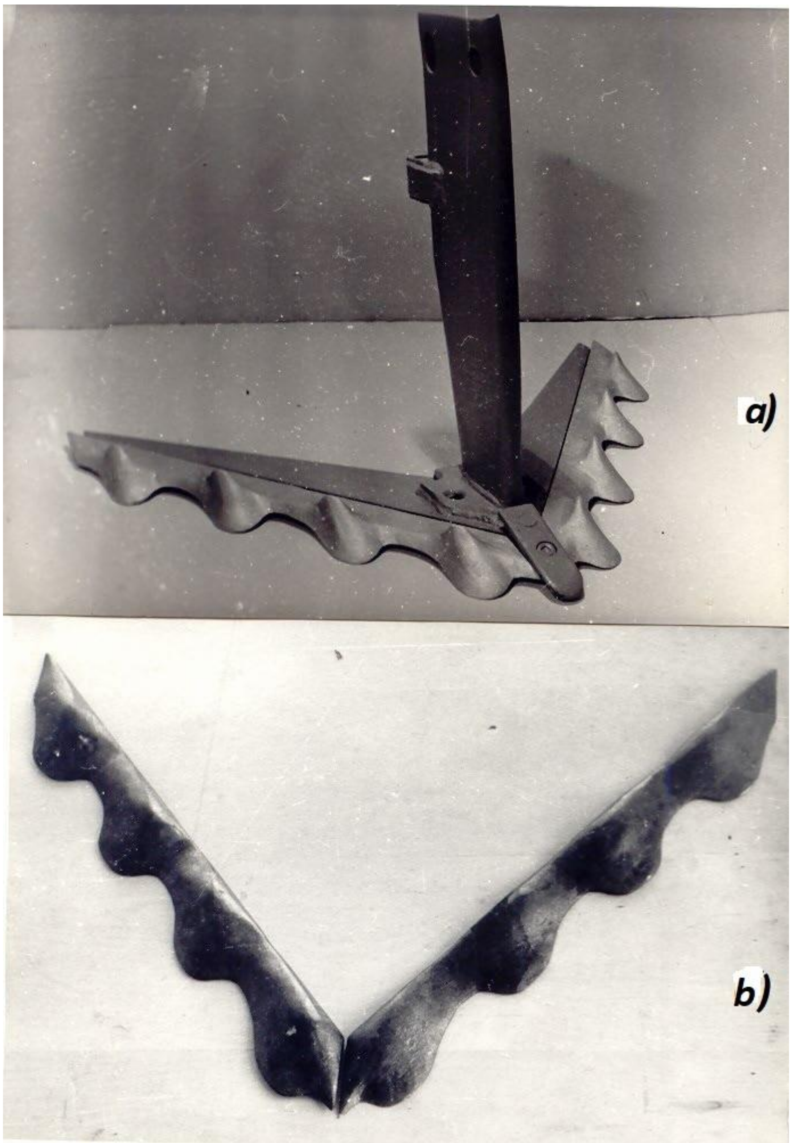

Figure 1 –a) The new toothed operating tool and b) its cutting part

If the process of traction resistance change is dominated by oscillations with a predominant frequency and amplitude, then such a process is an orderly one that proceeds with a certain regularity. If no predominance of any frequency is observed, the process of traction resistance change acquires the character of the so-called "white noise".

As a result of processing a number of realizations during the experimental study of the operation of one new (Fig. 1) and three serial toothed operating tools, obtained were normalised correlation functions (Fig. 2) and constructed were spectral density curves (Fig. 3) for four types of toothed operating tools.

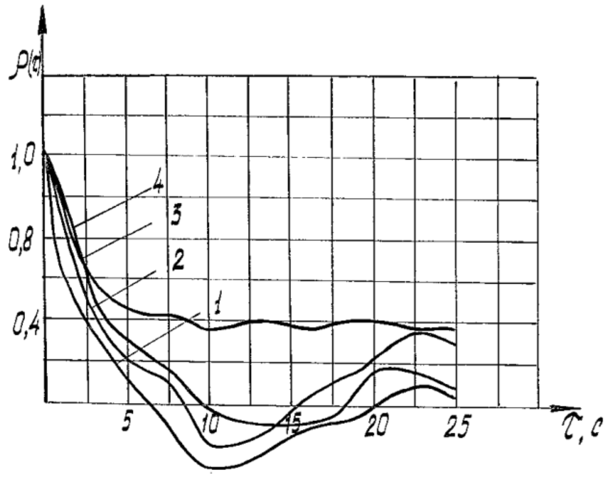

Figure 2 – Normalised correlation function for different types of toothed operating tools
1, 2, 3 are proposed new types of operating tools; 4 is a serial operating tool

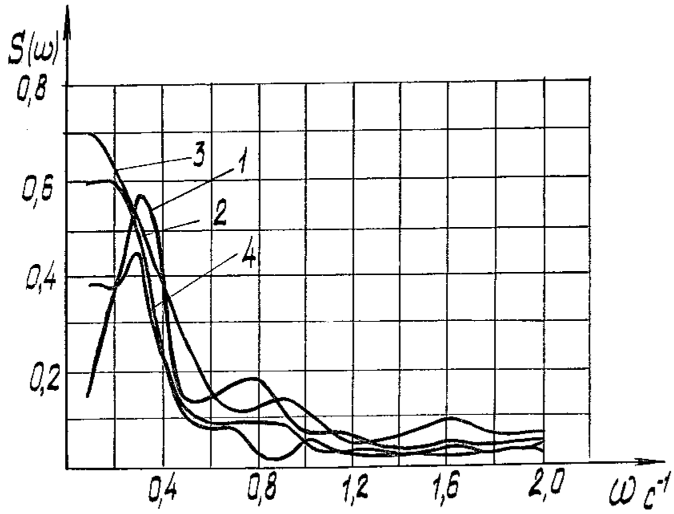

Figure 3 –Spectral density for different types of toothed operating tools
1,2,3 are proposed new types of operating tools; 4 is a serial operating tool

It is known from the theory of random functions that the more "ordered" a random process is, the slower the correlation function decreases, and the spectral density curve has a pronounced maximum on the interval of predominant frequencies, i.e. it stretches upwards, shrinking horizontally. If the random process is "white noise", the value of the correlation function decays very quickly, and the spectral density looks like a line parallel to the axis of change in oscillations frequency.

The nature of the obtained curves $R(\tau)$ and $s(\omega)$ allows us to draw some conclusions about the peculiarities of fluctuations in the traction resistance of the toothed operating tools. The graphs of the normalised correlation functions suggest the ergodicity of the process since $R(\tau)$ tends to zero at $\tau \rightarrow \infty$. The attenuation of the curves indicates that the process contains hidden periodic components with random ones, which is manifested in the operation of toothed operating tools. Analysis of the correlation functions shows that the toothed operating tools have stable oscillations.

Compared to the curves of the correlation function, the spectral density curves do not provide new information about the random process, but due to the transition from the time domain to the frequency domain, they clearly reveal the internal structure of the random process. The location of the spectral maxima in the frequency range of up to 2…3rad/s at *V=1m/s*is typical for tillage operating tools. At a travel speed of *V*=1.46

m/s the spectral maxima lie in the range of $\omega = 0.5 \quad 1/s$. This frequency range at low travel speeds constitutes mainly the sub-resonant region for oscillatory systems whose natural oscillation frequency is $f_0 = \omega_i / 2\pi \leq 3...4$ 1/s.

The decrease in traction resistance observed during functioning of toothed operating tools can be explained by the fact that the inter-tooth space of the cutting part of the ploughshare moves in the soil cracks formed by the tooth protrusion. Therefore, the energy consumption for crushing the soil layer is reduced, which in turn leads to a decrease in the energy intensity of the process.

Conclusions

1. The graphs of normalised correlation functions indicate the ergodicity of the oscillatory process that occurs when tilling the soil with toothed operating tools. In this case there are hidden periodic and random components of oscillations.
2. The spectral range of oscillations of toothed tool sat tilling is sub-resonant.

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