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Methodology of processing the results of field experiment monitoring of the technological procedure of sowing

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Abstract

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The non-uniformity of distribution of seeds sown in a row influences their productivity. To analyse and eliminate the causes of non-uniformities, the straight motion of coulters must be separated from generation of causes, i.e. the deviation of seeds from an ideal position on the coulter trajectory. A partial acceleration method can be effectively used to recover the coulter trajectory. It is based on the study of machine parts dynamics by measuring the three-dimensional projection of acceleration and its characteristic points. Fourier methods are used for approximation or interpolation of experimental data. The trajectory of a point is obtained by double integration of a Fourier series. Noise generation in acceleration measurement can be solved by smoothing with reasonable intensity. Also double integration leads to smoothing, the variability of the number of points participates in assessing the degree of harmonic distortion of reconstructed trajectory, based on which the required smoothing limit can be set. The method may be used for monitoring the farm machines dynamics based on the partial acceleration method.

Keywords: coulter trajectory; acceleration; amplitude; curve; Fourier transform

The non-uniform distribution of plant seeds in longitudinal direction (Onal et al. 2012) and distribution in depth (Karayel, Özmerzi 2007; Altikat 2012; Seidi 2012) significantly influences production (Korucu, Arslan 2009; Kurylo et al. 2013). In order to find and eliminate the causes of such deviations, researchers have developed suitable laboratory research methods (Önal, Önal 2009; Navid et al. 2011). However, many problems remain opened. In the study of lateral deviations of

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plants, there is an unaddressed question about the position of the row centre line. The deviation of the row centre line contributes to errors in estimating the distribution of seeds or plants along the row. The sowing depth of seeds can be relatively accurately estimated after measuring germinated parts of plants (Melnik 2012), but the effect of coulter oscillations on measurement result cannot be distinguished.

The above-mentioned problem underlies the role of separating three-dimensional deviations of plants due to errors of ideal sowing on the coulter trajectory, from the non-linearity of the trajectory alone. The solution of such task enables including the most important factors, assessing their relationship, and determining relevant technical and technological means of their elimination.

A GPS technology can be used to recover the coulter trajectory. It is an effective method, but is now used especially for monitoring the trajectory of the machine as a whole, rather than its individual parts (Backman et al. 2012; Fleischmann et al. 2013; Jingtao, Taochang 2014). The method of partial acceleration appears to be an alternative and effective supplement to GPS navigation, the implementation of which increases the overall productivity of work (Žitňák et al. 2014).

MATERIAL AND METHODS

Formulation of research problems. The trajectory of a point (coulter centre of gravity in this case) can be obtained by the method of partial acceleration through double integration of interpolated (harmonised) measured data. A special emphasis is put on creating the mathematical model of sowing, accompanying noise measurement, and formulating approaches to determine initial conditions.

Further development of the designed sowing model requires solving the problem of constructing the coulter trajectory (analytical illustration), which is considered more than projection on the horizontal plane of the coordinate system $0xy$, i.e. as the function $y = y(x)$.

Current situation of issues. The study of Melnik and Mohammed (2012) contains a mathematical model of sowing based on presenting the horizontal projection $y = y(x)$, in general case, the three-dimensional line of the row of sown plants, as a sum of three curves:

$$y(x) = \frac{1}{2}\sum_{k=0}^{3} A_k^{(y)} \cos\left(\frac{2\pi}{L_k^{(y)}} x + \varphi_k^{(y)}\right) + y_0 \quad (1)$$

where:

x – longitudinal coordinate of a row line point (identical with ideal direction)

y – current deviation from the ideal curve in straight row

$A_k^{(y)}$, $L_k^{(y)}$, $\phi_k^{(y)}$ – amplitude, wavelength and initial phase of the k^{th} curve

y_0 – shift of the straight ideal row with respect to the axis 0_x of the coordinate system

The numerical parameters in Eq. (1) are selected from the set of limits determined in a pseudorandom manner and, besides that, using the Monte Carlo method (Graham, Talay 2013), the model of probable underlaps, overlaps, seed germination, three-dimensional deviations of germinated seeds, and a relative trajectory of coulter motion.

Eq. (1) cannot correspond to any actual trajectory of the coulter; therefore, the above-mentioned problem remains unsolved. Presenting the relationship as trigonometric series is further monitored by us.

The research problem in the experiment can be solved through direct measuring of the coordinates (x, y), by examining the tracks of the coulter that remained on the field surface, or using GPS coordinates during the drive without using the seeder. The first method cannot be performed in economic terms. It is labour intensive and requires plenty of time, whereby the field of testing cannot be used for other purposes. The second method, as indicated herein above, has also many technical problems concerning the placement of special equipment, which corresponds to the required actual measuring point, i.e. the coulter.

The most appropriate method how to recover the function $y = y(x)$ is to compare the method of partial acceleration, to estimate the measured three Cartesian acceleration components of the point (x, y) of the coulter centre of gravity, and further mathematical processing of measurement results. To perform this, we recommend the following sequence of steps. The following algorithm is proposed for this purpose.

– Parametrical displaying of the function $y = y(x)$:

$$x = x(t),\ y = y(t) \quad (2)$$

where:

t – time

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– Measurement of time series, congruence with the coordinate axes 0_x and 0_y of axial (a_x) and lateral (a_y) horizontal acceleration components of the coulter centre of gravity:

$$t = t(k) = t_k \in \{t_0, t_1, ..., t_N\};\ k = 0, 1, ..., N \tag{3}$$

$$a_\alpha = a_\alpha(k) = a_{\alpha k} \in \{a_{\alpha 0}, a_{\alpha 1}, ..., a_{\alpha N}\};\quad k = 0, 1, ..., N;\ \alpha \in \{x, y\} \tag{4}$$

where:

α – index defining acceleration a_x (at $\alpha = x$) or a_y (at $\alpha = y$)

N – older element of time series

$$N = K - 1 \tag{5}$$

is determined by means of number of measurements (K) (elements of time series):

$$K = \frac{T}{\Delta t} + 1 \tag{6}$$

where:

T – time of measurement

Δt – technically taken from long-term time interval between measurements

– Presenting acceleration $a_x = a_x(t)$ and $a_y = a_y(t)$ in the form of the finite Fourier distributions (Privalov 2012):

$$a_\alpha(t) = \sum_{i=0}^{n} A_i^{(a_\alpha)} \cos\left(\frac{2\pi}{T} it + \varphi_i^{(a_\alpha)}\right);\quad T \in [0, T];\ \alpha \in \{x, y\} \tag{7}$$

where:

n – max. number of distribution elements specified later

$A_i^{(a\alpha)}$, $\varphi^{a\alpha)}$ – amplitude and initial phases of distribution

– Determination of distribution parameters ($A_i^{(a\alpha)}$ and $\varphi_i^{(a\alpha)}$) (Eq. 7).

In the results of direct discrete Fourier transformation (RAO et al. 2010) from ordered set (Eq. 4), we obtain the complex meaning $K = N + 1$:

$$\tilde{a}_{\alpha i} = \sum_{k=0}^{N} a_{\alpha k} \exp\left(\frac{-j2\pi}{K} ik\right);\quad i = 0, 1, ..., N;\ \alpha \in \{x, y\} \tag{8}$$

where:

j – variable

$\tilde{a}_{\alpha i}$ – complex number

$a_{\alpha k}$ – output of the measured data

i – numeral series

k – serial number in the series

Every complex $\tilde{a}_{\alpha i}$ will be written as the sum of real R_i and variable I_i:

$$\tilde{a}_{\alpha i} = R_i + I_i \tag{9}$$

and the quantities are defined (Rao et al. 2010):

$$\tilde{A}_i = \frac{1}{K}\sqrt{R_i^2 + I_i^2},\ \tilde{\varphi}_i = \text{arctg}\left(\frac{I_i}{R_i}\right) \tag{10}$$

where:

$\tilde{A}_i$ – complex number

$\tilde{\varphi}_i$ – complex number

Then, based on the values in series $\tilde{A}_i$ and $\tilde{\varphi}_i$ and with respect to an image effect of direct discrete Fourier transformation (Rao et al. 2010), we obtain the required parameters of distribution (Eq. 7):

$$n \le N/2,\ A_0^{(a_\alpha)} = \tilde{A}_0,\ A_{N/2}^{(a_\alpha)} = \tilde{A}_{N/2} \tag{11}$$

$$A_i^{(a_\alpha)} = 2\tilde{A}_i,\ i = 1, 2, ..., N/2 - 1 \tag{12}$$

$$\varphi_i^{(a_\alpha)} = \tilde{\varphi}_i,\ i = 0, 1, ..., N/2 \tag{13}$$

Now all the parameters of distribution (7) are determined.

– By recovering the axial $v_x(t)$ and lateral $v_y(t)$ horizontal components of the linear speed of coulter centre of gravity as a function of time t, we perform the integration of expressions (Eq. 7):

$$v_\alpha(t) = \tilde{v}_\alpha(t) + C_{v\alpha};\ T \in [0, T];\ \alpha \in \{x, y\} \tag{14}$$

where:

$$\tilde{v}_\alpha(t) = A_0^{(a_\alpha)} \cos\varphi_0^{(a_\alpha)} t + \sum_{i=1}^{n} A_i^{(a_\alpha)} \frac{T}{2\pi i} \sin\left(\frac{2\pi}{T} it + \varphi_i^{(a_\alpha)}\right) \tag{15}$$

and integration constant $C_{v\alpha}$ is generally determined from:

$$v_\alpha(t_0) = \tilde{v}_\alpha(t_0) + C_{v\alpha} \tag{16}$$

therefore, high accuracy of measuring the initial speed $v_\alpha(t_0)$ is required.

If C_{vy} is constant, this problem can be eliminated taking account of the fact that average speed v_y in time T must be equal to zero; therefore, C_{vy} will be determined from:

$$\sum_{k=0}^{N} v_y(t_k) = \sum_{k=0}^{N}\left[\tilde{v}_y(t_k) + C_{vy}\right] = 0 \tag{17}$$

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where:

$$C_{vy} = -\frac{1}{K}\sum_{k=0}^{N} \tilde{v}_y(t_k) = 0 \quad (18)$$

To calculate the constant of integration C_{vx} and to reduce the requirement for precise measurement of the axial component of speed v_x:

$$v_x = v_x(k) = v_{xk} \in \{v_{x0}, v_{x1}, ..., v_{xN}\}; k = 0, 1, \ldots, N \quad (19)$$

where every k corresponds to time t_k (Eq. 3), it is necessary to use an average value:

$$\bar{v}_x = \frac{1}{K}\sum_{i=0}^{N} v_{xk} \quad (20)$$

and the condition:

$$\frac{1}{K}\sum_{k=0}^{N}\left[\tilde{v}_x(t_k) + C_{vx}\right] = \bar{v}_x \quad (21)$$

wherefrom:

$$C_{vx} = \bar{v}_x - \frac{1}{K}\sum_{k=0}^{N} \tilde{v}_x(t_k) \quad (22)$$

– The recovery of parametric dependences $x(t)$ and $y(t)$ (2) is determined by integration:

$$\alpha(t) = \int v_\alpha(t)dt = \int\left[\tilde{v}_\alpha(t) + C_{v\alpha}\right]dt,\ \alpha \in \{x, y\} \quad (23)$$

Thus, we obtained:

$$\alpha(t) = \tilde{\alpha}(t) + C_{v\alpha}t + C_\alpha,\ \alpha \in \{x, y\} \quad (24)$$

where:

$$\tilde{\alpha}(t) = \frac{1}{2}A_0^{(a_\alpha)}\cos\varphi_0^{(a_\alpha)}t^2 - \sum_{i=1}^{n} A_i^{(a_\alpha)}\left(\frac{T}{2\pi i}\right)^2 \times \cos\left(\frac{2\pi}{T}it + \varphi_i^{(a_\alpha)}\right) \quad (25)$$

and integration constant:

$$C_\alpha = 0,\ \alpha \in \{x, y\} \quad (26)$$

To complete the algorithm of recovery, the parametric expression (2) is the sought function $y = y(x)$.

RESULTS

Analysis of the obtained solution

In practice, the measurement of acceleration a_{xk}, a_{yk} Eq. (4) and speed v_{xk} Eq. (19) is not technically demanding, but is accompanied by an inevitable 'admixture' of the Gaussian noise. Such being the case, Fourier methods include the use of smoothing procedures (Rao et al. 2010). In the process of presenting interpolated data using finite series Eq. (7), selected n is lower than the maximum, $\max\{n\} = N/2$, i.e.:

$$n << N/2 \quad (27)$$

In this way, high-frequency curves caused by the presence of Gaussian noise are excluded from the

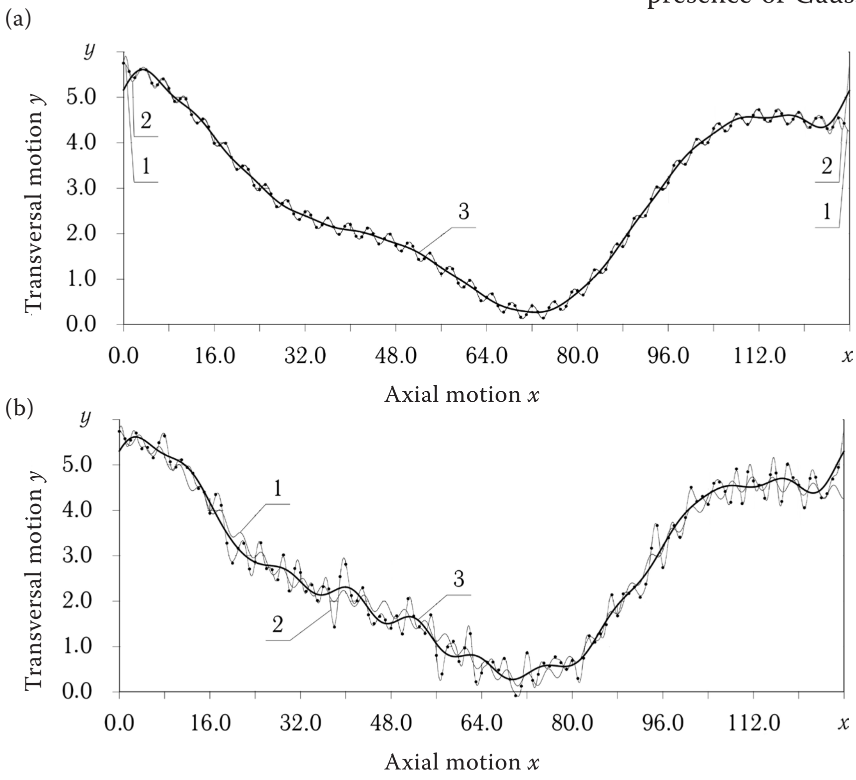

Fig. 1. Smoothing of discrete data using the Fourier method: (a) without Gaussian noise, (b) with noise 1 – defined curve; 2 – interpolation; 3 – approximation

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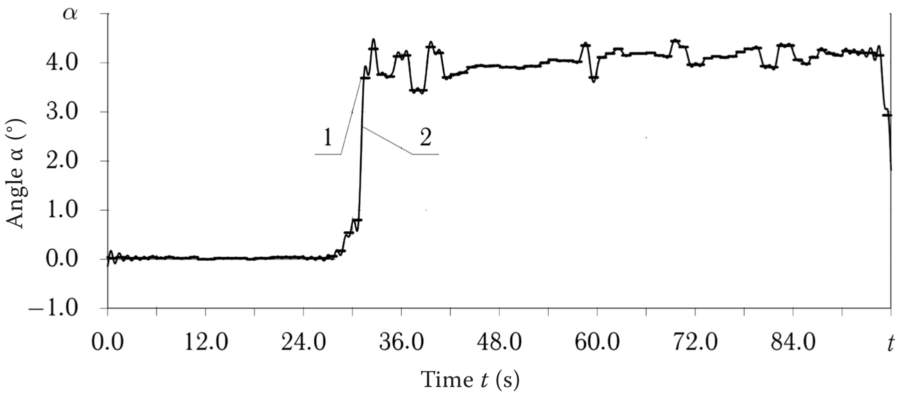

Fig. 2. Approximation of experimental data: angle α vs time t 1 – sequence of points from experimental data; 2 – approximation by the Fourier method

assessment. Fig. 1 illustrates an approximation example of generating discrete data by mathematical methods. The defined curve $y = y(x)$ (curve 1) is a sum of three curves.

The first case (Fig. 1a) illustrates the number of experimental data y_i, and values are obtained for $x_i = i$, where $i = 0, 1, \ldots, N = 128$. The pairs of values (x_i, y_i) are depicted by dots. Then, discrete data were interpolated (described by the above-mentioned Fourier methods), when smoothing is not performed and all 64 harmonic values are employed (curve 2; $n = N/2$). In case of smoothing (curve 3, approximation), only low-frequency harmonic values $I = 0, 1, \ldots, n = 32$ are employed.

Fig. 1a shows a high convergence level of recovered curves 1 and 2, which are distinguishable at the borders of the test interval only, and a high level of smoothing (curve 3), which has led to a complete filtering of a high-frequency component of defined curve 1.

This example illustrates well the possibilities of this method; however, taking account of present noise, problems may arise in the practical application of experimental data.

Fig. 1b shows the same case as in Fig. 1a, but the pair of values (x_i, y_i) was obtained in the presence of the Gaussian noise. The amplitude of standard deviation exceeds the amplitude of high-frequency harmonic curves $y = y(x)$. As can be seen, the reconstruction of curve 2 still perfectly interpolates experimental data, but does not correspond to curve 1 defined in advance. Smoothed curve 3 approximates relatively well the individual data points, but resembles to the given curve 1 only a little. That is the problem of selecting values n. If we imagine that the defined curve is unknown, then there are practically no criteria for determining values n.

However, the described problems do not appear in many experiments. That applies particularly to cases when there is practically no noise in measurements. For example, Fig. 2 illustrates the approximation of experimental data obtained by measuring the angle α of the coulter during sowing. Only 2% of the first harmonic curves are employed ($n = 2N/100$), and approximation results indicate that initial data (broken line 1) are practically inseparable from approximated curve 2. Their congruence level can be improved if the number n of harmonic curves increases.

With a significantly higher probability arises the problem with interpreting too noised experimental data, e.g. the Fourier method applied to smoothing the horizontal component a_y (m/c^2) of acceleration influencing the coulter during seeding, as shown

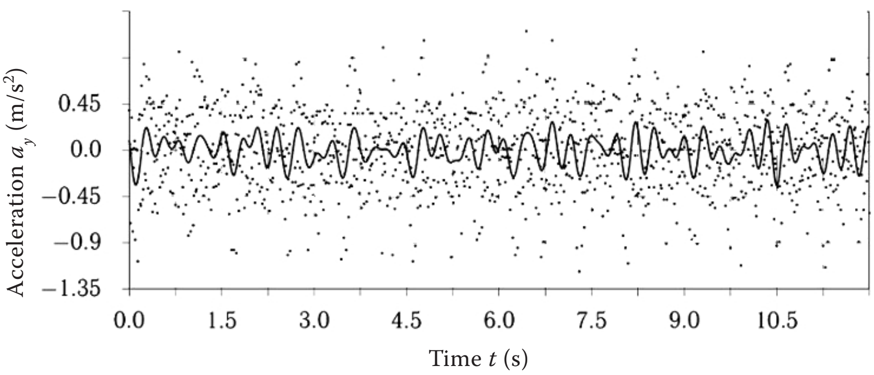

Fig. 3. Approximation of experimental data by the Fourier method: horizontal component a_y of coulter centre of gravity acceleration vs time t

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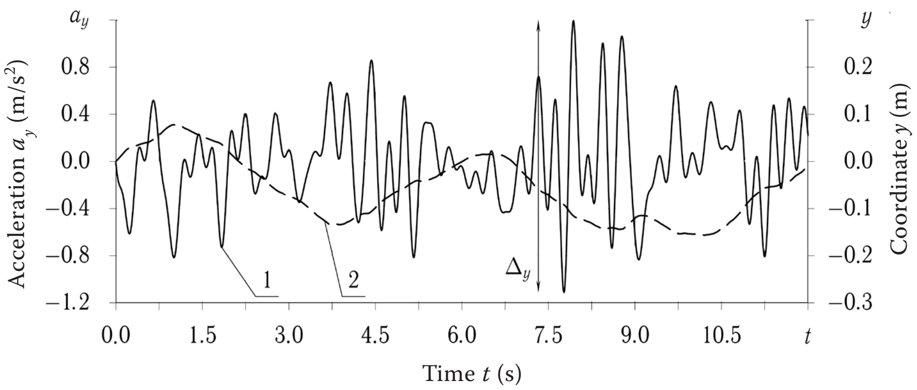

Fig. 4. Horizontal component a_y (1) of acceleration and coordinate y (2) of coulter centre of gravity vs time t

in Fig. 3. The reasons for noise generation are vibrations of the working mechanism, the over-slip of driving wheels, field micro-relief particularities, and a weak vibration of the seeder attached to the tractor. Smoothing was performed with respect to the fact that the first 50 curves (n = 50) were employed from 602 possible. As the value n is not justified, this graph is suitable for adopting a qualitative approach to prove the patterns.

Fig. 4 presents the results of functional dependence of lateral deviation $y(t)$ Eq. (24) of the coulter on time based on measuring horizontal acceleration. Source data are equal to those shown in Fig. 3: K = 1,205 (total number of measurements), T = 12 s (monitored period of time). Curve 1 corresponds to the recovered function $a_y(t)$ at n = 50 curves employed, and curve 2 is $y(t)$ where all n = 602 curves are employed.

The recovered function $y = y(t)$ Eqs (24–26) of parametric representation Eq. (2) of the trajectory $y = y(x)$ corresponds qualitatively to the actual trajectory of the coulter.

The particularity of this method is in automatic smoothing, multiplication $(T/2\pi i)^2$ in Eq. (25). The higher the value i of the curve, the higher the denominator, and therefore the lower the influence of amplitude $A_i^{(a\alpha)}$ of the resulting value $x(t)$ or $y(t)$. It is not difficult to verify in practice that a ten times decrease of n from max{n} = N/2 = 602 does not lead to a notable distortion of the dependence $x(t)$ or $y(t)$.

The last fact appears as an indirect consequence. Firstly, it is used to verify the adequacy of the theory of experiment, and secondly, to justify the minimum quantity n, and to define the required level of the experimental data smoothness by Eqs (4 and 7). It is for those who use the method of partial acceleration to explore other tasks of the dynamics of farm machines and originally did not expect the recovery of parametric dependences $x = x(t)$ or $y = y(t)$ Eq. (2) of the trajectory $y = y(x)$. This criterion should be implemented in the process of measuring the actual size of oscillation of the row trajectory Δ_y, and it is necessary to compare its theoretical value that is obtained after recovery of dependence $y(t)$ (25). It is reasonable to believe that the minimum n at which the difference between the theoretical and experimental values Δ_y will be within the permissible limit.

CONCLUSION

- Solving the problem of recovery of the coulter trajectory based on applying the method of partial acceleration.
- The proposed method of processing the experimental data on the coulter centre of gravity allows recovering the projection of the coulter trajectory to horizontal plane (the function of parametric presentation of the trajectory).
- The described procedure is usable for solving other problems related to the dynamics of farm machines.
- The reconstruction of the trajectory of motion of farm machine elements may be used to justify the smoothing level of measurement results by the Fourier method of partial acceleration in cases when the recovered trajectory itself is not the result of study.

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