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Methods of conducting a bench-scale experimental study with a spatially oriented knife of a bulldozer blade

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Abstract: The paper considers the assessment of the interaction of a spatially oriented knife of a bulldozer blade with the working environment, which was carried out on the basis of a one-factor experiment using high-tech measuring and recording equipment, which allowed to quickly obtain accurate results from the primary data. Oscillogram processing consisted of determining the average maximum ordinate of the cutting force P and finding its value. Thanks to the use of the designed and developed high-precision control system for feeding and transverse movement of the working body and high-tech measuring and recording equipment, which allows to quickly and without repetition obtain sufficiently accurate estimates of the interaction of the spatially oriented blade of the bulldozer blade with the working environment from the primary data and made it possible to process them using modern software, which eliminated the time-consuming data processing process. This, in turn, made it possible to minimise the number of measurements of the cutting force at a given accuracy and reliability of the test results with a data probability of 0,9 to 0,95.

Keywords: experimental study, test bench, spatially oriented knife, measuring and recording equipment, probability of inequality fulfilment.

1. Introduction

In experimental studies, physical simulation is often used to verify the conformity of the mathematical model or to investigate complex phenomena when it is impossible to build a mathematical model [5, 6].

The interaction of the spatially oriented knife with the working environment. It was evaluated on the basis of a one-factor experiment using high-tech measuring and recording equipment, which made it possible to quickly obtain accurate results from the primary data [7].

By rationally using the traction force of the base machine and moving the spatially oriented blade of the bulldozer blade, which will have a complex movement in accordance with the information model [14], applying the influence of several factors on the working environment simultaneously to ensure the preliminary formation of a compressed zone in the massif, which will lead to a decrease in the energy intensity of the load for separating the soil element [15].

2. Research aim

The aim of the research is to obtain sufficiently accurate estimates quickly and without repetition from the primary data by using the designed and developed high-precision control system for feed and transverse movement of the working body and high-tech measuring and recording equipment, which minimises the number of measurements of the cutting force and achieves high accuracy of the results.

3. Analysis of research

Oscillogram processing consisted of determining the average maximum ordinate of the cutting force *P* and finding its average value.

The required number of repetitions of experiments to determine the one-factor dependence was determined from the equation [1]:

$$P*\left\{|\Delta_x| \le \frac{z}{\sqrt{n}} W_x\right\} = \frac{2}{\sqrt{2\pi}} \int_0^z e^{\frac{t^2}{2}} dt, \qquad (1)$$

where $P*$ – is the probability of satisfying the inequality in curly brackets;

Δ_x – the deviation ratio of the empirical mean value of a random variable x from its true average value;

n – number of measurements of a quantity x;

W_x – coefficient of variation of the value x;

z – the upper limit of the probability integral, which characterizes the probability of the average value falling into a given confidence interval.

From expression (1), we determine the required number of measurements of the cutting force for each combination of experimental conditions

$$n \ge \frac{z^2 W_x^2}{\Delta_x^2}, \qquad (2)$$

where the value of z is determined according to the probability integral tables in accordance with the given probability $P*$.

In fig. 1 shows the graphs of dependence *n(Wp)* at different values of Δ_x and $P*$. For example, with a relative deviation of Δ_x=0,1 and probability $P*$=0,95 the required number of cutting force measurements for values of the coefficient of variation within 0,2 - 0,3 should be 15-35. Repeatability of the experiments was in the range from 3 to 5 (with the number of measurements in each experiment from 200 to 500), that at the coefficient of variation of the experimental values from 0,2 to 0,3 corresponds to the reliability of the data received from 0,90 to 0,95 [1].

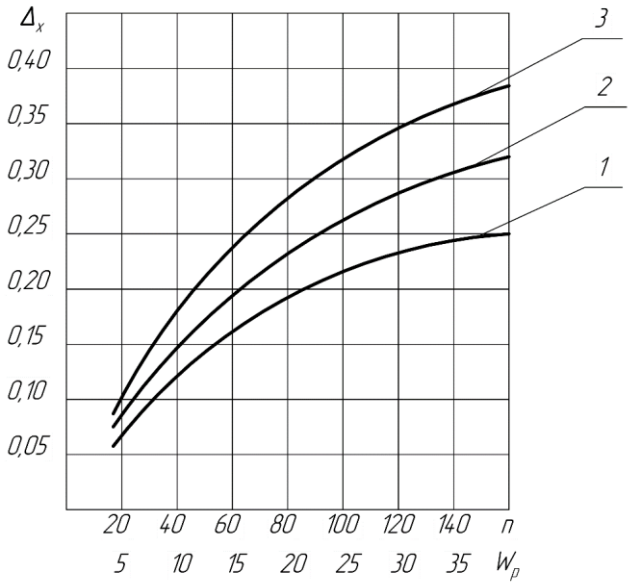


Fig. 1. Graph for determining the required number of cutting force measurements for a given accuracy and reliability of the test results:
1 – P*=0,99; 2 – P*=0,95; 3 – P*=0,9

Dynamometric bench for recording power load of the author's design of KNUBA [2] was modified to reproduction of the working hypothesis [12] and mathematical model [13] and study the physical model of the process of cutting the working environment with a spatially oriented knife fig. 2.

Fig. 2. The model of a spatially orientated knife is fixed in a test bench
1) Dynamometer trolley; 2) The drive of a spatially orientated knife; 3) Spatially orientated knife

Load cells *D1-D4* are glued to the side surfaces of the beam 1, which record the tangential force *P* acting on the spatially oriented knife. On the horizontal beam 2, there are load cells *D5-D8* that record the normal force *N* acting on the spatially oriented knife during cutting of the working medium fig. 3.

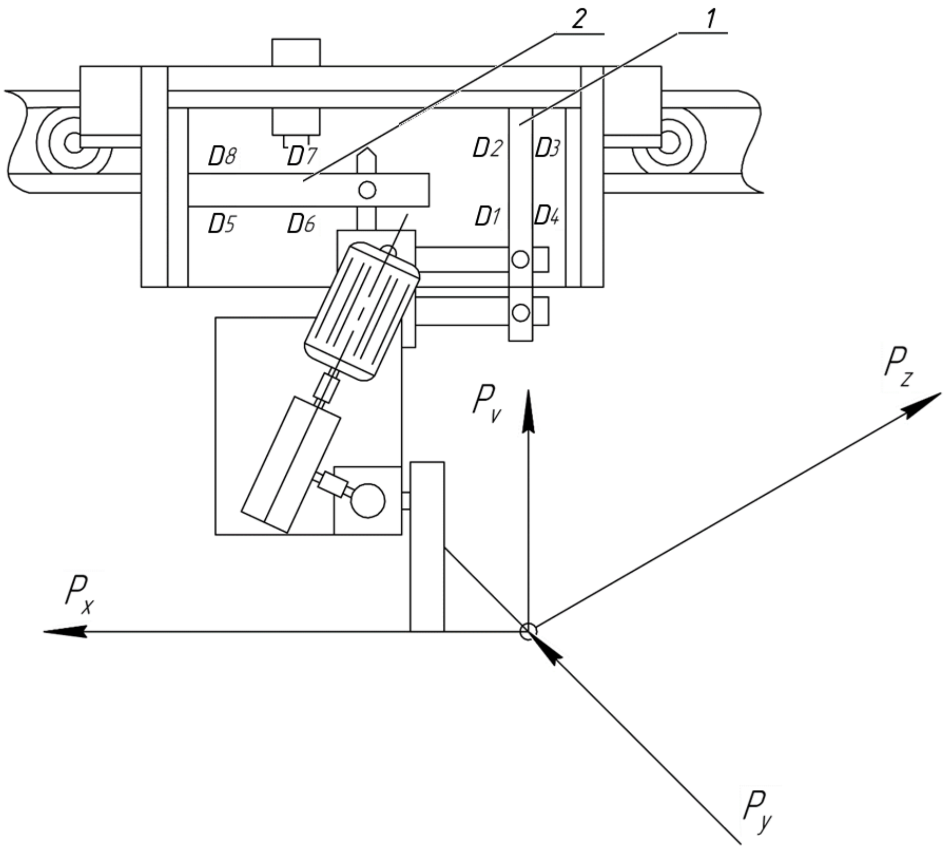


Fig. 3. Layout of sensors on the dynamometer trolley

The load cell groups are included in the electrical bridge circuits shown in fig. 4. The cutting force is transmitted through the design of the spatially oriented knife to the strain sensors, the deformations of which are transformed into a change in the resistance of the measuring elements, so that an imbalance appears in all bridge circuits.

The methods of measuring resistance with resistance sensors are based on the strain sensors effect, which is a change in the electrical (i.e., ohmic) resistance of the metal wire of the sensor during its elastic deformation [3].

The sensors are glued to the surface of the deformable beam with polymer glue using a special technology. When an electric current passes through the sensors as a result of deformation of the beam, the resistance of the sensors changes. As a result, the voltage in the electrical circuit changes. Since the deformation is proportional to the forces that cause it, the change in the current voltage in the electrical circuit will be proportional to them.

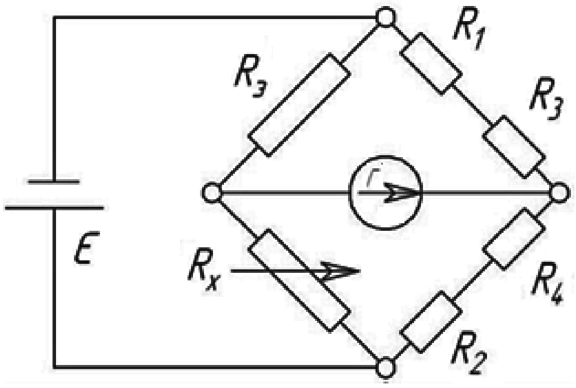


Fig. 4. Connection diagram of strain sensors into measuring bridges

The sensors are connected in a bridge circuit. In this case, four sensors are glued to each strain gauge beam fig. 3, which simultaneously perform the functions of operating and compensation sensors. This connection of the sensors allows recording only the voltage difference on the base section of the beam ℓi, which is closed between the sensors.

The balance states of the strain gauge schemes for measuring the tangential and normal components of the forces in fig. 4, acting on a spatially oriented knife and corresponding to the equality

$$(R_1 + R_3)R_x = (R_2 + R_4)R_\varepsilon \ , \tag{3}$$

$$(R_5 + R_7)R_x = (R_6 + R_8)R_\varepsilon \ , \tag{4}$$

where $R_{1...8}$ – is the resistance of the strain gauges (resistance bridge arms);

R_ϵ – reference resistance;

R_x – measuring resistance.

The set of measuring equipment fig. 5, includes: power supply 1; power cable 2; ADC module (analogue-to-digital converter); wideband amplifier and microcontroller control unit 3; signal transmission cable (SCI - Serial Communication Interface) 4; and personal computer (hereinafter referred to as PC) 5.

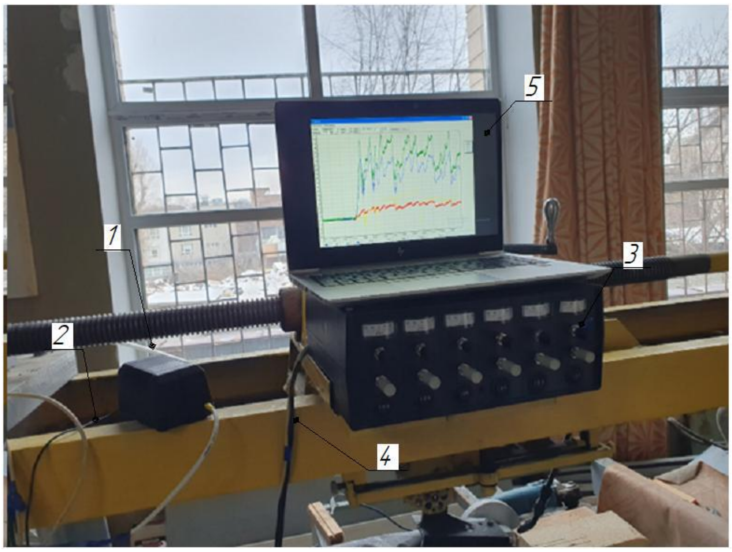


Fig. 5. A set of measuring equipment

The bridge unbalance signal with the inclusion of strain gauges is amplified using instrumental operational amplifiers fig. 6, switched on according to the differential amplifier circuit fig. 7 with the cancellation of in-phase interference.

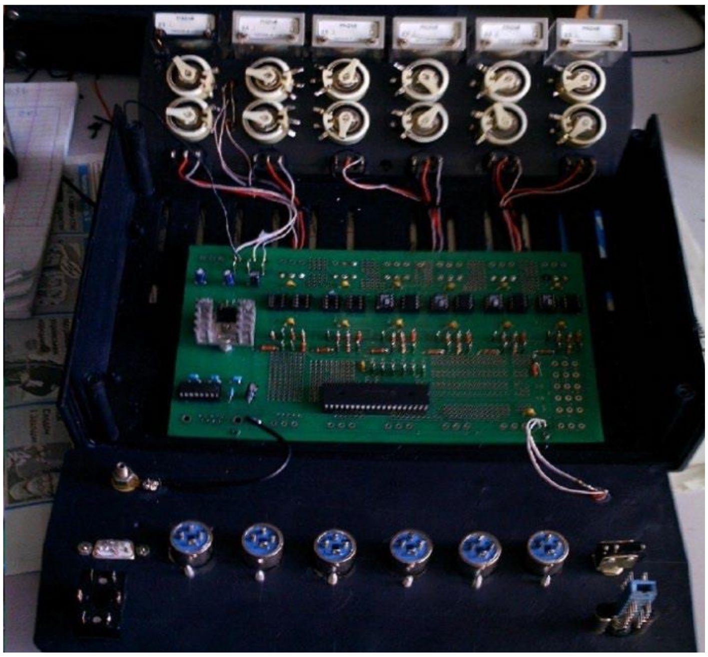


Fig. 6. ADC with amplifier unit

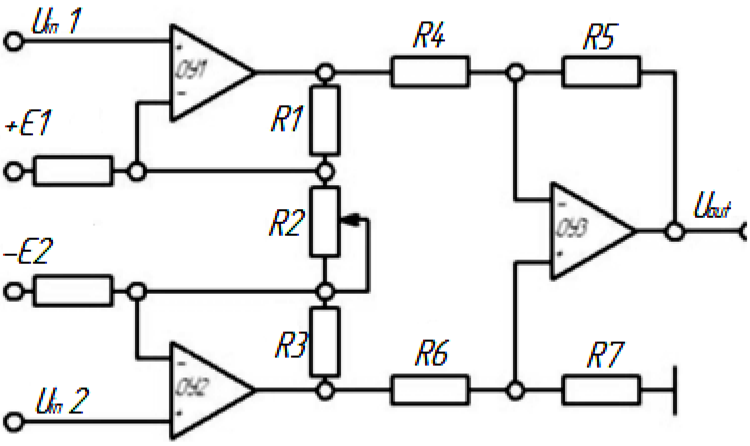


Fig. 7. Differential amplifier scheme

This makes it possible to amplify a very low level of electrical fluctuations with no increase in parasitic noise and a straightforward transfer characteristic. In addition, this circuit avoids the zero-drift inherent in conventional operational amplifier circuits.

Under the condition *R4 R7 = R5 R6* the transfer function can be represented as:

$$U_{out} = \frac{R_5}{R_4}\left(1 + \frac{R_1}{R_2} + \frac{R_3}{R_2}\right)\left(U_{in2} - U_{in1}\right). \quad (5)$$

A distinctive feature of the circuit under consideration is the complete independence of the gain control from the condition.

Modern instrumentation amplifiers manufactured by Analog Devices are used as operational amplifiers.

The amplified signal is fed to the ADC module for further processing. The device operates in two modes with signal gains of 1 and 2.

A 10-bit module, which is part of the PIC (Peripheral Interface Controller) microcontroller family, is used as an ADC fig. 8.

The ADC conversion time for the proposed controller is determined by
by the formula:

$$T_{AD} = N \cdot T'_{AD} + (11 - n)(2T_{OSC}), \tag{6}$$

where T'_{AD} – is the analogue-to-digital conversion time per bit (recommended 1,6 $\cdot 10^{-6}$);

n – number of ADC bits;

T_{OSC} – duration of one clock cycle of synchronising pulses.

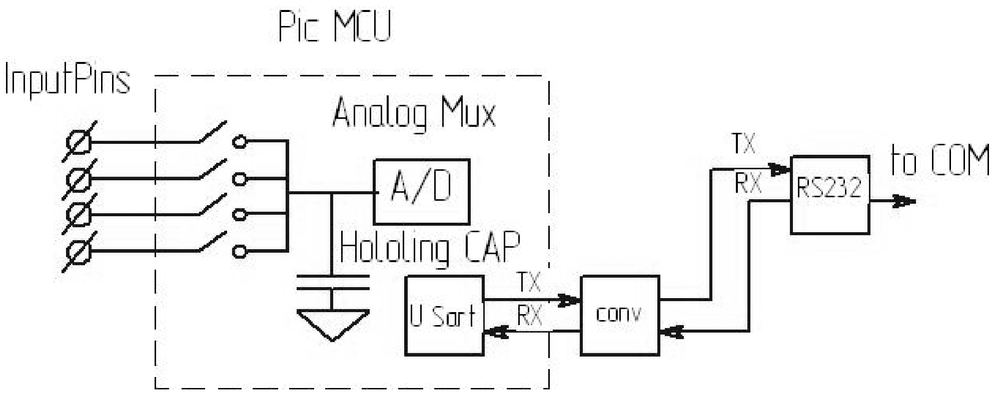


Fig. 8. General scheme of the ADC device

On average, at a clock frequency of 20 MHz, the conversion time per channel is 17,6 $\cdot 10^{-6}$.

The accuracy of the transformation depends on the quantization step, which should be calculated using the formula (7):

$$\Delta_u = \frac{U_{REF}}{2^n}, \tag{7}$$

where U_{REF} – is the reference voltage (5V);

$$\Delta_u = \frac{5}{2^{10}} = \frac{5}{1024} = 4.9mV .$$

The RS232 interface has atypical voltage levels, so a CONV converter must be used to match the levels of the microcontroller interface fig. 8.

The digital signal is sent to a PC for further processing using a specially written programme called “Tenzo Cut” [4].

- As a result, the signal is recorded in real time and displayed on the screen in the form of a graph fig. 9.
- The program allows:
- - simultaneously record data from two groups of sensors fig. 9;
- - to bring the data to the common ordinate of the image fig. 10;
- - perform taring, i.e., the transition from the image ordinate to the force acting on a spatially orientated knife fig. 11;
- - process the data (find the mean value and standard deviation over a given interval) fig. 12;

- - save data in a file at any stage of registration and processing;
- - save data in the form of a table of numbers for further processing by other tabular data analysis programmes (for example, Origin or Microsoft Excel).

4. Research result

The developed high-tech measuring and recording equipment allows to quickly and without repetition to obtain accurate estimates of the interaction of the working environment with the spatially oriented bulldozer knife from the primary data and makes it possible to process them using modern software, which will eliminate the time-consuming data processing process [10, 15].

The feed rate of the spatially oriented knife into the cutting zone was set by connecting the drive motor through a «Frecon» FR150A frequency converter, the connection diagram of which is shown in fig. 13 [8], and the speed of transverse movement of the spatially oriented knife was set by connecting the drive motor through a «Suswe» T13-750W-12-H frequency converter, the connection diagram of which is shown in fig. 14 [9].

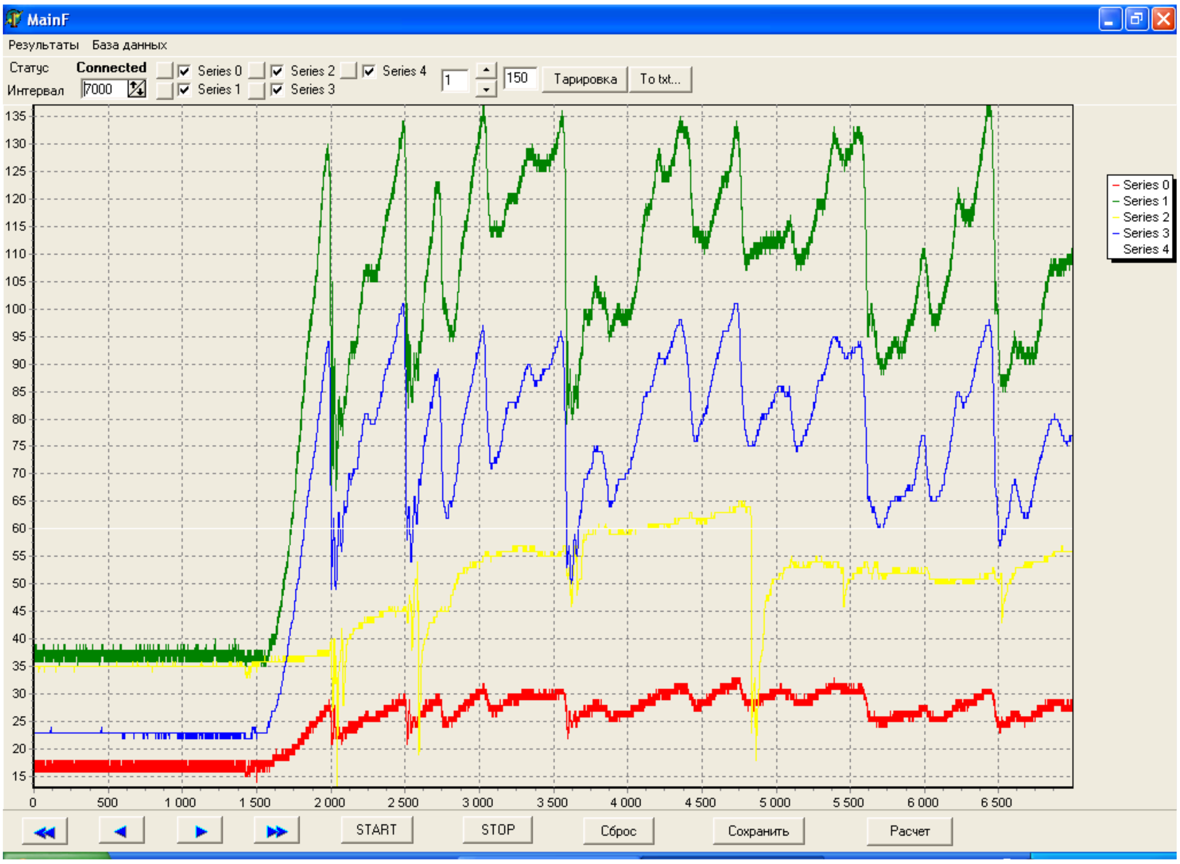


Fig. 9. Display of the reproduced signal on the screen

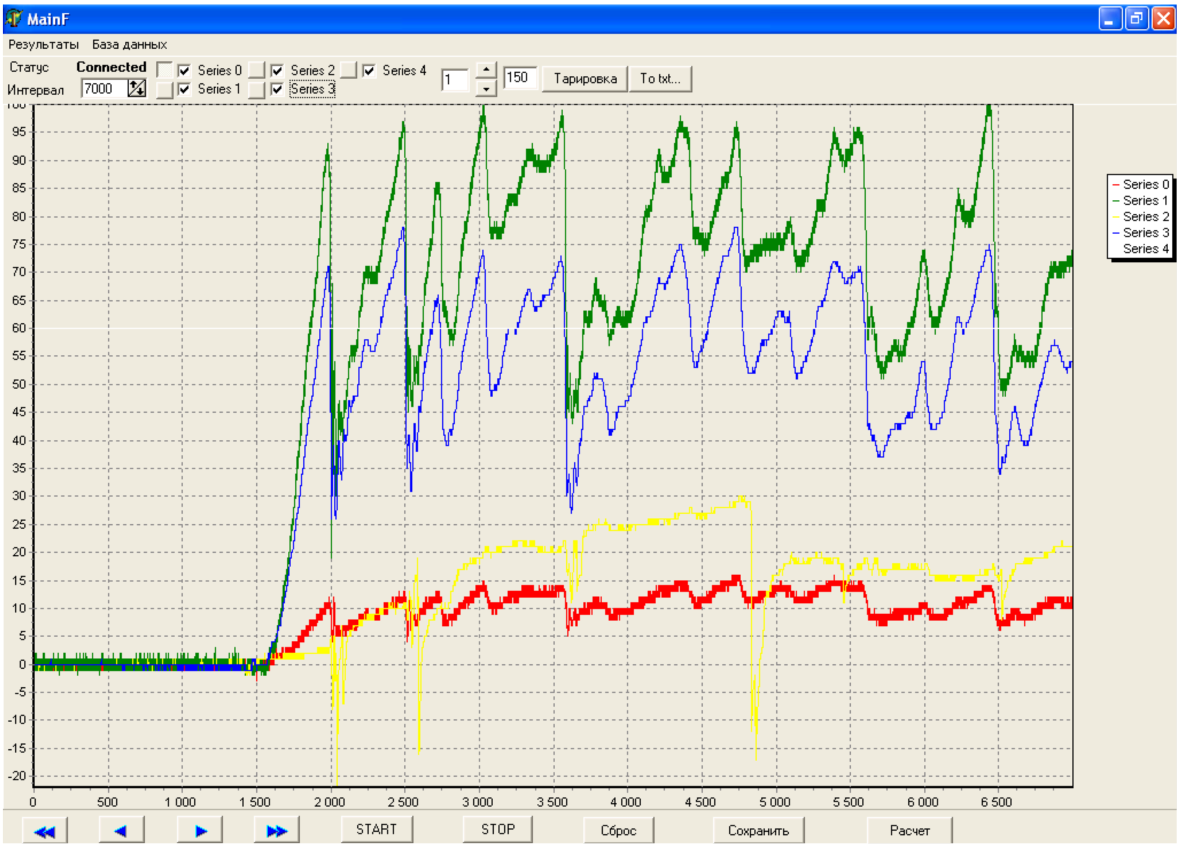


Fig. 10. Converting data to a common ordinate

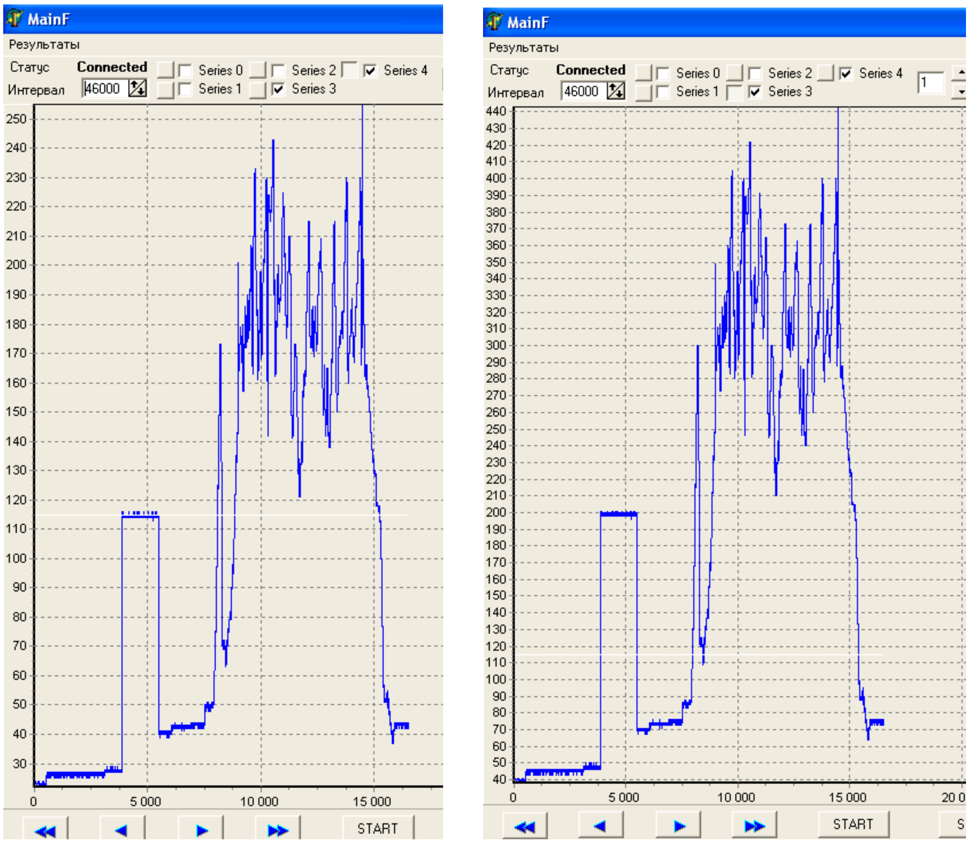


Fig. 11. Taring a) before taring, b) after taring

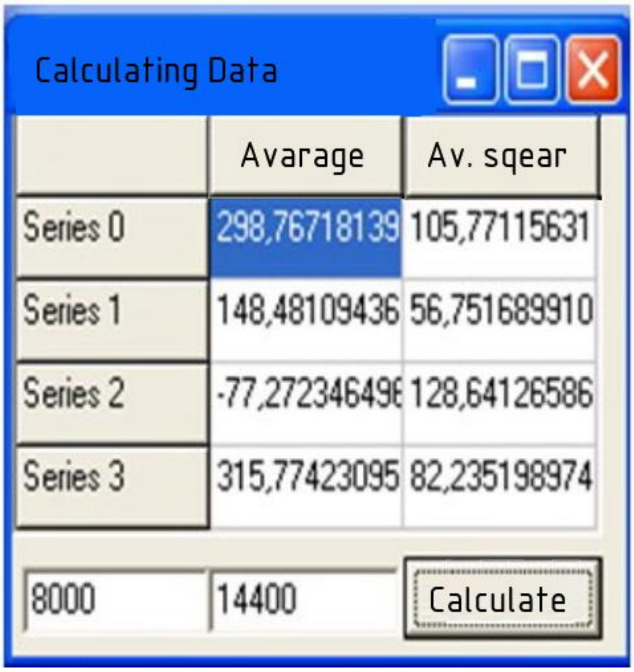


Fig. 12. The “Calculation parameters” window with calculation results

The feed rate into the cutting zone V_f, and the transverse displacement velocity $V_{t.d.}$ of the spatially oriented knife, is determined by the following relationship:

$$(V_{t.d.})\ and\ V_f = \frac{n_s P_g}{60 \cdot u_n}, \tag{8}$$

where $u_{n.}$ – transmission gear ratio;

n_s – motor shaft speed;

P_g – screw pitch of the helical gear.

The feed rate was controlled by changing the motor current frequency f on which the synchronous frequency (magnetic field rotation frequency):

$$n_m = \frac{60 f}{p}, \tag{9}$$

and the motor shaft speed is determined as follows:

$$n_s = n_m \cdot k_s, \tag{10}$$

where k_s – is the slip of the electric motor [11].

The technical characteristics of the electric motors are presented in Table 1.

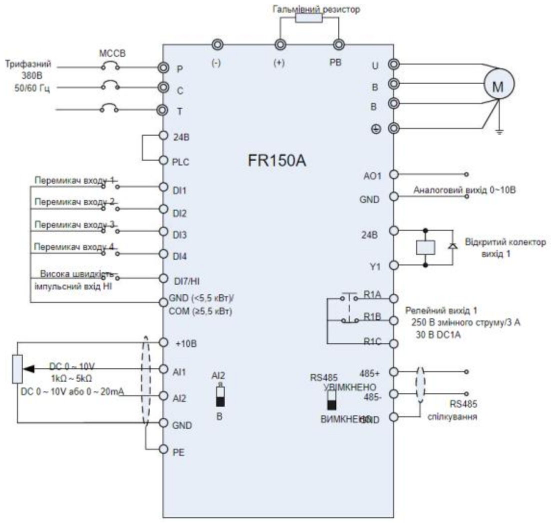


Fig. 13. Connection diagram of a three-phase inverter 380V

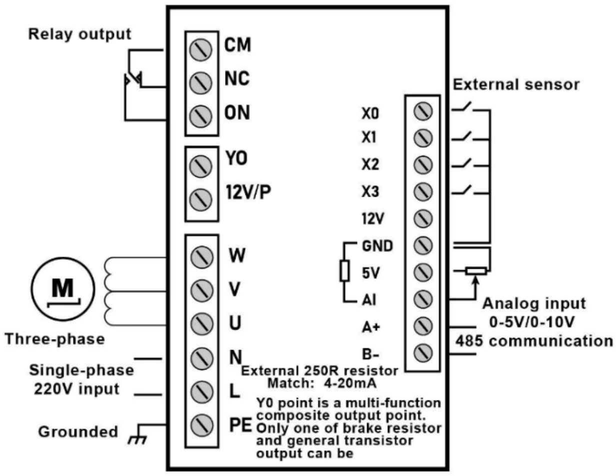


Fig. 14. Connection diagram of a single-phase 220V inverter

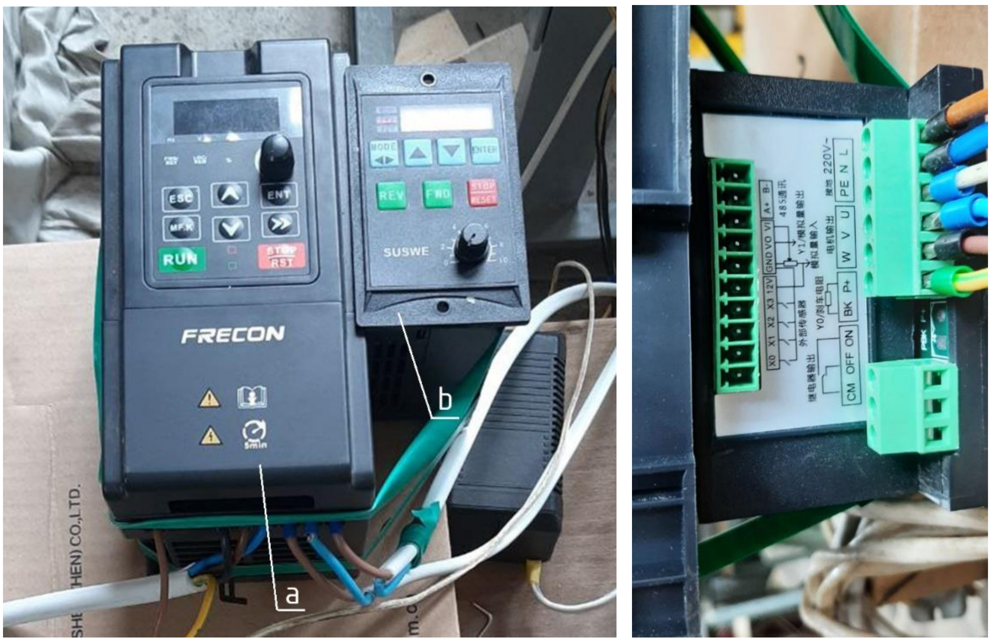


Fig. 15. Connection of inverters

a) Inverter for the spatially orientated knife feed motor; b) Inverter of the electric motor for moving the spatially orientated knife

Table 1. Technical characteristics of electric motors

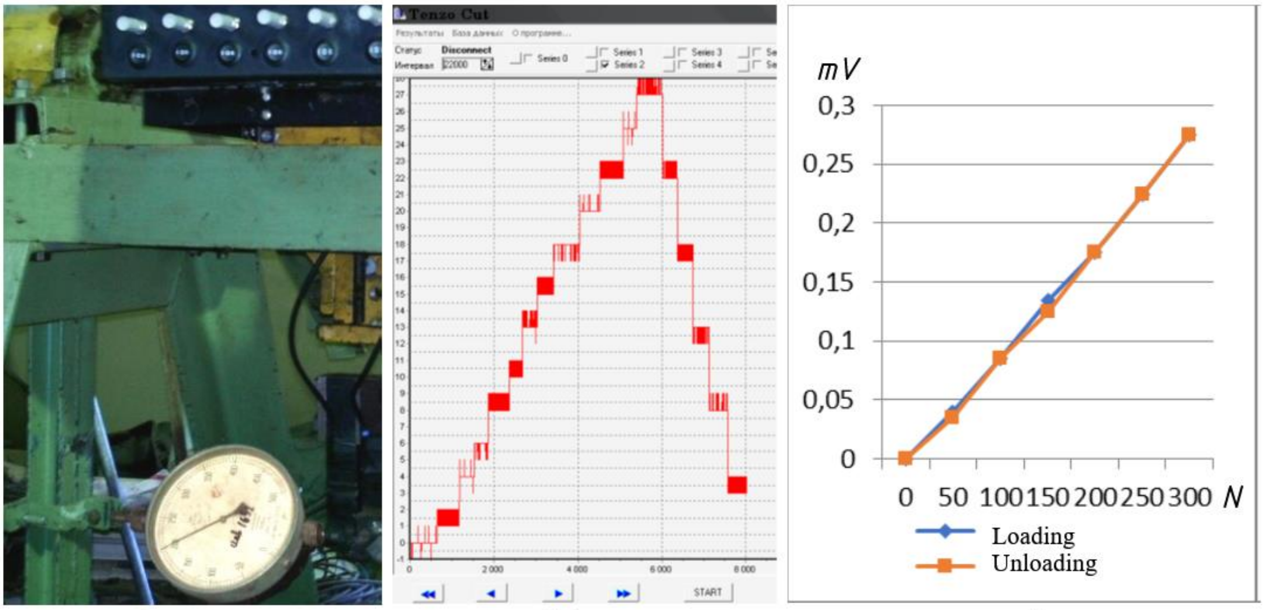
Engine size and type	Power, *kVt*	Sliding, *%*	Number of pole pairs	Efficiency, *%*	*cos φ*	Mmax/Mnom, *Nm*	Mstart/Mnom, *Nm*	Mmin/Mnom, *Nm*	Istart/Iном, *A*
4A100L6Y3	2,2	5,1	3	81	0,73	2,2	2	1,6	5,5
4AAM56B4HJJY3	0,2	3,1	3	64	0,72				1,78

Thus, by setting the appropriate current frequency using the «Frecon» FR150A and «Suswe» T13-750W-12-H frequency converters, we achieve the required speed of the working body feeding into the working area and the transverse movement of the spatially oriented knife.

Before conducting the experiments, the strain gauge beams were calibrated by mechanical loading in the direction of each of the components of the total cutting force using a dynamometer fig. 16.

The dynamometer was fixed to the taring mechanism with one clamp and to the strain gauge with the other. The movement mechanism was used to load and record the signal with recording equipment [3].

Fig. 16c shows a graph of strain sensor taring, which shows the dependence of the signal value on the force value during loading and unloading.



a) b) c)

Fig. 16. Taring of strain gauge beams: a) readings of the dynamometer on the stand; b) oscillogram; c) taring schedule

5. Conclusions

Thanks to the use of the following designed and developed: a high-precision control system for the feed of the working body and high-tech measuring and recording equipment, which allows you to quickly and without repetition from the primary data to obtain sufficiently accurate with relative deviation Δ_x=0,1 assessment of the interaction of the working environment with a spatially oriented knife of the bulldozer blade and made it possible to process them using modern software, which eliminated the time-consuming process of data processing. This made it possible to minimize the number of measurements of the cutting force at a given accuracy and reliability of the experimental results with the reliability of the data obtained from 0,90 to 0,95.

References:

1) Smirnov V.M. (2009). Osnovy teorii rizannia hruntiv prostorovo oriientovanymy nozhamy robochykh orhaniv zemleryinykh mashyn: Monohrafiia. – K.: «MP Lesia», – 260 s.

2) Pelevin L.E., Prystailo M.O., Prystailo T.Iu. Stend reiestratsii zusyl rizannia. Patent Ukrainy na korysnu model № 13846. Biul. № 4, 17.04.06

3) Pelevin L.Ie., Prystailo M.O., Prystailo T.Iu. (2005). Udoskonalennia reiestratsii syl rizannia v laboratornykh umovakh. *Hirnychi, budivelni, dorozhni ta melioratyvni mashyny: Vseukrainskyi mizhvid. zb. naukovykh prats*, – K.:KNUBA, Vyp. 65 – S. 58-62.

4) Pochka, K., Abrashkevych, Yu., Prystailo, M., Polishchuk, A. (2023). Metodyka provedennia eksperymentalnykh doslidzhen rizannia vysokoabrazyvnykh materialiv abrazyvnymy armovanymy kruhamy. *Modern Engineering and Innovative Technologies*, 1(25-01), 3–16. https://doi.org/10.30890/2567-5273.2023-25-01-016

5) Loveikin V., Pochka K., (2007) Metodyka provedennia eksperymentalnykh doslidzhen rolykovoi formuvalnoi ustanovky z rekuperatsiinym pryvodom. *Hirnychi, budivelni, dorozhni ta melioratyvni mashyny*. – № 70. – S. 43-47.

6) Loveikin V., Pochka K., Balaka M., Pochka O. (2023). Experimental research procedure of roller forming unit. *Hirnychi, budivelni, dorozhni ta melioratyvni mashyny*, (102), 31–37. https://doi.org/10.32347/gbdmm.2023.102.0302

7) Arzhaiev H., Pelevin L., Balaka M. (2008). Metodyka y informatsiino-vymiriuvalne zabezpechennia eksperymentalnoho vyznachennia parametriv reolohichnoi modeli pishchanohlynystykh gruntiv. Mashynoznavstvo, 12(138). Lviv: KINPATRI LTD. S. 40–42.

8) Vkazivky po shvydkomu montazhu ta vvedennia v diiu peretvoriuvacha chastoty na 4 kVt FRECON - FR150-4T-4.0 B - Vkhidna napruha: 3-f 380V Detalnishe: https://saeron.com.ua/ua/p1086136558-preobrazovatel-chastotykvt.html.

9) Vkazivky po shvydkomu montazhu ta vvedennia v diiu peretvoriuvacha chastoty na 0,75 kVt Suswe – T13-750W-12H - Vkhidna napruha: 1-f 220V.

10) Gorbatyuk Ie., Balaka M., Mishchuk D. (2021). Information model of bulldozer-looser movement. *The world of science and innovation.* Abstracts of the 7th International scientific and practical conference (February 10–12, 2021). Cognum Publishing House. London, United Kingdom. 54–59.

11) Yatsun M.A. (2004). Elektrychni mashyny: navch. Posibnyk dlia stud. vyshch. navch. zakl. – Lviv: vydavn. Lvivskyi natsionalnyi Universytet «Lvivska politekhnika», – 439s.

12) Rashkivskyi, V.P., Fedyshyn, B.M. (2023). Development of a parametric model of the spatially oriented knife on the bulldozer blade. *Strength of Materials and Theory of Structure: Scientific and technical collected articles.* Issue 111. P. 263-275. DOI: 10.32347/2410-2547.2023.111.263-275.

13) Rashkivskyi, V.P., Fedyshyn, B.M. (2023). Modelling of soil destruction process by bulldozer using a spatially oriented working unit. *Transfer of innovative technologies*, 6(1), 58–70. https://doi.org/10.32347/tit.2023.61.0202

14) Rashkivskyi, V., & Fedyshyn, B. (2023). Rozrobka informatsiinoi modeli protsesu rizannia gruntu prostorovo-oriientovanym nozhem dynamichnoi dii. *Hirnychi, budivelni, dorozhni ta melioratyvni mashyny*, (102), 24–30. https://doi.org/10.32347/gbdmm.2023.102.0301

15) Prystailo, M., Balaka, M., Mozharivskyi, V., Drachuk, V., & Honta, I. (2023). Innovative ways to improve machines for preliminary work given the needs of the modern construction industry. *Girnichi, budivelni, Dorozhni Ta meliorativni Mashini*, (102), 49–57. https://doi.org/10.32347/gbdmm.2023.102.0402