AGRISCIENCE AND TECHNOLOGY
Armenian National Agrarian University
ԱԳՐՈԳԻՏՈՒԹՅՈՒՆ ԵՎ ՏԵԽՆՈԼՈԳԻԱ АГРОНАУКА И ТЕХНОЛОГИЯ
International Scientific Journal
ISSN 2579-2822

Journal homepage: anau.am/scientific-journal

UDC 631.356.43

Analysis of the Research and Experimental Study Results in the Self-Driving Clod-Crusher of the Potato Digger

A.P. Tarverdyan, A.M. Yesoyan, A.V. Altunyan, H.H. Hayrapetyan
Armenian National Agrarian University
tarverdyan@anau.am, esoyan.62@mail.ru, artur_altunyan@mail.ru, hayrapetyanhayk1@mail.ru

A R T I C L E I N F O

Keywords:
soil clod-crusher,
planetary mechanism,
calibration,
resistance force,
torque moment

A B S T R A C T

Laboratory experiments on the self-driving rotary clod-crusher in the potato digger has been implemented which is aimed at the specification of kinematic and dynamic parameters resulted from the theoretical researches. During the experiments a torque measuring resistance strain gage of TRA-50K series, Zet-210 analog-to-digital converter, appropriate booster (Zet-410) and recording equipment have been used. Three finger types of the recommended clod-crusher have been experimented: cylindrical, cylindrical with hemispheric facade and conical. The experiments indicate that the theoretical research results accurately address the principle of the problem and they can serve as a background for the design and preparation of the clod-crusher.

Introduction

Different kinds of clod-grinders and clod-crushers are currently widely used in Armenia and CIS member countries to enhance the sifting rate of potato from the soil mass during the harvesting activities with the potato digger. Their main driving source is the tractor take-off power shaft. The application of such equipment leads to the tractor's extra energy consumption. The rotary clod-crusher of the potato digger developed by our research group (Tarverdyan, Yesoyan, et. al, 2020, Tarverdyan, Hayrapetyan, 2019) gets the drive due to the resistance forces of grouser wheel in the soil. As a result, the efficient tractor horsepower is saved, as well as the productivity of the aggregate and tractor on the whole becomes higher.

The rotary clod-crusher 1 (Figure 1) of the potato digger is attached to the front part of the potato digger through the lever-hinge 2 system. In the transport mode of the aggregate the crusher gets off the ground together with the potato digger by means of the tractor suspension system, while in the working state it is adjusted down on the bed dam. The sticking rate of the working parts and the grousers into the soil is regulated by the regulatory equipment. The regulatory equipment is a hydro cylinder 3 managed by the distributive system of the tractor oil pressure, which, with its one end is connected to the potato digger through the hinges and with another end to the lever-connecting horizontal bar. In the result of the studies and analyses quadri-circuit planetary mechanism with annular parasitic toothed-wheel has been selected to transmit rotational movement from the grouser wheel 4 of the recommended clod-crusher of the potato digger to the working rotors 5 (Tarverdyan, Hayrapetyan, 2019).

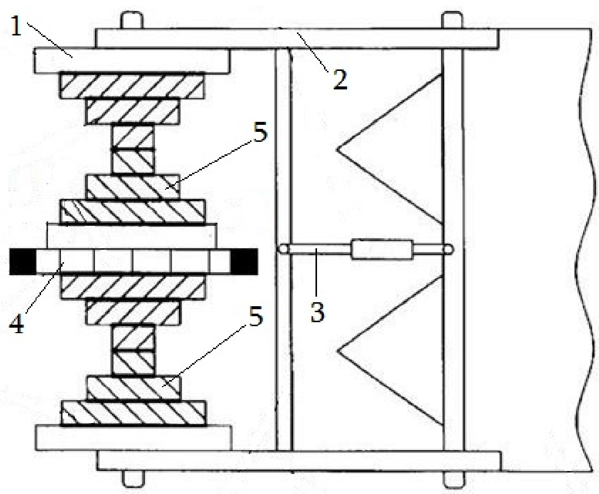

Figure 1. The diagram of the rotary clod-crusher of the potato digger *(composed by the authors)*.

Materials and methods

During the theoretical researches three finger types of the recommended clod-crusher (Tarverdyan, Yesoyan, et. al, 2020) have been studied: cylindrical with flat facade, cylindrical with hemispheric facade and conical (Figure 2).

Figure 2. The experimental fingers of the clod-crusher in the potato digger.

In the result of theoretical researches for the discussed three cases the following values of the sticking and moving resistance force for the clod-crusher's working part in the soil and the throwing speeds of the soil clods have been derived (Tarverdyan, Hayrapetyan, 2019):

1. In case of the clod-crusher with cylindrical flat facade we have P= 24.34 N, Vτ =9.76 m/s.
2. In case of the clod-crusher with cylindrical hemispheric facade - P= 15.03 N, Vτ =9.73 m/s.
3. In case of the clod-crusher wth conical top - P= 8.91 N, Vτ =9.63 m/s.

As a result of theoretical researches we have obtained an important expression, which identifies the equal rotation term in the rotor of the clod-crusher (Tarverdyan, Hayrapetyan, 2019).

$$M_4 = -\frac{(P_4 + 2P_2)(r_3 + r_2)\sin\varphi}{2} \quad . \tag{1}$$

Laboratory and field experiments have been conducted to verify the mentioned term (1) and to accurately determine the quantity and sizes of the grousers worn on the rims of the driving wheels, as well as to select the optimal form of the clod-crushing fingers.

The laboratory experiments have been conducted in the earth trench of the laboratory at the chair of "Tractors and Agricultural Machines" at Armenian National Agrarian University in conditions of 0.6 m/s – 1.4 m/s forward movement of the wheelbarrow equipped with rotary clod-crusher. The laboratory experiments have been implemented with the methodology developed and established through multiple trials by our research group (Vysotskiy, 1968, Loginov, 1976, Matevosyan, 2018, Grigoryan, Tarverdyan, 2001). The research experiments are aimed at the study of the exploitative and operational regulations of the clod-crusher, particularly the functional relation between the rotor and the torque moment of the grouser wheel, as well as at the disclosure of the impact size of the clod-crusher's finger forms, geometric and kinematic parameters, as well as that of soil properties and conditions on the crushing process of soil crust in the external surface of the tuber chain.

Throughout the experiments analog-to-digital recording equipment, particularly torque moment determining resistance strain gage (Figure 3) of TRA-50K series has been applied, by means of which the received analog signals are recorded through the innovative multi-wave analog-to-digital converter Zet-210. The analog signals received from the resistance strain gage are intensified in 1000 times through Zet-410 booster, which is converted to the digital data through Zet-210 analog converter. The converted digital information is transferred to the computer by Zet-210 by means of USB interface.

Figure 3. The general view of TRA-50K resistance strain gage.

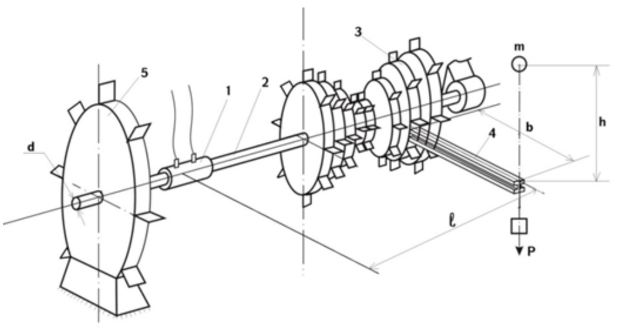

Figure 4. The diagram of static and dynamic calibration plant *(composed by the authors)*.

The digital information is recorded and stored through Zet Lab measuring-recording software, which enables to save and develop the digital outcomes recorded during the scientific experiments to determine the physical value chosen as an upgrading parameter for the research.

To determine the resistance force of the crushing fingers in the clod-crusher equipment, its kinematic parameters and sizes, as well as to identify the quantity of the soil grousers, calibration of TRA-50K must be implemented.

Calibration has been implemented through the methodology developed by our research group (Tarverdyan, Artemyan, 1992).

Based on the results of theoretical researches (Tarverdyan, Hayrapetyan, 2019), with some approximation we can state that the maximum theoretical moment M applied in one half shaft doesn't exceed 70 N-m (M=r·P·m·n, where r=0.18 m is the mid radius of the clod-crusher discs, P=24N is the maximum resistance force applied in one crushing finger, m is the number of crushing fingers of a disc completely stuck into the soil simultaneously, n is the number of the clod-crusher's discs).

According to the value of the torque moment we've selected the force value applied during the calibration (P) and the arm length of the force application.

After attaching the strain gage 1 to the half shaft 2, a hard bar with 0.82 m length 4 (Figure 4) was fastened to the disc 3 with mid radius (r = 0.18 m) through welding, providing 1 m length of arm force effect on the shaft axis. During the experiments the grouser wheel 5 was tightly fixed, so as to subject it to torque deformation.

During calibration not only the selection of the torque moment value but also the speed of the load with m mass at the moment of its striking to the hard bar is important. Upon the theoretical researches it has been stated that the maximum circular velocity of the clod-crushing finger is not related to the finger form and makes about 10 m/s (Tarverdyan, Hayrapetyan, 2019). To provide the average striking velocity (V_{av} =5.5 m/s) during the calibration it is necessary to allocate the load with m mass at the height of $h=\frac{V_{ave}^2}{2g}$ from the hard bar, which can show that $h \approx 1.3\,m$.

Results and discussions

Taking into account that the kinetic energy K in the striking elastic element (in our case into a half shaft) is completely turned into potential deformation energy U, the solution of the problem results in the determination of the potential deformation energy and the dynamical coefficient k_d.

The calibration has been implemented in the following way: first of all the static Ps force was applied to the free edge of the hard bar 4 and the deviation rate of the oscillogram coordinate Δ_S received from the signal of resistance strain gage was recorded from the zero line, which corresponds to the unloaded state. Then from the h height the load with m mass (it should be noted that *PS=mg*) is released, which strikes the free edge of the hard bar; in this case the deviation rate of the oscillogram coordinate (light point) is also recorded in the monitor and measured from the zero position Δ_d.

It is known that in case of twisting of the bar with round cutting the potential energy of the twisting deformation is determined through the following expression (Belyaev, 1976):

$$U_S = \frac{M^2 \cdot \ell}{2GI_\rho} = \frac{\tau^2_{s\,max} \cdot \ell \cdot W_\rho}{2GI_\rho},$$

where M is the torque moment of the bar, ℓ is its length, G is the sliding module of the bar material (for steel $G = 8 \cdot 10^5$ kgf/cm²), I_ρ is the polar inertial moment of the bar cross-section and W_ρ is its polar resistance moment. The torque angle of the bar (half shaft) in case of static load application is determined in the following way:

$$\varphi_S = \frac{M\ell}{G \cdot I_\rho}.$$

The dynamic coefficient k_d is determined through the following expression (Belyaev, 1976):

$$k_d = 1 + \sqrt{1 + \frac{V^2}{g\delta_S}}, \text{ or} \tag{2}$$

$$k_d = 1 + \sqrt{1 + \frac{K}{U_S}}, \tag{3}$$

where V is the load velocity at the start of striking ($V = \sqrt{2gh}$),

$\delta_s = \varphi_s$ is the static deformation,

K is the kinetic energy of the striking load at the striking moment $\left(K = \frac{mV^2}{2}\right)$.

U_S is the potential energy of the deformation for force static application.

Using the expression (3) we can have the following for the dynamic torque angle of the bar (half shaft):

$\varphi_d = k_d \cdot \varphi_s$, placing the values of φ_s and K_d we'll have:

$$\varphi_d = \sqrt{\frac{2K \cdot \ell}{G \cdot I_\rho}}. \tag{4}$$

The resistance strain gage, which is stuck at 45^0 angle against the bar axis, is subjected to the linear deformation due to the torque angular deformation and the final maximum tangential strain is recorded:

$$\tau_{d\,max} = k_d \cdot \tau_{S\,max} = \tau_{S\,max} \cdot \sqrt{\frac{K}{U_S}}, \tag{5}$$

where $\tau_{s\,max} = \frac{M_s}{W_\rho}$, $M_S = P \cdot b$, $W_\rho = \frac{\pi d^3}{16}$.

By placing the value of $\tau_{S\,max}$ (5), we'll have:

$$\tau_{d\,max} = \sqrt{\frac{2KGI_\rho}{\ell W_\rho^2}} = 2\sqrt{\frac{KG}{F\ell}} \tag{6}$$

$F = \pi r^2$ is the latitudinal cros-section area of the bar (half shaft).

Throwing the load with the following weights m = 1.0, 2.0, 3.0, 4.0 and 5.0 kg from different heights ($0 \le h \le 1.3$ m), we fix the corresponding deviations of the oscillogram coordinate, specify and identify the relations of kinetic energy and oscillogram ordinate at the striking moment of the load and then determine the scale.

In the laboratory experimental plant the numerical values of the abovementioned units are as follows: $m = 0.5 \div 10$ kg, b=1.0 m, l=1.2 (the length of the half shaft), d=2.5 cm (the diameter of the shaft at the sticking cross-section of the resistance strain gage), $G = 8 \cdot 10^4$ MPa, h=0.5 ÷1.3 m.

Based on the data received from the preliminary theoretical and calibration trials conducted for the enhancement of force factors in the recommended clod-crusher the baseline calibration data have been identified: P_s=98.1 N (it provides the needed torque moment: $M=P_s \cdot b$=98.1Nm), h=1.3 m, V=5.5 m/s, m=10 kg.

Repeating the experiment for several times the deviations of the oscillogram ordinate from the zero position Δ are recorded in the monitor of the measuring gadget.

In case of the abovementioned values the following values for the main calibration parameters have been received: at the start of the load strike at the hard bar the kinetic energy is K=130 Nm, the potential energy of the torque deformation in the half shaft in case of applying the static force P_s is U_s=2.21 Nm.

The dynamic coefficient is:

$$k_d = 1 + \sqrt{1 + \frac{K}{U_S}} = 8.73.$$

.

For the latitudinal cross-section of the strain gage shaft F=4.9·10-4 m², $W_\rho = 3.06 \cdot 10^{-6}$ m³, $I_\rho = 3.8 \cdot 10^{-8}$ m⁴.

In case of static load the maximum value of tangential strain will be:

$$\tau_{d\,max} = \frac{P_S \cdot b}{W_\rho} = 32.06 \text{ MPa}.$$

The dynamic tangential strain:

$$\tau_{d\max} = k_d \cdot \tau_{s\max} = 279.88 \text{ MPa.}$$

Since K >> U_s, in practical computations the dynamic tangential strain can be also determined through the (6) expression:

$$\tau_{d\max} = 2 \cdot \sqrt{\frac{KG}{F\ell}} = 266 \text{ MPa.}$$

The deviation of the tangential strains determined through two methods doesn't exceed 5 %.

The dynamic value of the torque moment will be:

$$M_d = \tau_{d\max} \cdot W_\rho = 813{,}9 \text{ Nm.}$$

M_d is determined also in the following way:

$$M_d = k_d \cdot M_S = 8.73 \cdot 98.1 = 856.4 \text{ Nm.}$$

In this case the deviation again doesn't exceed 5 %.

Repeating the experiments for several times the deviation of oscillogram ordinate from the zero line is recorded in the monitor of the measuring gadget.
In case of the abovementioned baseline data during the 5 experiments we have received the following values for Δ: 108 mm, 109 mm, 108 mm, 107 mm and 109 mm.The average value of Δ is: Δ_{av} = 108.2 mm.

The signal size of the dynamic torque moment recorded through TRA-50K resistance strain gage will be 7.7±0.2 Nm/mm in the recording gadget.

In the laboratory experiments the clod-crushing fingers were conventionally assigned: 1–cylindrical, 2–cylindrical with hemispheric facade/front, 3–conical.

In the laboratory plant such rotational numbers were provided to the input shaft of transmission gearbox of the pulley, which ensure the forward movement of the clod-crushing aggregate with 1.0 m/s, 1.3 m/s and 1.6 m/s velocity.

A number of modal outcomes of the laboratory experiments are introduced in the table. The data of the table testify that the increase in the velocity of the forward movement and consequently that of in the angular velocity of the driver by 30÷60 % leads to the increase of resistance moment, hence, to the force increase by 10÷15 %.

The table data show that the resistance forces derived from the theoretical calculations for three different fingers interrelate with each other nearly in the same way as the resistance moments received upon the experiments:

$$\frac{P_1}{P_2} = 1.6, \ \frac{P_2}{P_3} = 1.6, \ \frac{P_1}{P_3} = 2.28, \ \frac{M_1}{M_2} = 1.56,$$

$$\frac{M_2}{M_3} = 1.46, \ \frac{M_1}{M_3} = 2.28.$$

Such overlapping interrelations (with slightest deviations) state on the acurate interpretation of the problem's real content through theory. Thus, the obtained results can be taken as a sound background for the design and computation of the clod-crushing machine.

Table. Data on the forward movement and angular velocity in different fingers of the clod-crusher*

Velocity of the clod-crusher's forward movement, m/s	Digging finger form	The maximum ordinate Δ_{max}, mm on the paper carrier of the recording equipment	The dynamic torque moment of the half shaft in one side M, Nm
1.0	1	13.6	105.6
	2	8.7	67.5
	3	6.0	46.3
1.3	1	14.5	112.0
	2	9.2	70.8
	3	6.4	49.4
1.6	1	15.4	118.5
	2	9.7	74.7
	3	7.0	53.2

*Composed by the authors.

Conclusion

The expression for identifying the optimal grouser numbers determined through the theoretical researches in equal working terms of the self-driving clod-crusher's rotors in the potato-digger has been derived and analyzed through the results of the scientific experiments.

The ratio of the resistance force factors theoretically received for the recommended three finger forms (cylindrical, cylindrical with hemispheric front and conical) in the clod-crusher has been proved upon the experiments.

The theoretical expressions derived as a result of kinematic and dynamic analyses of the clod-crusher can be completely used for the development and design of such machine series.

References

1. Tarverdyan, A.P., Yesoyan, A.M., Marikyan, S.S., Hayrapetyan, H.H. (2020). "Rotary Clod-Crusher of the Potato-Digger", RA invention patent № 3359.
2. Tarverdyan, A.P, Hayrapetyan, H.H., Altunyan, A.V, (2019). "Rotary Clod-Crusher of the Potato-Digger", patent of RA useful model № 543 U.
3. Tarverdyan, A.P., Hayrapetyan, H.H. (2019). "Kinematic and Dynamic Study of the Rotary Crusher Transmission Gear in the Potato - Digger". Agriscience and Technology, - № (68)/4 - Yerevan, - pp. 23-28.
4. Tarverdyan, A.P., Hayrapetyan, H.H. (2019). "Theoretical Justification of Optimal Geometric and Kinematic Parameters in Moving Parts of Clod-Crusher in Potato Harvester". Agriscience and Technology, - № (68)/ 4 - Yerevan – pp. 16-22.
5. Vysotsky, A.A. (1968). Dynamometry of the Agricultural Machines. Modern Instrument Designs and Measurement Methods. M.: - Engineering, - 290 p.
6. Loginov, V.N. (1976). Electrical Measurements of Mechanical Values. M.: - Energy, - 104 p.
7. Matevosyan, A.A. (2018). "Designing the Structure of the Potato-Digger with High Sifting Rate and Justification of the Working Parts' Parameters". Thesis, Yerevan, ANAU, -154 p.
8. Grigoryan, Sh.M., Tarverdyan, A.P., Khachatryan, A.Ts., Petrosyan, D.P. (2001). "The Elements of Mathematical Statistics and the Theory of Research Experiments Planning". - Yerevan, - 210 p.
9. Tarverdyan, A.P., Artemyan, R.N. (1992). Determination of the Dynamic Parameters of the Osscillating Flat Cutting Apparatus. "Science and Production. Agro-Industry", - № 6-7-8, Yerevan.

Accepted on 14.04.2020
Reviewed on 11.05.2020