International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4454-4463

Influence of Structural Characteristics of Harrow Teeth on the Dynamics of Their Abrasive Wear And Resource Forecast

Leonid Prokopovych Shustik[1], Victor Vasylyovych Pogoriliy[1], Volodymyr Ivanovych Kravchuk[1], Oleksiy Anatoliyovych Hrynenko[2], Mykola Dmytrovych Zanko[1], Tetyana Leonidivna Babynets[1]

[1] *State scientific organization "Leonid Pogorilyy Ukrainian Scientific Research Institute of Forecasting and Testing of Machinery and Technologies for Agricultural Production" (Leonid Pogorilyy UkrNDIPVT), Doslidnitske, 08654, Ukraine.*

[2] *Limited Liability Company "Ukrainian Design Bureau of Transmissions and Chassis", Kharkiv, 61038, Ukraine.*

Abstract

The influence of structural characteristics of harrow teeth on the dynamics of their abrasive wear on the basis of accelerated laboratory tests is investigated and the forecast of comparative relative (normalized) resource is determined**.** Analysis of the design of the teeth of the harrows shows the presence of various parameters and characteristics, and the greatest abrasive load falls on the point. Determining its resistance to abrasive wear under operating conditions or by simulation in a rotating drum filled with abrasive material is a long and expensive procedure. The accelerated method of wear by local action of a movable abrasive on the working face of the tooth in the area at a height of 10 mm above the point with the same pressure and amount of abrasive and distance to the working face using a laboratory installation allows reduce time tenfold. The mass of metal removed from the tooth surface is a characteristic of its content in the most important for quality and energy consumption volumes of segments of horizontal sections of the tooth point at a height of 10, 20, 30 mm. This method allows you to set the resource rating of the point segments of the studied teeth, which can be interpreted in a table and graphically. The service life of the examined teeth almost 4/5 depends on the geometric factors associated with the parameters of the diamond-shaped profile of the base and the sharpness of the point and about 1/5 of the hardness. Manufacturers of agricultural machinery offer teeth with different characteristics that meet the requirements and financial capabilities of consumers: those who use harrows intensively and change teeth frequently, and those who practice situational use of harrows - which confirms the possibility of choosing an acceptable resource.

Keywords: harrow teeth, abrasive action, resource, rating, abrasive wear.

I. INTRODUCTION

In the international practice of crop production, along with the use of new technical and technological solutions, one of the trends is the improvement of traditional technologies and machines, as evidenced by the sale of plows and harrows [2]. Since the important operation of the main plow tillage with rotation of the soil layer is the closure of moisture by toothed harrows, soil harrowing is the most common environmentally safe, highly productive, multi-purpose method of tillage, which helps to destroy weeds in early development, soil moisture retention, air saturation of the surface layer. In today's climate change, the importance of using harrows, the main working element of which is a tooth, which determines the quality and reliability of the tool.

In Ukraine alone, the harrow park has about 160 thousand pieces [2]. If we consider the average harrow width of 6 m, then in total they will contain about 20 million teeth, the derivative of which is 30 thousand tons of total harrow weight. Improper geometry of the tooth sock can lead to a deterioration in the quality of the technological process, increase the energy consumption of the harrow and the additional cost of restoring the shape of the sock. During the annual season, up to 5 % of the weight of teeth (about 1.5 thousand tons of metal) can be lost.

The harrowing process is performed by toothed and spring harrows. The basic element of a tooth harrow is a tooth that interacts with the soil to a depth of 10 cm. According to the classification, harrows can be heavy, medium and light, this creates a load on the tooth, respectively 2-3; 1-2; 0.5-1 kg [3].

It is assumed that each tooth will be well immersed to the required depth and ensure quality only if it has a required sharpening on the most loaded part of the point, which is associated with the geometric and strength characteristics. The loss of sharpness is a derivative of abrasive wear, which affects fuel consumption, quality of work, finances and time [4, 5, 6].

Specialists in agricultural machinery consider toothed harrows one of the simplest tillage tools. At the same time, many works and dissertations are devoted to the theory and calculation of toothed harrows - this is the calculation of loads on the tooth, substantiation of structural parameters and of the arrangement of the tooth field on the harrow, optimization of the quality of the tooth work, calculation of equilibrium conditions and traction resistance of the tooth harrow, search for new shapes and properties of the tooth, etc. [3,7].

One of the most important factors in the reliability of harrow teeth is their abrasive wear resistance, which has been insufficiently studied. Although abrasive resistance research methods were introduced long ago, including the Brinell method [8], improved by Howart [9], concerning the replacement the metal disk with rubber, the search for new test methods did not stop [10, 11, 12, 13]. New approaches to testing specific working bodies operating in an abrasive environment are constantly being proposed. In particular, the authors [12] take into account the influence of various factors (type of abrasive, its fractional composition, humidity), and in studies [13] accounted the degree of abrasive density combined with torque for better understanding of abrasiveness. Taking into account the principles and categories available in these methods, related to the need for destruction of the test specimen, high cost, complexity of test equipment, and time costs, it is advisable to compromise speed and sufficient probability to make decisions on tooth evaluation for abrasion resistance.

II. SETTING THE TASKS

Different manufacturers offer their own approaches to the design of the teeth of finger harrows, which work in an abrasive environment, use different quality metal. Abrasive wear of working bodies of tillage implements is a world problem. For resistance to abrasive wear, the metallurgical industry offers a wide range of steels, technologies to increase its abrasion resistance, and scientists are working to improve it, which is noticeable in the analysis of publications, even in the near retrospective. Examples of this are, in particular, laser surface hardening [14], the use of multicomponent layers based on boron [15], the use of powder coatings by pulsation and detonation spraying [16], and so on.

The cost of such metal and the usage of these methods to improve its characteristics is high. Solving the problem of designing an abrasion-resistant working body can have a comprehensive solution that reduces the cost of production. This is achieved by the advantage of a synergistic combination of parts shape, material characteristics and affordable price. Taking into account the size of farms, their resources, technological culture and intensity of operation of machines, each producer of agricultural products has the opportunity to choose a working body with its inherent reliability and cost. Given the above, the study of harrow teeth and analysis of design features and parameters to compare their resistance to abrasive wear, even at an acceptable level of reliability with a minimum time resource, is relevant.

II.I. The purpose of the work

Determining the methodology and forecasting the resource of harrow teeth using accelerated laboratory tests**.**

- **Tasks to achieve this goal:**

- - simulation of wear of the fixed working face of the tooth by the action of a moving abrasive on it;

- - determination of criteria for evaluation of the forecasted resource;

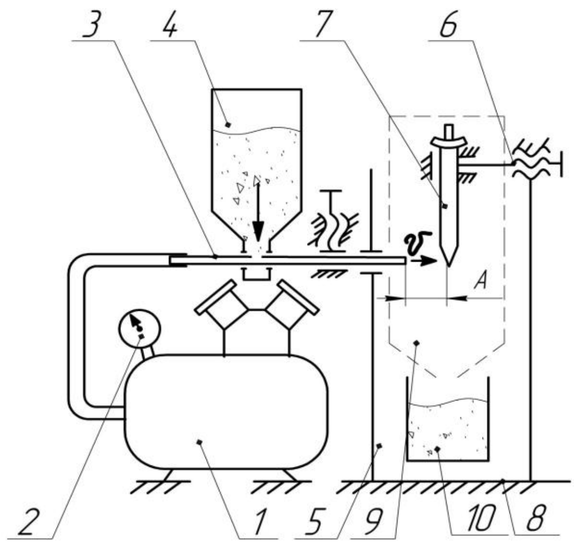
- - determination of the rate of removal of the mass of metal on a specific layered section of the points of the teeth;

- - forecasting the signs of reaching the resource limit by the level of quality of the technological process.

III. METHODS AND MATERIALS

According to the analysis of design features and parameters of harrow teeth influence on the resource during their abrasive wear, a method of accelerated abrasive wear is proposed [17] in a laboratory installation, the scheme of which is shown in Figure 1.

The installation scheme includes a compressor 1 with a pressure gauge 2. The compressor through a rubber hose is connected to a calibrated tube 3 with a cutout, over which is a hopper with abrasive sand 4. The tested tooth 7 is mounted on a tripod 5 by a three-dimensional fastening system 6, which provides the installation of the edge of the calibrated tube relative to the investigated area of wear of the tooth point. The spent abrasive is deposited through the cyclone 9 in the collection container 10.

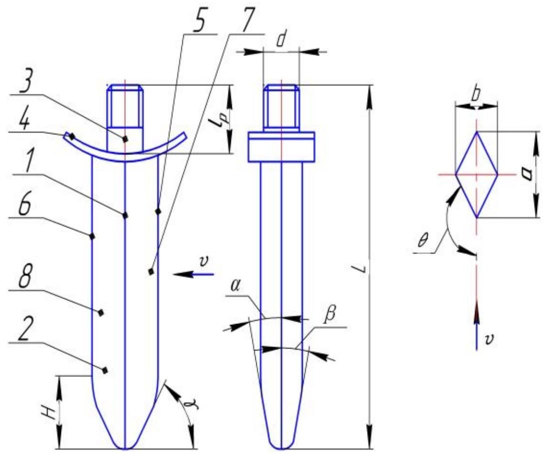


1 - compressor; 2 - manometer; 3 - calibrated tube; 4 - hopper with abrasive sand; 5 - tripod; 6 - three-dimensional fastening system; 7 - a finger; 8 - base; 9 - cyclone; 10 - prefabricated container of spent abrasive.

Figure 1. Scheme of the laboratory installation for local action of the abrasive on the fixed tooth point

The tooth of the harrow, being in the soil at the working depth, as a rule, up to 5 cm, absorbs the abrasive action primarily in the area of the working faces of the point and its ribs, behind which the abrasive action is practically not observed.

Figure 2 shows the design of the tooth with an illustration of the constituent parameters.



1 - base; 2 - point; 3 - shank with a thread; 4 - clamp; 5 - working rib;

6 - passive rib; 7 - working face; 8 - passive face; α, β - angles of sharpening (configuration) of the point; γ is the angle of entry of the point; θ - furrow opening angle; a – the cross-sectional length of the base profile; b – the cross-sectional width of the base profile; H – point height.

Figure 2. Components of the harrow tooth and its parameters

Basic elements, characteristics and parameters of the point: shape and profiles of the base of the point; hardness; angles: sharpening of α and β (configuration), entry into the soil γ, opening of the furrow θ; point height.

The test conditions provide for the simulation of wear by the action of a moving abrasive (sand) on the stationary working face of the tooth in the area at a height of 10 mm above the point [17].

The mode of operation determines the effect on all 4 teeth of the same pressure, the same supply of the amount of abrasive and the distance of its movement to the working face.

The evaluation criterion established the projected resource and efficiency of the tooth point in 3 sections: while maintaining the high quality of work in the segment of the tooth point height of 0-10 mm; with the provision of acceptable quality of work in the segment height of 10-20 mm, where there is the appearance of rounding; with low quality of work and complete disability in the segment height of 20-30 mm (marginal resource).

To calculate the volume of each tooth layer, use the formula for determining the volume $V_ш$ of the cut cone $V_ш = \frac{1}{3}(S_1 - S_2) \bullet h$ (where S_1 S_2 – the area of the tooth point on the upper and lower layered sections; h – the height of the layered section, mm) and the mass will be $m_ш = V_ш \bullet \rho$ (г). Knowing the mass of the metal in the layered section, the content of K mass $\overline{m}_a$ of abrasive wear is determined in the layered volume ($K = \frac{m_ш}{\overline{m}_a}$) or in other words, the rate of removal of metal from a particular layer of the tooth.

In fact, the rate of removal of the mass of metal on each layered section will determine the resource of this cut interval. By comparing the wear rate of the tooth layers of different batches, experts can analytically interpret their projected resource with the corresponding quality of work according to the matrix presented in table 1.

Table 1. Matrix of expert evaluation of the projected resource of harrow teeth

Height of a layered cut, mm	Projected layer-by-layer resource in batches				The level of technological process support	Projected sign of the resource limit reaching
	1	2	3	4		
10	$K_{1(10)}$	$K_{2(10)}$	$K_{3(10)}$	$K_{4(10)}$	High quality	Loss of sharpening
20	$K_{1(20)}$	$K_{2(20)}$	$K_{3(20)}$	$K_{4(20)}$	Acceptable	Significant rounding
30	$K_{1(30)}$	$K_{2(30)}$	$K_{3(30)}$	$K_{4(30)}$	Low	Complete loss of point configuration

According to the chosen methodology, the teeth from 4 batches with the displayed numbering 1, 2, 3, 4, which were presented by different manufacturers, were subjected to investigation. Prior to the abrasive procedure, measurements were performed, which are shown in table 2.

Table 2. Characteristics of harrow teeth

№ of a batch	Base profile				Point				Hardness (HRC) determination
	Shape. Base profile	Parameters		Angle of furrow opening Ɵ, grad.	Height H, mm	Configuration	Angles		
		length a	width b				sharpening α, grad.	entering γ, grad.	
1	**diamond**	19,5	14,5	145	30,0	sharp narrow hard	18	65	48 (hard)
2	**diamond**	23,1	17,4	150	30,0	sharpened wide hard	19	59	48 (hard)
3	**diamond**	22,4	16,0	152	30,0	sharp medium wide and medium hard	15	65	39 (hard)
4	**diamond**	24,2	16,2	150	30,0	sharp medium wide hard	15	70	48-49 (hard)

The cross-sectional shapes of the tooth points are shown in the figure 3.

1 2 3 4

Figure 3. Diamond-shaped cross-sections of tooth points

IV. RESULTS

According to the program of works the experiments on wear of each of 4 investigated teeth by a moving abrasive (sand) on their fixed working face at the height of 10 mm above a sock, with the pressure of 3 atm, and uniform feed of 2880 g of abrasive at the distance of 19 mm to the working face.

The overall view of wear of tooth points after abrasive action is given in figure 4.

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 12 (2020), pp. 4454-4463

а)

1 2 3 4

б)

1 2 3 4

Figure 4. Overall view of tooth points wear after abrasive action according to the presented groups: a - side view; b - front view.

Table 3 shows the parameters of the layer-by-layer cross-sections of the points of different teeth.

Table 3. Parameters of segments of layered sections of points of different teeth with a resolution of 10 mm

№ of a batch	Height of cross-section, mm (h)	Density of metal , g/mm^3 (ρ)	Volume of layer-by-layer cross-section, mm^2 ($V_ш$)	Mass of metal in layer-by-layer cross-section, g ($m_ш$)	Mass of abrasive removal, g ($\overline{m}_a$)	The content of removals in layers $K = \left(\frac{m_ш}{m_a}\right)$
1	10	0,00785	172,73	1,355931	0,857	1,58
	20		508,74	3,993609		4,66
	30		724,71	5,688974		6,64
2	10		339,70	2,666645	0,708	3,77
	20		709,24	5,567534		7,86
	30		921,21	7,231499		10,21
3	10		188,35	1,478548	0,661	2,24
	20		503,86	3,955301		5,98
	30		756,65	5,939703		8,99
4	10		233,00	1,829050	0,665	2,75
	20		590,68	4,636838		6,97
	30		843,94	6,624929		9,96

Table 4 shows the mass of metal removed from defined for the quality of work segments of the layered sections of the points of the teeth in accordance with the presupposing of the expert.

Table 4. The mass of metal removed from defined for the quality of work segments of the layered sections of the points of the teeth in accordance with the presupposing of the expert with a discreteness of 10 mm.

№ of a batch	Calculated mass of the removed metal in layers sections		
	10 мм	20 мм	30 мм
1 (sharp narrow hard)	1,58	4,66	6,64
2 (sharpened wide hard)	3,77	7,86	10,21
3 (sharp medium wide and medium hard)	2,24	5,98	8,99
4 (sharp medium wide hard)	2,75	6,97	9,96

If we take the maximum of the obtained contents of metal removals in segments of layered sections for one hundred percent resource (i.e. there is the most abrasion-resistant segment of a particular tooth with its inherent design parameters and characteristics), it is possible to interpret the abrasive stability of segments of all teeth. By imposing additional expert restrictions on the level of quality of the technological process, which correlates with the sign of reaching the resource limit, the teeth manufacturer or their consumer is able to assess the resource of teeth more popularly, as presented in Table 5 and interpreted in the graph (Fig. 5).

Table 5. Expert assessment of the predicted resource of harrow teeth

Height of layered section, mm	The normalized indicator of the resource of the segments of the point of the teeth in layered sections in different batches , %				The level of quality of the technological process	Predicted sign of reaching the resource limit
	1 (sharp narrow hard)	2 (sharpened wide hard)	3 (sharp medium wide and medium hard)	4 (sharp medium wide hard)		
10	16	37	22	26	High	Loss of sharpening
20	46	77	58	65	Acceptable	Significant rounding
30	65	100	88	93	Low	Complete loss of point configuration

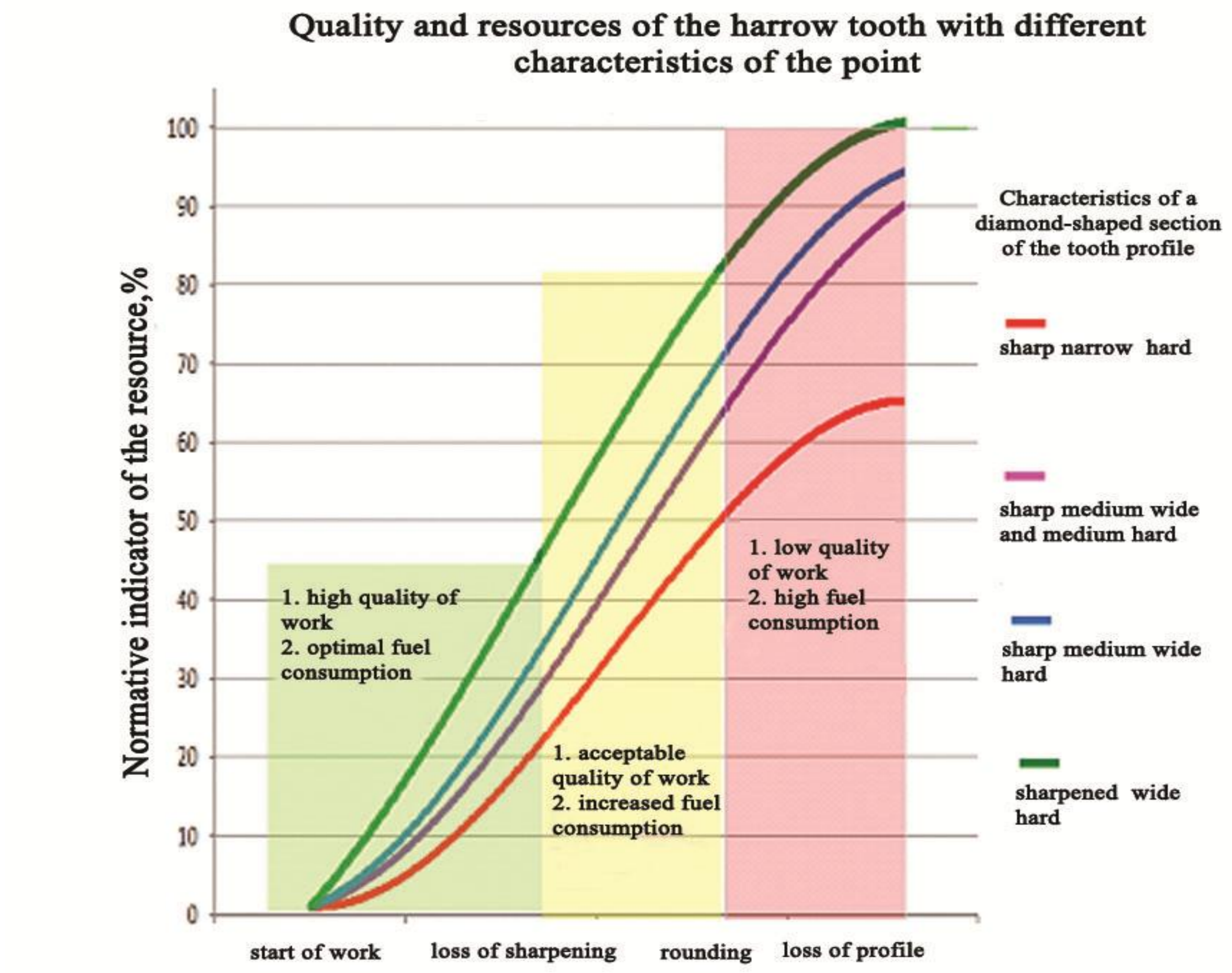


Figure 5. Quality and service life of the harrow tooth with different characteristics of the point

A pairwise comparative analysis of the changes in the resource values of different teeth related to point configuration factors, base profile and hardness parameters allowed to determine the degree of influence of each factor on the rate of abrasive wear of the compared teeth. In particular, the first variant of comparing the effect of the configuration of a sharp narrow hard point has a 25-35 % lower abrasion resistance than the sharpened wide hard one. In the second variant, the abrasion resistance of the sharp medium wide tooth is better compared to the sharp narrow hard by 10 %. The third option shows that the abrasion resistance of a sharp medium-wide tooth is higher than the sharp medium wide by 3-5 %. In the fourth variant, the sharpened wide hard is more stable by 10–15 % than the sharp wide hard one.

Having connected in the table the received values of a difference of resources with the specified factors it is possible to predict influence on a resource of each of them.

Table 6. Characteristics of the factor with equity shares

Characteristics of the factor with equity shares %				
A variant of pairwise comparison	Resource change limits	Point configuration (sharp - 50 sharpened - 50)	Base profile parameters (narrow - 33 Medium wide - 33 wide - 33)	Hardness (medium hard - 50 hard - 50)

1	25 - 30	7,5 - 10,5 7,5 - 10,5	5,0 -7,0 5,0 -7,0	-
2	10	-	2,0 2,0	3,0 3,0
3	3 - 5	-	-	3,0 – 5,0
4	10 - 15	3,0 – 4,5 3,0 – 4,5	2,0 – 3,0 2,0 – 3,0	-
Total value		21 - 30	18 - 24	9 - 11
Equity share		44 – 46	37 - 37	19 - 17

Summing up, it is possible to say that the influence on the abrasive wear of geometric factors, which include the configuration of the point and the parameters of the base profile, is 81-83 %, and the hardness of 17-19 %, respectively 4/5 and 1/5.

V. DISCUSSION

Known methods of testing for abrasive wear, involving the action of friction with an abrasive material that presses on the sample with a given force, are suitable for samples in which a plane is formed, the hardness of the sample is homogeneous. Obtaining a sample requires its manufacture or cutting [18]. The advantage of this methodology is the short duration of the test, which ranges from 40-60 minutes. [10,19].

Accelerated testing of the working bodies on circular stands with abrasive, its compaction, humidification, the procedure of re-installation of investigated parts sites, are long, energy-intensive, cumbersome and require significant investment [20].

The proposed approach of comparative studies and the results indicate an alternative possibility of its application with a number of advantages: participation in the experiment of the whole working body or a significant part of it, the ability to work on test samples of complex geometric shape, different layer hardness, resource limit achievement signs forecasting, related to the level of quality of the technological process.

Studies [21] were made on the abrasion resistance of a group of cultivator blades mounted on field-working units. The operating time for each blade is about 14 hectares and about 70 hours of observations. This approach to setting the resource for abrasion resistance is highly reliable, but the significant duration of the result, the complexity of implementation and the impossibility of reproducing other batches in identical conditions lose the advantage of having to make a series of decisions on the working body in a short time without waiting for the field season. Our research on abrasive wear requires about 60 minutes per tooth and subject to the study of an equivalent number of working bodies (13 teeth against 13 blades is achieved 5-fold acceleration, and when comparing one sample in two methodologies, the time differs by 70 times.

The authors' statement [21] that within different segments of one working body there may be different wear regimes is true. Therefore, we strictly monitored the uniformity of the places of action of the moving abrasive on the tooth. The obtained result was interpreted on layered sections of other segments of the tooth point.

The importance of the influence of the type of abrasive on the wear rate is confirmed in many studies, as the authors say [5]. In studies [21], the authors give an average rate of wear of the cultivator blade in the range of 0.94-5.28 g / km in accordance with sandy loam and loamy sand, which may be evidence of 5-fold acceleration only by changing the soil structure.

This confirmed the need to use one type of abrasive in our research in a strictly dosed feed rate.

The speed of movement of the working bodies in the abrasive environment has a great influence on wear [22]. In this regard, the effect of a mobile abrasive on a stationary tooth was achieved by us at a stable pressure with a compressor during all experiments. This allowed to deny the repeatability of the experiment for other possible batches of teeth, or to adapt this methodological approach to resource assessment for other working bodies.

Significant affiliation of abrasive wear of pipelines from the form of bending was studied [23] under the action of erodent in the form of a mixture of gas filler and fine quartz sand. The difference in abrasion resistance at angles of 20, 30, and 90º can reach 12 times. Taking into account these statements in our method, a strict requirement was to adhere to the uniformity of the angle of installation of the vertical axis of the tooth to the feed direction of the moving abrasive.

In studies [24], the authors say about the dependence of the rate of abrasive wear on the shape, which agrees with our studies. The shape factors include the configuration of the tooth point and the parameters of the base profile, which have a significant advantage over the hardness factor. And the authors [21] in their conclusions confirm that the possibility of increasing wear resistance is a variable geometry of the blades.

VI. CONCLUSIONS

The service life of the examined teeth is almost 4/5 dependent of the geometric factors associated with the parameters of the diamond-shaped profile of the base and the sharpness of the point and about 1/5 of the hardness.

Comparative resource forecast of tooth point segments on its layered horizontal sections 0-10 mm high; 10-20 mm; 20-30 mm by the method of accelerated wear by local action of the abrasive indicates that the largest resource in all segments of the layer sections is predicted by the teeth of the 2nd batch (sharpened wide hard), at the same time:

- in the segment of 0-10 mm, they manifest the longest sharpening, which provides quality work with optimal fuel consumption, and the teeth of other parties predict 1.4- 2.3 times less resource;

- the resource of teeth in the segment of 10-20 mm, with the appearance of rounding of the point, provides an acceptable quality of work with increased fuel consumption and will remain on the teeth of the 2nd batch longer than other batches 1.2-1.7 times;

- in the segment of 20-30 mm, where there is a predicted loss of configuration, which corresponds to a sharp deterioration in the quality of work and high fuel consumption, the teeth of the 2nd batch are more stable than others in 1.1-1.5 times.

According to the rating of the relative resource forecast of the examined teeth is distributed in the following sequence: place I – 2nd batch (sharpened wide hard), place II and III – 4th batch (sharp medium wide hard) and 3rd batch (sharpen medium wide and medium hard), place IV – 1st batch (sharp narrow hard).

Manufacturers of agricultural machinery offer teeth with different characteristics that meet the requirements and financial capabilities of consumers: those who use harrows intensively and change teeth frequently, and those who practice situational use of harrows - which confirms the possibility of choosing an acceptable resource.

REFERENCES

[1] State Statistics Service of Ukraine. Agriculture of Ukraine. Statistical Collection 2017. - Kiev, 2018.

[2] State Statistics Service of Ukraine. Availability of agricultural machinery and energy facilities in agriculture in 2016. Statistical Bulletin, / - Kyiv, 2017.

[3] Voituk DG, Baranovsky VM, Bulgakov VM, et al. Edited by Professor, Corresponding Member. UAAN Voytyuk D.G. Agricultural machines. Fundamentals of theory and calculation. Textbook . Kyiv Higher education 2005;- 464s.

[4] Fitzpatrick RW, Riley TW, Wright MJ, Fielke JM, Butterworth PJ, Richards BG, Peter P, Thompson JM, Slattery MG, Chin D, McClure SG. Highly abrasive soils and ground engaging tool performance. End of Grant Report (1988-1990) for the Australian Wheat Research Council (project No. SAlT 1W). 1990.

[5] Ferguson SA, Fielke JM, Riley TW. Wear of cultivator shares in abrasive South Australian soils. Journal of agricultural engineering research. 1998 Feb 1;69(2):99-105.

[6] Fielke JM, Riley TW, Slattery MG, Fitzpatrick RW. Comparison of tillage forces and wear rates of pressed and cast cultivator shares. Soil and Tillage Research. 1993 Jan 1;25(4):317-28.

[7] Burdega VYu. The results of the study of harrows with soil teeth. Coll. of sciences. XVIII ave. of sciences. Conf., Ternopil: Step, 2017: 31 - 33.

[8] Gee M. Measurement in tribology. InInt. Conf.“50th Anniversary of the “Jost Report. 2014.

[9] Spikes H. Liquid lubrication research; 1966 to the present day. InInt. Conf.“50th Anniversary of the “Jost Report. 2016.

[10] Vishnevsky AA, Davydov AS. Determination of the wear resistance of metals with a loose abrasive. G. Arms systems and military equipment. 2019;2(58).

[11] Cann P. Biotribology: opportunities and challenges. InInt. Conf.“50th Anniversary of the “Jost Report 2016.

[12] Wei YJ, Zheng X, Su F, Li MM, Li F, Yang YY. Evaluation of cutting tool wear of earth pressure balance shield in granular soil based on laboratory test. Journal of Testing and Evaluation. 2019 Feb 13;47(2):927-41.

[13] Wei Y, Yang Y, Tao M. Effects of gravel content and particle size on abrasivity of sandy gravel mixtures. Engineering geology. 2018 Sep 4;243:26-35.

[14] Kumar V, Rakshit R, Das AK. Mechanical and tribological performance of fiber laser cladded h-BN+ SS316 composite on SS316 surface. Journal of Materials Processing Technology. 2020 Apr 1;278:116509.

[15] Mishigdorzhiyn U, Chen Y, Ulakhanov N, Liang H. Microstructure and Wear Behavior of Tungsten Hot-Work Steel after Boriding and Boroaluminizing. Lubricants. 2020 Mar;8(3):26.

[16] Kang AS, Grewal JS, Cheema GS. Effect of thermal spray coatings on wear behavior of high tensile steel applicable for tiller blades. Materials Today: Proceedings. 2017 Jan 1;4(2):95-103.

[17] Shustik LP, et al. The Teeth of Harrows. Forecast of the influence of the parameters design features on the resource during their aggregative wear. Technical and technological aspects of development and testing of new machinery and technologies for agriculture in Ukraine: a collection of scientific works L. Pogorilyy UkrNDIPVT. – Doslidnytske. 2019;24(38):157-163.

[18] Kuzmenko AG, Vishnevsky OA. Test method for abrasive wear according to the Brinnel-Howarth (Br-Hv) scheme Part 1 Theoretical basis of the method. Problems of Tribology. 2012;4:102-108.

[19] Matlin MM, Mozgunova AI, Kazankina EN, Kazankin VA. Stiffness of the elastic-plastic contact of machine parts. Monograph - M .: Engineering. 2015: – 423 p.

[20] Aulin VV, Chernovol MI, Tikhiy AA. Wearing ability of soil environment and regularity of operation of parts of ROGM Tribology problems - Khmelnitsky: KSU. 2010;2:6-10.

[21] Kalácska Á, De Baets P, Fauconnier D, Schramm F, Frerichs L, Sukumaran J. Abrasive wear behaviour of 27MnB5 steel used in agricultural tines. Wear. 2020 Feb 15;442:203107.

[22] Owsiak Z. Wear of symmetrical wedge-shaped tillage tools. Soil and Tillage Research. 1997 Nov 10;43(3-4):295-308.

[23] Khan R, Ya HH, Pao W, Khan A. Erosion–Corrosion of 30°, 60°, and 90° Carbon Steel Elbows in a Multiphase Flow Containing Sand Particles. Materials. 2019 Jan;12(23):3898.

[24] Tong J, Mohammad MA, Zhang J, Ma Y, Rong B, Chen D, Menon C. DEM numerical simulation of abrasive wear characteristics of a bioinspired ridged surface. Journal of Bionic Engineering. 2010 Jun 1;7(2):175-81.