The study of the wear of the control knives of the straw chopper

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Abstract. The article considers the topical task of studying the wear rate of steel parts in the course of agricultural work. The wear of the knives of chopper-cum-spreaders used in agricultural works is determined and compared with control samples. Within the scope of the study, the relative linear and weight wear was being determined. The results of the study of dimensional parameters are given in the article. The dependence of wear on the operating time and zones of various wear of the part is determined. A graphic illustration of these dependencies is provided. The mechanism of wear of these parts is proposed. It was established that it is necessary to change the design of the hardsurfacing overlay used in order to maintain the acceptable cutting properties of the knife until it reaches its limit state, more specifically: firstly, to refuse applying hardening strips of hard alloy on the reverse side of the cutting edges by 1/3 of their length located at a distance of 65-70 mm from the flat end; secondly, to make the width of the strips variable, gradually increasing it to a size 1.5 to 2 times exceeding the blade width when approaching the flat end of the knife, i.e. give them triangular or curvilinear shape that is close to and/or overlapping the boundaries of the wear outline; thirdly, the triangular shape of the strips can be achieved due to the excessive material released from the unhardened 1/3 of the blade length.

1. Introduction

Wear of cutting tools is caused by material stress and thermal change at the tool edge, which in turn depend on cutting operations such as turning, milling, drilling, dicing, and scribing as well as cutting conditions and cutting fluid [1-3]. Cutting tool wear can be classified into abrasion (sub-microscale), attrition (microscale), chipping (mesoscale), and fracture according to the damage size [3]. As the micro-nano scale wear progresses, the morphology and dimensional accuracy of the cutting tool are reduced, and the worn cutting tool has to be replaced. For precision machining, maintaining a nanoscale sharpness of the tool edge through accurate measurement of the tool wear and determining different cutting positions, which is as important as tool wear, are critical in cutting tool edge condition and affect the form error and surface quality of a machined product [4]. Tool wear especially increases cutting force and heat generation, leading to reduced cutting stability and repeatability [5-8].

Cutting tools are typically replaced on a schedule. However, some are replaced according to the wear condition of the tool due to high costs. Currently, cutting tool conditions are inspected by machining operators both visually and off-site. However, the visual inspection method is less efficient and limited
to quantitatively derived micro-nanoscale cutting tool wear detection such as morphology, wear, and chipping conditions.

The objective of this paper is study of the wear of the part itself (linear, weight, determination of the preferred wear pattern, etc.) for designing the mold and the design of a reinforcing coating.

2. Materials and method
To develop new methods to increase the wear resistance of knives to values, no worse than those of their foreign counterparts, not only a reasonable selection of the base material and hardening coating is required, but also the study of the wear of the part itself (linear, weight, determination of the preferred wear pattern, etc.) for designing the mold and the design of a reinforcing coating.

To this end, in preliminary experiments the current wear of the control knives of the chopper-spreader IRS-1500 was determined by measuring and weighing 4 samples taken from the drum of the unit paired with defective, completely worn and deformed knives when eliminating failures, while operating time in: 47, 110, 162 and 225 hectares, respectively. Photographs of worn knives are shown in figure 1.

![Figure 1. Appearance of worn control knives of the chopper-spreader IRS-1500 of the Acros combine with different operating hours, ha: 1 to 47; 2-110; 3 - 162; 4 – 225.](image)

As can be seen from figure 1, worn parts have one-sided sharpening, the cutting edges are hardened on the reverse side by induction surfacing of the hard alloy, and are characterized by a similar shape of the wear pattern. It can also be seen that the knives 2, 3, 4 were turned upside down when they worked 47 hectares.

After cleaning all worn parts, their relative linear ($I_l$) and weight wear ($I_m$) were determined using the following formulas:

\[ I_l = 1 - \left( \frac{l_{zn}}{l_0} \right) \]  
\[ I_m = 1 - \left( \frac{m_{zn}}{m_0} \right) \]

where: $l_{zn}$, $m_{zn}$ - the characteristic size of the worn part or its mass; $l_0$, $m_0$ - the size or mass of the worn part.

Based on the shapes of worn knives shown in figure 1, the knife width $l(i)$, mm, measured at different distances from its edge, mm (5, 10, 20, 40, 60, 80, 100), was taken as the characteristic size when determining $I_l$.

3. Results and discussion
To calculate the wear using the formulas (1, 2), the following constants were adopted: $l_0 = 60$ mm, $m_0 = 325.0$ g. The results of determining the weight and size parameters of worn knives and the corresponding values of wear are shown in tables 1, 2.
Table 1. Parameters of worn control knives.

| Operating time, hectare | \(m_{\text{max}}, \text{g.}\) | 5   | 10  | 20  | 40  | 60  | 80  | 100 |
|-------------------------|--------------------------|-----|-----|-----|-----|-----|-----|-----|
| 47                      | 322,5                    | 52,5| 55,3| 56,2| 58,1| 58,6| 59,2| 59,8|
| 110                     | 310,2                    | 51,8| 52,3| 55,4| 57,3| 58,6| 58,6| 59,6|
| 162                     | 304,9                    | 50,8| 51,6| 55,7| 57,8| 58,6| 58,8| 59,9|
| 225                     | 298,3                    | 49,4| 50,7| 53,5| 57,1| 57,9| 58,6| 59,5|

As it follows from the data given in table 1, a reasonable gradual increase in the relative weight wear as well as decrease in the typical dimension depending on the mowed area is observed in the investigated parts, which indicates the established wear pattern. Also observed is the practical constancy of the width of the knife, measured at a distance of 80 and 100 mm from its edge, which indicates a low intensity of the wear process in this area of the part. The low wear rate of the knife at the beginning of the blade is associated with a decrease of 1.5-1.6 times the cutting speed along the length of the knife blade - from 98 m/s at its end to 61 m/s at the beginning of the knife.

Table 2. The calculated values of the relative wear of the control knives.

| Operating time, hectare | \(I_{m}, \%\) | 5   | 10  | 20  | 40  | 60  | 80  | 100 |
|-------------------------|--------------|-----|-----|-----|-----|-----|-----|-----|
| 47                      | 0,8          | 12,5| 7,8 | 6,3 | 3,1 | 2,3 | 1,3 | 0,3 |
| 110                     | 4,6          | 13,6| 12,8| 7,6 | 4,5 | 2,3 | 2,3 | 0,6 |
| 162                     | 6,2          | 15,3| 14,0| 7,2 | 3,6 | 2,3 | 2,0 | 0,2 |
| 225                     | 8,2          | 17,6| 15,5| 10,8| 4,8 | 3,5 | 2,3 | 0,8 |

Figure 2. Knife relative wear curve and its logarithmic approximation.
The integral process of wear of parts when forming wear patterns of complex shape on the surface most fully characterizes the value of weight wear.

Figure 2 shows the dependence of the relative weight wear for the investigated parts, depending on their operating time, and the corresponding approximation equation.

The appearance of the dependence shown in figure 2, and the high correlation coefficient of the approximation model confirm the established pattern of knife wear.

The corresponding family of linear wear curves for the knife widths, measured at a distance from its end face of 5, 10 and 20 mm, constructed based on the data in table 2 are shown in figure 3.

![Figure 3](image)

**Figure 3.** A family of curves of relative linear wear of knives constructed for their width at different distances from the end.

The complex course of the curves shown in figure 3, and the presence of kinks in them in the area of 110 hectares of production, does not indicate a change in the nature or mechanism of wear, but about the catastrophic wear of parts that occurred here due to separation of their parts (see figure 1). Therefore, these dependences were not subjected to approximation.

Since all the knives examined were operated in the same apparatus under similar conditions for different times, and there were no excesses, jumps, or emissions on the wear curve, this suggests the same wear mechanism for these parts - abrasive or abrasive-corrosion.

Additionally, the generality of the wear mechanism of the studied knives is also confirmed by the relationships between the relative weight and relative linear wear, measured, for example, at a distance of 5 and 10 mm from the edge of the knife, shown in figure 4, a, b.

![Figure 4](image)

**Figure 4. a.** The relationship between the weight and linear wear of the knives, measured at different distances from the edge 5 mm.

**Figure 4. b.** The relationship between the weight and linear wear of the knives, measured at different distances from the edge 10 mm.
The established pattern of wear and the constancy of the wear mechanism of the studied knives throughout the life of up to 225 ha allow us to experimentally establish the shape of the predominant wear pattern (diagram) and develop a new design of the knife hardening coating. The experimental plot of the wear of the blade of a knife at an operating time of 225 hectares is shown in figure 5.

![Figure 5. Plot of wear of a knife blade at an operating time of 225 hectares.](image)

The easiest way to determine the shape of the predominant wear pattern on the basis of available materials is by symmetric application of the most worn out half-contour of the knife with 225 hectares of life on a new knife blank on the front side (see figure 6).

![Figure 6. Outline of the prevailing knife wear pattern.](image)

As it follows from figure 6, when the mowed area reaches 225 hectares and above, the boundaries of the knives’ wear pattern up to distance of 10 mm from its end are completely beyond the cutting edge resulting in deteriorated cutting properties, enhanced cutting resistance, increased impact loads as well as excessive knife wear.

Apparently, the operating time of 200-225 hectares should be considered the limit for one of the cutting edges of this batch of knives, since when it was achieved, a complete replacement / rearrangement of the entire set was made, about which the combiner made an appropriate entry in the journal. The boundary parameter for replacing the knife, according to the operating documentation for the «Acros» combine, is wear of the cutting edges to the main thickness in any section of the knife. At the same time, even when reaching the maximum operating time, as can be seen from figure 4, only 2/3 of the length of the cutting edge from its end underwent wear, while the remaining 1/3 of the length of the blade, which was 65-70 mm away from the end, was not subjected to wear.

4. Conclusions

Thus, in order to maintain acceptable cutting properties of the knife until it reaches its ultimate state, it is necessary to change the design of the hardening coating used, namely: firstly, to refuse to apply hardening strips of hard alloy on the back of the cutting edges by 1/3 of their length located on distance...
from the end 65-70 mm; secondly, to make the width of the strips variable, gradually increasing it when approaching the edge of the knife to a size 1.5 to 2 times the width of the blade, i.e. give them a triangular or curvilinear shape that is close and / or overlapping the boundaries of the wear figure; thirdly, the triangular shape of the strips can be achieved due to the stock of material released from unstrengthened 1/3 of the length of the blade.

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