CONTRIBUTION TO PLOUGH SHARES AND CHISELS USEFUL LIFE OPTIMIZATION

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Plough shares and chisels are quite expensive and they represent typical spare parts in agriculture with high consumption. For technical practice it is very important to take into account the optimal choice and utilization of these parts from point of minimal costs and useful optimal life. In the paper the authors solve this problem giving priority to an economical approach using cost analysis. An example shows practical application of the developed methodology. Implementation of this methodology in the agriculture can save spare parts, raw material and money.

unit costs; operating time; renewal

INTRODUCTION

Material and technology engineering and industry develop and produce many kinds of materials for plough shares and chisels and their functional surfaces. In every case where the functional surface is coming into a contact with soil, it is necessary to think about using and choosing surfaces resisting to abrasive wear. Designers have to develop these plough shares and chisels not only from the point of dimensions and shapes but also from the point of strength and resistance to wear. Nevertheless, the designed plough shares and chisels and their parameters are necessary to be verified by unit cost and durability tests (Legát, Jurča, 2000). The objective of this paper is a design of methodology for durability testing of plough shares and chisels using cost criteria.

MATERIALS AND METHODS

Proper choosing of the plough shares and chisels is usually verified (estimated and evaluated) using comparison of mean resistance to wear of their functional surfaces o_p

$$o_p = \frac{t}{h} \tag{1}$$

where t is operating time of a functional surface (for example in hours) and h is wear magnitude (for example in grams during the same operating time t).

This criterion is used usually for durability tests in laboratories. The tests can be simulated, accelerated or shortened and provide data for verifying of proper choosing of layers (surfaces) resisting to wear (Horvat et al., 2008). According to the criterion (1), the layer is the best when it is the most resisting of wear or has the lowest velocity of wear. Advantages of the criterion are simplicity of the tests using different tribometers. With regard to the advantages these laboratory tests are indispensable and inevitable for developing of new materials for plough shares and chisels. On the other hand, the laboratory tests are rather limited from the point of operational condition keeping and difficulties of economical impacts recognizing. Therefore it is desirable not only laboratory tests but also field durability tests. The field tests are namely exacting from the point of time, management and money consuming but provide much better (actual) durability measures and making possibilities of full use of economical criteria for quality evaluation.

The principle of economical criteria usage is based on the fact that increasing wear of functional surfaces usually negatively influences probability of failure or causes lowering operational efficiency of tractor and plough as a whole or increasing of cutting tools work resistance. The processes cause increasing of machine operational costs. These criteria influence not only wear velocity change but also failure probability, efficiency, cutting resistance etc.

Furthermore, the economical criteria are significantly influenced by changing of plough shares and chisels price.

From the short analysis it is evident that the economical criterion can be in general formulated by the formula:

$$u(t) = \frac{N_O + N_P(t)}{t} \tag{2}$$

where $u(t)$ are specific (unit) costs (for the given option of material, design and technological solution of plough parts) on renewal and operation of a given plough parts in dependence on operating time t, N_o are costs (price) on preventive replacement of a given plough parts (a layer resisting to wear) and are given as a sum of purchase costs of plough shares and chisels, their assembly and non-operating state reduced by depreciated price at the disposal moment of a machine part, $N_p(t)$ are chosen cumulative costs connected with plough shares and chisels during operation and t is operating time of plough shares and chisels. Typical dependence of the criterion and its items on operating time is shown in Fig. 1.

Optimal option of the machine parts materials, their design and production choosing is given by minimum of the specific costs on renewal and operation of a given machine part. The minimum can be determined by the first-order derivative u against t or by other numerical methods.

It can be proved (L e g á t et al., 1996; L e g á t et al., 2002) that

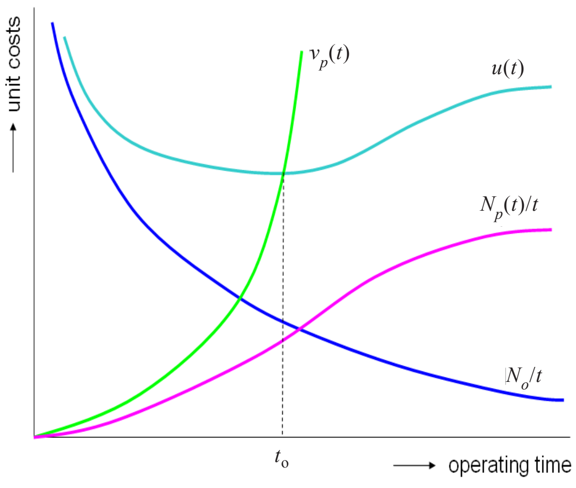
$$u(t_O) = \frac{N_O + N_P(t_O)}{t_O} = \frac{dN_P(t_O)}{t_O} = v_P(t_O) \qquad (3)$$

where $u(t_O)$ are minimal specific costs on renewal and operation of a given plough parts, $v_p(t_O)$ are optimal instantaneous specific costs just in optimal technical state for renewal and t_O is optimal operating time (useful life) (T i a n , 2009) a given plough parts.

From the issue mentioned above it is clear that the cost criterion (3) can much better identify quality of a plough parts design, material and technology than using only mean resistance to wear criterion (1). Complexity of the cost criterion is based on the following circumstances:

(a) resistance to wear is automatically included in instantaneous specific cost of operation $v_p(t)$,

(b) in addition the cost criterion includes an influence of different purchase costs contained in price of



$v_p(t)$ – instantaneous specific costs
$u(t)$ – specific costs on renewal and operation
N_o/t – specific costs on preventive replacement
$N_p(t)/t$ – specific chosen cumulative operating cost
t_o – optimal useful time

Fig. 1. Typical dependence of the criterion (costs) and its items on operating time

preventive renewal (maintenance, adjustment, repair, replacement) of a plough parts N_o due to usage of different technical solution (design, materials and technology),

(c) further the cost criterion includes wear impact on cost increasing of given plough parts operation $N_p(t)$ due to:

increasing probability of failure occurrences,

decreasing plough parts operating effectiveness.

(d) secondary, product of the cost criterion usage (from the point of optimization of the plough parts materials, their design and production choosing) is determination of useful life t of a plough parts.

RESULTS AND DISCUSSION

Theoretical and methodological way out is the usage of mentioned cost criterion – the specific (unit) costs on renewal and operation of a given plough parts. Moreover, it can be supposed that it is possible to do durability tests of all options of a plough parts according to the following methodology:

(a) from a relative large number of plough parts we choose those, which are (according to our qualitative and quantitative experiences) promising success (for example from ten possible options we choose three promising options of plough shares and chisels),

(b) using cost calculation we determine cost (price) on preventive renewal for all preliminary chosen machine part options,

(c) in the case of multistate plough parts we determine experimentally operational costs due to plough efficiency, capacity, accuracy, quality etc. decreasing as a function of operating time.

From the input data (obtained by means of the above mentioned procedure) the minimal specific (unit) costs of renewal and operation can be calculated (using equation 3).

Optimal option of design, material and technology solution of a plough parts is given by the lowest magnitude from particular minimum of specific (unit) costs of renewal and operation.

Cost criterion usage example

Designed methodology has been applied to two options of plough shares and chisels produced according to different designs and technologies and from different materials.

The objective of experimental durability test was the estimation of which from given plough shares and chisels is the best in same soil conditions.

Characteristics of experiment

Designed methodology has been verified in operational conditions, which can be briefly characterised in the following way:

• tractor JOHN DEERE 7800,
• plough LEMKEN Vari - Diamant 160, average ploughing depth 25 cm, reversible, one side set up with plough shares and chisels VOGEL NOOT and other side set up with plough shares and chisels METAZ,
• plough shares and chisels
  ◦ VOGEL NOOT, forged steel, hardness from 29 up to 51 HRC,
  ◦ METAZ, cast steel, hardness from 19 up to 42 HRC,
• fuel gauge OP-20,
• mean heavy sandy-clay soil, tepid till moist state, after potato harvest, total ploughed 114 hectares, it means 9.5 ha/one plough share.

Modified model and input data

The general model giving equations (2) and (3) was modified (for tested plough shares and chisels) into the following formula

$$u(t_1, t_2) = \frac{N_O + A_1 t_1 + a_1 t_1^{b_1} + A_2 t_2 + a_2 t_2^{b_2}}{t_1 + t_2} \tag{4}$$

where $u(t_1,t_2)$ are specific (unit) costs of plough share and chisels replacement and operation, N_o are costs of one plough share and two chisels replacement, A_1 are specific (unit) costs of a new plough share and chisel operation (unit costs of fuel consumption in the condition), A_2 are specific (unit) costs of the plough share after the first chisel replacement and a new chisel operation (unit costs of fuel consumption), a_1, a_2, b_1, b_2 are parameters characterising increasing costs of the plough share and chisels operation under the same condition (fuel consumption increasing due to plough shares and chisels wear), t_1 is operating time (in hectares) of the first chisel and a plough share and t_2 is operating time (in hectares) of the second chisel and the same plough share (it means that $t_1 + t_2$ is operating time of the plough share).

Calculated magnitudes of input data (costs of replacement and parameters of operation cost functions obtained by means of regression analysis) are presented in Table 1.

Results of experiment

The specific (unit) costs of replacement and operation of plough shares and chisels were calculated using input data from Table 1 and the equation (4) and obtained results (minimal costs and optimal operating time) are presented in Figs. 2 and 3.

CONCLUSION

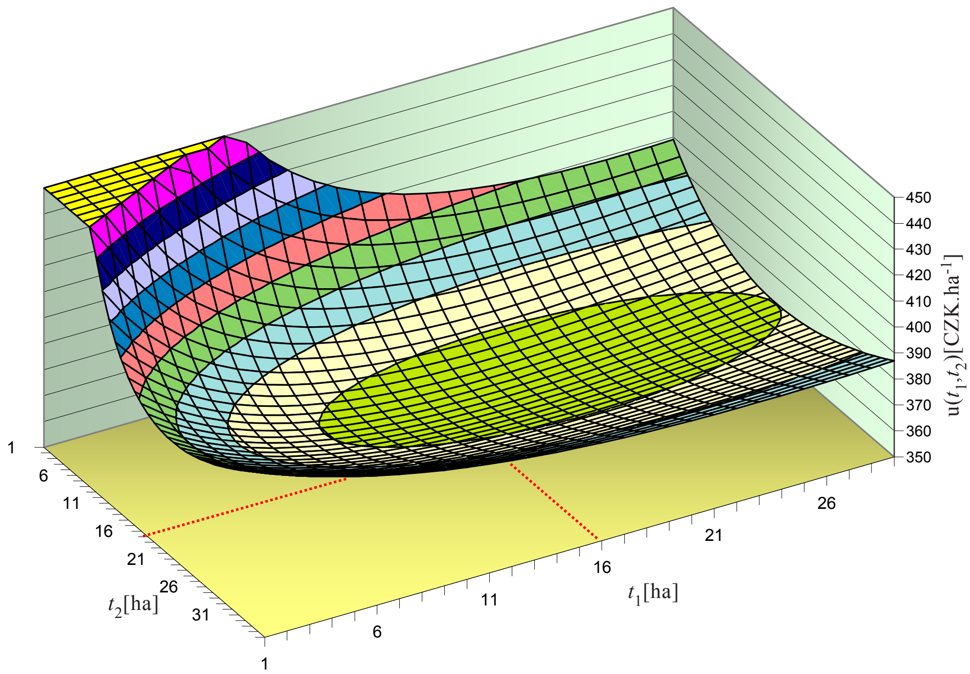
Designers and technologists require knowledge of results and impacts of design, material and technology solution on operation of machine parts generally and layers resistant to wear particularly. The classical evaluation criterion (resistance to wear (1) or velocity of wear (2)) has shown itself as unsatisfied and very narrow (non-complex). Therefore, it has been designed the cost criterion (3) for optimization of material, design and technology solution of a machine part using costs of renewal and operation of the machine part in a machine as a whole (L e g á t et al., 2002).

The experiment with plough shares and chisels verified that the defined cost criterion for optimizing the machine parts' materials, their design and production solution is fully acceptable. Specific (unit) costs of renewal (replacement) and operating of plough shares and chisels VOGEL NOOT amounted to 445 CZK/ha and plough shares and chisels METAZ amounted to 409 CZK/ha. The difference 36 CZK/ha makes an advantage for plough shares and chisels METAZ which represented the saving of 4111 CZK within 114 ha ploughing respectively more than tree plough shares and chisels METAZ sets including assembly on a plough.

On the other hand, it has to be emphasized that mainly the chisels METAZ broke down from time to time under conditions of stony soils at some part of area of land. The first research carried out showed

Table 1. Input data for calculation of minimal specific costs of renewal (replacement) and operation of two types of plough shares and chisels

Type of plough shares and chisels –input data	VOGEL NOT	METAZ
Costs of replacement (one plough share and two chisels)	N_o = 1569.60 CZK	N_o = 1164.80 CZK
Parameters up to a first replacement of chisels	A_1 = 252.14 CZK/ha a_1 = 3.837172 b_1 = 1.970113	A_1 = 262.00 CZK/ha a_1 = 2.059682 b_1 = 2.282832
Parameters after the first replacement of chisels	A_2 = 268.22 CZK/ha a_2 = 7.808865 b_2 = 1.697244	A_2 = 279.95 CZK/ha a_2 = 6.158033 b_2 = 1.620583
Ideal optimum	$u(t_1$ = 16 ha, t_2 = 17 ha) = 364.36 CZK/ha	$u(t_1$ = 24 ha, t_2 = 10 ha) = 351.84 CZK/ha
Real optimum	$u(t_1$ = 5 ha, t_2 = 4. 5 ha) = 445.15 CZK/ha	$u(t_1$ = 5 ha, t_2 = 4,5 ha) = 409.09 CZK/ha



t_1 – operating time up to first chisel replacement (ha),

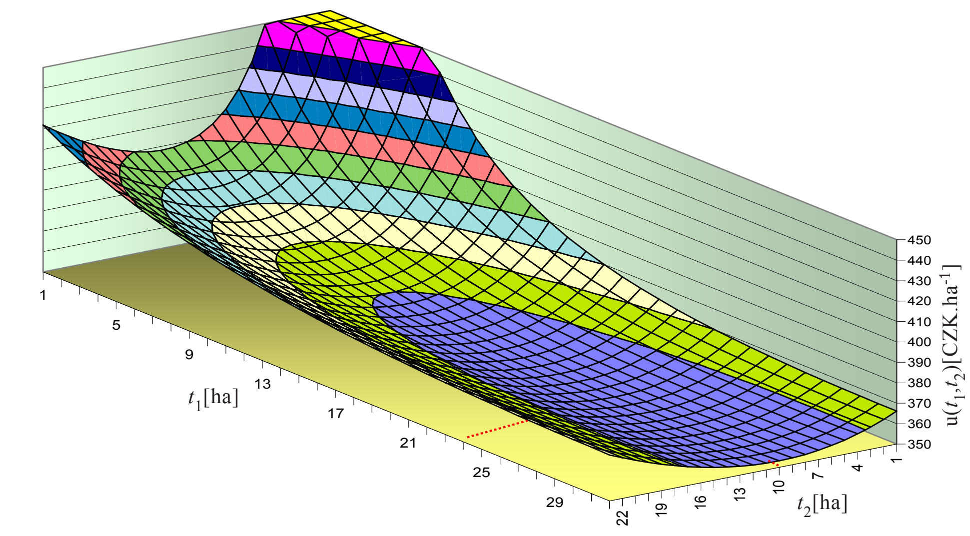
t_2 – operating time after second chisel replacement and operation (CZK/ha) replacement (ha),

u(t_1,t_2) – specific (unit) costs of plough shares and chisels

Ideal optimum: t_1 = 16 ha, t_2 = 17 ha, u(t_1,t_2) = 364.36 CZK/ha

Real optimum (limited by physical life of plough shares and chisels): t_1 = 5 ha, t_2 = 4.5 ha, u(t_1,t_2) = 445.15 CZK/ha

Fig. 2. Dependence of extrapolated specific costs u(t_1,t_2) of plough shares and chisels VOGELNOOT on operating time t_1,t_2



t_1 – operating time up to first chisel replacement (ha),

t_2 – operating time after second chisel replacement and operation (CZK/ha) replacement (ha),

u(t_1,t_2) – specific (unit) costs of plough share and chisels

Ideal optimum: t_1 = 24 ha, t_2 = 10 ha, u(t_1,t_2) = 351.84 CZK/ha

Real optimum (limited by physical life of plough shares and chisels): t_1 = 5 ha, t_2 = 4.5 ha, u(t_1,t_2) = 409.09 CZK/ha

Fig. 3. Dependence of extrapolated specific costs u(t_1,t_2) of plough shares and chisels METAZ on operating time t_1,t_2

that it is necessary and useful to continue in these experiments and to test different types (from point of material, design and product technology) of plough shares and chisels under different soil conditions.

The given example of the criterion usage has shown its better information capability for evaluation and optimization on one hand but more requirements on its experimental determination (it is necessary to monitor cost parameters and functions) on the other hand. Obtained results have indicated that these higher requirements (including higher experimental test costs) shall return both to producers (higher product quality) and to product users (lower costs of renewal and operation).

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Příspěvek k optimalizaci užitečného života plužních čepelí a dlát

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V příspěvku je řešena problematika stanovení užitečného života plužních čepelí a dlát v zemědělských provozních podmínkách. Jde o pracovní nástroje pluhů, jejichž spotřeba je veliká a rovněž náklady na tyto součásti tvoří významnou složku celkových provozních nákladů. Metoda stanovení užitečného života těchto nástrojů vychází z použití ekonomického kritéria – jednotkových nákladů, a to z nákladů na provoz a obnovu. Náklady na provoz jsou primárně vyvolány postupným opotřebením čepelí a dlát a sekundárně zvýšenými řeznými odpory, které zvyšují tahovou sílu, spotřebu paliva a následně náklady na spotřebované palivo. K negativním důsledkům, byť obtížně ekonomicky hodnotitelným, patří zhoršení jakosti orby, dna brázdy, ničení plevelů, zhoršení schopnosti zapracování rostlinných zbytků, zahlubování apod. Tyto vybrané náklady na provoz mají charakter variabilních nákladů a s dobou provozu (s počtem zoraných ha) rostou. Náklady na obnovu jsou v tomto případě tvořeny cenou čepelí a dlát, náklady na případnou renovaci, pracovními náklady na jejich výměnu a ztrátami z prostojů a mají charakter fixních nákladů.

Celkové náklady na provoz a obnovu se vydělením dobou provozu (zoranými ha) převedou na náklady jednotkové, přičemž jednotkové náklady na obnovu s dobou provozu klesají a jednotkové náklady na provoz s dobou provozu rostou. Součtová funkce má lokální minimum a tomuto minimu odpovídá optimální hodnota užitečného života čepelí a dlát. Uvedená metoda dále umožňuje vybírat z nabídky různých výrobců (různý materiál a zpracování) a dodavatelů i optimální čepel a dláto.

Z provedeného experimentu je zřejmé, že navrženou metodu lze použít pro oba případy – jak pro výběr výrobního provedení čepelí a dlát, tak pro určení jejich užitečného života. Experiment dále ukázal, že teoretický užitečný život podle ekonomického kritéria a pro dané podmínky je delší, než život reálný, který byl omezen fyzickými vlastnostmi a reálnou odolností čepelí a dlát proti opotřebení. Ekonomický přínos optimalizace byl rovněž prokázán. V neposlední řadě celá řada provedených experimentů také potvrdila všeobecně známou skutečnost, a to velkou variabilitu výsledků měření danou proměnlivými půdními podmínkami a počasím.

jednotkové náklady; doba provozu; obnova

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