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USE OF OPTIMIZATION METHODS IN AGRICULTURAL MACHINE DESIGN

VYUŽITIE OPTIMALIZAČNÝCH METÓD PRI NÁVRHU POĽNOHOSPODÁRSKEHO STROJA

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ABSTRACT: The paper deals with the conception design of a special agricultural machine intended to mow and cultivate lands between rows of planted corn. In the design process there were used and verified Concurrent Engineering Principles. The frame of the designed agricultural machine was put to an optimization using the software system Pro/MECHANICA. The used method was a multivariable optimization procedure where optimization variables were diameter and wall-thickness of the frame pipe. The goal function was created with the aim to reach a mass (cost) reduction keeping the given strength 120 MPa. The process has resulted into a reduction of the cross-section area of the machine supporting frame pipe providing us with a mass reduction of 10.4%.

agricultural machine; supporting frame; strength; multivariable optimization; Finite Elements Methods (FEM)

ABSTRAKT: Článok sa zaoberá koncepčným návrhom špeciálneho poľnohospodárskeho stroja určeného na kosenie a kultiváciu pôdy medzi riadkami pestovanej kukurice a optimalizáciou jeho nosného rámu. V procese tvorby tohto stroja, ktorého virtuálny model je vidieť na obr.1, boli aplikované a verifikované princípy paralelného konštruovania založené na využití CAD/CAM systému Pro/ENGINEER. Všeobecná formulácia optimalizačnej úlohy nosnej konštrukcie je uvedená matematickými zápismi (1) až (8). Vzťah (9) je symbolickým popisom našej optimalizačnej úlohy. Pri použitej viacparametrickej optimalizačnej metóde ako premenné optimalizácie boli stanovené priemer rúry d nosného rámu a jej hrúbka h. Výpočtový model spracovaný za pomoci programového systému Pro/MECHANICA je na obr. 2. Výsledky statickej analýzy rámu pôvodnej konštrukcie, pred optimalizáciou, sú ukázané na obr. 3. Je vidieť, že maximálne napätia Von Mises sú len 62,29 MPa, teda rám je predimenzovaný a je účelné ho podrobiť optimalizácii. Cieľom optimalizačného procesu bolo dosiahnuť zníženie hmotnosti (ceny) pri zachovaní zadefinovanej pevnosti 120 MPa a funkčných rozmerov (pripojovacie rozmery trojbodového závesu a šírka stroja). Výsledkom tohto postupu bolo zmenšenie plochy priečneho prierezu a dodržanie požadovanej pevnosti nosného rámu konštruovaného poľnohospodárskeho stroja pri súčasnom znížení jeho hmotnosti o 9,2 kg. Na základe globálnej citlivostnej analýzy možno vysloviť záver, že na zváranú konštrukciu nosného rámu špeciálneho stroja je možné použiť rúru s vonkajším priemerom 60 mm a hrúbkou steny 6,5 mm.

poľnohospodársky stroj; nosný rám; pevnosť; viacparametrická optimalizácia; metóda konečných prvkov (MKP)

INTRODUCTION

Highly advanced production technologies have always been influencing the quality of a product, and through the quality also the success of the product on the market. Utilization of advanced technologies has gradually become more and more decisive for the product quality as well as for the future product design stage. Tools, which can nowadays significantly influence this technical preparation of reduction, are CA technologies. CA technologies utilize Concurrent Engineering Principles what is a strategy based on time limit and depends on the following three main objectives:

1. reduction of the time required to introduce a new product on the market,
2. improvement of product quality,
3. improvement of design quality and reduction of production process.

However, to achieve the desired level of reliability of a designed device or machine the designers in Slovakia still mainly use excessive over-expansion of machine components and optimization methods are used very rarely. This has a very unfavorable impact on total economical indexes of the construction design. Production of such products takes then about 30–50% more material than comparable production in industrially advanced countries.

On the basis of the above-mentioned strategy a solution for the conception design of a special agricultural machine intended to mow and cultivate lands between the rows of corn is presented here. In the design process Concurrent Engineering Principles were used and verified. After construction design, frame of the machine was exposed to an optimization using the software system Pro/MECHANICA in an integrated mode with CAD system Pro/ENGINEER. This process has resulted into a reduction of the machine supporting frame pipe section by keeping its required strength and reduction of its mass.

REVIEW OF LITERATURE

Optimization is a very important integrated part in the process of a new product designing. During the construction optimization it is explored what are the values of input parameters (of machine elements) for which the output parameters selected in advance (allowable stress, allowable deformation, maximum mass, cost, etc.) attain optimal values.

Optimization methods were already developed in 1970s and 1980s. Each of them differs not only in their content but also in a type of the tasks which can be solved by using them (Iljin, 1977). Above all, it is necessary to distinguish between algorithmical and analytic methods. In analytic methods an extreme position is calculated by means of a mathematical formula, which is reasonable. But creation of a mathematical formula usually requires introduction of many simplifications and restrictions for the derived formula validity. That is why the result is always loaded with a great error, also in the case of a very simple construction.

These limitations do not stand for algorithmical methods in which the extreme is not calculated directly according to a uniformly defined mathematical formula, but there is given only an algorithm of a gradual search for the extreme. Algorithmical optimization methods can be further divided into regular and statistical ones.

In application of optimization proceedings the current program systems broadly use Finite Elements Methods (FEM) consisting of structural analysis, accuracy analysis (solution convergency) and form and strength analysis (Oberle, Grimm, 1989).

A detailed description of various optimization methods applied in structure mechanics is presented in Baier's work (1994). All the described algorithms are elaborated in such a way that all the system functions can be solved by means of FEM.

MATERIALS AND METHODS

A general formulation of an optimization scheme is as follows:

$$Minimalize\ z = mass\ (x_1, x_2, \ldots x_n) \qquad (1)$$

with design variables subjected to limitations:

$$x_i^u \le x_i \le x_i^0 \qquad i = 1, \ldots, n \qquad (2)$$

Further, following limitations can be adopted:

– displacement limitations:

$$1 - \frac{u_d\left(x, t^*\right)}{u_D} \ge 0 \qquad d \in D \qquad (3)$$

– acceleration limitations:

$$1 - \frac{\ddot{u}_j\left(x, t^*\right)}{\ddot{u}_D} \ge 0 \qquad j \in J \qquad (4)$$

– self-oscillation limitations:

$$1 - \frac{\omega_k(x)}{\omega_k^0} \ge 0 \qquad k \in K \qquad (5)$$

$$\frac{\omega_k(x)}{\omega_k^u} - 1 \ge 0$$

– stress limitations:

$$1 - \frac{f\left(\sigma_{lm}\left(x, t^*\right)\right)}{\sigma_{Dq}} \ge 0 \qquad q = 1, \ldots, l,\ m = 1, \ldots \qquad (6)$$

System equations are:

$$s_p(u, \ddot{u}, \omega, \sigma, x) = 0 \qquad p = 1, \ldots \qquad (7)$$

The vector of design variables has the form of:

$$x = \left(x_1, x_2, \ldots x_n\right)^T \qquad (8)$$

Thus, the vector (8) is to be optimized regarding its limits, x_i^0 and x_i^u, an allowable displacement vector, u_D, an allowable acceleration vector, $\ddot{u}_D$, self-oscillation limits, ω_k^0 and ω_k^u, and an allowable stress vector, σ_{Dq}. To express a dynamic behavior it is necessary to know discrete values of time t_j^*.

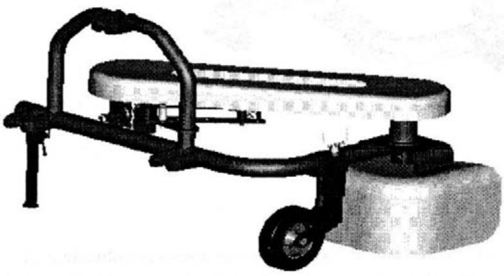
Currently we use Finite Elements Methods as the processor of system equations. Elements and mesh division are modified during every iteration, so it is a type of a discrete optimization task.

DESCRIPTION OF THE MACHINE CONCEPTION

The following agro-technical requirements, which the machine has to meet, were a starting point for the conceptual design of the special agricultural combined machine:

- drive from a power take-off shaft of a universal carrier (tractor),
- attachment to a three-point hitch,
- exchangeable active elements determined for:
  - mowing of clover planted between corn rows,
  - cultivation of land with vertically rotating tools,
  - distribution of industrial fertilizers,
  - engagement width of 50 cm,
  - distance between corn rows 70–75 cm.

Basic conception of the machine was designed according to agrotechnical requirements for required working engagement. The drive for different functions was designed to use the simple change of working velocity and system of active elements exchange. The machine was designed using Concurrent Engineering Principles and CAD system Pro/ENGINEER. A virtual model of the machine is shown in Fig. 1. The supporting frame is designed in a form of a welded construction consisting of bent pipes appropriately supplemented with stiffeners and consoles.



1. Virtual model of the machine

SUPPORTING FRAME OPTIMIZATION

As mentioned above, optimization is a process of search for such values of independent variables which would lead – with some restrictions set on them – to an extreme value of a dependent variable. Independent variables are indicated as an n-dimensional vector of optimization variables. The types of these variables are related to the type of an optimized object and to the type of problems. In the continuum mechanics these can be variables expressing geometrical, kinematic, mass, material, thermodynamic and other characteristics. Limiting conditions of the independent variables have a form of inequalities $g_k(x) \leq 0$, equations $h_k(x) = 0$, or natural side conditions $x_{i.\min} \leq x_i \leq x_{i.\max}$. The dependent variable, which is optimized, is indicated as a goal (object, test, cost) function $z(x)$. This means that the optimization task is to search for such a vector of optimization variables x, for which the scalar goal function $z(x)$ reaches the extreme value while meeting limiting conditions for variables x_i.

In our case the supporting frame of the agricultural machine, a calculated model of which is presented in Fig. 2, was exposed to strength testing by means of the Finite Elements Method and by means of optimization subsequently. Constructions were defined in a three-point hitch, where 5 degrees of freedom were withdrawn from every neck, and in a beam of a supporting wheel, where one degree of freedom was withdrawn. The load was defined in relation to belt tension, while the calculated output power was 10 kW, and speed of shaft 9 s^{-1} during the hardest operation – land cultivation. It means this is a horizontal force F_H = 2,183 N, which represents the resultant tractive force in a belt directing towards the vertical axis of a gear box shaft. In the axis of a working vertical shaft there was also set a vertical force F_V = 1,500 N which represents the load caused by machine mass. The supporting frame itself is designed to be made of a steel weldless pipe with the initial diameter of 90 mm, the initial wall-thickness of 8 mm, i.e. from the steel 11 523 according to Slovak Technical Standards STN 42 6711.

The goal function for the supporting frame optimization can be expressed in the following symbolic way:

$$z = z(d,h) \tag{9}$$

where: d and h – a diameter and a wall-thickness of the supporting frame pipe, respectively, subjected to limitation $d \in$ <50, 90> and $h \in$ <6, 10>, respectively.

The stress limitation has been assumed as follows:

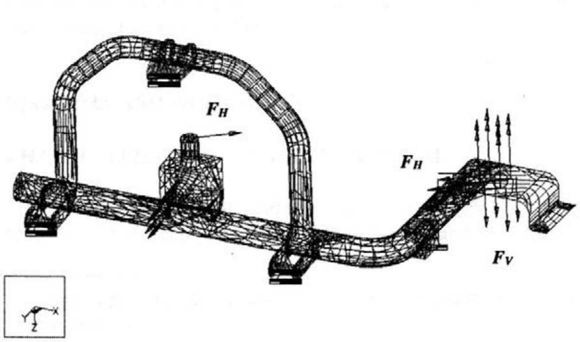
$$\sigma_{HMH} \leq 120 \text{ MPa} \tag{10}$$

Distribution of reduced stresses of the supporting frame is shown on Fig. 3.

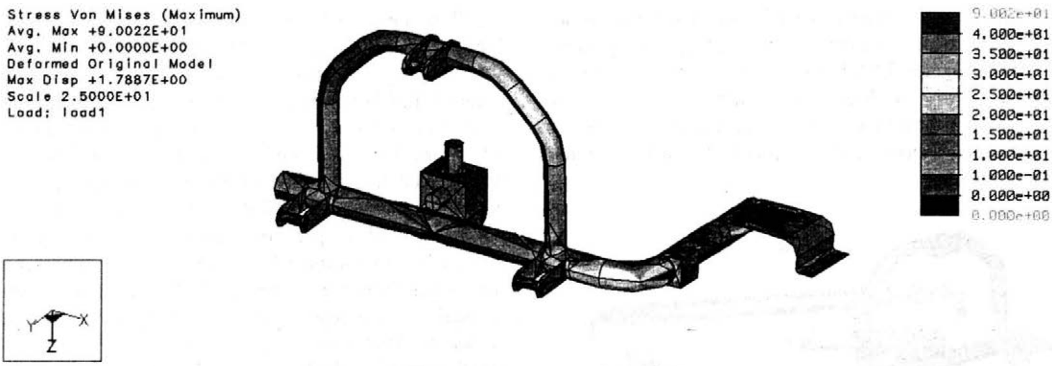
RESULTS OF OPTIMIZATION

The wall-thickness, h, and the diameter, d, of the supporting frame pipe minimizing the goal function (9) and meeting the limitation (10) have been determined by means of the software system Pro/MECHANICA and integrated CAD system Pro/ENGINEER. The presented analysis yields that starting with an initial design covered by initial values of design variables

$$h = h_0 = 8 \text{ mm}, \quad d = d_0 = 90 \text{ mm}$$



2. Calculated model of the supporting frame



3. Distribution of reduced stresses

with corresponding initial mass $m = m_0 = 88.4$ kg, an optimum design can be reached as follows:

$$h = 6.5 \text{ mm}, \quad d = 60 \text{ mm}, \quad m = 79.2 \text{ kg},$$

the mass reduction thus being $\Delta m = 9.2$ kg, i.e., 10.4%. The optimized structure approaches the world standards in the ratio mass/power output.

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MODELLING – METHOD OF DRYING PROCESS RESEARCH

MODELOVANIE – METÓDA VÝSKUMU PROCESU SUŠENIA

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ABSTRACT: In this paper authors present analytical models of ideal drying process of meadow hay. They use i-x-w diagram of wet air completed with lines of equilibrium moisture of meadow hay. Authors introduced a new characteristics i.e., "drying potential". Authors present analytical models of statics and dynamics for an ideal drying process course of meadow hay. Authors recommend how to profit obtained knowledges in the praxis of agricultural drying.

drying of meadow hay; modelling of drying process; curve of drying

ABSTRAKT: V práci autori predkladajú analytický model sušenia lúčneho sena. Používajú i-x-w diagram vlhkého vzduchu so zakreslenými krivkami rovnovážnych vlhkostí lúčneho sena. Autori zaviedli nový charakteristický ukazovateľ „potenciál sušenia" a predkladajú analytické modely statiky a dynamiky ideálneho procesu sušenia lúčneho sena. Odporúčajú využitie získaných poznatkov v praxi v poľnohospodárskom sušiarenstve.

sušenie lúčneho sena; modelovanie procesu sušenia; krivka sušenia

INTRODUCTION

In the theory of drying we solve in the statics of drying values of heat and mass flows in the drying process, and in the dynamics of drying values of rate changes of this heat and mass flows.

Therefore the statics of drying needs basic information about heat and mass flows in form of characteristics of dried material and characteristics of the drying medium.

In dynamics of drying we need in addition information about the arrangement of the dried material layer and about the dryer efficiency.

In this paper authors present one exemple of calculation of the statics and dynamics of an ideal drying process course of meadow hay. As result is presented in graphic form the curve of drying.

Authors used with great advantage their new i-x-w diagram of wet air with equilibrium moisture content of meadow hay, and their specific characteristic of the drying process, potential of drying.

MATERIAL AND METHODS

CHARACTERISTIC OF THE DRIED MATERIAL

Dry basis and humidity create the mass of the dried material. In the green grass mass the humidity is partly in form of free water and partly in form of adsorbed humidity. Adsorbed humidity is in water equilibrium with ambient air humidity.

This dependences we can appoint with laboratory experiments and demonstrate in graphic form as adsorption isothermes. In Fig. 1 authors present adsorption isothermes of meadow hay, taken from Segler (1958). Authors derived from this adsorption isothermes (Fig. 1) values of relative equilibrium air humidity φ_E for all necessary values of equilibrium moisture content d.b. u_E of the dried hay and his competent temperatures T_E.

Authors drawed values of equilibrium moisture content w.b. w_E of meadow hay into the i-x diagram of wet air (Fig. 2) as curves of constant equilibrium hay humidities w_E.

Authors (Havelka, 1973) proposed for this diagram designation i-x-w diagram of wet air and meadow hay.

In this work authors used equation for moisture content w.b.

$$w = \frac{M_W}{M_M} 100 = \frac{u}{1+u} 100 \qquad (\%) \qquad (1)$$

and equation for moisture content d.b.

$$u = \frac{M_W}{M_{DB}} = \frac{w}{100-w} \qquad (\mathrm{kg.kg^{-1}}) \qquad (2)$$

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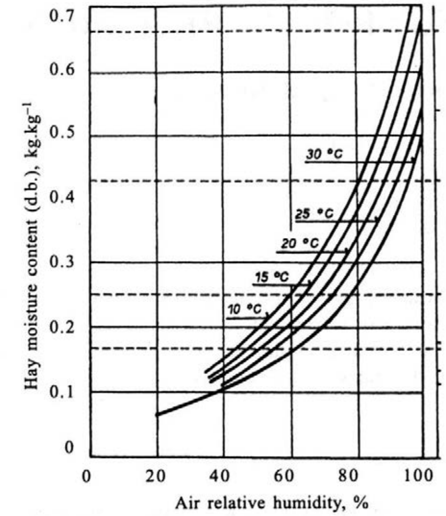


1. Adsorption isotherms of meadow hay

DRYING MEDIUM CHARACTERISTICS

In hay drying only the pure ambient air is used as drying medium. Characteristics of this air are demonstrated with great advantage in the i-x diagram (Chyský, 1963) of wet air in Fig. 2.

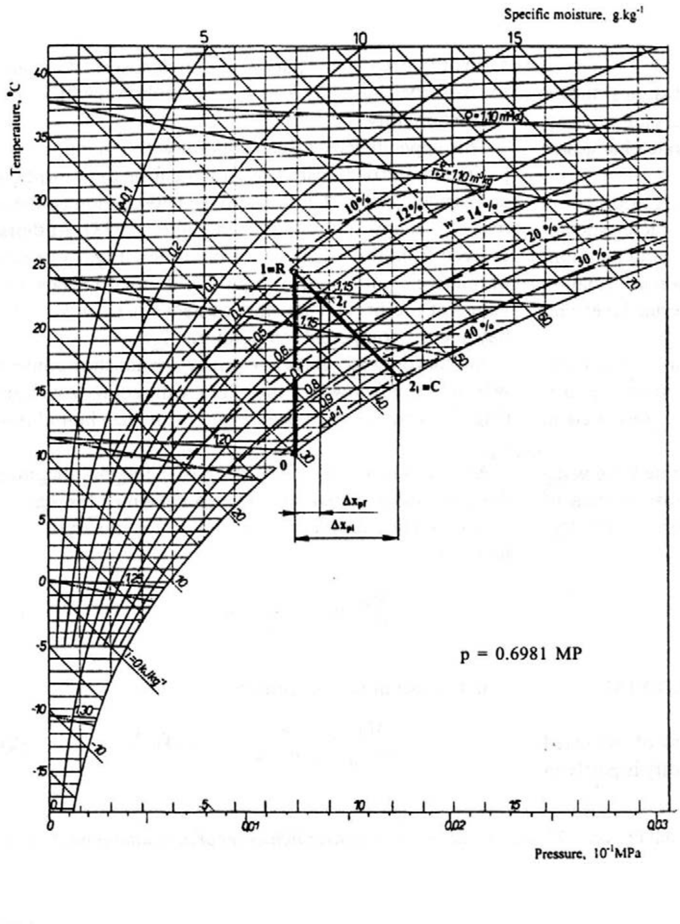
Authors solved the ideal course of the drying process with values of drying medium states, drawn in this i-x diagram, for an ideal course with i = const.

With help of w_E curves authors described in detail the whole drying process course, what enables the most accurate description of heat and mass transfers, and also of the dynamics of drying in form of the curve of drying.

As basic condition for the drying process serves the fact that the value of relative air humidity φ_1 of the drying medium is lower as equilibrium air humidity φ_E due to the instantaneous state of the dried material.

Therefore authors (Vitázek et al., 1999), proposed a new characteristics of the process of drying as "drying potential" defined by the equation:

$$\Delta x_P = x - x_1 \quad (\text{kg.kg}^{-1}) \tag{3}$$



2. i-x-w diagram of wet air with equilibrium moisture content w.b. lines of meadow hay

RESULTS

DRYING PROCESS COURSE

In this work authors analyse a process of artificial drying with heated air (Havelka et al., 1989).

Green grass mass is placed in a dryer and through its layer a stream of heated air will be introduced till it is dried to the standard final moisture content. Scheme of this dryer is in Fig. 3.

Authors calculated the model of an ideal artificial drying process with heated air for a standard green mass with initial moisture content w.b. $w_1 = 80\%$, and for the dried hay with standard final moisture content w.b. $w_2 = 14\%$, with final dry hay mass $M_{M2} = 100$ kg, arranged in one very thin layer.

For drying medium input authors calculate with an air fan with air output $V_1 = 6\ m^3.s^{-1}$.

DRYING MEDIUM CHANGES IN I-X-W DIAGRAM

Authors draw the drying medium state course in the i-x-w diagram as line i = const.

The drying process is divided into two sections:

1. Section of permanent rate of drying (SPRD) where equilibrium air moisture content for the instantaneous material state has only one value, $\varphi_E = 1$, and therefore the drying potential $\Delta x_p = x - x_1 = x_C - x_1$ = const. End of this section is named as "critical point C".

2. Section of falling rate of drying (SRFD) where $\varphi_E < 1$ and the drying potential $\Delta x_p = x - x_1$ is not constant, diminishes through the section. End of this section is named as "equilibrium point E" as asymptote in time infinity.

From this air state representation in the i-x-w diagram authors took following important values:

Ambient air state, point 0:

$$t_0 = 10\ °C,\ \varphi_0 = 1,\ x_0 = 0.0079\ kg.kg^{-1},\ w_E = 11\%,\ u_E = 0.125\ kg.kg^{-1}.$$

Heated air state, point 1:

$$t_1 = 24\ °C,\ \varphi_1 = 0.41,\ x_1 = x_0,\ \rho_1 = 1.14\ kg.m^{-3},\ w_E = 11\%,\ u_E = 0.125\ kg.kg^{-1}.$$

Output air of the dryer at the end of SPRD, point $2_i \equiv$ C:

$$t_C = 15.5\ °C,\ \varphi_C = 0.99,\ x_C = 0.0111\ kg.kg^{-1},\ w_C = 40\%,\ u_C = 0.666\ kg.kg^{-1}.$$

Output air of the dryer at the end of the drying process, point 2_f:

$$t_{2f} = 21.9\ °C,\ \varphi_{2f} = 0.51,\ x_{2f} = 0.0086\ kg.kg^{-1},\ w_2 = 14\%,\ u_2 = 0.163\ kg.kg^{-1}.$$

BASIC MASS CALCULATIONS

Evaporated moisture mass:

$$M_W = M_{M2}\,\frac{w_1 - w_2}{100 - w_1} = 330\ \text{(kg)} \tag{4}$$

Green grass mass with moisture content w.b. $w_1 = 80\%$, is:

$$M_{M1} = M_{M2} + M_W = 430\ \text{(kg)} \tag{5}$$

In theory of drying we calculate with dry basis of the dried material and with moisture content d.b. Therefore:

$$M_{DB} = M_M - M_W = M_M - M_M\,\frac{w - 0}{100 - 0} = 86\ \text{(kg)} \tag{6}$$

HEAT AND MASS TRANSFER – STATICS OF DRYING

According to (Vitázek, Havelka, 1998)

Evaporated humidity mass:

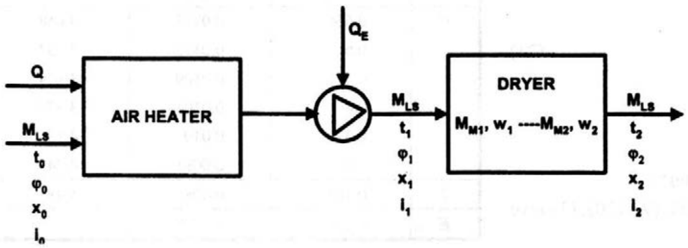
$$M_{Wpr} = M_{M1}\,\frac{w_1 - w_C}{100 - w_C} = 287\ \text{(kg)} \tag{7}$$

Mass of the dry air necessary for humidity evaporation:

$$M_{DApr} = \int_1^C \frac{dM_W}{\Delta x_p} = \frac{M_{Wpr}}{x_C - x_1} = 89{,}688\ \text{(kg)} \tag{8}$$

Calculated wet air mass:

$$M_{WApr} = M_{DApr}\,(1 + x_0) = 90{,}397\ \text{(kg)} \tag{9}$$



3. Scheme of a dryer with air heating

Calculated wet air volume:

$$V_{WApr} = \frac{M_{WApr}}{\rho_1} = 79{,}296 \quad (m^3) \qquad (10)$$

Heat consumption for air heating:

$$Q_{pr} = M_{DApr}\ (i_1 - i_0) = 1{,}273.6 \ \ (MJ) \qquad (11)$$

Drying time i.e., air fan work time:

$$\tau_{pr} = \frac{V_{WApr}}{V_1} = 13{,}216 \ s = 3.67 \ (h) \qquad (12)$$

Section of falling rate of drying from $w_C = 40\%$ to $w_2 = 14\%$, $\varphi < 1$, therefore $\Delta x_p = x_C - x_2$ changes from the initial highest value to the lowest final value.

Evaporated humidity mass:

$$M_{Wfr} = M_{M2}\ \frac{w_C - w_2}{100 - w_C} = 43.3 \quad (kg) \qquad (13)$$

Mass of the dry air necessary for humidity evaporation: coefficient 2.125 was calculated for individual values in this example

$$M_{DAfr} = \int_C^2 \frac{dM_W}{\Delta x_p} = \frac{2{,}125\ M_{Wfr}}{(x_{2i} - x_1) + (x_{2f} - x_1)} = 23{,}294 \quad (kg) \qquad (14)$$

Calculated wet air mass:

$$M_{WAfr} = M_{DAfr}\ (1 + x_0) = 23{,}478 \quad (kg) \qquad (15)$$

Calculated wet air volume:

$$V_{WAfr} = \frac{M_{WAfr}}{\rho_1} = 20{,}595 \quad (m^3) \qquad (16)$$

Heat consumption for air heating:

$$Q_{fr} = M_{DAfr}\ (i_1 - i_0) = 333.4 \quad (MJ) \qquad (17)$$

Drying time i.e., air fan work time:

$$\tau_{fr} = \frac{V_{WAfr}}{V_1} = 3{,}433 \ s = 0.95 \ (h) \qquad (18)$$

Heat consumption for air heating in the whole drying process:

$$Q = Q_{pr} + Q_{fr} = 1{,}607 \quad (MJ) \qquad (19)$$

Drying time of the whole process:

$$\tau = \tau_{pr} + \tau_{fr} = 4.62 \ (h) \qquad (20)$$

Energy input for air heating:

$$P = \frac{Q}{\tau} = 97 \quad (kW) \qquad (21)$$

DYNAMICS OF DRYING

According to (Vitázek, Havelka, 1997)

Using overmentioned equations (7), (9), (10), (14) we arrange the dependence for τ:

$$\tau = \frac{V_{WA}}{V_1} = \frac{M_{WA}}{\rho_1 . V_1} = \frac{M_{DA}\ (1 + x_0)}{\rho_1 . V_1} =$$

$$= \frac{1 + x_0}{\rho_1 . V_1} \int \frac{dM_W}{\Delta x_p} = \frac{1 + x_0}{\rho_1 . V_1} \int \frac{M_{DB} . du}{\Delta x_p}$$

$$\tau = \frac{M_{DB}(1 + x_0)}{\rho_1 . V_1} \int \frac{du}{(x - x_1)} \qquad (22)$$

CURVE OF DRYING

Section of permanent rate of drying

The whole section course is represented with point $C \equiv 2_i$:

$w_1 = 80\%$, $w_C = 40\%$, $\varphi = 0.99$, $\Delta x_P = x_C - x_1 = \text{const.}$

Equation for the $\tau = f(u)$:

$$\tau = M_{DB}\ \frac{(1 + x_0)}{\rho_1 . V_1} \int \frac{du}{x - x_1} =$$

$$M_{DB}\ \frac{1 + x_0}{\rho_1 . V_1}\ \frac{u_1 - u_C}{x_C - x_1} = 13{,}203 \ s = 3.668 \ (h) \qquad (23)$$

Section of falling rate of drying

This section is represented with direct line from the point $C \equiv 2_i$ to point 2_f:

$w_C = 40\%$, $w_2 = 14\%$, $\Delta x_P = x - x_1$ is not constant.

Equation for the $\tau = f(u)$:

$$\tau = M_{DB}\ \frac{(1 + x_0)}{\rho_1 . V_1} \int \frac{du}{x - x_1} \qquad (24)$$

This integral solved authors with suitable accuracy as total Σ

$$\tau = M_{DB}\ \frac{(1 + x_0)}{\rho_1 . V_1} \Sigma \frac{\Delta u}{\Delta x_P} \qquad (25)$$

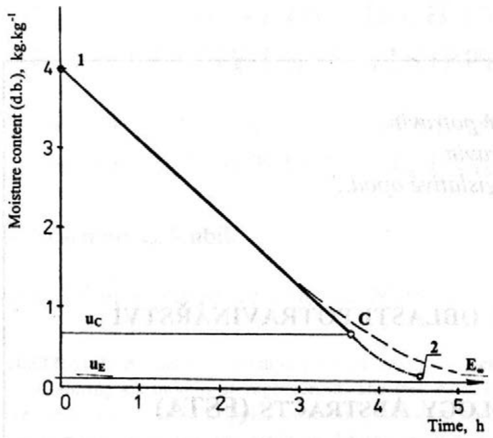
In this case authors deducted necessary values in the i-x-w diagram and realized the calcul of τ in Tab. I.

Outcomes of this Tab. I are graphically represented in Fig. 4 as curve C–2.

Outcome of this dependence is presented in Fig. 4 in coordinate τ, u as direct line 1–C.

I. Time table for falling rate of drying

Point	u (kg.kg^{-1})	x (kg.kg^{-1})	τ (h)
C	0.666	0.0113	3.668
	0.6	0.0112	3.737
	0.5	0.0109	3.849
	0.4	0.0104	3.977
	0.3	0.010	4.13
	0.2	0.0091	4.343
2	0.163	0.0086	4.48
E	0.124	0.0079	



4. An ideal drying curve of meadow hay

- - • • • • • ideal drying curve
- - - - - - - real course of a drying curve

DISCUSSION

In the whole Section of permanent rate of drying the humidity in the dried material appears as free water. Therefore the real course of a drying process is very similar to the calculated ideal drying curve.

In the Section of falling rate of drying the drying rate depends not only on thermodynamic conditions in the drying medium, but also on the diffusion of the humidity inside the drying material. Diffusion rates are very low, therefore the real drying process course in this section will significantly slow down in comparison with the ideal curve of drying.

Theoretical dependences of this diffusion phenomenons are so extensive that in acceptable time they can be appointed only by laboratory experiments.

CONCLUSION

With this analytical model of the ideal drying process of meadow hay authors present particular theoretic information about course conditions of the drying process.

Research workers and dryer producers obtain in this paper further knowledge for technological evaluations of various drying process situations and therefore will be able to propose better optimal courses of drying.

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MEASUREMENT OF MECHANICAL PROPERTIES OF APPLES BY LASER DOPPLER VIBROMETRY

MERANIE MECHANICKÝCH VLASTNOSTÍ JABĹK POMOCOU LASEROVEJ DOPPLEROVSKEJ VIBROMETRIE

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ABSTRACT: An acoustic method for non-destructive testing has been used to measure maturity of Golden Delicious apples during six months storage period. The method is based on new approach in agriculture engineering, an acoustic excitation and the laser Doppler vibrometry allowing non-contact detection of the frequency response. In this introduction study the emphasis was made on the engineering aspects of the method. The resonant frequency and the damping factor were determined from the frequency response spectrum. The damping factor, which indicates fruit ripeness, increased with storage time, while the resonant frequencies, which are proportional to the firmness index, decrease with time. The method is suggested to compare with the sensoric analysis that will be presented in next paper.

apple; Doppler vibrometry; resonant frequency; acoustic methods

ABSTRAKT: V článku je popísaná akustická nedeštruktívna metóda pre hodnotenie zrelosti jabĺk Golden Delicious počas šiestich mesiacov skladovania. Metóda je založená na princípe akustického budenia a laserovej Dopplerovskej vibrometrie použitej pre snímanie vibrácií jablka. V článku bol dôraz kladený na technické zvládnutie metódy. Vyhodnocované boli rezonančná frekvencia a útlm v závislosti od času skladovania, ktoré súvisia s procesom dozrievania. Zistený bol pokles rezonančnej frekvencie a nárast útlmového faktoru, čo je v súlade s očakávaniami.

jablko; Dopplerovská vibrometria; rezonančná frekvencia; akustické metódy

INTRODUCTION

A food quality parameter which is of great importance and should be optimized is the texture (De Baerdemaeker, Segerlind, 1978). Often mechanical properties of fruit tissue are used to determine texture characteristics. Nondestructive measurement of mechanical properties of apples by the acoustic resonance method has been an important research topic in the past decades. Abbott et al. (1968) reported that the second lowest resonant frequency (usually between 900 Hz and 1,400 Hz) corresponds to the flexural vibration and is influenced by the apple size and firmness while the lowest resonant frequency (60–150 Hz) is associated with longitudinal vibration. Finney (1967), Van Woensel, De Baerdemaeker (1983) and others found good correlation between the resonant frequencies derived from vibration tests and the mechanical properties of fruits, mainly in apples. Most of these studies suggested that the firmness index of fruit can be calculated as

$$F_i = \left(f_{n=2}\right)^2 m^{\frac{2}{3}}$$

where: $f_{n=2}$ – the second resonant frequency detected in a vibration test,
m – the mass.

Cooke, Rand (1973) proposed a mathematical model for the interpretation of the vibrational behaviour of intact fruit. They showed that the Elastic Modulus (Young's Modulus) can be estimated satisfactorily as follows

$$E = f^2 m^{\frac{2}{3}} \rho^{\frac{1}{3}}$$

where: f – the resonant frequency,
m – the mass,
ρ – the density.

Recently, several acoustic method based on mechanical or acoustic impuls excitation have been developed to measure fruit firmness. Yamamoto et al. (1980) measured apple firmness by recording sounds generated in the fruit by striking it with a wood pendulum. Duprat et al. (1997) determined elasticity modulus by acoustic impulse response method for apples and tomatoes excited by small hand-held rod. Chen et al. (1992) conducted an experimental study on factors affecting the frequency spectra of apples. Results showed that the acoustic spectra, the amplitudes in particular, were significantly affected by fruit holding method and striking method as well as sensor's (microphone) location.

In all reported works the acoustic response measurements gave a reliable indication of the change in mechanical properties of fruit before, during and after harvest. In particular there were indications that the acoustic response may give additional information on fruit water status which is not detectable by conventional firmness measurements. Given the non-destructive nature of acoustic response measurements, the method appears to have considerable promise as a technique for the evaluation of the post-harvest condition of apples.

In the present work, partial results are presented of study of the state of maturity of the apple cultivar Golden Delicious obtained by the laser Doppler vibrometry. The overall objective of the work was to perform the laser Doppler vibrometry of apples during long term storage period, to determine mechanical properties and to find a correlation with results of the sensoric analysis. The specific objectives of this paper were:

1. to apply the laser vibrometry in order to determine some mechanical properties of apples;
2. to find a suitable experimental arrangement for apple holding, acoustic excitation and detection of acoustic response by laser vibrometer;
3. to develope the software for real time measurement in order to measure a large number of samples;
4. to determine how the resonant frequencies and damping factor obtained from laser vibrometer are related to storage time under specific conditions.

MATERIALS AND METHODS

APPLES

In the current experiment two groups of Golden Delicious apples were selected from harvested fruit. Apples of the group were harvested from the same part of a tree. Four apples from each group of approximately equal shape and size were selected for the measurement. The fruit were stored at 7 °C and at a relative humidity of 90%. Measurements were conducted on each apple of the groups after allowing samples to reach room temperature (18 °C). Measurements were taken in three-week time steps during over a half year storage period.

LASER DOPPLER VIBROMETRY

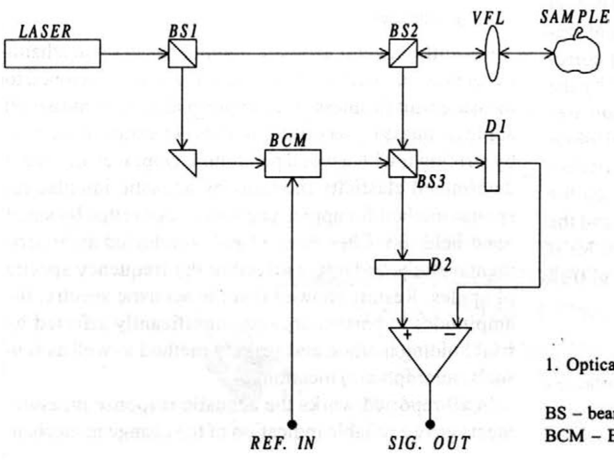
Operating principle

Laser Doppler vibrometer (Polytec, 1998) is an instrument which measures surface motion from a remote position using interferometric techniques. It is composed of two functional blocks, the interferometer with optical head and the electronic signal processor followed by a computer. The optical head is equiped with a He-Ne laser source and a variable focus lens system which focuses light at the surface under investigation. The lens system also functions as a collecting lens and returns the scattered light into the interferometer. The phase of the signal beam is dependent on the path length travelled and therefore also on the instantaneous position of the surface. The interferometer effectively makes an optical phase comparison of the recovered light with an internal reference beam.

Optical interferometry allows the measurement of displacements much smaller than the wavelength of light by utilizing the sinusoidal relationship between the output of an interferometer and the difference in optical path lengths traversed by its beams. By allowing the motion of the surface of interest to modulate the path lengths travelled by the laser beams, the interferometer can be used to detect vibrational signals of sub-nanometer amplitude.

To allow object motion to affect the interferometer phase, one beam must be allowed to exit from the inner interferometer cell, hit the sample and be coupled back into the interferometer. An arrangement that satisfies these requirements is shown in Fig. 1.

The Bragg cell modulator frequency shifts the traversing light beam by an amount f_B that is determined by an electrical signal REF_{IN}. This frequency shift results in a



1. Optical head as modified Mach-Zehnder interferometer

BS – beam splitter, VFL – variable focus lens system, D – detectors, BCM – Bragg cell modulator modulation of the detected interference signal. The sinusoidal dependence of the interferometer outputs then produce intensities at the detectors as follows

$$I_{(1)} = \frac{1}{2}A^2\left\{1+\cos\left[2\pi\left(f_B t+\frac{2\Delta z}{\lambda}\right)\right]\right\} \quad (1)$$

$$I_{(2)} = \frac{1}{2}A^2\left\{1-\cos\left[2\pi\left(f_B t+\frac{2\Delta z}{\lambda}\right)\right]\right\} \quad (2)$$

where Δz denotes the displacement of the sample with respect to a fixed reference position.

Substracting the output signals from the photodetectors by an operational amplifier and removing the DC content, a SIG. OUT voltage is

$$u = K\cos\left[2\pi\left(f_B t+\frac{2\Delta z}{\lambda}\right)\right] \quad (3)$$

This is signal that is processed to extract the displacement information Δz. K is constant taking into account detector efficiency and amplifier gain that is calibrated.

The Doppler effect

Last equation relates the output voltage u from the optical head to a displacement of the sample. Displacing the sample by an amount Δz phase-shifts the detected signal by

$$\theta = 4\pi\frac{\Delta z}{\lambda} \quad (4)$$

If the sample moves towards the head at a constant speed $v = \Delta z/\Delta t$, the output phase shift turns into an output frequency shift, the well known Doppler shift f_D with

$$f_D = \frac{2v}{\lambda} \quad (5)$$

Thus, the output frequency of the head can be expressed as

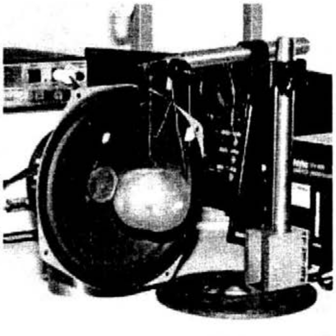
$$f_{OUT} = f_B + f_D \quad (6)$$

Depending on the direction of the movement, the sign of v changes (and so does that of f_D).

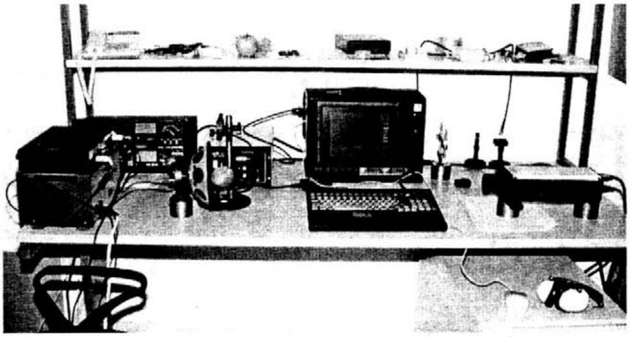
ACOUSTIC MEASUREMENTS

The acoustic response method was used for vibrational measurements. The apple was hung in two point manner on silk threads to avoid a constraint by coupling material (Fig. 2). The forced excitation was performed in range from 500 Hz to 2,000 Hz by a speaker feeded with the tunable sinus signal from generator. The speaker was placed in a given distance (several centimeters) from the apple (Fig. 3). The measurement of acoustic response was made at the opposite point of apple. At the point the reflectance sticker was applied to increase the reflection of laser light propagated from the vibrometer head. The typical vibration response spectrum obtained from the vibrometer is presented in Fig. 4. The second resonant frequency was shown to be related to apple firmness (Steinmetz et al., 1996) therefore this frequency peak was processed. The internal damping of structures is an important parameter for fruit because it may be associated with fruit maturity, degree of ripeness and composition of fruit tissue. The conventional algorithm called the √2 method (Plander, Tomáš, 1964) was used for calculation the damping factor where two √2-power resonant frequencies (f_1,f_2) are determined for resonant peak. The damping factor can be then calculated by next equation

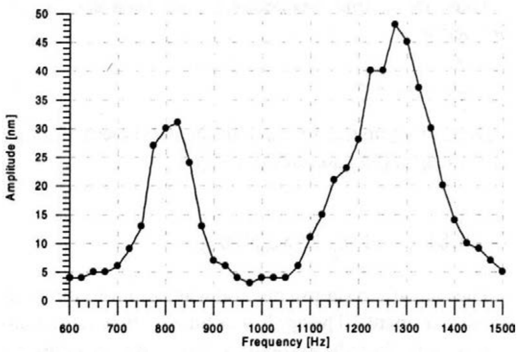
$$b = \frac{f_1 - f_2}{f_r + \frac{1}{8}\frac{(f_1 - f_2)^2}{f_r}} \quad (7)$$



2. Investigated apple hung in front of the speaker. The reflectance sticker at measured point is visible



3. Laboratory experimental arrangement for laser Doppler vibrometry of apples. From left: low frequency generator and amplifier, speaker, apple, computer, He-Ne laser head

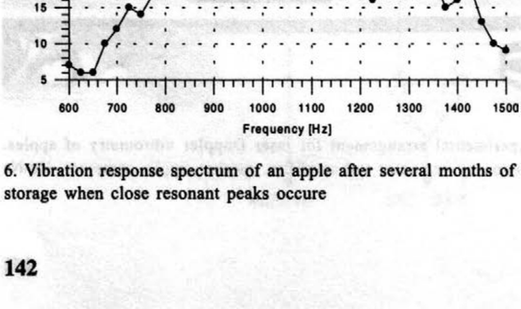


4. Vibration response spectrum of an apple obtained from the vibrometer

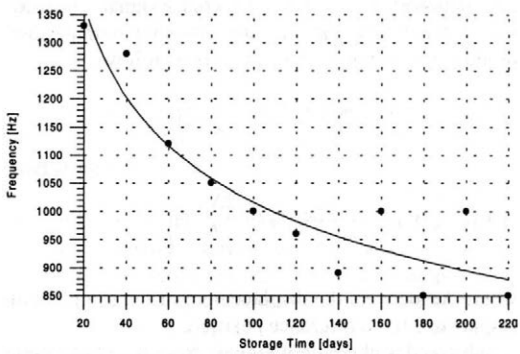
RESULTS AND DISCUSSION

The repeatability of the laser vibrometric measurements was tested with the 4 Golden Delicious apples. Consistent frequency response was obtained when repeated tests were conducted at the same location (reflectance sticker). The first resonant frequency remained unchanged (about 800 Hz) and their amplitude decreased that is according to the theoretical predictions (Lu, Abbott, 1996). The second resonant frequency decreased with the storage time and the peak shapes indicated increasing damping.

The results for resonant frequency course during the investigated storage period are in Fig. 5. An oscillation on the graph during second half of investigated storage period occured which can not be explaned by measurement error or inaccuracy of the method. It is probably caused by differences among samples. It is obvious from the theory that the stiffness coefficient or the Elastic Modulus have the similar exponential decrease. Identification of the resonant frequency in the frequency spectrum, the frequencies for the $\sqrt{2}$ method and processing for the damping factor estimation was made by a routine in the MS Visual Basic© software. The reliable calculation



6. Vibration response spectrum of an apple after several months of storage when close resonant peaks occure



5. Dependence of resonant frequency on storage time

Fit Results

Equation:

log(*Y*) = –0.183792 × log(*X*) + 7.77003

Alternate equation:

Y = pow(*X*, – 0.183792) × 2,368.55

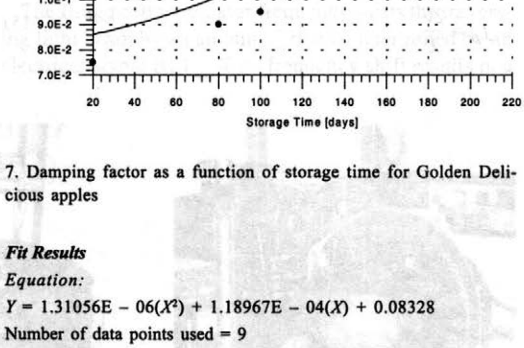
Number of data points used = 11

Regression sum of squares = 0.187539

Residual sum of squares = 0.0339461

Coefficient of determination, *R*-squared = 0.846735

Residual mean square, sigma-hat-sq'd = 0.00377179



7. Damping factor as a function of storage time for Golden Delicious apples

Fit Results

Equation:

$Y = 1.31056E - 06(X^2) + 1.18967E - 04(X) + 0.08328$

Number of data points used = 9

Sums of squares of residuals about polynomial

Degree 0: 0.00782889

Degree 1: 0.00147292

Degree 2: 0.00125737

Coefficient of determination (*R*-squared)

Degree 0: 0

Degree 1: 0.811862

Degree 2: 0.839393

of the damping factor by $\sqrt{2}$ method can be performed only when resonant frequencies are well apart from each other. That means the method has a limitation when two close resonant frequencies appear in the frequency spectrum. This case may occure for several reasons: for an irregular apple shape, for a complex apple structure with non-uniform ripening, when the frequency spectrum may include two or more very close resonant peaks. In the experiment the close resonant peaks were gradually detected for some samples when ripening was in progress (Fig. 6). Only the samples with well distinguishable peaks were used in the experiment.

In the experiment the damping factor increased with increasing storage time (Fig. 7). Each point in the graph is the average value from measurement of four samples. The points can be fitted by several types of functions. A polynomial function was chosen for slightly better statistics parameters than other linear or nonlinear functions, thus the dependence seems to be slightly nonlinear. For the decision if the course of the damping factor is a nonlinear or a linear it would have to be performed more frequent measurements during longer storage time.

CONCLUSIONS

The laser Doppler vibrometry can be used to determine basic mechanical characteristics of apples which can follow the ripening process. There is a possibility reliably determine the resonant frequency, the damping and other acoustic and mechanical parameters by this method. Both the resonant frequency and the damping parameter have exponential change with increasing storage time. The second resonant frequency decreased and the damping parameter increased during investigated storage period.

In several cases the close resonant peaks in the frequency response spectrum occured when the standard $\sqrt{2}$ method used for calculation of the damping factor was not reliable.

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During experimental measurement following values were recorded continually:

- output pressure of hydrogenerator p_G,
- speed of hydrogenerator n_G,
- engine speed n,
- velocity of tractor v_p,
- depth of ploughing h.

On the basis of loading characteristics ploughing loading cycles for laboratory life test were determinated.

The graphical presentation of typical loading cycle is shown in Fig. 3. Functional chart of loading device for dynamic system simulator is shown in Fig. 1.

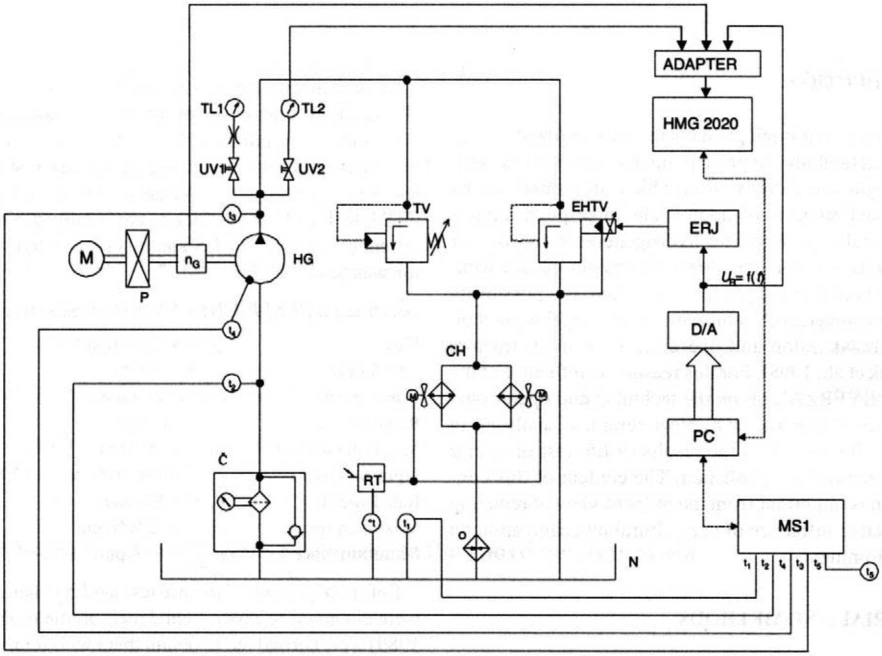
Tested hydrogenerator HG is connected by clutch, photo-electric speed transducer n_G and mechanical transmission to the electric motor M. Input of the hydrogenerator HG is equipped with filter Č.

The outlet of the hydrogenerator is connected by pipeline to the electro-hydraulic proportional pressure valve EHTV. The electro-hydraulic proportional valve is a part of the electro-hydraulic system of the simulator and it continually converts electric current into pressure of working liquid. Heating of the working liquid is implemented by direct electric-flow heater O and cooling by radiators CH with electric fans. Required temperature of the working liquid is controlled by thermoregulator RT which is built-in in the tank. The oil filter Č is also equipped with manometer to measure pressure in intake pipe and strain gauge manometer TL2 is placed in the outlet of hydrogenerator HG. For disconnecting the manometers two closing valves UV1 and UV2 are used.

The electronic control part of the testing device consists of personal computer PC which is able to generate required loading by means of suitable programmed control. The strain gauge manometer and also the photo-electric speed transducer are connected with the recording unit HMG 2020 by means of a universal adapter. For recording of input oil temperature t_2, output oil temperature t_3, surface temperature of hydrogenerator t_4, oil temperature t_1 in tank and outside air temperature t_5 a digital recording unit MS-1 was used. All temperature transducer as mentioned above are of the type Pt 100 in assembly TR-045, TR-17 and G-4 products of MARET Ltd. Nové Mesto nad Váhom, Slovakia.

Evaluation of all recorded valves by the recording unit HMG 2020 and digital recording unit MS-1 was realized by a PC LAP TOP WALKOM LP-3452. In this case the evaluation of the recorder values was made fully automatical and independent of the human factors.

Before building of a testing device it is necessary to calculate essential parameters of hydraulic circuit.



1. Functional chart of loading device for dynamic system simulator

HG – tested hydrogenerator; M – electric motor; P – mechanical transmission; N – tank; UV – closing valve; TV – pressure valve; EHTV – electro-hydraulic proportional pressure valve; CH – radiator; O – heater; Č – filter; RT – thermoregulator; TL1 – manometer; TL2 – strain gauge pressure transducer; MS1 – digital record unit; PC – personal computer; D/A – digital analog converter; ERJ – electronic-control unit; HMG 2000 – recorder

The input parameters are:

– flow of hydrogenerator $Q_G = 5.33.10^{-4}\ m^3.s^{-1}$

– rated pressure $P_G = 16.10^6$ Pa

– rated speed of hydrogenerator $n_G = 31.167 s^{-1}$

– total efficiency $\eta_G = 0.7$

The input power may by calculated by following formula:

$$P_G = \frac{p_G.Q_G}{\eta_C} \quad (W) \qquad (1)$$

After using input parameters we obtain:

$$P_G = \frac{16.10^6.5.33.10^{-4}}{0.7} = 12{,}189.7 \quad (W)$$

With respect to required power reserve and efficiency an electric motor with power 17 kW at rated speed n_E = 24 $s^{-1}$was used. Because the rated speed of the electric motor was lower than required it was necessary to insert a mechanical transmission between the electric motor and hydrogenerator. The gear ratio was calculated as follows:

$$i_p = \frac{n_E}{n_G} = \frac{24}{31.167} = 0.77 \qquad (2)$$

The choice of other additional hydraulic components was realized on the base of maximum values of essential parameters of the hydraulic circuit and the loading device as follows:

1. Electrohydraulic proportional pressure valve type NW 10 TGL 550 80, product of ORSTAHYDRAULIC with following parameters: rated flow 100 $dm^3.min^{-1}$, maximum pressure 32 MPa, temperature of working liquid from 0 to +70 °C, required filtration 25 μm.
2. Pressure valve VP2-20-1/20 with following technical data: rated flow 100 $dm^3.min^{-1}$, range of adjustable pressure from 1 to 16 MPa, temperature of working liquid from –20 to +60 °C, required filtration 30 μm.
3. Hydraulic filter FS 32-10-1 with technical dates: rated flow 45 $dm^3.min^{-1}$, rated input pressure –0,025 MPa, rated ability of filtration 30 μm.

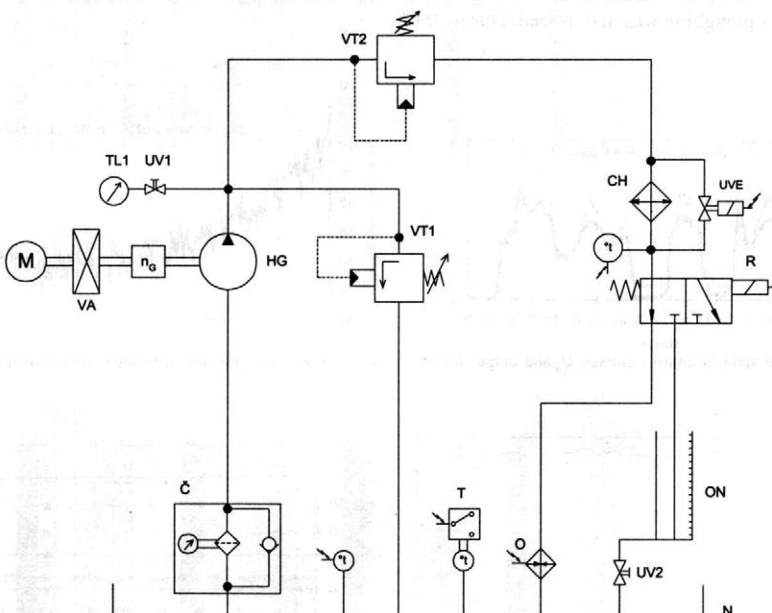
The laboratory test consists of long time test of tractor hydrogenerator type PZ 2-19 KS loaded by the working pressure. The loading cycle of test was the same as during ploughing. The speed of hydrogenerator was n_G = 1,870 min^{-1} and working temperature 50 ± 2.5 °C.

The measurement of flowing characteristics $Q = f(p)_n$ and $Q = f(n)_p$ of the tested hydrogenerator and analyze of oil EKOUNIVERZAL was made after each 50 hours of test.

The testing device for measurement of flowing characteristics is shown in Fig. 2.

The driving electric motor EM with variator VA is connected with the tested hydrogenerator by a photo-electric speed transducer.

The tested hydrogenerator is loaded by means of two-degree pressure valve VT 2. The two-degree pressure



2. Functional layout of testing device for measurement of flowing characteristics

EM – electric motor, VA – variator, HG – hydrogenerator, Č – full flowing filter, VT – two-degree pressure valve, UV – closing valve, R – divider, ON – measuring tank, N – tank, CH – radiator, O – heater, T – thermoregulator, UVE – electromagnetic closing valve

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LIFE TESTS OF TRACTOR HYDROGENERATORS BY USING PLANT OIL EKOUNIVERZAL

SLEDOVANIE ŽIVOTNOSTI TRAKTOROVÝCH HYDROGENERÁTOROV S PRACOVNOU KVAPALINOU EKOUNIVERZAL

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ABSTRACT: A design of a device for measuring the durability of PZ 2-19 KS tractor hydrogenerators is presented including the measurement methodology, the measurements proper, and the obtained results. The design of the device and laboratory measurements ensue from the load characteristics of hydrogenerators tracked in conditions of field operation. EKOUNIVERZAL oil was utilized for studying the durability of tractor hydrogenerators.

tractor hydrogenerator; hydrostatic circuit; proportional pressure valve; load characteristics; durability

ABSTRAKT: V príspevku uvádzame návrh zariadenia na meranie životnosti traktorových hydrogenerátorov PZ 2-19 KS ako aj metodiku merania, vlastné meranie a dosiahnuté výsledky. Návrh zariadenia a laboratórne merania vychádzajú zo zaťažovacích charakteristík hydrogenerátorov sledovaných v prevádzke. Na sledovanie životnosti traktorových hydrogenerátorov sa použila pracovná kvapalina EKOUNIVERZAL.

traktorový hydrogenerátor; hydrostatický obvod; proporcionálny tlakový ventil; zaťažovacia charakteristika; životnosť

INTRODUCTION

Tractor with plough presents the most utilized attachment in agriculture. At present mounted and semi-mounted ploughs are usually used which are connected by three-point hitch to the tractor. The three-point hitch is hydraulically powered by hydrogenerator and one or more hydraulic cylinders. From the environmental, technical and economical point of view there is a possibility to replace mineral oil by biologically degradable plant oil in the transmission and hydraulic systems of tractors (Podolák et al., 1998). For this reason the influence of the EKOUNIVERZAL oil on the technical and operational properties of the tractor hydrogenerator is analysed in this contribution. Also the results of life test of tractor hydrogenerator are published. The content of this contribution is important from the point of view of reducing the negative influence of agricultural mechanization on the environment.

MATERIAL AND METHODS

According to Rusňák (1982), three essential methods of shortened life tests of hydraulic components may be performed by following methods in practice: very polluted working liquid, higher working pressure, quick loading cycle.

In the transmission and hydraulic systems of ZTS UR II. and UR IV. tractors mineral oil PP 80 is used and oil fill is the same or common for both transmission and hydraulic systems. Before beginning of the life test a special testing device was built (Petranský, Drabant, 1989). The ZTS UR II. and UR IV. tractors are equipped with the hydrogenerator PZ 2-19 KS and this type of hydrogenerator was tested.

Technical date of PZ 2-19 KS hydrogenerator:

Flow	$Q_G = 41$ dm^3.min^{-1}
under pressure	$Q_G = 16$ MPa
and speed	$n_G = 2{,}390$ rpm
Rated pressure	$p_{G_n} = 16$ MPa
Maximum pressure	$p_{G_{max}} = 20$ MPa
Input pressure	$p_{G_{in}} =$ from –0.03 to +0.12 MPa
Rated speed	$n_{G_n} = 2{,}390$ rpm
Maximum speed	$n_{G_{max}} = 2{,}500$ rpm
Minimum speed	$n_{G_{min}} = 600$ rpm

Before beginning of the life test loading characteristics were unknown so experimental measurement (Petranský, 1989) were carried out to obtain them with semi-mounted a mounted ploughs as follows:

- ZTS-16145 tractor with 5-PN-30 mounted plough and draught, position and mixed control,
- ZTS-16145 tractor with 7-PHX-35 semi-mounted plough and position control.

valve VT 1 works as a safety valve. Heat is largely dissipated by radiator CH and also by tank N and oil is heated by flowing heater O. The filter Č is placed in the inlet of the hydrogenerator to filtrate the working liquid. The pressure in the inlet pipe is measured by a manometer which is equipped with the closing valve UV 1. The temperature of working liquid is measured in the tank N and also in the outlet of hydrogenerator by electric resistance thermometer with measuring range from 0 to 100 °C. The flow of hydrogenerator is measured by measuring tank ON and at the same time by electric clock. The measuring tank ON is equipped with electric divider R and closing valve UV 2. There is no need to measure the flowing resistance of gear hydrogenerator.

The required temperature of the working liquid is by controlled thermoregulator T, which is connected with the coil of the electromagnetic closing valve UVE. When the closing valve V is opened working liquid passes through the radiator CH.

The measurement of flowing characteristic was realized under following conditions and input parameters:

– speed: 600; 1,000; 1,500; 1,870; 2,000 rpm,
– pressure for each speed: 5; 8; 12; 16 MPa,
– oil temperature: 50 ± 2.5 °C,
– each measurement was repeated three times.

RESULTS AND THEIR EVALUATION

On the basis of field measurement the loading of hydrogenerator for ploughing was determined. During the laboratory test the hydrogenerator was loaded by this time dependent pressure. The time dependent state of output pressure of the tested hydrogenerator is shown in Fig. 3. First of all the time dependent state was analyzed.

Spectral density (output cross spectrum to input, cross spectrum) is:

$$G_{pUR}(f) = S_p(f) S^{+}_{U_R}(f) \qquad (3)$$

where: $S_{U_R} = FFT(X_{U_R})$

$S_p = FFT(X_p)$

+ – means complex unity

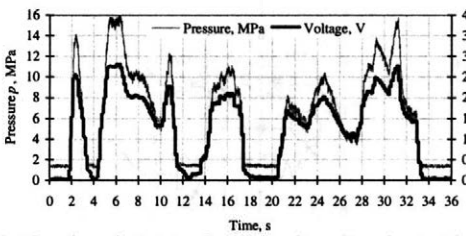
Then:

$$G_{pU_R}(f) = FFT(X_p)(FFT(X_{U_R}))^{+} \qquad (4)$$

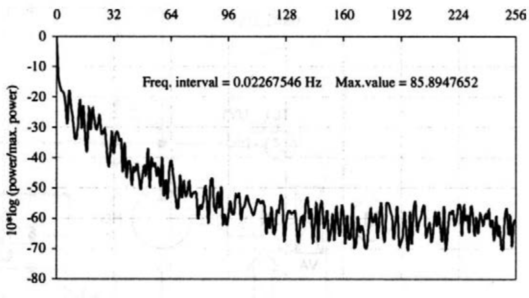
Crosse correlation is:

$$R_{pU_R}(t) = \int_{-\infty}^{\infty} X_{U_R}(\psi) X_p(\psi - t) d\psi \qquad (5)$$

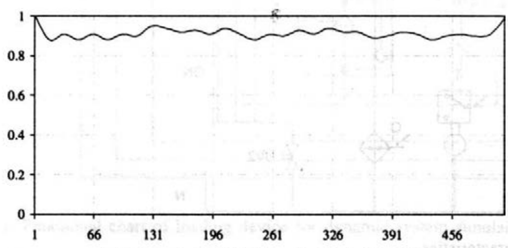
The analysis mentioned above was effected for the time dependent state shown in Fig. 3 for which the cross spectrum is shown in Fig. 4 and the cross correlation in Fig. 5. On the basis of this analysis we can state that the simulation device is able to effect working loading of the hydrogenerator by pressure with requires accuracy in laboratory conditions because the output cross correlation to input is better than 0.9 and it has no drop and also the substatic part of cross spectrum is dominated.



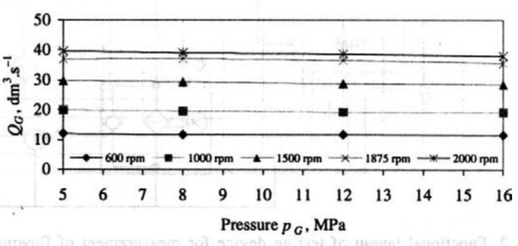
3. Time dependent state of control voltage U_R and output loading pressure p_G



4. Cross spectrum for time dependent state shown in Fig. 3



5. Cross correlation for time dependent state shown in Fig. 3

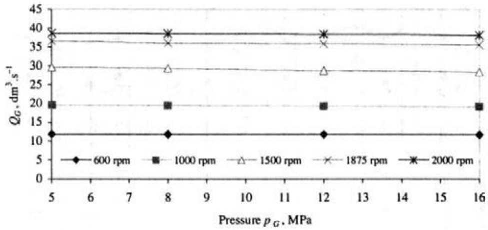


6. Flowing characteristic of hydrogenerator $Q = f(p)_n$ at the beginning of test

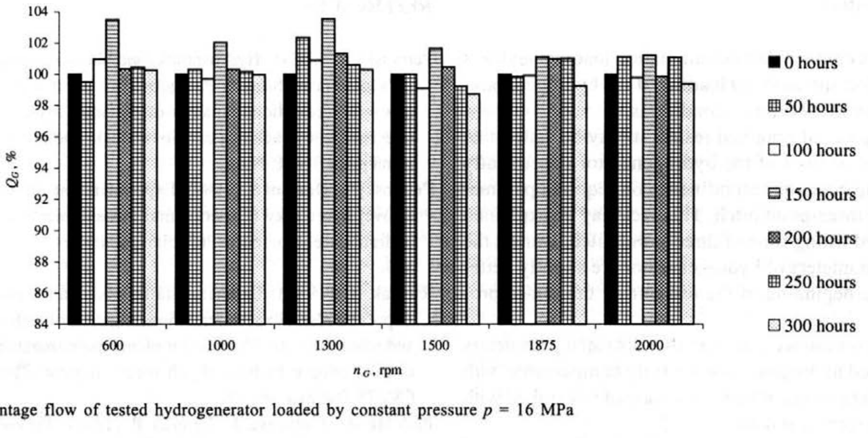
The frequency analysis also confirms that time dependent states are practically the same. The output signal is exactly determinated by input.

The measured and calculated values of flowing characteristics $Q = f(q)_n$ for tractor hydrogenerator type PZ 2-18 KS at the beginning and at the end of the test are shown in Fig. 6 and 7.

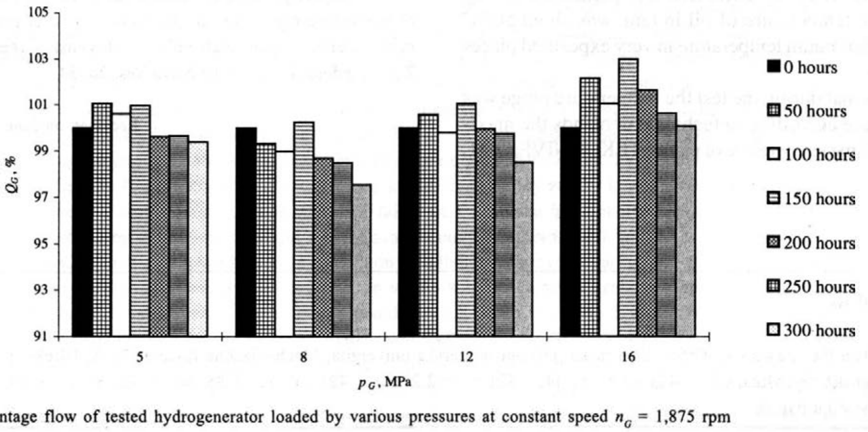
Percentage comparison of characteristics $Q = f(p)_n$ and $Q = f(n)_p$ after working 0; 50; 100; 150; 200; 250 and 300 hours is shown in Fig. 8 and 9. Typical time dependent state of input t_2 and output t_3 oil temperature, surface temperature t_4 of hydrogenerator, oil temperature t_1 in the tank and ambient air temperature t_5 are shown in Fig. 10. During the test the parameters of hydrogenerator varied slightly. The drop of flowing efficiency was 2.5% approximately in the measured place with respect to the initial value. In some cases the flowing efficiency of hydrogenerator was higher than at the beginning due to run-in process. After 300 hours of working the tested hydrogenerator is able to continue in working without negative influence on required properties of hydraulic circuit. It means that plant oil EKOUNIVERZAL is able to hold the quality parameters during all time of the test.



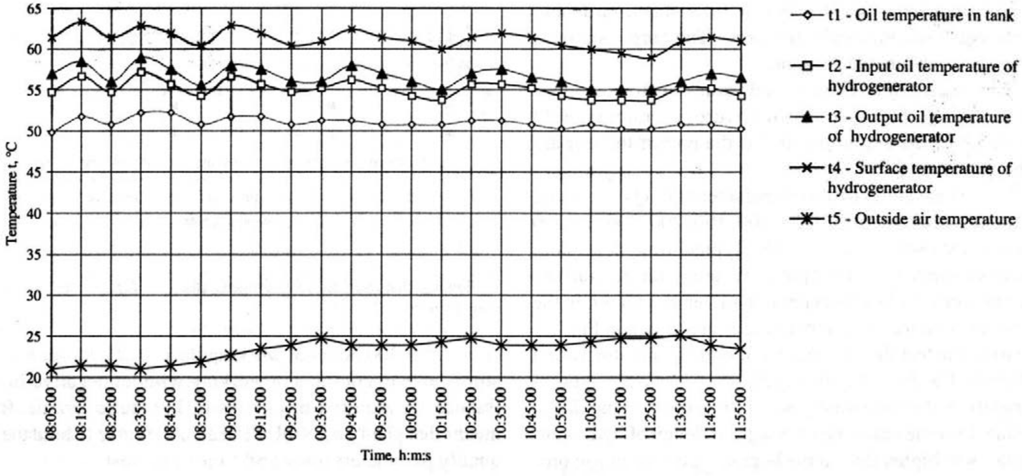
7. Flowing characteristic of hydrogenerator $Q = f(p)_n$ at the endinning of test



8. Percentage flow of tested hydrogenerator loaded by constant pressure p = 16 MPa



9. Percentage flow of tested hydrogenerator loaded by various pressures at constant speed n_G = 1,875 rpm



10. Time dependent state of temperatures during test of hydrogenerator loaded by working pressure – the part of interval from 200 to 250 hours

CONCLUSION

The tests confirm that the simulation loading device is able to effect the working loading of the hydrogenerator by pressure in laboratory conditions.

On the basis of obtained results it may be stated that the change of flow of the hydrogenerator dependently on working hours has no influence on required parameters of the three-point hitch. This fact may be explained by required lifting time of three-point hitch. During the test the parameters of hydrogenerator are slightly better than at the beginning of the test during the run-in process.

For this reason we can state that obtained parameters of the tested hydrogenerator are fully compareable with standard parameters obtained by using of mineral oil with respect to technical data.

From the point of view of the practical application of the plant oil EKOUNIVERZAL it is important that during the test the temperature of oil in tank was about 50 °C while the maximum temperature in very exposured places was 64 °C.

It means that during the test the temperature range was held because according to technical demands the maximum long time temperature of plant oil EKOUNIVERZAL is 70 °C.

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TECHNICAL STATE OF TRACTORS AND TRENDS IN REPAIR COSTS IN RELATION TO THEIR AGE

TECHNICKÝ STAV TRAKTOROV A VÝVOJ NÁKLADOV NA OPRAVY V ZÁVISLOSTI OD ICH VEKU

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ABSTRACT: The paper analyses the actual situation in wear progress of agricultural tractors utilized in plant production in relation to both repair costs and tractor age. The results generally document a high level of wear of tractors and negative trends in the age structure of tractors. There exists a close relation between age of tractors and repair costs. It was found that after 7–8 years of tractor exploitation repair costs are increasing very rapidly in relation to actual price of tractor. In case of imported tractors this critical age is in interval of 3–5 years of operation. There is recommended to unify methodics of data collection and evaluation of indicators of tractor operation ability. These data and their continuous evaluation would allow to optimalize the utilization of tractors.

wear; service life; repair cost; tractor

ABSTRAKT: Na základe analýz vykonaných v poľnohospodárskych podnikoch je možné konštatovať, že vekové opotrebenie používaných traktorov je veľmi vysoké. Počty traktorov sa neustále znižujú, čo nasvedčuje tomu, že ich technický stav je zlý a dochádza k vyraďovaniu techniky. Na druhej strane je potrebné vidieť, že sa do poľnohospodárstva dostávajú stroje, ktoré dosahujú vyššie sezónne výkonnosti a vyššiu spoľahlivosť. Vývoj počtu traktorov v rokoch 1990–1997 v SR je uvedený v tab. I. Na zistenie súčasného stavu poľnohospodárskej techniky boli použité údaje o vekovej štruktúre traktorov používaných v náhodne vybraných poľnohospodárskych podnikoch Trenčianskeho kraja. Spracovaním získaných údajov bol zistený priemerný vek traktorov a miera ich vekového opotrebenia. Hodnoty týchto ukazovateľov sú uvedené v tab. II. Na obr. 1 je uvedené grafické vyjadrenie vývoja počtu traktorov v jednotlivých vekových kategóriách, ktorý dokumentuje progresívny postup zastarávania traktorového parku. Bola tiež spracovaná metodika na stanovenie trendu narastania prevádzkových nákladov v závislosti od veku strojov. Na určenie trendov vývoja nákladov na opravy bol zavedený koeficient nákladov na opravy, ktorý ukazuje trend vývoja nákladov na opravy v závislosti od aktuálnej hodnoty strojov. Uvedená metodika bola overená na dvoch obmedzených súboroch údajov. Ako podkladové materiály o prevádzke a nákladoch na opravy súborov traktorov boli použité údaje z PD Dvory nad Žitavou a PD Šamorín. Výstupnými charakteristikami sú priemerné náklady na opravy, priemerné jednotkové náklady na opravy a koeficienty nákladov na opravy za jednotlivé roky sledovania v závislosti od veku strojov. Na obrázkoch sú uvedené ukážky grafických závislostí pre traktory z PD Dvory nad Žitavou za roky 1997 a 1998. Na obr. 2 a 3 je pozorovateľný takmer konštantný objem nákladov na opravy jednotlivých skupín strojov podľa roku zaradenia do prevádzky. Na obr. 4 a 5 sú uvedené závislosti jednotkových nákladov na opravy ($Sk.h^{-1}$) v závislosti od veku strojov. Na obr. 6 a 7 sú uvedené závislosti jednotkových nákladov na opravy ($Sk.l^{-1}$) v závislosti od veku strojov. Koeficienty nákladov na opravy boli stanovené v dvoch variantoch. Prvý variant uvažuje s aktuálnou hodnotou stroja bez zohľadnenia indexu rastu cien strojov a druhý variant v sebe zhrňuje vplyv indexu rastu cien strojov. Číselne sú medzi hodnotami indexov rozdiely, ale trendy v oboch prípadoch sú porovnateľné a u starších strojov ukazujú jasný trend zrýchleného (exponenciálneho) nárastu nákladov na opravy s vekom stroja (obr. 8 a 9). Takýto priebeh koeficientu nákladov na opravy sa dá vysvetliť tým, že stupeň fyzického opotrebenia traktorov vedie k rastu nákladov na opravy. Hodnotené súbory informácií boli relatívne obmedzené, a preto kvantitatívne charakteristiky ich zhodnotenia sú poznačené touto skutočnosťou. Potvrdili však kvalitatívne trendy zmeny koeficientov nákladov na opravy s vekom strojov. Hodnotené obdobie je poznačené rušivými faktormi z hľadiska homogenity hodnotených súborov vo viacerých smeroch, a to prudkými cenovými zmenami a zaraďovaním nových zahraničných traktorov ťažko zrovnateľných z hľadiska úžitkových vlastností a cenovej hladiny s pôvodnou skladbou traktorového parku, ako aj zmenami súvisiacimi s investičnou politikou v poľnohospodárskej prvovýrobe, čo viedlo k nesystémovým krokom v správaní sa poľnohospodárskych subjektov. Z výsledkov sledovania a spracovania podkladových údajov vyplývajú zaujímavé poznatky o dopadoch nehomogénneho a nesystémového ovplyvňovania vývoja technických prostriedkov v poľnohospodárskej prvovýrobe. Nedostatok finančných zdrojov neumožňuje budovanie systému starostlivosti vedúceho k optimalizácii zabezpečenia prevádzkyschopnosti strojov. Poruchy vysokovýkonných importovaných traktorov takmer rádovo zvyšujú náklady na opravy, čo je často spôsobené aj tým, že sa pri oprave nevymieňa iba poškodená súčiastka, ale často celá strojová podskupina.

Z vývoja hodnôt koeficientov nákladov na opravy v závislosti od veku strojov vyplýva, že približne v 7.–8. roku prevádzky strojov dochádza k výraznému nárastu týchto nákladov vzhľadom k aktuálnej hodnote strojov.

opotrebenie; životnosť; náklady na opravy; traktory

INTRODUCTION

Realized research and analyses show that the global wear of machinery in Slovak agriculture is more than 77% and only 23% of machines are within their predicted lifetime. Machinery older than 8 years is used at the cost of escalating operational costs to secure its operational capability. Average age of machines is 10.89 years and for single monitored types of machines it moves between 6 and 12.2 years. From that followed high requirements on annual recovery of mechanization resources (Zacharda et al., 1998).

In relation to a need to solve the question of economic effectiveness of agricultural mechanization the question of its lifetime is coming to foreground. Without lifetime knowledge it is impossible to specify reasonable and business convenient rates of depreciation. It is also impossible to calculate efficiency of utilization of capital and operating expenditures embedded into mechanization. Neither technical and financial feasibility of used and new machines and technologies nor effective renewal of machine park used in agricultural production is possible. From the point of view of a producer, the knowledge of the lifetime of agricultural machinery has significant importance in planning of production volumes, volumes and range of spare parts, in machine modernization etc. (Havlíček et al., 1989).

Only a little attention was given to a comprehensive solution of this problem because it is a relatively complex problem that contains issues of physical and moral depreciation of machinery. The difficulty of a comprehensive problem solution is based most of all in the complicated reaction of agricultural machinery in the agricultural production process.

ACTUAL SITUATION IN STATE AND RENEWAL OF TRACTOR PARK

Age waste of used tractors is very high. Based on analysis made in agribusiness we can claim that the survey of machine numbers testifies an overburdening of real needs. After 1990 the number of tractors continually decreased which indicates that their technical state is worsening and that aged machinery is put out of operation. On the other side it is necessary to see that new machines coming in to agriculture are on higher technical level, reach higher seasonal efficiency, higher reliability and quality of work. Although the loss of tractors is generally offset by using new and more efficient types, currently it is not the case. Development of number of tractors in 1990 to 1997 in Slovak Republic is presented in Tab. I.

Financial situation of most of agribusinesses, deficiency of credit sources and their high interest rates stop regular machine replacement. High wear of tractor park still lasts and repair costs and costs of spare parts are growing. Possibility of eliminating these negative influences lies in better exploitation of new machinery in agribusiness or in using new service forms provided by specialized businesses. In both cases we talk above economically effective exploitation of machinery, decreasing cost of realized work and securing of appropriate return on invested resources.

WEAR DEGREE

To assess the current condition of agricultural machinery data about age structure of selected tractors used in randomly selected agribusinesses from Trenčín county were used. All forms of businesses and production areas of Slovak agriculture were proportionally represented in the selection.

The key parameter obtained was the utilization time. It is an indicator which expresses calendar time of utilization of certain tractor type. From data about utilization time (age) of individual tractor types their average age was determined. For the complementing of technical condition evaluation a new parameter was defined, viz. the so-called degree of age-wear:

$$m = \frac{\bar{t}}{T_o} \qquad (1)$$

where: m – degree of age-wear (%),
$\bar{t}$ – average value of machine age (years),
T_o – depreciation time of machines (years) (4).

With processing of obtained data the average age of tractors and degree their age-wear were calculated. Val-

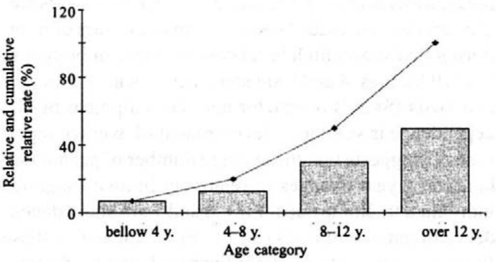
I. Development of tractor numbers in Slovak Republic in 1990–1997 (in: Zacharda et al., 1998)

Type		1990	1991	1992	1993	1994	1995	1996	1997
Tractors	total	36,912	34,980	33,009	30,851	29,810	27,746	26,650	25,820
	new	1,405	172	109	132	122	233	419	500

II. Quantification of evaluated parameters for tractors (in: Zacharda et al., 1998)

Type of machine	Number of machines in age category				Together	Average age (year)	Standard deviation (year)	Degree of age wear (%)
	under 4 y.	4–8 y.	8–12 y.	over 12 y.				
Tractors	132	248	565	948	1,893	10.92	6.93	136.50

ues of these indicators are shown in Tab. II. As follows from Tab. II, very high number of tractors are older than 8 years.



1. Graphical evaluation of wear level of tractors

Fig. 1 shows a graphical presentation of the development of tractor numbers in simple age categories which documents progressing obsolescence of the tractor park.

COSTS OF TRACTOR REPAIR AS A FUNCTION OF ITS AGE

Evaluating costs related to physical wear of machines due to their utilization is a relatively complicated process. The issue of moral wear is also very difficult.

Therefore basis for this evaluation is monitoring of costs of tractor repair in relation to the time of their utilization.

MATERIALS AND METHODS

The project goal was to create an applicable methodology for determining the trends of operational costs in dependence upon the tractor age. To justify the proposed methodology the limited set of data on cost of repair in relation to age and depreciation of tractors from agribusinesses documentation was used.

Starting point material were data about tractor operation costs in agribusiness in relation to its age. The following data are required to evaluate the repair costs trend:

- year of putting the tractor into operation,
- number of tractors integrated to operation in single year,
- acquisition price of the tractor,
- annual depreciation,
- annual costs on repair (wages, spare parts, costs on repairs carried out by other organizations),
- fuel consumption in litres,
- time of operation in hours (production hours).

Tractors were allocated into R groups according to the year when they were put into operation. Tractors put into the operation before 1989 are in one group. Based on obtained data were calculated unit repair costs in relation to fuel consumption and to time of operation, as well as average values for each individual tractor group:

$$u_{SRr} = \frac{N_{cRr}}{S_{Rr}} \qquad (2)$$

where: u_{SRr} – unit costs on repair of tractors in the R^{th} group for a particular year r according to fuel consumption,
N_{cRr} – total repair costs of tractors of R^{th} group for a particular year r,
S_{Rr} – total fuel consumption of tractors of R^{th} group for a particular year r.

$$u_{TRr} = \frac{N_{cRr}}{T_{Rr}} \qquad (3)$$

where: u_{TRr} – unit repair costs of tractors of R^{th} group for particular year r according to production hours,
T_{Rr} – sum of operating time in hours (production hours) of tractors of R^{th} group for particular year r.

$$\bar{u}_{SRr} = \frac{\sum_{j=1}^{n_R} u_{SRrj}}{n_R} \qquad (4)$$

where: $\bar{u}_{SRr}$ – average unit costs on repair of tractors of R^{th} group for particular year r according to fuel consumption,
n_R – number of groups.

$$\bar{u}_{TRr} = \frac{\sum_{j=1}^{n_R} u_{TRrj}}{n_R} \qquad (5)$$

where: $\bar{u}_{TRr}$ – average unit repair costs of tractors *of* R^{th} group for a particular year r according to operation hours.

Calculated values of average costs and average unit repair costs were processed graphically in dependence to the year when the device was put into the operation both for each individual year and for the whole monitored period.

COEFFICIENT OF REPAIR COSTS

One of project goals being the determination of repair costs trends, the coefficient of repair costs was defined.

It shows the trend of repair costs in dependence upon actual book price of tractors. The coefficient of repair costs for machines divided into groups according to their age for a particular year can be determined by formula (Kročko et al., 1999):

$$K_{NcR} = \frac{\overline{N}_{cR}}{\overline{C}_a} \qquad (6)$$

where: K_{NcR} – coefficient of repair costs for tractors of R^{th} group,
$\overline{N}_{cR}$ – average total costs for tractors of R^{th} group,
$\overline{C}_a$ – average actual book price of tractors of R^{th} group.

Actual book price of tractor C_{ar} in each individual year of its age is declining with depreciation at the rate of O_k

$$O_k = \frac{C_k - Z_k}{T_{ok}} \qquad (7)$$

where:

$$C_{ar} = C_k - O_k . p_{rk} \quad \text{for } p_{rk} = <1, 2, ..., 8> \qquad (8)$$

$$C_{ar} = Z_{kr} \quad \text{for } p_{rk} = <9, 10, ...>$$

where: C_k – price of acquired new tractor,
Z_{kr} – price of the tractor in particular year r (from 9th year of machine age the price of tractor remains constant at 15% C_k),
T_{ok} – depreciation time (for tractors T_{ok} = 8 years),
p_{rk} – age of tractor.

To eliminate the influence of price increases in each year of monitoring, actual prices of tractors, as well as coefficients of repair costs, were multiplied by price index in respect to year 1989.

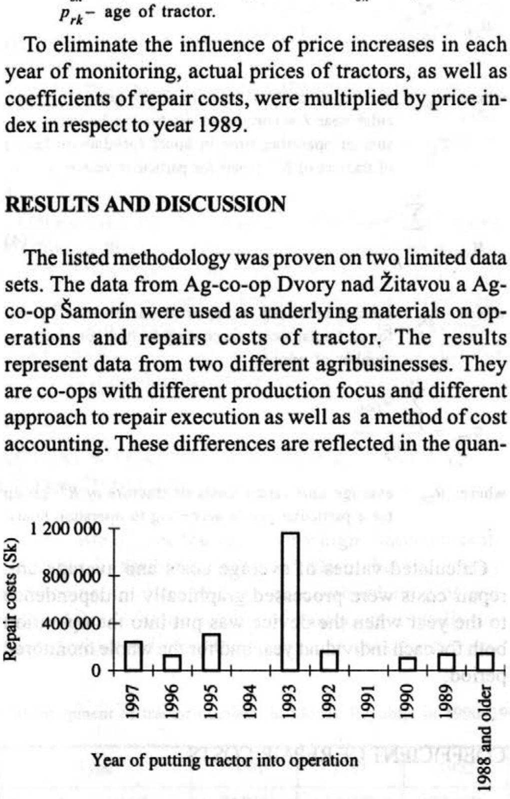
RESULTS AND DISCUSSION

The listed methodology was proven on two limited data sets. The data from Ag-co-op Dvory nad Žitavou a Ag-co-op Šamorín were used as underlying materials on operations and repairs costs of tractor. The results represent data from two different agribusinesses. They are co-ops with different production focus and different approach to repair execution as well as a method of cost accounting. These differences are reflected in the quantified output parameters. These differences, however, do not materially influence the tested trends of costs development with machine age.

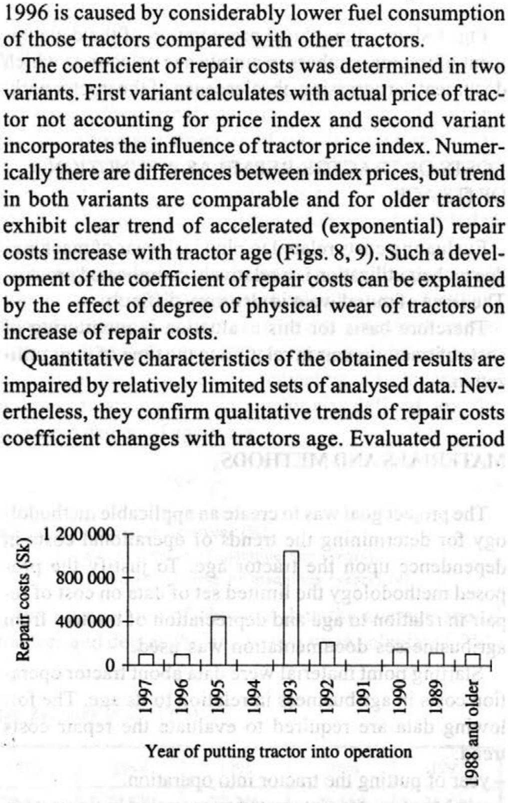
Output parameters are average repair costs, average unit repair costs and coefficients of repair cost for each individual year of monitoring in dependence on tractor age. Figures show samples of graphical dependence for tractors from Ag-co-op Dvory nad Žitavou in years 1997 and 1998. No tractors were bought in years 1991 and 1994, therefore respective areas in graphs are empty. In Figs. 2 and 3, an almost constant size of repair costs in individual tractors groups is visible. Extraordinary value occurred only for tractors bought in year 1993, where breakdowns occurred. Breakdowns repair represents significant cost increase. This occurs in both years of monitoring that shows high breakdowns of tractor bought in year 1993. Figs. 4 and 5 are show dependence of unit repair costs (Sk.h^{-1}) on tractor age. Development of this dependence is similar to development of average repair costs. It suggests that the average number of production hours in a year changes in relatively limited range for individual tractor groups. Figs. 6 and 7 are show dependence of unit repair costs (Sk.l^{-1}) on tractor age. In these figures we can see two extraordinary values. One for tractors put into operation in 1993 is for the already mentioned reasons. Second for tractors put into operation in 1996 is caused by considerably lower fuel consumption of those tractors compared with other tractors.

The coefficient of repair costs was determined in two variants. First variant calculates with actual price of tractor not accounting for price index and second variant incorporates the influence of tractor price index. Numerically there are differences between index prices, but trend in both variants are comparable and for older tractors exhibit clear trend of accelerated (exponential) repair costs increase with tractor age (Figs. 8, 9). Such a development of the coefficient of repair costs can be explained by the effect of degree of physical wear of tractors on increase of repair costs.

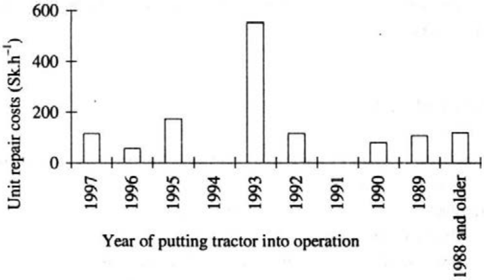
Quantitative characteristics of the obtained results are impaired by relatively limited sets of analysed data. Nevertheless, they confirm qualitative trends of repair costs coefficient changes with tractors age. Evaluated period



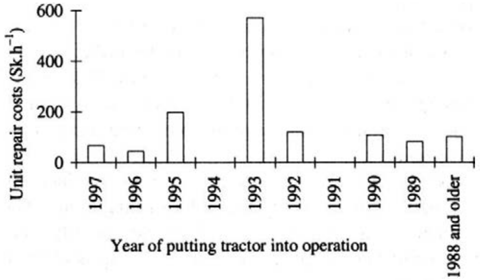
2. Dependence of repair costs (Sk) upon tractor age in 1998



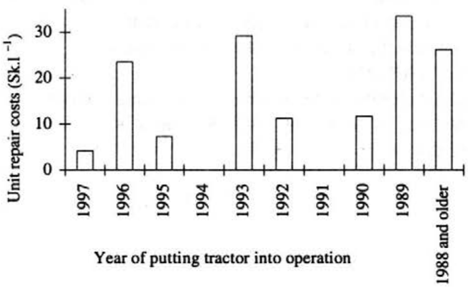
3. Dependence of repair costs (Sk) upon tractor age in 1997



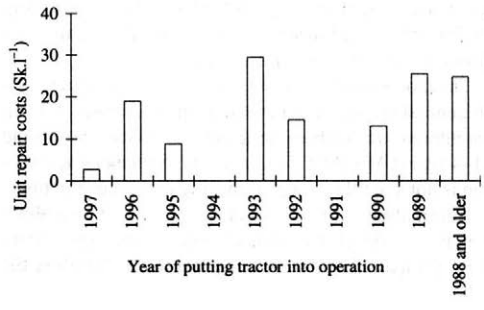
4. Dependence of repair costs (Sk.h^{-1}) upon tractor age in 1998



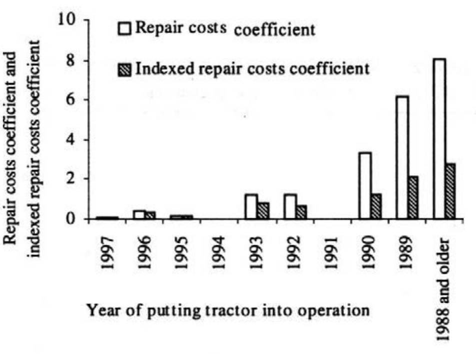
5. Dependence of repair costs (Sk.h^{-1}) upon tractor age in 1997



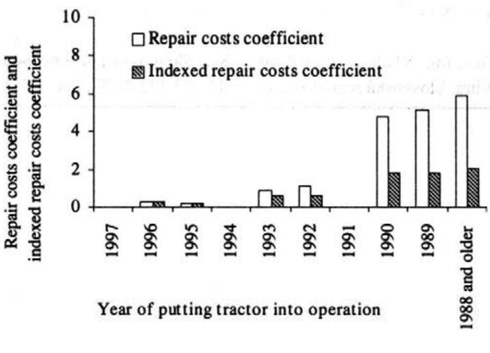
6. Dependence of repair costs (Sk.h^{-1}) upon tractor age in 1998



7. Dependence of repair costs (Sk.h^{-1}) upon tractor age in 1997



8. Coefficient of repair costs and indexed coefficient of repair costs related to tractors age in 1998



9. Coefficient of repair costs and indexed coefficient of repair costs related to tractors age in 1997

is affected by spurious factors from the point of view of homogeneity of evaluated data, both in respect to intense price changes and introduction of foreign tractors incomparable from the point of view of utility and price level with original composition of tractor park. Important are also changes related to investment policy in agribusinesses which redounds to systemless steps in behaviour of agricultural subjects.

CONCLUSION

Obtained results lead to the formulation of the following recommendations:

1. Unification of methodology for data collection relevant to securing the maintenance of agricultural machines. These data and their continuous computer processing according to known methodology shall enable to optimize of tractors exploitation and can serve as a decision tool in tractor exploitation. This methodology makes clear the development of repair costs of individual tractors in agribusiness during the year as well as for the year as a whole. This enables significant financial savings (clarifies financial flows on spare parts, fuel costs, lubricants costs etc.).
2. Based on this methodology it is possible to define recommended repair cost coefficients for evaluation of tractors and other agricultural machines exploitation

profitability.

Based on the obtained data we can infer that the unsystematic decision – making negatively influences the status of the machinery in agribusinesses. Shortage of financial resources disallows creating the system of maintenance that would lead to optimizing of machine serviceability.

Breakdowns of imported high power tractors increase the repair costs almost by the order of magnitude. The cost increase is often due to the fact that not only a defective part but an entire machine subgroup is often to be replaced.

Development of repair costs coefficient values in dependence upon tractor age indicates that approximately in 7th–8th year of machine's operation the repair costs boost compared to actual tractor price.

The monitoring of the repair costs and operating costs in general is a weak point in the agribusinesses. If even monitored so it has been done only for a short time period (1–4 years). Mostly it is limited only to financial accounting is not suitable for the above mentioned evaluation.

Information value of presented calculated data about repair costs development in accordance with age of tractors is impaired by limited original data. Therefore the statistical evaluation may have only be considered as indicative.

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As recommended by Board of Publishers of the Czech Academy of the journal Agricultural Sciences all papers in Research in Agricultural Engineering will be published solely in English since 1st January 2001.

EVALUATION OF COMBINE HARVESTER CUTTING TABLE MECHANISMS WORK QUALITY AT THE HARVEST OF SEED CLOVER CROPS

HODNOTENIE KVALITY PRÁCE MECHANIZMOV ŽACIEHO STOLA OBILNÉHO KOMBAJNU PRI ZBERE ĎATELINOVÍN NA SEMENO

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ABSTRACT: Monitoring of quality of standard combine harvester cutting table mechanisms work in the seed clover crops (meadow clover, sown lucerne) harvest was made in dependence upon stand condition and its moisture. Losses caused by pick-up reel were monitored in dependence on λ parameter size. The best kinematic behaviour is at λ = 1.4–1.6. The height of stubble is to be chosen with 10 cm, because in this case harvest losses do not arise at normal conditions. With stubble height over 10–15 cm harvest losses increase from 10 to 20%. Stand divider losses were not indicated (0.03–0.06%).

meadow clover; sown lucerne; mowing; seed losses; pick-up reel; stand divider

ABSTRAKT: Kvalita práce mechanizmov klasického žacieho stola obilného kombajnu pri zbere ďatelinovín na semeno (ďatelina lúčna, lucerna siata) bola sledovaná v závislosti na stave porastu a jeho vlhkosti. Straty spôsobené prihŕňačom boli sledované v závislosti od veľkosti λ. Najvhodnejší kinematický režim je λ = 1.4–1.6. Pri kosení by sme mali voliť výšku strniska do 10 cm, kedy straty v normálnych podmienkach pri zbere nevznikajú. Pri voľbe výšky strniska nad 10 až 15 cm straty narastajú na 10–20 %. Straty za oddeľovačom porastu neboli preukazné (0.03–0.06 %).

ďatelina lúčna; lucerna siata; kosenie; straty semien; prihŕňač; oddeľovač porastu

INTRODUCTION

Clover crops harvest for seeds was performed by a direct harvest after stand desiccation with adapted combine harvester. The adaptation of combine mechanisms for seed clover crops harvest was paid attention more frequently than to the cutting table mechanisms (Mikulík, 1960; Nilsson, 1966; Jech, 1972). Closest evaluation of the cutting table mechanisms function for harvest of plants in question was not analysed till now. In practice, there are mechanisms mainly adjusted analogically to cereals harvest. This paper is devoted to particularities of clover crops harvest for seeds and on requirements on the cutting bar mechanisms.

The aim of work was to verify functional and technological ability of the combine harvester cutting bar mechanisms at the direct harvest of meadow clover and sown lucerne seeds with respect to work quality and work behaviour evaluation.

METHOD

WORK QUALITY MONITORING

Work quality – seeds losses caused by mechanisms of cutting table (cutting bar, pick-up reel, divider, gleaning auger) was evaluated in dependence on:

1. Monitored parameters:

a) harvested plant variety (meadow clover, sown lucerne),
b) condition of stand (stand height, stand density, biological yield, distribution of shells over stand height),
c) stand moisture change at the harvest (9–32%),
d) stubble height (7–34 cm),
e) λ rate size of pick-up reel (λ = 1.19–2.1),
f) in relation $\lambda = \frac{v_o}{v_p}$.

where: v_o – circumferential speed of finger end points of pick-up reel ($m.s^{-1}$),
v_p – combine harvester working speed ($m.s^{-1}$).

2. Work quality was evaluated by determination of:

- losses caused by cutting bar at various heights of stubble,
- losses caused by pick-up reel at various λ,
- losses caused by pick-up reel at various moisture content of harvested matter.

3. Taking of samples:

Performed on 20 m distance, always after filling of the cutting table by harvested plants, accordingly to the normal technological process. Thresher caused losses were excluded by retaining of straw and chaff into sheet.

Working speed was defined from measured time on monitored distance.

From measured operating speed and from pick-up reel radius was defined the circumferential speed – v_o of the pick-up reel, from which was always defined the required rate:

$$\lambda = \frac{v_o}{v_p}$$

Losses behind the cutting table mechanisms were taken from whole engagement of the cutting table, always from 1 m^2 area. From each distance (20 m) were taken three areas of one square meter for each of monitored parameters. Seed losses were vacuumed by vacuum cleaner from soil surface. Objective values of losses were estimated in laboratory after cleaning.

From weighted rates of biological yield and losses the percentage of actual seed losses was calculated.

4. Used machinery and apparatuses

At the harvest a classical combine harvester's cutting table (Fig. 3) was used. Cutting table parameters were pick-up reel radius $R = 51$ cm, number of pick-ups $z = 5$, gleaning auger radius $r = 23$ cm, work height was 10 cm, distance of cutting bar from auger axle $l_3 = 60$ cm. Other parameters (H, h, e, l_1, l_2) were changed according to pick-up reel adaptation. Adjustments were made only on thresher mechanisms. Because no evaluation of threshing quality was done it will not be presented next. Combine harvester thresher mechanisms work quality was evaluated in works of Jech (1978a,b).

There were made no constructional adaptations on the cutting table only working behaviour of cutting table mechanisms was changed.

Taking of loss samples from soil surface was made by vacuum cleaner powered by mobile power generator.

Further there were used standard laboratory apparatuses and measures for determining of moisture, weight and monitored stand conditions.

RESULTS

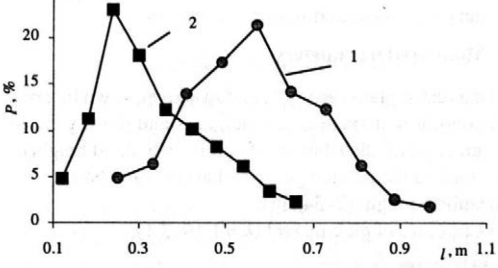
STAND CONDITIONS EVALUATION

Meadow clover and sown lucerne stand characteristics were obtained by taking and analysing of square meter areas. Stand status of monitored area at the harvest is characterized in Tabs. I and II.

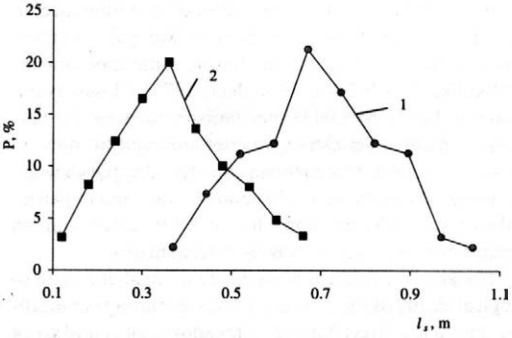
Stands were standing, relatively equable. Meadow clover stand had higher density and was more equable. Meadow clover seed yield according to taken square meter areas varied from 281 to 603 $kg.ha^{-1}$ and from 70 to 151 $kg.ha^{-1}$ for sown lucerne. Quantity of weeds was very low. In terms of cutting table mechanisms loading and combine harvester's working speed it was very important to define the weight of one square meter area of stand (Tabs. I and II) and its equability. Meadow clover weight varied from 0.40 to 0.58 $kg.m^{-2}$, but for lucerne the value variance was considerably higher from 0.21 to 0.48 kg per m^{-2}. From presented values it results that the cutting table is unequally loaded also at steady working speed of combine harvester. This stand status is typical at the harvest of seed clover crops.

In terms of the cutting table mechanisms work quality evaluation was very important to state the stands height and distribution of shells and heads over stand height, because these factors affect mowing losses.

Stand height and distribution of shells over stand were measured on different places in stand. Total number of measurements was $N = 300$. Graphic figuration of stand height is presented in Fig. 1.



1. Sown lucerne (1) and meadow clover (2) stand height, p – frequency of monitored parameter appearance



2. Sown lucerne shells (1) and meadow clover (2) heads onset height's distribution over stand height: p – frequency of monitored parameter appearance, l_s – height of shells and heads onset over stand

I. Characteristics of sown lucerne stand

Stand characterizing parameters		Taken one square meter areas									
		1	2	3	4	5	6	7	8	9	10
Stand weight from 1 m^2	($kg.m^{-2}$)	0.375	0.320	0.247	0.212	0.372	0.240	0.207	0.476	0.480	0.396
Culture plants stems number	(1 m^{-2})	242	176	138	118	201	186	154	284	123	111
Number of weed stems	(1 $m^{-2)}$	13	78	148	69	17	94	88	307	72	96
Weight of weeds	($kg.m^{-2}$)	0.005	0.009	0.024	0.012	0.017	0.018	0.022	0.043	0.0190	0.016
Weight of culture plants	($kg.m^{-2}$)	0.370	0.311	0.223	0.200	0.355	0.222	0.185	0.433	0.461	0.380
Number of shells	(1 m^{-2})	2,878	3,255	2,785	2,820	3,310	2,238	2,723	0.407	2,791	2,812
Weight of shells	($kg.m^{-2}$)	0.0319	0.0383	0.0348	0.0333	0.0359	0.0274	0.0323	0.0507	0.0461	0.0382
Weight of seeds	($kg.m^{-2}$)	0.0070	0.0109	0.0107	0.0104	0.0081	0.0075	0.0098	0.0151	0.0105	0.0106
Weight of empty shells	($kg.m^{-2}$)	0.0249	0.0274	0.0241	0.0229	0.0279	0.0199	0.0225	0.0356	0.0356	0.0276
Weight of straw	($kg.m^{-2}$)	0.3630	0.3000	0.2120	0.1900	0.3740	0.2150	0.1750	0.4180	0.4149	0.3418
Seed to straw rate	($kg.kg^{-1}$)	1:52.00	1:27.00	1:19.80	1:18.26	1:42.80	1:28.66	1:17.86	1:27.68	1:39.51	1:32.25
Biological yield	($kg.m^{-2}$)	0.007	0.0109	0.0107	0.0104	0.0081	0.0075	0.0	0.0151	0.0105	0.0106
Weed ratio	(%)	1.33	2.81	9.72	5.66	4.57	7.50	10.62	9.03	3.96	4.04
Weight of thousand seeds	(kg)	0.0016	0.0012	0.0019	0.0022	0.0019	0.0023	0.0025	0.0017	0.0018	0.0017

II. Characteristics of meadow clover stand

Stand characterizing parameters		Taken one square meter areas									
		1	2	3	4	5	6	7	8	9	10
Stand weight from 1 m^2	($kg.m^{-2}$)	0.455	0.485	0.550	0.575	0.480	0.400	0.545	0.520	0.580	0.573
Culture plants stems number	(1 m^{-2})	265	260	286	225	188	195	193	241	256	248
Number of weed stems	(1 m^{-2})	–	28	142	51	59	97	85	96	11	–
Weight of weeds	($kg.m^2$)	–	0.016	0.070	0.025	0.030	0.035	0.040	0.037	0.020	–
Weight of culture plants	($kg.m^{-2}$)	0.455	0.469	0.480	0.550	0.450	0.365	0.505	0.483	0.500	0.573
Number of shells	(1 m^{-2})	777	767	896	805	541	661	833	971	769	694
Weight of shells	($kg.m^{-2}$)	0.134	0.165	0.170	0.180	0.100	0.140	0.173	0.197	0.162	0.171
Weight of seeds	($kg.m^{-2}$)	0.0419	0.0572	0.0542	0.0505	0.0281	0.0456	0.0572	0.0603	0.0580	0.0420
Weight of empty shells	($kg.m^{-2}$)	0.0921	0.1078	0.1158	0.1295	0.0719	0.9440	0.1358	0.1367	0.1040	0.1210
Weight of straw	($kg.m^{-2}$)	0.4131	0.4118	0.4258	0.4995	0.4219	0.3194	0.4678	0.4227	0.4160	0.4020
Seed to straw rate	($kg.kg^{-1}$)	1:9.86	1:7.20	1:7.86	1:9.85	1:15.00	1:7.00	1:8.17	1:7.00	1:7.17	1:9.57
Biological yield	($kg.m^{-2}$)	0.0419	0.0572	0.0542	0.0595	0.0281	0.0456	0.0372	0.0603	0.0580	0.0420
Weed ratio	(%)	–	3.29	12.72	4.34	6.25	8.75	7.34	7.12	3.45	–
Weight of thousand seeds	(kg)	0.0170	0.0026	0.0023	0.0020	0.0016	0.0019	0.0021	0.0018	0.0018	0.0017

III. Statistical evaluation of Figs. 1 and 2 dependence

Evaluated parameters	Meadow clover		Sown lucerne	
	stand height	shells distribution	stand height	shells distribution
N	300	300	300	300
σ	12.99	13.04	15.25	16.27
V	0.350	0.395	0.220	0.2887
$\bar{x}$	36.86	33.00	69.37	56.34

It is evident from Fig. 1 that meadow clover stand height varied in range from 0.13–0.66 m. A stand height average value was $\bar{x} = 36.86$ cm. Sown lucerne stand reached higher value. It varied in range from 0.34 to 1.09 m. The average value of this height was $\bar{x}_1 = 69.37$ cm. It is important to mention that stands were not lodged.

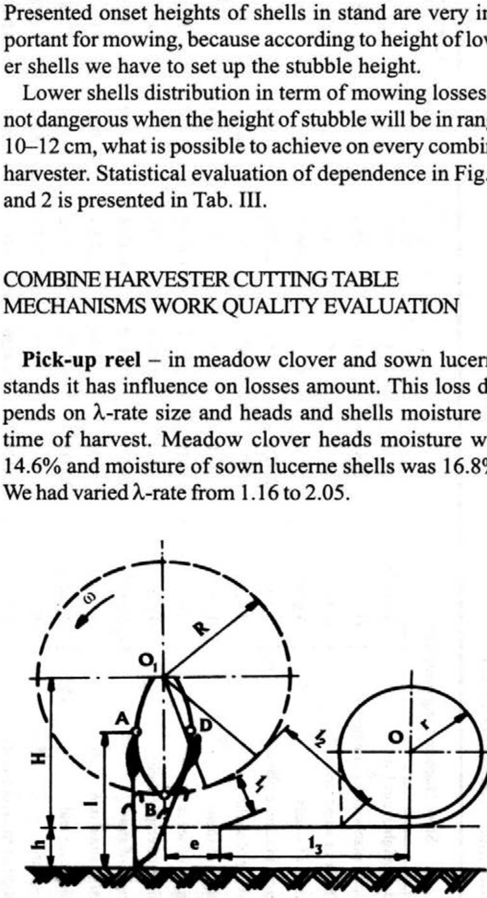
Distribution of shells and heads of observed plants over stand height is visible in Fig. 2. Meadow clover has 5% of onset heads at 13 cm stand height, at 18 cm it was totally 15.8% of heads (Fig. 2).

Sown lucerne has the first onset of shells at stand height 23 cm and at height 33 cm it was totally 11.8%. Presented onset heights of shells in stand are very important for mowing, because according to height of lower shells we have to set up the stubble height.

Lower shells distribution in term of mowing losses is not dangerous when the height of stubble will be in range 10–12 cm, what is possible to achieve on every combine harvester. Statistical evaluation of dependence in Fig. 1 and 2 is presented in Tab. III.

COMBINE HARVESTER CUTTING TABLE MECHANISMS WORK QUALITY EVALUATION

Pick-up reel – in meadow clover and sown lucerne stands it has influence on losses amount. This loss depends on λ-rate size and heads and shells moisture in time of harvest. Meadow clover heads moisture was 14.6% and moisture of sown lucerne shells was 16.8%. We had varied λ-rate from 1.16 to 2.05.



3. Pick-up reel adjustment: l – stand height, h – stubble height, H – vertical displacement of pick-up reel

Fig. 3 is presenting adjustment of pick-up reel. Parameters R, r and l_3 are constant for every type of cutting table.

During the working process we could change e, l_1, l_2, h and H (Fig. 3). Change of these parameters depends on stand status and its conditions, especially stand density, stand height, and eventually degree of lodging.

Pick-up reel forward position in front of cutting bar about e value is undesirable at clover crops harvest, because seed clover crops are rare during the harvest. Mowed plants fall through the cutting bar and they are cut again. Pick-up reel has low ability to transport mowed plants from the cutting bar to gleaning auger in this case, because e value change changes l_1 and l_2 values.

Mowed off material is cumulating on cutting bar and is unequally moving along auger to slope conveyor. In consequence of this fact the losses grow undesirably high (15–35%). Pick-up reel works well, when its axle is over or a little bit behind the cutting bar, it means that $e = 0$.

Losses caused by pick-up reel at different λ-rate are presented in Fig. 4.

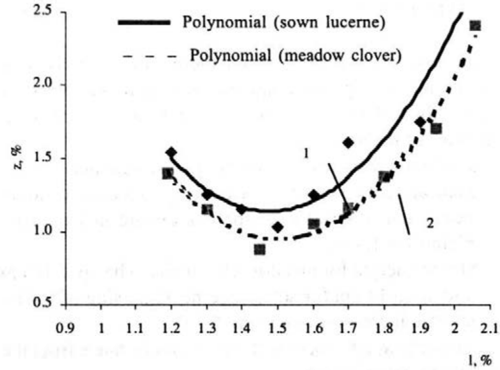
From Fig. 4 it results that λ-rate has influence on losses. At $\lambda < 1.5$ losses are softly increasing to 1.5%. By $\lambda > 1.5$ losses also increase but with opposite tendency. From $\lambda = 1.7$ losses increase progressively and at $\lambda = 2.08$ they reach 2.4–2.9%. According to our results the best λ-rate for given heads and shells moisture is 1.4–1.6.

It was interesting to observe losses caused by pick-up reel at different meadow clover heads and sown lucerne shells moisture (Fig. 5).

Seed losses caused by pick-up reel markedly decrease from moisture 8–15% (Fig. 5). Decrease from moisture 15–32% is soft.

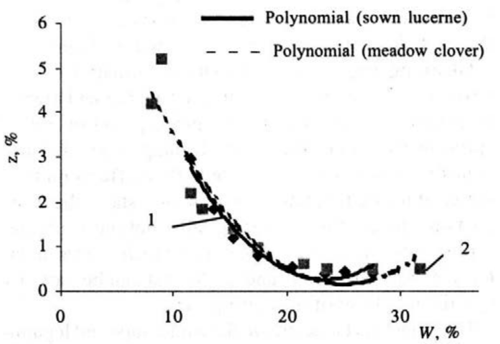
In terms of threshing quality it is very favourable when heads and shells moisture is lower than 15%. In term of pick-up reel losses it is better when heads and shells moisture is higher than 15%. Combination of these two requirements for satisfactory work quality of all combine harvester mechanisms makes a result for optimal harvest and threshing moisture from 14 to 18%.

Cutting bar – was monitored at different stubble heights (8–34 cm). Losses caused by cutting bar are presented in Fig. 6. Stand moisture during measurements was 14.6% for meadow clover and 16.8% for sown lucerne. Combine harvester working speed was 0.95–1.04 m. For every stubble height presented in Fig. 6 seed losses on observed distance (20 m) from three different places were



Sown lucerne: $y = 4.6606x^2 - 13.767x + 11.307$, $R^2 = 0.9397$
Meadow clover: $y = 4.5064x^2 - 13.562x + 11.152$, $R^2 = 0.9764$

4. Sown lucerne (1) and meadow clover (2) seed losses at the harvest caused by pick-up reel for different λ – parameter, meadow clover heads moisture 14.6% and sown lucerne shells moisture 16.8%, stubble height h = 10 cm, z – seed losses



Sown lucerne: $y = 0.0177x^2 - 0.8291x + 9.9587$, $R^2 = 0.9684$
Meadow clover: $y = 0.0149x^2 - 0.7457x + 9.4842$, $R^2 = 0.8872$

5. Sown lucerne shells (1) and meadow clover heads (2) moisture influence on seed losses caused by pick-up reel by λ = 1.45–1.55, w – heads and shells moisture, z – seed losses

taken, always from whole engagement of the cutting bar from 1 m² area.

Stubble height to 34 cm were chosen wittingly in order of possibility to asses the course of seed losses and stubble height relation. Stubble height 15 cm is in common use. There is evident from results that at the meadow clover harvest we have to spend increased attention at stubble height choosing, because losses can arise from 1.6 to 5.1% already at the stubble height 10–15 cm. There are no seed losses at the sown lucerne harvest up to stubble height 15 cm. This is given by the higher stand height and greater distance of lower shells from soil surface. At the stubble height over 10–15 cm losses are progressively increasing and they can be 10–20%.

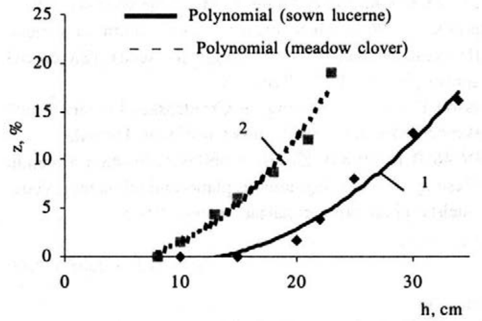
Fig. 7 is presenting dependence of the stubble height distribution at the meadow clover and sown lucerne harvest for seed at adjusted stubble height on the cutting table 7 cm and at combine harvester working speed 1.04 m.s^{-1}, h – stubble height, p – frequency.

Difference from adjusted stubble height under 7 cm or over 7 cm is caused by monitored field soil surface undulation. Statistical values for Fig. 7 are next:

Meadow clover	Sown lucerne
δ = 1.83	δ = 2.3648
v = 0.2711	v = 0.3810
$\bar{x}$ = 6.75	$\bar{x}$ = 6.2066

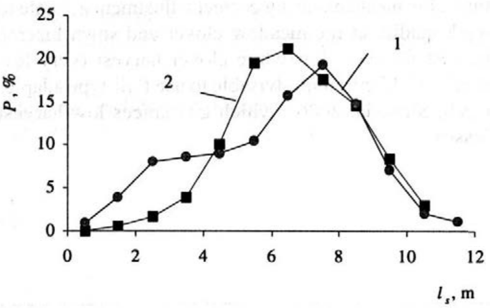
From these results it is evident that unequal soil surface can have serious influence on mowing losses.

Stand divider used at the harvest was short streamlined. That type which is used on the cutting table for cereal harvest. Losses monitoring in listed conditions did not show any dependence. Determined losses were ap-



Sown lucerne: $y = 0.0278x^2 - 0.4924x + 1.5796$, $R^2 = 0.9774$
Meadow clover: $y = 0.0535x^2 - 0.5188x + 1.2333$, $R^2 = 0.9735$

6. Dependence of meadow clover (2) and sown lucerne (1) seed losses from stubble height: h – stubble height, z – seed losses



7. Stubble height distribution at the seed sown lucerne (1) and meadow clover (2) combine harvest by adjusted stubble height on the cutting table 7 cm: h – stubble height, p – frequency of monitored parameter appearance

proximately from 0.03 to 0.06%. It is possible to assume that in dense stand and lodged stand (very rare case at the seed clover harvest) these losses will be higher.

Gleaning auger is sharing in the deformation of conveyed material coming from the cutting bar and always in precise portions rationed by pick-up reel operating speed or by λ-rate. Incorrect gleaning auger distance adjustment from a cutting table bottom affects on total losses of the cutting table. Very small distance between gleaning auger and the cutting table bottom badly deforms (cuts) the conveyed material which causes an intensive crunch of heads and shells that can be partially upthrown in front of the cutting bar.

This effect is characteristic for winter rape and leguminous plants harvest. There is no appearance of this effect at the clover crops harvest because gleaning auger loading is lower and because clover seeds has small weight (1,000 seeds weight is about 1.6–1.7 g) and almost always they are in shells. These facts reduce skew throw dynamic effect of seeds by gleaning auger.

In our case gleaning auger was outlying from the cutting table bottom at 20 mm distance and gleaning auger loading was 1.5–3.0 $kg.s^{-1}$.

DISCUSSION

Measurements showed that clover crops are specific at the harvest. Moisture markedly affects mowing losses.

It resulted from distribution of heads over stand, that stubble height for quality harvest has not to be higher than 10 cm for meadow clover and 15 cm for sown lucerne. In arid stands, it means that heads and shells moisture is lower than 15%, the pick-up reel could be a source of undesirable losses. Its work behaviour has to be in range $\lambda = 1.4–1.6$, as it is evident from pick-up reel function evaluation (Fig. 4). Stand divider caused very low losses (0.03–0.06%) and there was no relation from monitored parameters found out.

At the end we could state, that combine harvester cutting table mechanisms by correct adjustment are able to work quality at the meadow clover and sown lucerne harvest for seed. For white clover harvest (very low stand, 10–15 cm) it is advisable to use flail-type adapter (Jech, Sloboda, 2000), which guarantees low harvest losses.

CONCLUSION

Following results obtained there can be stated that seed clover crops have specific requirements on work behaviour of combine harvester cutting table mechanisms at the harvest.

Folowing facts result from our measurements:

- Pick-up reel has to work according to meadow clover heads and sown lucerne shells moisture in kinematic régime $\lambda = 1.4–1.6$.
- Stubble height for meadow clover has to be up to 10 cm and up to 15 cm for sown lucerne. Choosing of higher stubble increases losses on 10–20%.
- Gleaning auger works well up 25 mm distance from the cutting table bottom.
- Stand divider in given conditions almost did not inflict losses (0.03–0.06%).

Combine harvester cutting table is satisfying for seed clover crops harvest when above mentioned work behaviour is respected and in this case total losses after cutting table would not overrun the 1.5–2% value.

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Volume 46, No. 4 2000

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