МЕХАНІКО-ТЕХНОЛОГІЧНІ ПРОЦЕСИ, ВИКОНАВЧІ ОРГАНИ ТА МАШИНИ ДЛЯ ТВАРИННИЦТВА

UPC 631.3:519.233.3

EFFICIENCY IN THE DESIGN OF AGRICULTURAL MACHINERY BY THE CRITERIA OF SIMILARITY

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SUMMARY

The main results of a study of operating modes and processes of fragmentation in the handling of feed and other materials are presented.

Under the theory of similarity have been proposed basic criteria that can be used for design and examination of machines for mechanical processing of fodder.

Key words: shredding, chopping, milling, hammer, knife, auger, criterion, similarity, family.

УДК 631.3:519.233.3

ЕФЕКТИВНІСТЬ КОНСТРУЮВАННЯ СІЛЬСЬКОГОСПОДАРСЬКИХ МАШИН ЗА КРИТЕРІЯМИ ПОДІБНОСТІ

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РЕЗЮМЕ

Наведено основні результати досліджень процесу приготування комбікормів. Виходячи з теорії подібності базових критеріїв, їх можна застосувати під час розробки машин і механізмів для фуражних цілей.

Ключові слова: подрібнювання, вдаряти, фреза, комбайн, ніж, свердло, критерій, подібність, сімейство.

УДК 631.3: 519.233.3

ЭФФЕКТИВНОСТЬ КОНСТРУИРОВАНИЯ СЕЛЬСКОХОЗЯЙСТВЕННЫХ МАШИН ПО КРИТЕРИЯМ СХОДСТВА

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РЕЗЮМЕ

Приведены основные результаты исследований процесса приготовления комбикормов. Исходя из теории подобия базовых критериев, их можно применить во время разработки машин и механизмов для фуражных целей.

Ключевые слова: дробление, ударять, фреза, комбайн, нож, сверло, критерий, сходство, семейство.

In the chopping of materials and in particular the feed material the significant energy spent is vital, as it related to their ruination. Apart from that, the energy intensity is in direct relation and with the provision of certain quality requirements during this process. Yearly large quantities of feed material undergo through the chopping process. This is why the usage of appropriate machines for chopping, providing minimal specific energy expenditure and the appropriate quality indicators is always one of the most important issues in the process mechanization in livestock keeping.

This means that in the design of new machines (silage-combine, hay and silage chopper, feed chopper and etc.) follows the proceeding from established (experimental and theoretical) basic principles for selection and determine the type of the device and its construction, modes of operations and basic sizes.

It would be Correct to start in the following sequence:

1. Choosing of an appropriate principle of the feed fragmentation, type and structure of the device.

This is particularly important, because it is in relation not only to the quality of the chopped feed, but primarily to the opportunity of accomplishment of minimal energy expenditure (per unit mass processed) taking into consideration the physical properties of the processed feed and the work conditions, which vary widely. For example it is not correct to use hammer apparatus for feed chopping (straw, hay, cornstalks and etc.) because cutting cannot be performed using blunt knifes (hummers). The repeated hits crush the stems (if they are dry). In this case, the energy consumption is several times higher, compared to normal cutting and in addition creates dust fraction above the permissible quantity. On the other hand, according to zootechnical requirements, the chopped coarse fodder should be softened for better absorption by some animals, which cannot be achieved from machines with knives (drum, disc, etc.).

From our multiannual experiments [1, 2, 3] has found that the lowest specific energy consumption and versatility of operation could be achieved by using machines with combined chopping, where at successive stages the blades cut stems, the hammers simultaneously soften, dispose (transport) and load them into trailers or other equipment. The same machines whether with or without changing the blades could be used for milling the feed and controlling the size of the feed using different sieves. In principle, to ensure of high productivity, the feed chopping machines should have an open working chamber, i.e., to work without sieves or with sieves only when milling of concentrated feed.

The overall productivity of the chopping machines is determined from the throughput ability of the main and subsidiary working bodies. The limitation comes mainly from the «live» cross section f of the entrance of the working chamber.

Structural feature is the utilization rate of the blade (hammer), which maximum value could be equal to 1. Practically, however, known constructions of disc and drum cutting machines work with very low values of about 0,1. With the increasing of the values of this coefficient in fact increases the working stroke of the blade (hammer), which can become virtually equal to the circumference of the disc or drum on which the blades (hammers) are located. This provides chopping during the whole process (without empty movement) and even load on the shaft.

In a comparative assessment of apparatus for crushing the feed with a view to the rational using of the working volume and the blades (Fig. 1) can be found that it is the best in the combined apparatus (Fig. 1D). Assuming the ratio of the cross section f of the opening for submission of the mass to the entire area F described by the blade i.e. $K = \frac{f}{F}$, evidently this coefficient will be bigger in case D, where the mass is submitted and cut over the entire circumference (cylinder surface – $\pi D v$),, reduced only by the area of the contra knifes.

Obviously the size of the cross section is essential for the performance. Additionally, the traditionally used principles are related with means for submission, compacting and discharging of material. These are special conveyors and feeding rollers, and in many cases, additional fans for disposal of chopped material, what complicate and aggravate the structure, and significantly increase energy expenditure. The combined machines do not require such assisting means, because here the cutting apparat takes the role of disposing fan, and the mass goes to the working chamber under its own weight and with an auger, which can beforehand to cut the material.

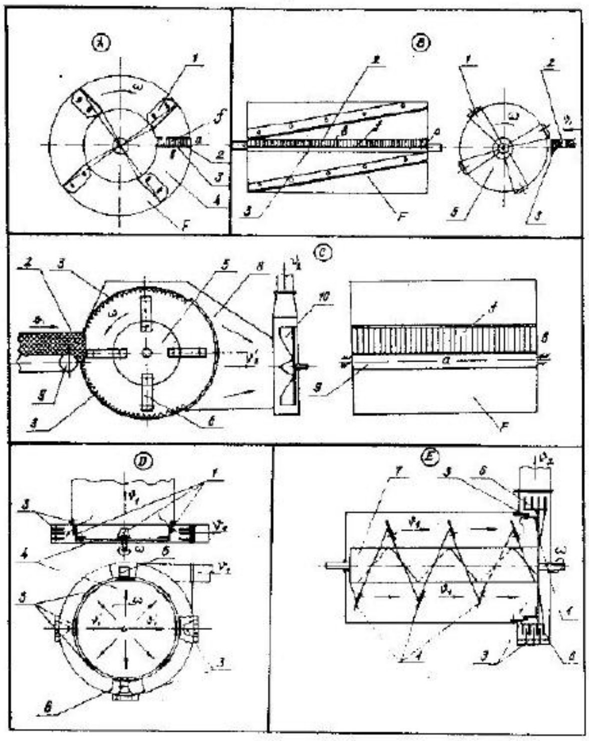

Fig. 1 Types of chopping machines with different coefficient K

A) Disc – like cutting device; B) drum – like cutting device; C) hammer – like cutting device; D, E) combined cutting device with vertical D or horizontal E placement.

2. Selection of the optimal peripheral speed v_{opt} of the working body for shredding.

There is a direct relationship (Fig. 2) between peripheral speed *V* of the working body, productivity *Q* and specific energy consumption *q*. With the increasing of the speed, the productivity increases up to certain limits, then it remains constant, but the growth of specific energy consumption is significant. As an initial velocity v can be suggested values between 50 and 70 m.s^{-1}, where the specific energy consumption q is minimal [1, 2]. The optimal peripheral speed v_{opt} of the working body (the speed of cutting/chopping, and hence the frequency of rotation of the rotor) could be determine by examination of the already produced machine in specific controlled conditions. The necessary power P_x after the optimal speed v_{opt} increases due to congestion, but also because increases energy consumption at idle, as at the same time the rotor works as a fan. In this case, the power P_0 grows in the third degree of the increasing of speed, i.e.

$$P_0 = \eta_1\left(v^3\right).$$

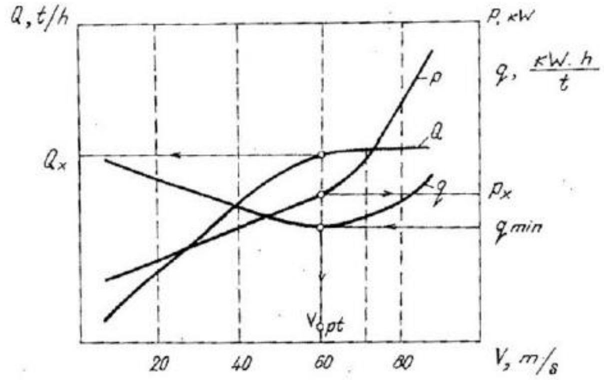

Fig. 2 General characteristics of machines for chopping:

P – power, kW; *Q* – productivity, t.h^{-1}; *v* – peripheral speed, m.s^{-1}; *q* – specific energy consumption, kW.h.t^{-1}.

3. Defining of productivity *Q* and basic dimensions of the machine.

In general, the productivity is set depending on the specific requirements. The chosen performance must be provided by the designed unit, under certain parameters (diameter of the rotor, width, speed and etc.).

In the most common case the productivity of chopping machines depends on the basic dimensions of the rotor, respectively the size of the working chamber (width *B* and diameter *D*), on the peripheral speed of the rotor *v* and on the density ρ of the feed (kg.m^{-3}). Then the productivity Q (t.h^{-1}) will be:

$$Q = 3{,}6CDBv\rho \tag{1}$$

Where: The coefficient *C* depends on the structure of the machine, the physical properties of the feed and others. It should be determined experimentally for each type of machine when working with the given type of feed. This coefficient *C* acts as a criterion of similarity [3].

$$C = \frac{Q}{DBv\rho} = idem \tag{2}$$

Which means that if there is a produced machine (model) with proven optimal parameters marked with an index «*M*» we can determine the values of the dimensions D_0, B_0, v_0 and ρ_0 to get other productivity *Q* or specify *B* or *C* at the appropriate productivity. Therefore,

$$\frac{Q_м}{D_м B_м v_м \rho_м} = \frac{Q_0}{D_0 B_0 v_0 \rho_0} \quad \text{or}$$

$$Q_0 = Q_м \frac{D_0 B_0 v_0 \rho_0}{D_м B_м v_м \rho_м} \tag{3}$$

Often this applies to the same type of feed ($\rho_0=\rho_M$) at the appropriate speed of chopping ($v_0=v_M$), i.e.

$$Q_0 = Q_м \frac{D_0 B_0}{D_м B_м} \quad (4)$$

It should however to bear in mind that if you need to increase productivity of manufactured machines for cutting, it generally can be ensured by increasing the width *B*. The attitude $\frac{B}{D} = k$ is also a criterion of similarity, which should be identical for a type (family) machines which i.e. $B=k.D$.

The determination of the diameter *D* is based on studies of similar structures under specific conditions. Increasing the productivity by excessive enlarging of diameter is not favorable because according to theory of similarity of the fans, the required power *P* increases significantly (in the fifth degree) i.e. $P = \eta_2(D^5)$. If we introduce the concept of specific load for the chopping apparatus (the machine) *q'* like ratio of productivity to provisional unit area,

i.e. $q' = \frac{Q}{BD}$, (t/h.m^2) or (kg/s.m^2) as an experimentally found concrete measure of a particular machine type, then the productivity *Q*, t.h^{-1} could be represented respectively as

$$Q = q'BD \quad \text{or}$$
$$Q = 3{,}6q'BD \quad (5)$$

4. Determination of the necessary power *P*.

Power *P* required to drive the working bodies of the machine depends from the productivity *Q*, the peripheral speed *v* and the principle of fragmentation of the product. To determine the required for shredding power it is necessary first to define the specific work for shredding, which depends on the mechanical properties of fragmentation feed. For example, the specific work *A* for shredding of roughage can be determined using the following formula:

$$A = c(\lambda - 1), \text{ kJ.kg}^{-1} \quad (6)$$

Where: λ is the degree of chopping $\lambda = \frac{D}{d}$ or $\lambda = \frac{L}{l}$

D, L, d, l – initial and final dimensions of material being processed;

C – experimentally determined coefficient which characterizes each type of feed.

For example:

- For straw $C=0{,}9 \div 1{,}2$ kJ.kg^{-1};
- For hay $C=1{,}8 \div 2{,}2$ kJ.kg^{-1};
- For green feed $C=1{,}4 \div 1{,}8$ kJ.kg^{-1}.

The degree of shredding of the coarse feed may be determined approximately by the formula,

$$\lambda = \frac{D}{d} = \frac{D^3}{d^3} = \frac{V_н}{V_k} = \frac{m_н \rho_н}{m_k \rho_k}, \quad (7)$$

where: V_H, V_K, m_H, m_K, ρ_H and ρ_K are corresponding volumes, masses and densities, respectively before and after the fragmentation.

Then the necessary power for chopping P_x, kW (Fig. 2) could be beforehand determined using the formula:

$$P_x = AQ_x \quad (8)$$

where: Q_x is the productivity in kg.s^{-1}.

If the power required for such machine or for a machine, adopted as a model of projected family is known, the power of any other similar machine or the rest of the machines from the same family can be determined, proceeding from the criterion of similarity of power [3]:

$$\prod = \frac{P}{Qv^2} = idem \quad (9)$$

This criterion of similarity of power should be the same for all machines from the same family. Since the rotor speed is the same for all machines, i.e. $v=const$, the criterion of similarity is reduced to the attitude:

$$\prod = \frac{P}{Q} = q \quad (10)$$

Formula (10) represents the specified consumption of energy *q* in kWh.t^{-1}. As it must be equal for all *i* – number of machines, it follows that

$$\frac{P_м}{Q_м} = \frac{P_1}{Q_1} = \frac{P_2}{Q_2} = \ldots\ldots \frac{P_i}{Q_i} = q_м$$

(11)

Alternatively:

$$P_i = \frac{P_м}{Q_м} Q_i \quad \text{or}$$

$$P_i = q_м Q_i \qquad (12)$$

This method is appropriate for quick determination and evaluation on particular machines [4, 5].

To take into account the influence of humidity over the energy consumption, the following dependence can be used:

$$P_0 = \frac{P_м}{Q_м} Q_0 \frac{100 - W_м}{100 - W_0}, \qquad (13)$$

where: P_0 and Q_0 are the power and productivity of the machine in a different humidity W_0;

P_M and Q_M – the power and productivity during humidity W_M.

This dependency is particularly important for the study, creation and evaluation of machinery for crushing of roughage. By the proposed method can be shown the impact of so-called disturbing, but controllable factors in the studies and tests of shredders for roughage in which the main comparison parameters shall be adapted to the same value of the relevant factor. For example, by recalculation of the experience gained values of power P_M and productivity Q_M for one and the same moisture content of the material (14%) respectively will be obtained more exact values of $P_м^{14}$ and $Q_м^{14}$.

So with significantly greater accuracy it can be made an objective comparative assessment of different models of machines or to predict the basic parameters of a new designed machine.

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