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To the Determination of Required Power on the Drive of Movable Operating Elements of the Universal Collector-Fodder Shredder

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Abstract: It is offered the harvesting technology of shredded hay which essence is that the dried-up hay is selected from a swath; it is shredded, loaded in conveyors of facilities and ricked under a canopy. At the same time, it is provided decrease in specific operating costs in 2-2.5 times in comparison with swathed technology of harvesting of rough forages. It is developed for implementation of technology the collector - fodder shredder, consisting of a collector without racetrack, the adding reels, the screw and a hammer mill. As a result of theoretical researches there are received analytical expressions for determination: the required power of the propelling worm and under-pressing reels of the collector-fodder shredder. Reliability of the received analytical expressions is checked by pilot studies. Comparison of theoretical calculations and results of pilot studies was shown that a discrepancy of a calculated value of required power of the collector-fodder shredder with the actual values there are in limits 1.3-7.0% and this discrepancy with optimum productivities of the machinery makes only 1.3-2.0% that indicates on reliability of the received analytical expressions.

Key words: The collector-fodder shredder, the hammer rotor, the pickup mechanism, the under-pressing reel, the screw

INTRODUCTION

Now for harvesting of rough forages, haylage and silage there are developed various forage harvesters, collector-fodder shredders and carts-collectors for example, Russia makes the TPF-45 carts-collectors, the PN-400 forage harvesters, Ukraine makes the KPI-2,4A trailed forage harvester (Valga and Dobrinov, 2004).

Deer and Co and NewHolland» firms (USA) make self-propelled fodder harvesting complexes and their total mass of each makes more than 9000 kg. “Krone” firm (Germany) makes self-propelled forage harvesters of modification “BigXV8”, “BigXV 10”, “BigXV 12” where the total mass of each-more than 11000 kg. Also, the analysis of foreign literature shown that by foreign researchers much attention is paid to processes of harvesting of a silage, preparation of feed mixtures, mixed fodders and premixes (Mohan *et al*., 2004; Pishgar-Komleh *et al*., 2011; Mohd-Setapar *et al*., 2012; Khan *et al*., 2012).

In many works of foreign researchers there are considered questions of grinding of the caulescent forages of hemp and sugar cane by the cutting movable operating elements. At the same time, there are determined a power consumption of grinding process of the caulescent forages by the cutting movable operating elements and also it is determined the critical velocity of the cutting of the caulescent forages by knife movable operating elements (Chattopadhyay and Pandey, 2000). At the same time, it is established that depending on a type of the caulescent forages, the critical velocity of a knife is equal 15-30 m sce^{-1}.

Besides, much attention is paid to researches of grinding of the caulescent forages by hammer movable operating elements. For example, in research (Mani *et al*., 2006) there are determined the specific power consumptions of grinding of the lucerne at installation of the sieves 5, 6 mm. In research (Chattopadhyay and Pandey, 2001) it is considered the mathematical model of the movement of the crushed particles in the deflector of the forage harvester.

Forage harvesters and pickup attachments are supplied with reel knives; they provide grinding of green mass and harvesting of a haylage and silage. Besides, they are used for grinding of rough forages. At the same time they grind in a dry form the rough forages very largely and they don’t split stems along fibers, therefore these rough forages are repeatedly ground at winter variant of stocking of the feed mixtures and another one lack of these machines is only their seasonal use, i.e., in winter time the existing forage harvesters and pickup attachments don’t work.

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In the existing technologies of stocking of the pressed rough forages, losses of the most valuable leaf part reach up to 14% of the general harvested mass of hay. It is known that in leaf part of herbs in comparison with stem part it is more of vitamins and carotene in 10 times. If to consider that the leaf part for bean herbs makes 40-50% of total mass, then the above-stated losses on qualitative structure are equivalent 30% of general harvested mass of hay.

Besides, the stocked swaths and small-sized bales are stayed in the field during several days, so in the top layers of these pressed forages there is a total loss of carotene and vitamins, therefore it is possible to note that the existing technologies don't promote to the harvesting of the qualitative rough forages, providing increase of production of animal husbandry at the dairy and feeding farms.

Earlier harvesting of rough forages in summertime was considered as separate system, i.e., system of harvesting of rough forages which was begun with haymowing and came to the end with ricking of hay in spreading type in small-sized bales or in swaths. Laying-in of fodder and feeding of forages in winter time were also considered as separate system. Proceeding from it, earlier, there were developed various types of feed processing buildings. Winter feed storage the full-ration feed mixtures for cattle and sheep are followed by grinding of the rough forages, silage or haylage and also preparation of mixed fodders. For essential decrease in operating costs we are offered to consider as uniform system these two systems of preparation of mixed fodders. At the same time it is offered to make harvesting of rough forages in the grinding type, i.e., the dried-up hay in swaths to keep to humidity 18-20% and it is not necessary to press or to form in shocks but there is necessary to select, grind to the required size 20-30 mm (for sheep) or to 30-50 mm (for cattle) to load in transportation and to rick under a canopy. In this case in winter time it is necessary to load serially into a body of the distributor mixer the crushed hay, silage or haylage and the crushed grain forages or mixed fodders, i.e., feed storage the full-ration feed mixtures becomes simpler. For example, at harvesting of rough forages in a swathed type all number of operations, beginning from haymowing to winter feeding are equal 12, and at stocking of rough forages in the grinding type the total operations is equal 7. The carried-out economic calculations show that application of the offered technology of stocking of the ground hay in comparison with the existing technologies of harvesting of rough forages provides decrease in specific operating costs in 2.0-2.5 times.

For introduction of this technology it is required to develop the universal collector-fodder shredder, providing harvesting of rough forages in the grinding type and grinding of all types of the caulescent forages at permanent study area. Now a current trend of development of technology is development of multipurpose equipment. Proceeding from it and from the applied direction of scientific researches in the field of agrarian and industrial complex, the development of a universal multipurpose collector-fodder shredder for harvesting of rough forages on new technology and also for grinding of all types the caulescent forages and preparation of mixed fodders from rough forages, the silage or a haylage, providing decrease in number of operations and improvement of quality of the stocked and made forages, is an actual problem of modern agriculture.

At developing of a new universal collector-fodder shredder, it is installed the new pick-up mechanism, possessing a high work reliability. The main technical novelty of the pick-up mechanism that that it has no racetrack, swathers and cranks. During the collector work these details are quickly worn out and they are often failed.

The universal collector-fodder shredder is supplied with the hammer mill, providing of an adjustment of fineness of the crushed particles in the open crushing chamber.

Research objective: Development of a universal collector -fodder shredder for harvesting of rough forages in the grinding type, a haylage and the crushing of the caulescent forages at permanent study area, reducing specific operating costs of harvesting and stocking forages in 2-2.5 times.

MATERIAL AND METHODS

There are conducted the theoretical and pilot researches for determination of required power of movable operating elements of a universal collector-fodder shredder and also it was determined a reliability of the received analytical expressions. At carrying out of the theoretical researches there were applied methods of theoretical mechanics and probability theory. Methods of one-factorial pilot studies were applied at pilot studies. Determination of required power on the drive of movable operating elements of a universal collector-fodder shredder is carried out by a tensiometric cardan and, together with it, the torque of the drive of the universal collector-fodder shredder was registered by the oscillographic paper.

RESULTS AND DISCUSSION

The constructive and technological scheme of the universal collector-fodder shredder Is proved in 2012 (Fig. 1). Figure 1 it is visible that at the movement

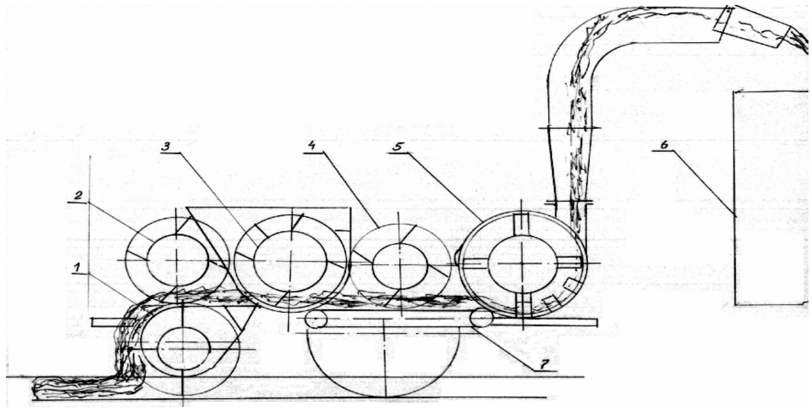

Fig. 1: experimental dependence; 2 theoretical dependence

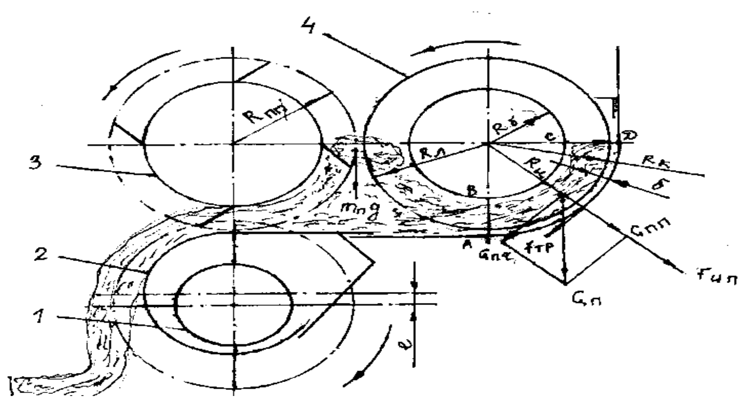

Fig. 2: Scheme of work of a collector, under-pressing reel and screw conveyor

of the aggregate with a velocity V_a, collector's fingers lift weight from a swath and at the same time the power, spent for lifting of the swath by the selecting reel is determined by a Eq. 1:

$$N_{\Pi r} = \frac{m_{rm} \pi D_{\Pi} V_a}{V_{\Pi} Q_{\Pi}} \left(q + 2\omega_r \frac{(1_m - ?) n_r}{30} \right) R_{rm} \frac{\pi n_r}{30} \text{ watt} \quad (1)$$

Where:

- m_{rm} = Weight of the one running meter hay swath (kg m^{-1})
- D_n = Diameter of a circle of rotation of a finger to the center of gravity of a bunch of hay (m)
- V_a = Velocity of the movement of the aggregate (m sec^{-1})
- V_n = Linear velocity of a reel on the ends of fingers (m sec^{-1})
- Q_n = Quantity of rows of the selecting fingers on a reel
- ω_a = Angular velocity of a reel (radius sec^{-1})
- 1_m = The maximum length of the fingers, overhang from under rings-slopes (m)
- a = The minimum length of the fingers, overhang from under rings slopes at vertical position of fingers (m)
- n_r = Frequency of rotation of the reel (min^{-1})
- R_{rm} = Radius of a circle of rotation of a finger with the hay bunch center of gravity at horizontal position of a finger (m)

The operation scheme of the under-pressing reel is given in Fig. 2. Figure 2 it is visible that the mass of hay lifted by the selecting reel moves further by under-pressing reel 3 to the screw conveyor 4. At rotation of under-pressing reel and its turn on an angle between radiuses of the next rows of fingers of a reel there passes time Δt:

$$\Delta t = \frac{60}{Q_{pf} n_r} \text{ s} \quad (2)$$

Where, $Q_{pб}$, quantity of rows of the under-pressing fingers. During Δt, the aggregate with a velocity moves to distance:

$$\Delta S = \Delta t V_a = \frac{60 V_a}{Q_{pf} n_r} \text{ m} \quad (3)$$

Depending on the mass of hay which is on the one running meter of a swath m_{rm}, a certain portion of mass rises by the collector and further moves to the under-pressing reel. At moving of the aggregate on distance ΔS, the mass of a portion m_n is determined by a Eq. 4:

$$m_n = \Delta S m_{rm} = \frac{60 V_a m_{rm}}{Q_{pf} n_r} \text{kg} \quad (4)$$

In this case the moment of resistance of the given mass to the under-pressing reel is determined by a Eq. 5:

$$M_{pr} = m_{\Pi} g R_{pf} = \frac{60 V_a m_{rm} g R_{\Pi}}{Q_{pf} n_r} \text{nm} \quad (5)$$

Power, required on the drive of the under-pressing reel, is analytically expressed as follows:

$$N_{pr} = M_{pr} \omega pf = \frac{60 V_a m_{rm} g R_{pf}}{Q_{pf}} \quad (6)$$

$$\frac{\pi}{30} = \frac{2\pi V_a m_{rm} g R_{rm}}{Q_{pf}}, \text{Watt}$$

Further, the given mass moves to the chamber of the screw. In the collector-fodder shredder the step of flights of the screw makes 0,6m. For example with a width of swath of 1.2 m there will be worked 3 parts of the blade of the screw simultaneously. At the same time, it is possible to consider that the movement of mass of hay happens on all length of the screw, and the cross section of the screw is given in Fig. 2.

In this case, it is possible to consider that intensive movement of the mass of hay, moving to the chamber of the screw, happens on sector ABCD. For determination of the maximum value of required power, we consider the provided assumption justified. Proceeding from it, the mass of hay in the volume, limited to square ABCD, by the total length of the screw L_s is determined by a formula:

$$m = \frac{\pi\left[\left(R_b+\delta\right)^2 - R_r^{\,2}\right] L_s d_h}{4} \text{kg} \quad (7)$$

Where:

R_b, R_r = The screw blade radius, radius of a reel (m)
δ = A clearance between a finger of the blade and the case of the screw (m)
L_s = Total length of the screw (m)
d_h = Density of the hay which is in the case of the screw (kg m^{-3})

It is known from the power analysis that resistance to rotation of the screw is created by the tangential force component of weight of hay and weight friction force. At the same time, for determination of required power of the screw it is offered the following analytical expression:

$$N_{и} = F_c R_c \omega_s = \left(G_{?\tau} + F_{??}\right) R_c \omega_s = G_{\Pi\tau} + \left(G_{pf} + F_{c\Pi}\right)$$

$$f_{тр} R_c \frac{\pi n_s}{30} = \left[G_{\Pi} \sin\alpha + \left(G_{\Pi} \cos\alpha + m\left(\frac{\pi n_s}{30}\right)^2 R_c\right) f_{тр}\right] \times$$

$$R_c \frac{\pi n_s}{30} = \left[mg \sin\alpha + \left(mg \cos\alpha + m\left(\frac{\pi n_s}{30}\right)^2 R_c\right) f_{т?}\right]$$

$$R_c \frac{\pi n_s}{30} = \frac{\pi\left[\left(R_b + \partial\right)^{2\blacklozenge} - R_r^2)\right] L_s \rho_?}{4} \times$$

$$\left[g \sin\alpha + g \cos\alpha f_{тр} + \frac{\pi^2 n_s^2}{900} R_c f_т\right] R_c \frac{\pi n_s}{30} \quad (8)$$

Where:

f_{mp} = Friction coefficient at the movement of hay on a steel surface
n_s = Frequency of rotation of the screw (min^{-1})
R_c = Radius of the center of gravity of hay in the screw case, the radius of a chamber of the screw (m)

At determination of required power of the screw conveyor, in our opinion, it is necessary to consider all length of the screw, i.e. here it is necessary to consider in addition a screw sector with rectilinear bars. As at this sector there is no back wall, value of frictional force of the hay bunch can be a little overestimated. However, this increase of value of friction force can be neglected.

Further, mass is taken by the under-pressing reel of a grinder and it provides giving of mass into a grinding chamber. In the screw chamber the mass of hay with the cross section ABCD is moved along screw length with a velocity:

$$V_{ls} = S_b / \Delta t_1 = \frac{S_b}{n_{sv}} \text{m/sec} \quad (9)$$

Where:

S_b = A step of the blade of the screw (m)
Δt_1 = Time for 1 turn of the screw (sec)
n_{sv} = The frequency of rotation of the screw, (sec^{-1})

At the movement of hay mass along screw length with a velocity, value of the hay mass, moving under rectilinear bars of the screw, having length, is determined by a Equation:

$$m_{pf} = \frac{\pi\left(R_c^2 - R_r^2\right) lpf\rho_c}{4} \quad (10)$$

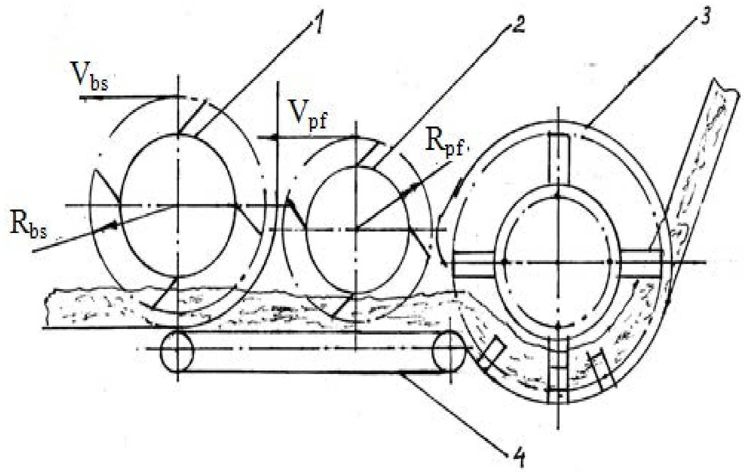

Fig. 3: The operation scheme of the screw and under-pressing reel during transfer of mass to the grinding chamber

Where, R_c the radius of the screw chamber (m). The hay mass, moving under screw bars, moves to the throwing grinder reel. At the same time bars of the screw throw mass with a velocity (Fig. 3). The 1-screw; 2-under-pressing reel; 3-grinding chamber; 4-conveyor. The velocity, transferred by screw bars to mass at the initial moment will be equal to the circular velocity of bars V_{bs} determined by a Equation (m sec^{-1}):

$$V_{bs} = \frac{\pi n_s}{30} R_{bs} \tag{11}$$

Where, R_{bs} screw radius on the ends of bars, fixed at the end of the screw, m. It should be noted that process of mass transfer from screw bars to fingers of the under-pressing reel, generally, happens for a quarter of the screw turn and this time is determined by a Equation:

$$\Delta t_h = \frac{1}{\frac{n_s 4}{60}} = \frac{15}{n_s} s \tag{12}$$

During this time mass moves under finger impacts of the under-pressing reel, receives the velocity which is equal to the circular velocity of fingers of a reel which is determined by a formula:

$$V_{pf} = \frac{\pi n_{pf}}{30} R_{pf} \tag{13}$$

Where:

n_{pf} = The frequency of rotation of the under-pressing reel (min^{-1})

R_{pf} = Radius of the under-pressing reel on the ends of fingers (m)

Depending on the chosen kinematic mode, the under-pressing reel is rotated with high linear velocity and at the same time, arising inertia force, i.e., resistance of the under-pressing reel is determined by a Equation:

$$F_{ipr} = m_{pf} \frac{V_{pf} - V_{bs}}{\Delta t_h} = \frac{\pi\left(R_c^2 - R_r^2\right) l_{pf} \rho_c}{4} \times \frac{\left(V_{pf} - V_{bs}\right) n_s}{15} = \frac{\pi\left(R_c^2 R_r^2\right) l_{pf} \rho_c \left(V_{pf} - V_{bs}\right) n_s}{60} H \tag{14}$$

Considering, that the force, has to be generally applied for the ends of fingers of the under-pressing reel, i.e. on radius, at the same time, required power on the drive of the under-pressing reel of a grinder, is determined by a Equation:

$$N_{ipr} = F_{ipr} R_{pf} \omega_{pr} = \frac{\pi\left(R_c^2 - R_r^2\right) l_{pf} \rho_? \left(V_{pf} - V_{bs}\right) n_s R_{pf}}{60} \times \frac{\pi n_{pr}}{30} = \frac{1}{1800} \pi^2 \left(R_c^2 - R_r^2\right) l_{pf} \rho_? \left(V_{pf} - V_{bs}\right) n_s R_{pf} n_{pr} \text{watt} \tag{15}$$

where: n_{pr} the frequency of rotation of the under-pressing reel (min^{-1}).

According to the put constructive and technological scheme of the universal collector-fodder shredder there are remained not considered the feeding belt transporter and a grinder of forages. The belt transporter has very small load at feeding of forages, therefore value of required power on the drive of the conveyor can be neglected. In this case, need for the conveyor, generally, arises at feeding of damp forages, i.e., at feeding of the silage or haylage.

Fig. 4: The universal collector - fodder shredder

Table 1: Power-intensity of selection processes, grinding and loading of the ground hay in the body transportation

Type of the forage	Humidity (%)	The forage mass on 1 running meter of the swath (kg m^{-1})	Aggregate movement velocity (m sec^{-1})	Productivity (t h^{-1})	Power consumption (KW)	Power-intensity (kWh t^{-1})
Lucerne	15.7	1.0	0.926	3.33	11.3	3.40
Lucerne	15.7	1.5	0.926	5.0	13.4	2.68
Lucerne	15.7	2.0	0.926	6.67	14.6	2.18
Lucerne	15.7	2.5	0.926	8.33	15.5	1.86
Lucerne	15.7	2.7	0.926	9.0	16.2	1.80

In earlier conducted researches it is received the analytical expressions for determination of required power on the drive of the open type grinder.

Thus, as a result of the theoretical researches, conducted in 2013, there were received analytical expressions for determination of required power on the drive of the selecting reel, the screw conveyor and the under-pressing reels of grinder and for determination of required power on the drive of other movable operating elements of a collector-fodder shredder there were received analytical expressions at earlier conducted researches; therefore results of theoretical researches allow to determine analytically full required power on the drive of movable operating elements of the universal collector-fodder shredder.

Reliability of the received analytical expressions is specified by results of pilot studies. We were developed design documentation and it is made experimental sample the universal collector-fodder shredder for implementation of the technologies of harvesting of rough forages in the grinding type and haylage (Fig. 4).

At pilot studies according to justification of parameters of the collector-grinder of forages it was determined its required power by tensometric cardan. Values of rotational torque and velocity of rotation of the driveshaft were registered on oscillographic paper.

At selection and grinding of a lucerne with humidity of W = 15.7%, the velocity of aggregate movement was equal to 0.926 m sec^{-1} and productivity of the collector-fodder shredder was regulated by various values of mass which was spread out on the 1 running meter of a swath. In these experiences the forage mass which was spread out on the 1 meter of a swath was in limits m_s = 1.0-2.7 kg m^{-1} and at the same time, productivity of the machine changed within Q_p = 3.33-9.0 t h^{-1} and power consumption varied from 11.3-16.2 kW.

Experimental results on determination of power-intensity of selection processes, grinding and loading of the ground hay in the body transportation are given in Table 1.

Experimental and theoretical dependences of the required powers of the processes, which are carried out by the universal collector - fodder shredder are given in Fig. 5.

The analysis of dependence of power-intensity of selection processes, grinding and transportation of the ground hay by an air stream shows that at optimum productivity Q = 8-9t h^{-1} value of power-intensity is in limits 1.8-2.0 kWh t^{-1}. All this shows that process of grinding of rough forages happens with smaller power-intensity almost in 2.0-2.5 times in comparison with a usual grinder.

This sharp decrease in power-intensity is connected with the fact that feeding of rough forages in grinding chamber is carried out with high uniformity and it is also one of the main advantages of technology of harvesting of the ground hay by the universal collector-fodder shredder.

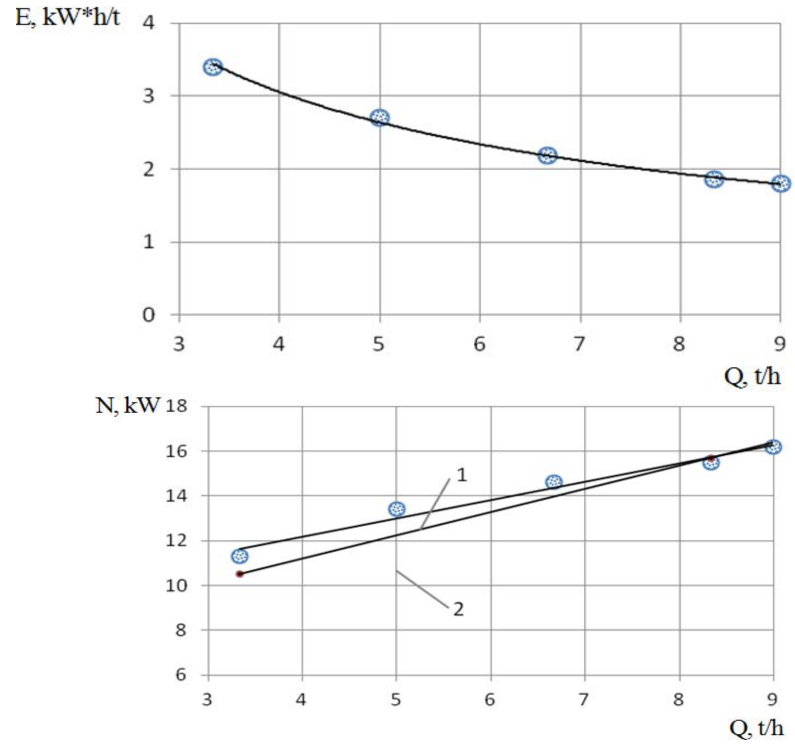

Fig. 5: Value of required power and specific power-intensity of process of change of lucerne depending on productivity of a collector - fodder shredder\

Determination of theoretical value the required powers were carried out by the received analytical dependences. At the same time there were determined required powers of processes of hay selection, costs of work of the under-pressing reels, the screw and on hay grinding process by the grateless grinder, supplied with rows of counter-hammers.

The difference between theoretical and experimental values is in limits 1.3-7.0%. Given difference decreases with big productivities of the machine, i.e. with optimum productivities of the collector-fodder shredder a difference between theoretical and experimental values of the required powers make only 1.3-2.0% and it shows reliability of the received analytical dependences.

There are included hay density in a ring layer in the screw chamber in the analytical expressions, intended for determination of required power of the screw and the under-pressing reel of grinder. Actually hay density in the screw chamber depends on its mass, lifted by the selecting reel from the swath. Together with it, hay density in a flume of the screw can be determined by a Equation:

$$pc = \frac{m_n}{V_s} \quad (16)$$

Where, V_s the volume of the screw, filled with the moving mass. For calculation of volume of the screw flume, where hay is compressed, it is possible, with some assumption, to choose the volume of a ring layer which thickness is equal to clearance between blades and the screw flume, and at the same time volume can be determined by a Equation:

$$V_s = \frac{\pi\left(R_c^2 - R_c^2\right) B_B}{4}$$

Where, B_B width of swath (m). Actually, hay mass, lifted by the one row of fingers, depends on the mass, located on the one running meter of a swath m_{rm}.

At calculating of the required power of the screw and under-pressing reel of a grinder, hay density is chosen from Fig. 6. It is visible that theoretical values of the general requirement of capacities are coordinated well with experimental values and it shows reliability of theoretical dependences.

Thus, results of theoretical and pilot studies show reliability of the received analytical expressions, therefore these formulas can be applied at design of the similar collectors grinders of forages and forage harvesters.

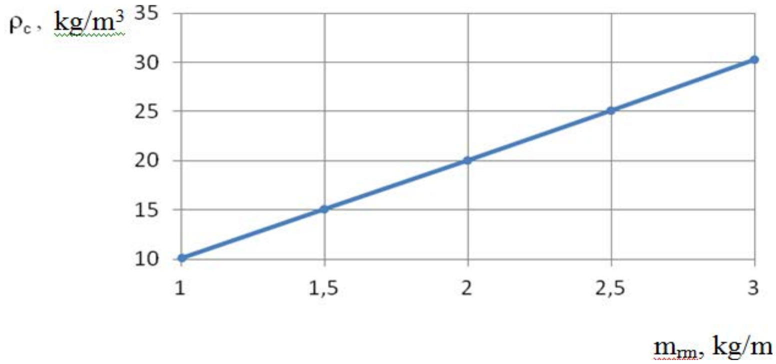

Fig. 6: Value of hay density in the screw chamber, depending on the hay mass which is on the one running meter of the swath

CONCLUSION

For improvement of quality and decrease in specific operating costs it is offered the technology of harvesting of the grinding hay, i.e. the dried-up hay to humidity 18 - 20% is selected from a swath, it is ground to the required size with splitting stems along fibers, then it is loaded in transportation and ricked under the canopy. At the same time, total number of operations, beginning from haymowing to winter feeding of rough forages decrease by 1.7 times and specific operating costs in 2.0-2. 5 times in comparison with stocking of the pressed rough forages.

It is developed for implementation of technology the collector-fodder shredder, consisting of a collector without racetrack, the adding (under-pressing) reels of the collector and grinder, the screw and a hammer mill.

As a result of theoretical researches there are received analytical expressions for determination of the required powers on selection processes, under-pressing and hay transportation by the screw movable operating element. With a productivity of the collector-fodder shredder of 8- 9 t h^{-1} a difference between theoretical and experimental values of the general required powers of the machine make only 1, 3-2% that proves reliability of the analytical expressions.

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