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Development of Universal Pick-Up Chopper for Harvesting of Chopped Hay and Haylage

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Abstract: To implement the proposed technology for chopped hay and haylage harvesting, the universal pick-up chopper equipped with a hammer-knife working elements and a new picking mechanism without a treadmill has been developed. The use of the technology for harvesting of chopped coarse forage provides a reduction in specific operating costs by 2.45 times compared with the technology for harvesting of pressed forage. The goal of the research is the development and implementation of the proposed technology and universal pick-up chopper which reduces operating costs, improves the quality of chopped coarse forage. To theoretically justify the picking up process with a picking mechanism without a treadmill, the methods of theoretical mechanics were applied. In order to determine the optimal parameters of the pick-up chopper, one-factor experimental researches were used. As a result of theoretical studies, analytical expressions were obtained for determining the forces acting on the forage when lifting it up with the fingers of the pick-up. The values of the resultant forces were determined and the possibility of operating the mechanism without disturbing the technological process of selecting coarse forage was justified. All this proves the reliability of the obtained analytical expressions. As a result of experimental researches and laboratory-field research tests we determined that the universal pick-up chopper, equipped with a new picking mechanism with hammer-knife working elements, provides harvesting of chopped hay with a capacity of 9.0-9.5 t/h and haylage with a capacity of 5.83-7.56 t/h.

Key words: Picking mechanism, pick-up chopper, resultant forces, hay picking from the swath, resultant forces

INTRODUCTION

Today in Russian Federation and the Republic of Kazakhstan, livestock farms are being enlarged; dairy and fattening farms are being established. For these farms, harvesting of high-quality coarse forage is a priority. Harvested coarse forage must be distributed in a chopped form. If you distribute coarse forage without chopping it, you will face the losses up to 25% (Medeubekova, 1981). It is known that feeding cattle with chopped hay with a maximum fraction size of up to 100 mm, i.e. with an average particle size of 30-50 mm, the average daily weight gain is increased by 35%, compared to feeding animals with unchopped hay (Peter, 1986).

The process of chopping the stems of various plants was considered in the works of foreign scientists (Attar *et al*., 2013; Ajav and Yinusa, 2015; Enhessari *et al*., 2013; Zastempowski and Bochat, 2014). Over the decades, energy crisis is one of the most important concerns of human societies. This happens under conditions that consumption of fossil energy and the climatic pollutions and changes caused by it has been changed into a problem that buildings can be considered as one of the most effective factors in accelerating this issue (Ghasemi, 2017; Attar *et al*., 2013).

In these works, the cutting speed of maize and sorghum stalks was determined and it is 16.4 .35.3 m/sec, the parameters of the knife-type working elements (cutting angle, sharpness and knife thickness) were determined and mathematical model of the cutting process of plants by radial knives was formed.

In this researcher, the process of chopping coarse forage with humidity of 17.1.31.66% is considered. It is determined that the average cutting length should be within the range of 20-40 mm (Bhandari *et al*., 2008).

The process of chopping coarse forages in hammer crushers and other machines is also considered in the works of foreign scientists (Adgidzi, 2007; Ghorbani *et al*., 2013. In the researches of the scientists (Yin, 2014; Wang *et al*., 2010), the process of adjusting the height of the picking finger from the surface of the earth was considered and the loss of hay by picking finger was

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determined and it was >1%. In the research of foreign scientists (Rotz and Sprott, 1984; Dange and Thakare, 2010; Long *et al*., 2016; Tahmassebpour, 2017, 2016; Bhandari *et al*., 2008), questions of alfalfa crushing and determination of the quality of alfalfa hay and haylage harvesting technology as well as cows feeding with alfalfa hay are considered. It is noted that the norm of feeding with haylage was 19.2-21.2 kg/day.

Today, for the timely and high-quality harvesting of coarse forage we propose a new technology for harvesting chopped hay and haylage. The use of the technology of harvesting coarse forage in a chopped form provides a reduction in the number of operations (from mowing to distribution) by 2 times and the specific operating costs for harvesting and preparation of coarse forages by 2.45 times (Abilzhanuly and Abilzhanov, 2014). In addition, when chopping coarse forage to the required size in winter, there isnoneed for a stationary feed-processing building which provides savings for farming. When using the proposed technology, harvesting of feed is carried out in time, i.e., the quality of harvested hay improves.

For harvesting chopped hay, existing forage harvesters can be used. However, they are equipped with cutting and chopping apparatus that does not ensure the splitting of the stems along the fibers when chopping coarse forage with a moisture content of 17-18%.

Based on this, the goal of the research is the development and introduction into agriculture the technology of harvesting chopped hay and universal pick-up chopper, ensuring the preparation of coarse forage with reduced operating costs and high quality of harvested hay.

To achieve this goal, it is necessary to solve the following problems of theoretical and experimental research and testing: analysis of the forces acting on the stem during the picking of hay by a pick-up chopper; carrying out of experimental researches on definition of optimum power consumption of coarse forages picking and chopper processes; carrying out laboratory-field tests of the pick-up chopper during the preparation of haylage and its stationary operation.

MATERIALS AND METHODS

In this study, in order to justify the parameters and the possibility of the new picking mechanism, theoretical studies were carried out using methods of theoretical mechanics. To determine the optimal productivity and energy intensity of the picking and chopping of coarse forage, one-factor experimental researches were made. Experimental researches were carried out to determine the productivity and energy intensity of the process of alfalfa chopping with a moisture content of 16.4% and wild grasses with a moisture content of 17.1%. The experiments were carried out at different values of the roll mass on one running meter and at 1.25 m/sec moving speed of the unit.

In all experiments, the required power of the pick-up chopper was determined by a strain gauge cardan. In this case, the torque value and the speed of the cardan were recorded on an oscilloscope study. The determination of productivity and the recording of the required power were carried out at a roll length of 50 m.

Experimental researches were carried out in “Zhaniko” farm of Ile district, Al-maty oblast. The experiment was repeated three times. Mean-square deviation was 0.29 kW, i.e., the coefficient of variation is only 2.16%.

RESULTS AND DISCUSSION

The universal pick-up chopper was developed in 2012-2014 under the budget program 212 of the Ministry of Agriculture of the Republic of Kazakhstan taking into account the advantage of harvesting technology of chopped hay and the quality harvesting of coarse forages with splitting of stems along the fibers as well as for the harvesting of haylage.

The universal pick-up chopper consists of a new pick-up mechanism without a treadmill, an auger feeder, a chopper equipped with hammer-knife working elements, a deflector, a reducer, a hitch tongue and a drive mechanism.

Hammer chopper is used due to the fact that the hammer working elements provides chopping of coarse forage (18-20%) with splitting of the stems along the fibers, i.e., in accordance with zootechnical requirements.

Analysis of existing pick-up units, self-propelled harvesters, grain combines and pick-up presses shows that they use picking drums with rotating fingers.

To rotate the fingers during the rotation of the picking drum, at the end of the finger axis a crank with a roller is mounted which rolls along the profiled track of the side plate. The shape of the profiled track ensures finger movement without hay capture under the finger covers.

The main disadvantage of this mechanism is that there are great di fficulties in repairing the treadmill in farm conditions. In addition, many parts of the mechanism, such as the treadmill, rollers, cranks and bearings wear out during operation and reduce the reliability of the machine. In the proposed pick-up unit, the picking fingers are installed radially, the ends of the fingers are bent in the direction opposite to the rotation of the fingers or the front wall of the fingers end can be skewed and the finger covers are installed eccentrically about the axis of the picking drum (Adgidzi, 2007). When lifting hay on the surface of the finger covers, the fingers gradually enter finger covers. In this case, there is a friction force that helps to drag the hay stalks into the finger covers as well as the inertia forces F_i and Coriolis forces F_c, therefore, in order to accurately determine the ratio of these forces and their effect on the hay stems as the fingers rotate, it is necessary to conduct theoretical studies.

Taking into account the turning time of the fingers to the circumference of the picking drum which is bounded between the ends of adjacent rows of fingers and the unit speed, the length of the loaded part of the fingers l_f is determined by Eq. 1:

$$l_f = \frac{\pi D_p \upsilon_a}{\upsilon_p N_f} \tag{1}$$

Where:

- D_p = Diameter of the picking drum at the ends of the fingers (m)
- υ_a = Speed of the machine (m/sec)
- υ_p = Linear speed of the drum at the ends of the fingers (m/sec)
- N_f = Number of finger rows

To determine the forces acting on the finger, it is necessary to know the value of stem mass picked by one finger m_{1f}. With a known value of the hay mass on one running meter of the roll m_{fm}, the mass of hay picked from the roll by one finger is determined by Eq. 2:

$$m_{1f} = \frac{m_{fm} l_f}{n_{fr}} = \frac{m_{fm} \times \pi D_f \upsilon_a}{\upsilon_p \times N_f \times n_{fr}} \tag{2}$$

where, n_{fr} Number of fingers in one row. Considering the length of the hay wisp path along the fingers L_n and the time consumed by half the turn of the picking drum t_n, the relative speed of the hay wisp υ_{rs} is determined by Eq. 3:

$$\upsilon_{rs} - \frac{L_n}{t_n} - \frac{(l_M - a) n_\sigma}{30} \tag{3}$$

Where:

- L_m = The maximum length of the fingers protruding from the circle of finger covers (m)
- a = The length of the fingers protruding from the finger covers along the upper part of the picking drum vertical axis (m)
- n_d = Rotational speed of picking drum (min^{-1})

In these theoretical studies, it is important to determine the direction of the resultant force F_r along the finger length, i.e., it is necessary to clarify the value of the force dragging the stems into the finger covers. If the value of the frictional force F_f dragging the stalks inside the finger covers is too large, some stems may enter the finger covers and this can lead to clogging of the picking drum, i.e., to the disruption of the technological process.

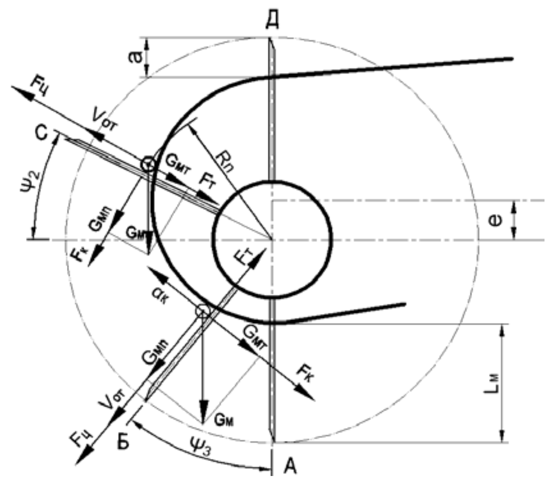

Fig. 1: Scheme of forces acting on the stem during harvesting of hay

When determining the resultant force F_r along the length of the finger in different quarters of the circumference of the picking drum, it should be taken into account that there is a change in the direction of gravitational force component acting in the direction of the picking drum radius, therefore it is necessary to make a theoretical analysis to determine the force F_r in the third and second quarters of the drum circumference separately.

The value of the resultant force F_r in the third quarter of the circle of the pick-ing drum is defined as the sum of forces projections acting along the length of the finger (Fig. 1):

$$\begin{aligned} F_p &= F_i + G_s \cos\varphi_3 - F_f = m_{1f}\omega_d^2 R_f + m_{1f} \\ & g\cos\varphi_3 - (m_{1f} g \sin\varphi_3 + 2 m_{1f} \upsilon_{OT} \omega_d).f_c = m_{1f}\omega_d \\ & (\omega_d R_f - 2\upsilon_{OT} f_c) + m_{1f} g (\cos\varphi_3 - \sin\varphi_3 f_c) \end{aligned} \tag{4}$$

Where:

- G_s = Stem force of gravity (H)
- F_i = Inertia force (H)
- F_f = Friction force (H)
- F_{cor} = Coriolis force (H)
- m_{1f} = Weight of hay picked by one finger (kg)
- υ_{rs} = Relative speed of the hay wisp along the finger's length (m/sec)
- ω_d = Angular velocity of the picking drum (rad/sec)
- f_c = Coefficient of friction
- R_f = Finger radius (m)

The value of the resultant force in the second quarter is also determined from the following Eq. 4:

$$\begin{aligned} F_p &= F_i G_s \sin\varphi_2 - F_f = m_{1f}\omega_d^2 R_f - m_{1f} g \sin\varphi_2 - \\ &(2m_{1f}\upsilon_{rs}\omega_d + m_{1f} g \cos\varphi_2) f_c = m_{1f}\omega_d^2 R_f - \\ &m_{1f} g \sin\varphi_2 - 2m_{1f}\upsilon_{rs}\omega_d f_c - m_{1f} g \cos\varphi_2 \\ &f_c = m_{1f}\omega_d^2 R_f - 2m_{1f}\upsilon_{rs}\omega_d f_c - m_{1f} g \sin\varphi_2 - \\ &m_{1f} g \cos\varphi_2 f_c = m_{1f}\omega_d(\omega_d R_f - 2\upsilon_{rs} f_c) - \\ &m_{1f} g(\sin\varphi_2 + \cos\varphi_2 f_c) \end{aligned} \quad (4)$$

Taking into account the known values of existing pick-up units parameters and also using the value of some theoretically determined parameters of the picking mechanism, i.e., D_p = 0.65 m, L_m = 140 mm, a = 40 mm, e = 50 mm, n_d = 60 min^{-1}, m_{nm} = 3.0 kg/m, the resultant force was calculated as a function of the finger rotation from point A to point D, i.e., indicating angle φ from 0-180°.

Figure 2 shows that at the beginning of the picking by the fingers the forces of inertia and gravity act in one direction on the hay, so the resultant force has the maximum value. In the second quarter, the forces of friction and the tangential force component in the opposite direction of the inertia force and in this connection value of the resultant force decreases. At the end of the rotation of the fingers there is a slight increase in the resultant force this is due to the fact that the component of the Coriolis force will not affect the value of the frictional force. It should be noted that the value of the resultant force is positive and always directed along the radius to the end of the fingers, i.e., the value of the force dragging the mass inside finger covers is zero.

As a result of the theoretical studies on the justification of picking mechanism parameters and previous experimental studies aimed at justifying the parameters of the open-type hammer chopper, the universal pick-up chopper has been developed that provides harvesting of chopped hay and haylage (Abilzhanuly, 2007).

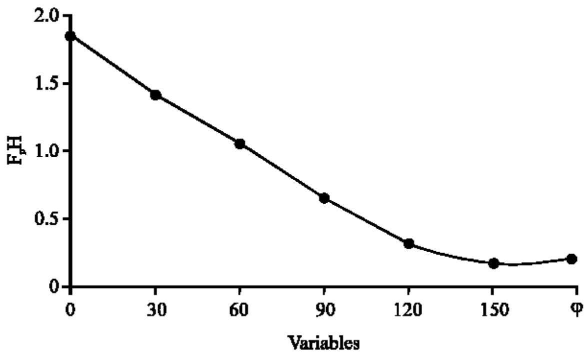

Fig. 2: Dependence graph of resultant force value on the angle of fingers rotation in the third and second quarter of the circumference of the picking drum

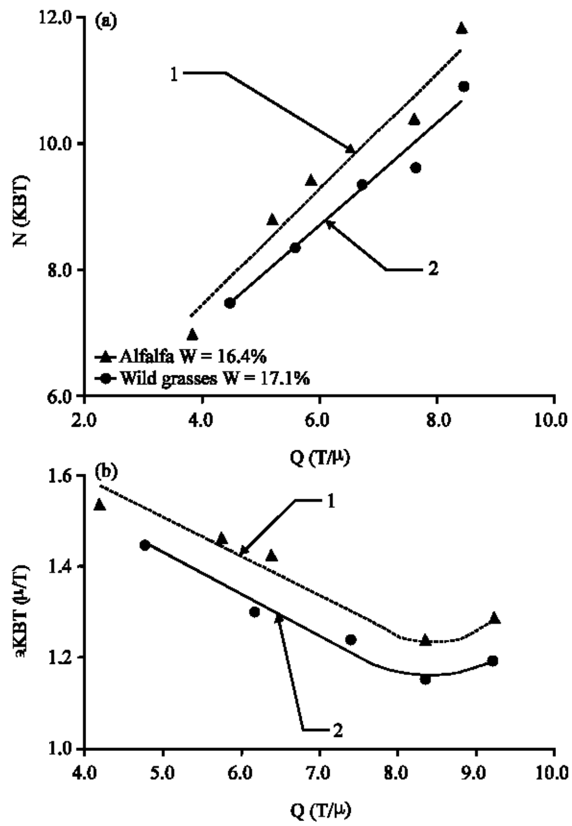

Fig. 3: a) The results of experimental studies on the determination of productivity (Q) and b) energy intensity (E) of alfalfa and wild grasses

Harvesting of coarse forage in chopped form: Harvesting of chopped hay was carried out with the picking and chopping of alfalfa and wild grasses. At the same time, experimental studies were carried out to determine the optimum productivity of the pick-up chopper. The results of the experimental studies are shown in Fig. 3. The figures show that the values of the pick-up chopper optimum productivity for alfalfa with humidity of 16.4-17.1% and wild grasses are approximately the same 9.0-9.5 t/h and the energy intensity of the chopping process of coarse forages at 10 t/h and more starts to increase. Analytical expressions were obtained to determine the required power of the pick-up chopper and their reliability was determined by experimental studies (Abilzhanuly *et al*., 2016). For the quality chopping of coarse forages in the grinding chamber, 2 rows of counter hammers are installed with a pitch of 60 mm and the last row with a pitch of 30 mm. The mass fraction of chopped particles is up to 30 mm 91.5%, up to 50 mm 96%, <50 mm 4%. The abovementioned values of the pick-up chopper productivity during the picking of hay there were no disturbances in the technological process in the rolls, i.e., the pick-up chopper ensures the preparation of coarse forage in a chopped form. In this case, the quality of the chopped forage corresponds to the zootechnical requirements, i.e., it does not require second chopping.

Harvesting of haylage by a pick-up chopper: The process of chopping alfalfa with a moisture content of 45... 60% for harvesting haylage was included in the testing program. For stable flow of this process in the grinding chamber, radial blades with a pitch of 120 mm were installed in the hammer rotor together with the hammers. These blades provide preliminary grinding of moist long stems, further grinding is performed by a hammer working element.

The process of harvesting haylage was carried out on alfalfa with a moisture content of 50.4%. At the same time, the speed of the unit was 1.0 m/sec, the mass was selected from the roll and from the swath.

The productivity of the pick-up chopper for picking up the roll (m_r = 2.1 kg/m) was equal to 7.56 t/h, the consumed power is 18.4 kW and the energy intensity of the process is 2,43 kWh/t. Harvesting of alfalfa from the swath was performed in a more productive part of the field, i.e., the mass on the area of 1 m2 was equal to 0.9 kg. In this case, the productivity of the machine was 5.83 t/h and the energy intensity of the process was 2.24 kWh/t. On equal parts of the field, harvesting can be made at a higher unit speeds, i.e., the possibility of increasing productivity is available. Thus, the forage pick-up chopper with a working width of 1.8 m provides the preparation of haylage, picking the mass directly from the swath.

During the chopping of wet alfalfa, there were no disturbances in the technological process, i.e., the developed pick-up chopper provides the preparation of haylage, picking the mass directly from the swath and the possibility of implementing the proposed technology is proved.

Picking of hay from the swath during the harvesting of coarse forage in a chopped form: In the test program, we provided the picking of alfalfa and wild grasses from the swath. The productivity of the pick-up chopper during the picking of wild grasses was 4.5 t/h on alfalfa 5.83 t/h. The obtained results showed that the developed pick-up chopper can be used for picking from the swath during the harvesting of coarse forage in a chopped form and for the haylage. Given that the hay on the swath is drying evenly, the haylage is done by picking the hay directly from the swath. Today, for the productive picking of hay from the swath an additional pick-up chopper with a working width of 1.2 m is installed in front of the tractor.

In this case, the universality of the machine is increased, i.e., the pick-up chopper is used for picking hay from roll (without attachment) and for picking hay from swath. With the picking of dry hay directly from the swath, the productivity of the pick-up chopper reaches up to 8.06 t/h (Abilzhanuly *et al*., 2016). After the passage of the pick-up chopper, there was no loss of alfalfa and wild grasses stems.

With manual supply of coarse forage in autumn winter period, the productivity of the pick-up chopper in stationary position was 0.94 t/h and the energy intensity of the process was 5.65 kWh/t. The productivity of the pick-up chopper was limited by the productivity of the operator because of the low productivity the energy intensity of the chopping process of coarse forage in stationary position was increased. The results showed that the pick-up chopper can be used as an attachable chopper of forages during the whole year.

To reduce the specific operating costs and improve the quality of produced hay, the technology of chopped hay harvesting was used and the universal pick-up chopper was developed, equipped with hammer and knife working elements and a new picking mechanism without a treadmill, cranks, rollers and bearings.

As a result of theoretical studies analytical expressions were obtained for determining the forces acting on the forage during the picking with the fingers of the pick-up chopper. The values of the resultant forces are determined and the possibility of the mechanism operation without disturbing the technological process of coarse forage picking from the roll and the swath during harvesting of the haylage is justified. A new design of the picking mechanism is developed based on the theoretical studies.

As a result of experimental studies and laboratory field research tests, it was determined that the universal pick-up chopper, equipped with a new picking mechanism, hammers and knife working tools, provides harvesting of chopped hay with a capacity of 9.0-9.5 t/h and haylage with a productivity of 5.8-7.5 t/h.

CONCLUSION

During the experimental studies and field research tests, observations were made on the work of the new picking mechanism which showed the reliability of the picking mechanism, there was no violation of the technological process of hay picking from the roll and from the swath during the operation. Thus, the developed new universal pick-up chopper, equipped with a new picking mechanism, provides harvesting of chopped hay and haylage without losses as well as chopping of stem forages in stationary position.

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