International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 24 (2016) pp. 11786-11793
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Engineering Development of Wide Pickup-chopper for Making Chopped Hay and Silage

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Abstract

To reduce the operational costs and to improve quality of harvested hay new technologies have been proposed to produce chopped hay and silage. The essence of the technologies after harvesting hay is dried on the swath to humidity up to 18…20% (when haying) or to humidity of 45…60% (when producing silage), thereafter the hay is picked up directly from the swath, chopped to the required size, loaded into transport facilities and transported to be placed under a shelter and unloaded into a trench, thickened and covered according to the renowned technology. In comparison with rolling technology, the quantity of operations (cutting - distribution) is reduced by 2.0 times, while operational costs per unit are reduced by 2.7 times. To implement the proposed technologies, a detachable pickup was developed, which allows increasing working width of forage pickup chopper FPC-1.8 up to 3.0 meters. As a result of theoretical research the analytical expressions for the determination of the rotational speed of the pickup reel, the value of discarded force, steam acceleration value at the entrance to the auger chamber were obtained. As a result of experimental research the optimal rotational speed of the pickup reel was equal to $n_p = 50$ min^{-1}. In picking up dry hay from the swath the average productivity of wide pickup chopper was equal to 6.76 t/h, and the quality of the prepared hay met the required parameters of the first class hay and zootechnical requirements.

Keywords: detachable pickup, rotational speed, pickup reel, technology of making hay.

INTRODUCTION

In recent years the cattle breeding sector has been rapidly developed in the countries of the Eurasian Union. Specifically, annual growth of cattle population in Kazakhstan is 3…5%.

Considering Kazakhstan's major climate conditions, the conservation of rough feed for winter reserve stock is a challenging issue for the modern agriculture. Currently rough feed conservation is mainly implemented by rolling technology and in small-size bales. However, these technologies include many operations and they do not promote conservation of high-quality rough feed. For instance, in applying rolling technologies or in conservation of rough feed in small-size bales, the rolls and bales are left in fields for several days after pressing. At the same time there occur big losses of carotene and vitamins in upper layers of each rolls and small-size bales.

In addition, previous studies established that during conservation of rough feed according to the rolling technology, the leaf losses reach 14% [1]; observation of operation of baling machines demonstrates similar leaf losses during haymaking in small-size bales. Therefore it may be considered that existing methods fail to ensure conservation of high-quality rough feed.

Work analysis of the haymaking machines showed that commercially available machines are metal and energy consuming, are also quite expensive, which is unacceptable to small farms.

In addition, there is a risk of damage of a bale wrapping film during the loading and unloading it to the vehicles [2]. As well as using of roughage for feeding in the pressed form by existing technology is impossible without preliminary preparation (unfolding roll, cutting dispensing). The most time-consuming and at the same time more common is cutting process [3]. An effective solution to the problem of preparation of forages for cattle, reducing labor costs and increasing the productivity of animals determines the rational use of technical solutions for its implementation.

To reduce operational costs per unit in producing hay and silage utilized by country's feeding and dairy farms we propose resource-saving technologies to produce chopped hay and silage. The essence of the technologies proposed is included in the fact, that after harvesting, the hay is dried at the swath to humidity of up to 18…20% (when haying) or to humidity of up to 45…60% (when producing silage), thereafter the hay is picked up directly from the swath, chopped to the required size, loaded into transport facilities

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and transported to be placed under a shelter and unloaded into a trench, thickened and covered according to the renowned technology. At the same, all you need to do in winter time is to load finished chopped hay or silage to feeder which mixes it with other components, and to distribute it among feeders. In comparison with the rolling technology, the quantity of operations in this haymaking technology (cutting - distribution) is reduced by 2.0 times, while operational costs per unit are reduced by 2.7 times [4].

Since for conservation of chaffed rough feed modern forage combine harvesters may be used, the main review of books and Internet sources was performed across commercially available forage combine harvesters manufactured in Russian Federation, Belarus, Ukraine, Germany, the USA and other foreign countries [5].

Analysis of choppers of modern forage combine harvesters demonstrated that all harvesters currently manufactured in different countries are equipped with knife chopping devices, i.e. are mainly design for preparation of silage or green mass. All these harvesters may be used to pick up and chop dry mass, i.e. to produce chopped hay. However, when chopping dry rough crops, the knives do not split caulis along the fibers, and progressively as knives are teared, the coarseness of chopped rough crops is increased, which requires additional chopping in winter.

Research objective is **a** development of resource-saving technology and a prototype model of a wide pickup chopper for production of chopped hay and silage, which ensure reduction of operation costs per unit by 2.0…2.5 times.

The purpose of the present paper is to carry out the theoretical and experimental researches on the parameters justification of the wide pickup mechanism.

MATERIALS AND METHODS

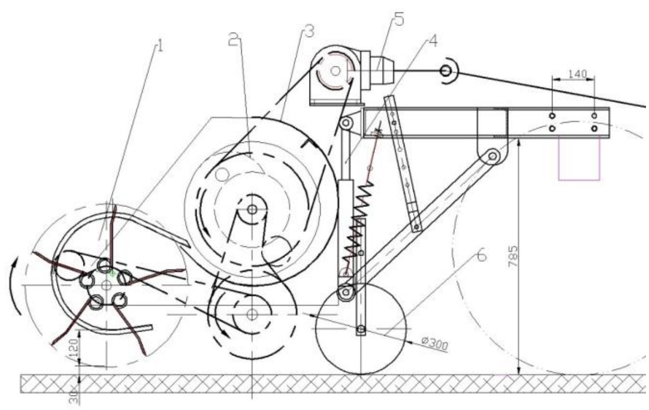
Theoretical researches based on engineering mechanics laws; engineering design of farming machinery, and agricultural machinery testing; determination of quality of rough feed; determination of chemical composition of feed. Laboratory and field tests were conducted using first, second and third crop alfalfa at the family farm that occupy 40 ha of fields, called "Zhaniko" Ili district of Almaty region. The crop was harvested and cut with forage pickup cutter which was mounted on the MTZ-80 (59.7 kW) and chopped material was conveyed into a trailer 2PTS-4. Stopwatch, tachometer, dynamometer and thermometer were also used during the experiment. Other devices were: express moisture meter VLK-01, scales VLKT-500m, Express analyzer InfraHast (for determination quality of chopped hay) of firm Foss.

In consideration of the foregoing, for conservation of chopped hay or silage we propose to utilize choppers equipped with hammers and knives. Therefore, for conservation of chopped hay or silage we have developed a general-purpose type pickup for crops with operating width of 1.8m. The machine is equipped with hammers and knives and a new pickup device without running track, which picks hay mass up both from the roll and the swath [6, 7]. Quality of chopping of crops meets corresponding zootechnical requirements. To ensure more productive operation on the proposed technologies it is necessary to equip it with wide-cut pickup (with operating width of 3.0 m).

In the process of research a number of technical solutions were considered that form the basis of the creation of constructive-technological scheme of wide-pickup mechanism.

Accordingly, to increase the operating width of the pickup it was decided to develop an additional detachable pickup, designed to pick the hay up from the swath in front of the tractor.

Detachable pickup consists of a pickup with operating width of 1.2m, a cantilever auger, a drive gear, a hydraulic cylinder and a frame (Figure 1). Detachable pickup is driven by a side power take of the tractor. During its operation, the pickup picks the mass from the swath up, and then the bubble-up auger by moving it across the width of the pickup, puts the mass on the swath within the operating zone of the main pickup of the machine. The use of such additional detachable pickup has no impact on flexibility of the machine; the detachable device is used only in harvesting directly from the swath. When producing silage as well as when using the machine as a pull-type chopper, the detachable pickup is demounted from the front part of the tractor. In addition this provides for installation of a wheel with a lesser diameter than that on the main crop chopper. Accordingly, the auger framing may be installed at the height of 280…300mm from the ground level, at that, the upper end of finger cover is installed with a certain tilt from above towards the front wall of the auger conveyor box.



1 – Pickup; *2* – cantilever auger; *3* – frame of auger; *4* – a hydraulic cylinder; *5* – reducer; 6 – the support wheel

Figure 1 - Scheme of detachable pickup with operating width of 1.2 m

Such engineering change shall ensure supply of the hay picked up by pickup fingers directly to the auger. At the same time, this allows avoiding the necessity for installation of compacting drum within the frame of the detachable pickup.

Here the basic design of the pickup is developed according to provisional Patent RK No.19961, we have obtained, and its main originality is the fact that pickup fingers are attached to the drum rigidly, i.e. without any running tracks, cranks, rollers, or bearing and further without any profile detachable devices (as forage harvester of Krone company).

RESULTS AND DISCUSSION

Theoretical research

Determination of the rotational speed of the pickup reel

According to the design and process chart, to increase the operating width of the pickup up to 3 m we decided to install an additional detachable device in front of a tractor with the working width of 1.2m. According to the design and process chart, the additional detachable pickup picks the mass from the swath up, and then the cantilevered auger by moving it across the width of the pickup, puts the mass on the swath, i.e. in front of the main pickup of the machine (Figure 2). At the same time, the working width of the forage pickup chopper is increased up to 3 meters.

For its intended purpose, the pickup reel picks the mass directly from the swath up, accordingly, the justified rotational speed of the pickup reel for picking the swath up may be apparently increased. When reel fingers picks the mass up from the swath, the linear line speed of fingers shall not be too high. At higher speed of fingers, firstly, the caulis are thrown frontwards and further; when the certain mass is accumulated, the hay is picked along finger cover up. To pick up the hay lying on the swath, within the time for turning to φ angle, which equals to angle of arrangement of fingers around the full circle of the pickup reel, the assembly must travel to the distance which equals to the radius of the pickup reel = R_p. At the same time the rotational speed of fingers shall be the minimum, and be harmonized with the assembly travel speed.

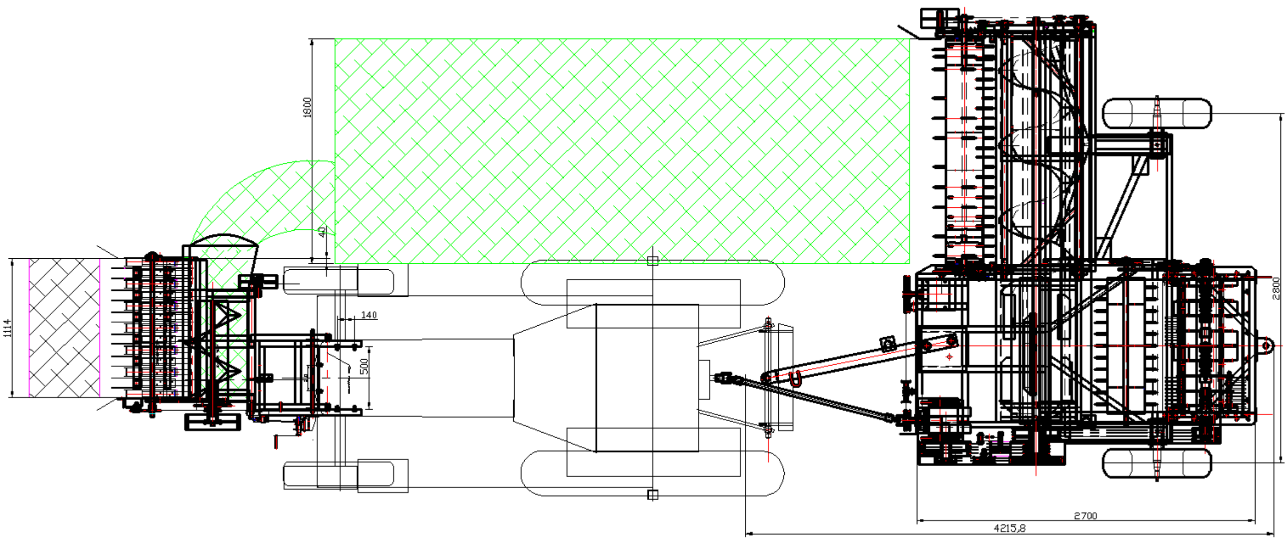


Figure 2 – Technological scheme of the wide pickup chopper for making chopped hay and silage

For description of the proposed hypotheses we determine time spent for one rotation of a finger t_{f1}:

$$t_{f1} = \frac{1}{n_{fs}} = \frac{60}{n_f}, \quad (1)$$

where n_{fc}, n_f – is the rotational speed of the reel fingers per second and per minute, s^{-1}, min^{-1}.

Time spent for rotation of fingers to φ angle is determined according to the following formula:

$$t_{f\varphi} = \frac{\varphi}{360} \cdot \frac{60}{n_f} = \frac{\varphi}{6n_f}. \quad (2)$$

Time spent for travelling of the assembly to the distance, which equals to the radius of the pickup reel is determined according to the following formula:

$$t_t = \frac{R_p}{V_a}, \quad (3)$$

where V_a - the speed of the assembly, m/s.

To ensure optimized behavior of hay pickup process depending on the assembly travel speed, it is necessary to keep the following condition: time spent for rotation of finger to □ angle shall be less than or equal to value of time spent by the assembly to travel to the distance equal to the radius of the pickup reel:

$$t_{f\varphi} \leq t_t, \qquad \frac{\varphi}{6n_f} \leq \frac{R_p}{V_a}. \qquad (4)$$

According to previous experimental researches it is known that optimum speed for travelling of assemblies, forage pickup chopper, and baling machine equals to 1.0…1.2 m/s, taking into account the that R_p = 0.27m based on condition (4) we can determine the value of the rotational speed of the pickup reel as follows:

$$n_p \geq \frac{\varphi V_a}{6R_p}. \qquad (5)$$

By putting parameters according to Formula (5) we determine the minimum value of the rotational speed of the pickup reel:

$$n_p \geq \frac{72 \cdot 1{,}0}{6 \cdot 0{,}27}, \qquad n_p \geq 44{,}4 \text{ min}^{-1}.$$

Hence it is clear that the rotational speed must be equal to $n_p = 50$ min^{-1}. For the determination of this certain value of the pickup reel rotational speed in consideration of the fact that $V_a = 1$ m/s, the condition determined by Formula 4 has the following value:

$$\frac{\varphi}{6n_p} \leq \frac{R_p}{V_a}, \qquad \frac{72}{6 \cdot 50} \leq \frac{0{,}27}{1{,}0}$$

$$0{,}24 \leq 0{,}27 \text{ s}.$$

It should be noted that the line speed of finger travel depends on its radius R_f and is determined by the following formula:

$$V_f = \frac{\pi \, n_f R_f}{30}.$$

To ensure correct operation of the pickup reel when picking-up hay from the swath, the line speed of a finger at the level of its middle section must be approximately equal to the assembly travel speed. When the radius of a reel at the end of fingers is R_f= 0.27m, and maximum length of fingers, extended from underneath of the finger cover is 120mm, then the radius of a middle section is R_{mf}= 0.21 m, while at rotational speed n_p=50min^{-1}, the line speed of the finger according to this radius is 1.1 m/s, i.e. this speed is nearly equal to the assembly travel speed.

At such speed of assembly travel, caulis must be lied down on the surface of fingers without throwing the mass ahead, and this must create optimum conditions when picking the mass up from the swath. Results on determination of the speed of mass throwing depending on the radius of fingers are provided in Figure 3.

According to the hypotheses we propose, at such finger radius level, its linear speed must be harmonized with the assembly travel speed V_a. According to the observations, the optimum assembly travel speed for our field conditions equals to V_a=1.0 m/s, accordingly, at the finger radius level R_f=0.2…0.25 m, the finger linear speed or speed of throwing of caulis by pickup fingers must be equal to $V_f \approx$1.0 m/s.

On the level of the fingers radius R_f=0,275 m, particularly at pickup reel's rotation frequency n_c = 50…60 min^{-1}, fingers linear speed V_f ≈1,3…1,67 m/sec, i.e. a bit more, than the aggregate speed (Figure 3).

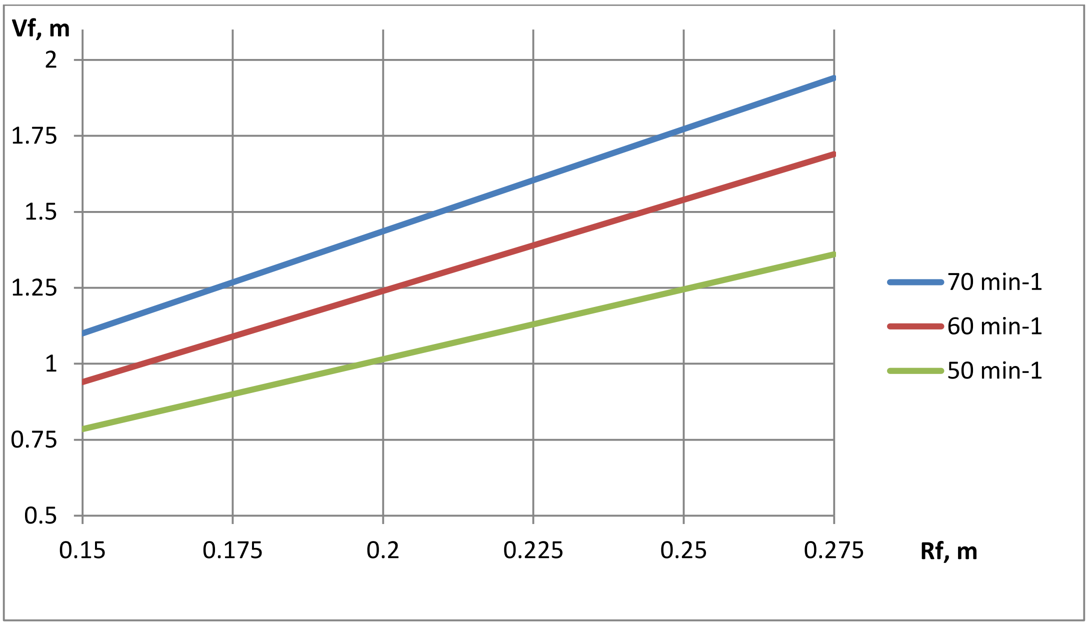


Figure 3 – The linear speed of a finger depending on its radius

Accordingly, by teoretical researches it was determined that optimal rotation frequency of pickup reel is n_p= 50…60 min^{-1}. However, basic research data accuracy shall be confirmed by the experimental studies.

Analysis of the pickup finger work in feeding steam into the screw cell

In accordance with the construction of ring slope by its circumference in the first quarter in the beginning of the fingers rotation on the angle α, i.e. in the beginning of hay gathering from the surface of ring slope, because of the ring slope surface is bent radially, equal to the ring slope radius, then at the moment of steam descent from its surface, definite forces will affect on the steam (Figure 4).

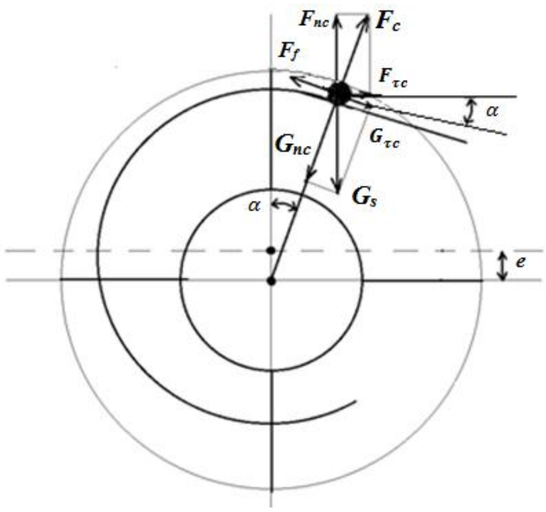


Figure 4 – Forces movement scheme on the steam at the moment of its gathering from the ring slope surface

When finger rotate to the angle α, inertial force F_i, steam gravity force G_s and frictional force F_f will affect on the steam.

In this case, the inertial force F_i and normal component of gravity force G_{nc} move by the one line and in rightabout. If $F_i > G_{nc}$, then the steam will be in suspension state. Herewith, the gravity force is fully compensated by centrifugal force, i.e. $G_{c\tau} = 0$, F_f=0, then discarded force values can be determined by the formula:

$$F_d = (F_c - Gc)\sin\alpha = (m_s W_f^2 R_p - m_s \cdot g \cdot \cos\alpha)\sin\alpha = m_s(W_f^2 R_p \sin\alpha - g\cos\alpha\ \sin\alpha)$$

where m_c –mass of steam, kg;

W_f - fingers angular speed, rad/sec.

R_p – fingers radius, m.

If $G_s > F_c$, then $F_c = 0$ and herewith the discarded force values can be determined by the formula:

$$F_d = (G_s - F_c cos\alpha)sin\alpha - (G_s - F_c cos\alpha)cos\alpha f_f =$$
$$= (m_s \cdot g - m_s W_f^2 R_p cos\alpha)(sin\alpha - cos\alpha f_f) \quad (7)$$

where f_f – steam coefficient of friction by the steel surface.

It is clear, that in this case the discarded force value will be defined as the difference of tangential gravity force and frictional force. Considering, that in many cases $G_s < F_c$, then the discarded force value is determined by the formula 6.

When the discarded force affects on steam, then steam receives definite acceleration a_s and it is determined by the formula:

$$a_s = \frac{F_d}{m_s} = W_f^2 R_p \cdot \sin\alpha - g\sin\alpha \cdot \cos\alpha. \quad (8)$$

Taking into account the steam travel time, at its rotation by the circle on the angle α, steam gathering speed from the ring slope can be determined by the formula:

$$V_s = a_s \cdot t_{p\alpha} = a_s \cdot \frac{\alpha}{6\,n_p} =$$
$$\frac{\alpha}{6\,n_p}\left(W_f^2 R_p \cdot \sin\alpha - g\sin\alpha \cdot \cos\alpha\right). \quad (9)$$

Accepting the rotation frequency of pickup reel n_p=60 min^{-1} and herewith $W_f = \frac{\pi n_p}{30} = \frac{3{,}14\cdot 60}{30} = 6{,}28$ rad/sec, R_p=0,3m and α=30°.

Determine the steam acceleration value as affected by discarded force F_d:

$$a_s = W_f^2 R_p \cdot \sin\alpha - g\sin\alpha \cdot \cos\alpha =$$
$$6{,}28^2 \cdot 0{,}3 \cdot 0{,}5 - 9{,}81 \cdot 0{,}5 \cdot 0{,}866 = 1{,}66 \text{ м/с}^2$$

From the calculation it is clear, that at selected parameters, the value $F_{цс} > G_{nc}$.

Basic researches results show, that at the end of the first quarter circle of the ring slope the infusion of the circle form ensures the steam gathering with the acceleration and receipt the additional speed by it, which is added linear speed to the steam moving by the ring slope and such steam gathering additional speed from the ring slope surface, is determined by the formula:

$$V_s = \frac{\alpha}{6\,n_p}\left(W_f^2 R_p \cdot \sin\alpha - g\sin\alpha \cdot \cos\alpha\right) = \frac{30\cdot 1{,}66}{6\cdot 60} = 0{,}14 \text{ м/с}.$$

Accordingly, developed construction of pickup mechanism, provides the steam gathering from the finger with the additional speed 0,14 m/sec. Such speed shall ensure the optimal behavior of mass feeding process from the pickup reel to the console screw of supplementary detachable pickup.

After such theoretic substantiations of some detachable pickup parameters, a drawing documentation was developed, detachable pickup was manufactured and its factory tests were conducted.

Results of experimental studies and laboratorial-field research tests

For the detachable pickup work examination jointly with experimental sample of multifunctional forage pickup-chopper FPC-1,8, an aggregate was prepared, consisting of pickup- chopper FPC-1,8 and detachable pickup (Figure 5).

Determination of chopper productivity and working capacity, i.e. productivity of pickup- chopper FPC -1,8 was realized in the family farm called «Zhaniko».

Working capacity examination of this aggregate showed, that detachable pickup and pickup chopper the harvested mass from the swath with the good result, i.e. detachable pickup's work is coordinated with the main engine's pickup. Herewith, the detachable pickup was cleanly picked up the mass of hay in front of the field-engine and put the mass into the zone of main engine's pickup work (Figure 6).

Figure 5 - General view of the experimental model of detachable pickup with universal pickup-chopper with width of 1.8 m (side view)

Figure 6 – Picking up mass in the low-yielding field area

There were three specific areas on lucerne field: on the first area of 3 m^2 the average weight of the lucerne was 1,08 kg, on the second m_c-2,27kg and on the third - 2,47 kg. The determination results of productiveness on these areas of lucerne filed are showed in the table.

Table 1 – The determination results of productiveness wide pickup- chopper

Plant	Moisture content, %	Mass of hay on 3 m^2, kg	Speed of the machine m/s	Productiveness, t/h
Alfalfa	11,2	1,08	1,19	4,63
Alfalfa	11,2	2,24	1,0	8,06
Alfalfa	11,2	2,47	0,855	7,60

The work results of forage pickup chopper showed, that its average productiveness is 6,76 t/h, i.e. productiveness of the chopper more than 2 times bigger that the productiveness of roll and baled press-pickups (productiveness of the roll press-pickups is about 3,1 t/h).

The examination of chopper work showed that the gathering quality is good, i.e. mass losses by the pickup were not observed.

After the examination of forage pickup-chopper work, experimental studies on determination of rotation frequency of the pickup reel were conducted. There was an observation of the main pickups engine work at different reel rotation frequencies. For the analysis of the pickup reel work, an video recording of its work at different rotation frequency was done.

Observation over the pickup's work at different pickup reel rotation frequency showed that at reel rotation frequency n_r = 75min^{-1}, some mass dropping forward till accumulation of definite mass is observed in front of the pickup.

At pickup reel rotation frequency n_r = 50…60 min^{-1} pickup reel fingers lifting the hay by solid mass, not breaking the net of the hay, laid for the swath, i.e. the forward weight dropping not occurs. This is explained by pickup reel diameter on the fingers end is 640 mm, if considering that the picking mass up from the swath takes place at the finger length from the end until 70mm, i.e. at finger radius 250...320mm. At these finger radiuses, its circular speed is within 1,3…1,67 m/sec. At aggregate movement speed 1,0…1,2 m/sec, the linear speed until the fingers end has a bit bigger value, i.e. such reel rotation frequency conforms with the aggregate movement speed.

Videotaping and observations over the pickup reel work at rotation frequency 40min^{-1}, showed the satisfactory pickup's work, in work videotape some increase of reel rotation frequency was observed.

Here at pickup reel radiuses 0,25m and 0,32m, its linear speed is within 1,0…1,3m/sec. It shows that the aggregate speed more than 1,0 m/sec, the fingers linear speed in working zones of finger radius will turn up less that the aggregate speed. It is clear that the optimal pickup reel rotation frequency is 50min^{-1} and such value also corresponds to the value, which was determined as the result of basic researches, which show also the accuracy of basic researches.

Furthermore, in the result of conducted experimental studies and laboratorial-field research tests, the values of finger brow were specified in the upper part of ring slope, theoretical analysis accuracy of pickup finger work was proved at feed of the steam into the screw chamber. Herewith the finger brow in the upper part of finger cover was 40 mm and manufacturing of the top horizontal part of the ring slope with the inclination, ensured the continuous steam feed into the screw chamber, as well as provided the normal continuous mass feed into the main pickup's work zone. Accordingly, the accuracy of the theoretically proved parameters in the result of exploratory tests was proved.

The result of the sample analysis crushed hay, showed that the mass fraction of crushed particles sized till 30mm – 86,1% and untill 50mm – 93,4%, it shows that the quality of the crushed hay conforms the zoocultural requirements for sheeps and cattles (for sheeps the mass fraction of crushed particles till 30 mm, shall be not less than 80%, but for the cattle till 50mm - not less than 80%).

Analysis results, conducted by the quality field center of agricultural product of Kazakh scientific and research institute of cattle breeding and feed production showed that 1 kilogram of crushed hay, prepared in the second hay cutting has the following quality indexes: feeding unit – 0,55; digestible protein – 13,43% (134,3 gramm); dry matter – 80,85%; cellulose – 31,36% and carotene – 25,27 mg.
It is known that in 1 kg of high quality hay (1 class) contained 0,45…0,55 feed unit; 65…80 gr. (6,5…8%) of digestible protein; 24…30% of cellulose; 81…85% of dry matter and 30 mg of carotene [8]. Comparison of qualitative indexes of crushed hay even in the second hay cutting showed that they conforms required parameters of good first-class hay, but the indexes of feed unit and digestible protein has the very high indexes. This shows that the effectiveness of the technology offers are not only on the operational expenses, but also on quality indexes of prepared hay.
At tests of experimental sample of the multifunctional pickup-chopper FPC-1,8, we found that the losses at storage of the crushed hay compose only 1,83%, i.e. such loss is allowable for the fodder harvesting machines (the losses shall be untill 2% by the national standard). This is all proves that at application of the offered technology, the high quality of prepared hay is proved.
Accordingly, an implementation of the forage pickup-chopper into the household and new resource-saving technology, a storage of the high quality hay is provided without the losses and with specific operating costs decreased in 2,0…2,5 times.

CONCLUSION

To reduce the operational costs and to improve quality of harvested hay new technologies have been proposed to produce chopped hay and silage. As a result of theoretical research the analytical expressions for the determination of the rotational speed of the pickup reel, the value of discarded force, steam acceleration value at the entrance to the auger chamber were obtained. By teoretical researches it was determined that optimal rotational frequency of pickup reel is n_p= 50…60 min^{-1}. Analysis results, conducted by the quality field center of agricultural product of Kazakh scientific and research institute of cattle breeding and feed production showed that 1 kilogram of crushed hay, prepared in the second hay cutting has the following quality indexes: feeding unit – 0,55; digestible protein – 13,43% (134,3 gramm); dry matter – 80,85%; cellulose – 31,36% and carotene – 25,27 mg.

ACKNOWLEDGMENT

The authors are highly thankful to the Erasmus Mundus CASIA program for the opportunity to present this study and Government Grant (Ministry of Education and Science of RK) that supported development of forage pickup-cutter for preparing roughage and silage.

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