EurAsian Journal of BioSciences
Eurasia J Biosci 13, 749-756 (2019)

Mechanization of the haylage rolls wrapped with film on the basis of the modernization of drive of the mower-conditioner cutting machine

Omirserik Zhortuylov [1*], Anuarbek Adilsheyev [1], Askar Rzaliyev [1], Gani Zhumatay [1], Ulan Bekenov [1], Azamat Zhortuylov [1]

[1] «Scientific Production Center of Agricultural Engineering» Almaty, KAZAKHSTAN
*Corresponding author: Omirserik Zhortuylov

Abstract

Harvesting haylage in rolls is one of the most effective ways of harvesting grass fodder. High-quality haylage cannot be obtained without the use of mowers-conditioners, reducing the drying time of the grass mass. The method of vector contours was used to study the crank-beam-drive mechanism of the mower-conditioner knife drive. Analytical equations are obtained, which describe the laws of travel, speed and acceleration of the knife movement. The parameters and modes of the knife drive mechanism are substantiated, tested under production conditions, which allow to reduce the power required by 1.6 times and partially reduce the oscillations of the knife.

Keywords: haylage, roll, technology, winding, film, crank-beam mechanism, drive, cutting unit, inertial forces, crank, double knife stroke

Zhortuylov O, Adilsheyev A, Rzaliyev A, Zhumatay G, Bekenov U, Zhortuylov A (2019) Mechanization of the haylage rolls wrapped with film on the basis of the modernization of drive of the mower-conditioner cutting machine. Eurasia J Biosci 13: 749-756.

INTRODUCTION

The current state of fodder production does not meet the requirements of animal husbandry and cannot provide the necessary productivity. It has been proved by science and practice that high milk yields and weight gain can be obtained only if there are feeds with a high concentration of metabolizable energy (EE) and protein in the livestock diet.

According to the data of V.R. Williams All-Russia Research Institute of Feeding, high productivity of animal husbandry can be provided with a content of 10-11 MJ of exchangeable energy and 12-14% of raw protein per 1 kg of dry matter. With such feed, an annual yield of at least 6000 kg is ensured (Osobov 2010).

The traditional technology of preparation of feed by natural field drying to standard moisture is associated with large nutrient losses. It has been established that during the harvesting, about 50% of the exchange energy and almost 80% of vitamins, up to 30 ... 35% of protein are obtained. The main reason is uneven dehydration of leaves and stems, as the leaves dry 2.0-2.5 times faster than the stems and they crumble due to drying.

The most rational way to use herbs when they are harvested for feeding farm animals is the production of haylage.

Haylage according to Perm technology is canned food prepared from green grass, dried to a moisture content of 50-55%, and pressed into rolls in sealed containers. With such humidity, the water-holding force in plant cells reaches 5.5-6.0 MPa, and the suction force of many bacteria does not reach these indicators and is 5.0-5.5 MPa. Thus, the process of decay is eliminated, and with the observance of the entire technology, canned food is obtained (Asonov 2002). According to their physicomechanical properties and fodder advantages, haylage is closer to green grass than hay and silage.

The technology of harvesting and storage of haylage and silage with packaging in polymeric materials has become widespread in the world, having proved itself to be cost-effective, reliable and providing consistently high results (Samosyuk et al. 2012). There are several varieties of technology for harvesting haylage in rolls by pressing and individually wrapping with a film; with haylage winding stretch film in line (long sleeve). Technologies provide high quality feed, almost 100% level of mechanization of the technological process and undeniable economic advantages compared with traditional methods of harvesting. Fodder preparation with the use of polymeric materials does not depend on climatic conditions, because the speed of the billet is high. It takes less than a day from the moment of mowing

Received: February 2019
Accepted: June 2019
Printed: July 2019

to packaging. The process can be suspended without loss until the onset of favorable weather. Forage packaged in foil can be stored on any suitable size site up to the side of the road or the edge of the field. Special storage is not required. Losses of nutrients do not exceed the biologically inevitable, labor costs per ton of feed constitute 0.07-0.09 man-hours (Complex of machines for … 2005, Technology and technical means … 2005). The exchange energy is 10.7-11.2 MJ / kg dry matter, the preservation of sugar, protein, carotene; increase in livestock productivity (weight gain, milk production), preservation of productive longevity of animals (4-5 lactations); high quality products (improving the grade of milk). Effective use of several grass mowing for 5 months, from May to September ("Perm" technology harvesting … 2017). The listed advantages in the final result ensure that about 1 ton of milk or 120 kg of beef meat is obtained additionally from 1 ha of land.

In the CIS countries in the field of research and development in technology leading position is under the Republic of Belarus and Russia.

The technology for harvesting haylage in film-wrapped rolls is still new for Kazakhstan. It is carried out mainly by the «Salyut» or «KOKON» machines, which fulfill an interconnected technological cycle (Complex of machines for harvesting … 2010): mowing the grass while weaving or conditioning; turning and tilling grass mass; roll formation; selection of rolls and pressing into rolls; packaging rolls of haylage in a special film; chopping and distribution of finished feed to animals.

The Belarusian technology of harvesting and storing green fodder in film-wrapped rolls is performed by «KOKON» machine complex of the «Bobruiskagromash» RUPE. The complex includes the following equipment: mower disc trailed gearbox-3,1; GVR-630 rake rake; PR-F-145 baler; wrapping rolls OR-1; seizure of rolls ZR-1 with loader PSN-1; TP-10 rolls transporter (Complex of machines for harvesting … 2010).

LLC «Permagromash» (Russia) produces a set of machines for harvesting green fodder (KPC) with packaging in film "Haylage in packaging" (Technology and technical means … 2005). The complex includes agricultural machines that perform an interconnected technological cycle for harvesting hay and haylage with foil wrapping: Rotex R5 mower conditioner, RT5800N tedifier, H90 / V10 rake roll mower, R12 / 155 Super round baler, FW 10 roll wrapper / 2000S ("Perm" technology harvesting … 2017), Front Lift roll loader and shredder (distributor) of IRK-01 rolls. LLC «Permagromash» has developed for large farms «Permskaya» the technology of harvesting haylage in line, including the optional SPEEDWAY 120 high-speed packer of rolls. The capacity of the line is 4.0-5.0 times higher than with individual winding of rolls, and the film consumption is less than 1.6 ÷ 2.0 times ("Perm" technology harvesting … 2017).

Firms "Claas" and "Krone" (Germany), which are among the world leaders in the production of forage harvesting equipment (Baler "Rollant 250RC Univrop" n.d., Combi Pack 1250 round baler 2010), produce combined balers, balanced with coil wrappers. Claas manufactures a Rollant 250RC Univrop mobile unit, including a round baler and packer. The quality of haylage is enhanced by the simultaneous processes of forming and packing rolls. Krone also produces a similar baler -«Krone Combi Pak», and «New Holland», the baler wrapper «BR6090 Combi» (RR 6090 baler n.d.). However, there is a danger of damage to the film when careless unloading, loading the roll, which contributes to the penetration of air into the roll, causing it to rot. Therefore, it is advisable to wind the rolls in the hospital, i.e. on the place of storage of haylage in rolls wrapped with film.

The main operation in the technology of harvesting haylage in film-wrapped rolls is achieved by a mower conditioner. The mower conditioner is also used for harvesting hay in a pressed and loose form.

With a yield of up to 15 t / ha, perennial grasses should be mown and laid in rolls. Annual grasses (pea-vetch-oat mixture, Sudanese grass, etc.) are cut only in rolls, since in the selection of dried plants from the swaths, the mass is polluted with earth. For fast and uniform wilting, the mass of freshly mown plants in the felling should not exceed 4.0-5.0 kg per 1 cm^2. The swath width should be of the baler width. If the yield is more than 15 t / ha, the grasses are stacked.

For mowing grasses abroad, mainly rotary, disc and drum mowers are used. They allow you to work at high translational speeds, limited only by the topography of the field and the capabilities of the tractor. The use of rotary cutters increases the efficiency of the technological process when mowing high-yielding, rough and prone to lodging herbs. The performance of such mowers is 30% higher than the segment-finger with reciprocating movement of knives.

The disadvantages of rotary mowers are: high energy intensity (about 12.0-15.0 kW per meter of grip width); high specific fuel consumption and high cost; the risk of injury (significant acceleration of the movement of falling foreign objects) and soil contamination by grass when mowing grass on sandy and loose soils.

To speed up the process and reduce the loss of leaves and inflorescences, legume grasses and bore-grass cereal mixtures should be planted.

At present, for mowing annual and perennial grasses with simultaneous flattening of the stems and laying them in the swath on the stubble, leading companies produce various mowers: "Disco-300" ("Claas", Germany) (Disco-300 mower conditioner n.d.), "Easy Cut 320" ("Krone", Germany) (Easy Cut 360 mower conditioner n.d.), "FC 202R" ("Kuhn", France), KPRN-3A (CJSC "Lyubertsy Plant of Agricultural Engineering", Russia) (KPRN-3A mower conditioner n.d.), KPP-3, 1

(Bobruiskagromash OJSC, Republic of Belarus), etc. Foreign companies mainly produce mowers with rotary cutters.

In Disco-300 mower conditioner with a working width of 3.0 m, the minimum power consumption is 40 kW without a conditioner and 51 kW with a conditioner. The required power of the Easy Cut 360 mower conditioner with a width of 3.1 m is 50 kW, and with a conditioner 66 kW and with a capacity of 3.0-3.8 ha / h (Easy Cut 360 mower conditioner n.d.).

For foreign fodder harvesters characteristic of the intensification of the working bodies, the achievement of the maximum possible productivity of labor, unlimited choice for the aggregation of wheeled tractors of any capacity. Foreign manufacturers of mowers achieve maximum performance with various combinations in the preparation of cleaning units. The firms «Claas» and «Krone» (Germany) have created units consisting of three air conditioner mowers mounted on a special power tool. «Claas» has created a Cougar self-propelled mower with a 350 kW engine and a working width of 14 m while maintaining a transport width of 3.0 m. Five working sections with a Disco rotor are mounted on the frame. Productivity mowers over 20 ha / h (Klochkov 2006).

In Kazakhstan, the use of rotary mowers is not always effective. At low yields of hayfields, mowers with segment-finger cutting machines are widely used. Due to lower metal consumption and lower power consumption, such machines are much cheaper than rotary mowers.

In the CIS countries, mower conditioners with segment-finger cutting apparatuses PN-540 "Prostor" (OJSC "Tula Combine Plant", Russia), KPS-5G, KPP-4.2 (PO "Gomselmash", Republic of Belarus), UPC are manufactured -0.1, SKP-0,2 (OJSC "Red Star", Ukraine) (Mower-conditioner PN-540 "Prostor" n.d., Our mowing machines n.d., Mower conditioner SKP-0,2 n.d.). The advantages of these mowers are in precise cutting, low energy capacity for mowing the grass (about 2.0-2.5 kW per meter of grip width), low pollution of the forage mass and cost.

The power consumption of the PN-540 mower conditioner with a grip width of 3.6 m is 24.8-31.0 kW, the output per 1 hour of basic time is 2.8 ha / h, the drive of the knives is a crankshaft-connecting rod mechanism with a straight a combination of rocker arms with a knife head.

In Kazakhstan, self-propelled mowers E-281, 301 (Germany) and КПП-4,2 (Russia) with double-blade cutting machines are mainly used for mowing seeded grasses with simultaneous flattening and roll them (KPP-4,2 mower conditioner n.d.).

The drive of the cutting units of the grass headers of the KSK-100, E-301, and E-302 forage harvesters is driven by two rocking washer mechanisms mounted on the right and left sides of the header.

The drive of the two-knife cutting machine of the harvesting machines is very complex and metal-sheet, as it contains two separate mechanisms interconnected by long intermediate shafts and consisting of complex parts that require manufacturing at a high class of accuracy and thoroughness of assembly (Adilsheev 2017). In this regard, the "Schumacher" planetary gear is used as a drive for the cutting units of the KPP-4,2 mower conditioner. One of the promising ways to improve the reliability of the mower conditioner is to improve the drive of the cutting unit.

In scientific works Rustamova (1981), Osobova (2010), Osobova and Vasilyev (1983), Reznikov et al. (1991), Dolgov (1987), Bosogo (1978) analyzed all known drive mechanisms used in mowers, reapers, copyright certificates and patents. In order to improve the performance of the mower, reduce the frequency of rotation of the crank shaft and, thereby reducing inertial loads, improve the reliability of the mower, we use a cutting unit with a double knife stroke. The work of Popova (1978), Drozdova (1961), Zhortuylov et al. (2012), Bosos (1978) are devoted to the work of the cutting apparatus with double travel mowing segments. The advantage of the cutting unit with double run of segments, as compared with the unit with single run of segments, is that the angular speed of the crank decreases 1.5-2.0 times, the feed of the cutting apparatus can be increased 1.6 times decrease 1.1-1.3 times (Popov 1978).

In Kazakh Research Institute of Mechanization and Electrification of Agriculture a mower drive mechanism has been developed in which the reciprocating movement of the knife is carried out by a crank-beam mechanism. The technical novelty of the invention is protected by innovative patents of the Republic of Kazakhstan No. 26421 and No. 29916 (Zhortuilov et al. 2015, Zhortuylov et al. 2012). Theoretical studies to substantiate the parameters of the mechanism were conducted. Analytical expressions, which determine the movement, speed and acceleration of the knife of the mower's cutting apparatus, are obtained Experimental models of mechanisms were made, tests were carried out under production conditions. The disadvantage was that there were some fluctuations from the dynamic loads of the cutting unit with a double knife course (Zhortuylov et al. 2017, Zhoruylov et al. 2017).

The purpose of the work is the development and substantiation of the design parameters and operating modes of the mechanism for driving the mower-conditioner drive unit, which ensures the reduction of dynamic loads and high-quality execution of the technological process.

In this regard, in the following tasks:

1. Select the most appropriate constructive technological scheme of the drive mechanism of the cutting unit and determine the rational relationship between its individual parameters.

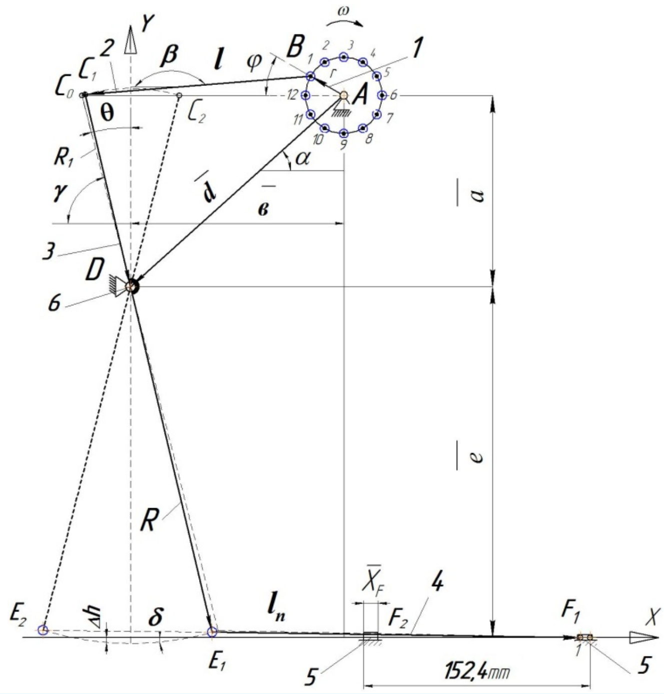

Fig. 1. Diagram of the crank-beam drive mechanism of double-cutter cutting unit

2. Conduct a study of the kinematic and dynamic characteristics of the drive mechanisms of the cutting unit and determine the main parameters.

RESEARCH METHODS

Studies were conducted using classical methods of theoretical and applied mechanics, the theory of mechanisms and machines.

The kinematic study of the mechanism carried out by the method of vector contours. According to this method, the planar lever mechanism, located in a rectangular coordinate system xOy, is represented as a closed polygon consisting, depending on the complexity of the mechanism, of one or several closed vector contours. Closure conditions are written in a vector form or in the form of a projection on the coordinate axes (Zinoviev 1972).

The numerical analysis of the equation of motion of the knife drive of the mower cutter was performed using standard Excel programs, Matcad. When processing the results of experimental studies, the provisions of mathematical statistics were used.

RESULTS AND DISCUSSION

In Kazakh Research Institute of Mechanization and Electrification of Agriculture a mower-conditioner drive mechanism has been developed. The mechanism consists of a drive shaft rack with a crank connected by means of a connecting rod to one end of the rocker arm. The other end of the rocker arm is connected to the knife head through a leash.

Determination of Parameters of the Drive Mechanism of the Cutting Apparatus

In the mower to drive the knife used crank-beam mechanism. It converts the rotational movement of the crank into the swinging movement of the rocker and the return-but-forward movement of the knife.

Fig. 1 shows a crank-beam drive mechanism for a single-cutter and double cutter drive. The mechanism consists of crank 1, connecting rod 2, rocker arm 3, leash 4, ram-head knife 5 and stand 6. The beam has a length DE = R. The ratio of the lengths of the rocker $K = \frac{DE}{DC} = \frac{R}{R_1}$.

A lead of length l_4 is connected to point E. An analytical study of the mechanism is given by the method of vector contours developed by Zinoviev (1972). To determine the kinematic parameters of the mechanism, consider the six-tiered, shown in **Fig. 1**, and construct the vector closure equation *ABCDEF*. When the mechanism is in operation, the CDE, rocker, swinging about the axis D, describes the arc C_1C_2 and E_1 E_2.

The position of the rocker *CD*, corresponding to the extreme position of the knife, should be symmetrical about the axis O_Y, i.e. OC_1=OC_2, OE_1=OE_2. This installation of the rocker ensures reliable operation of the cutting unit. If the cranks are in line with the connecting rod, the knife will take extreme positions. In the initial position at φ=0, the crooked thorn *AB* and the rod *BC* lie along one straight line $l = d\cos\alpha$. The stroke of the knife depends on the length of the rocker arm and its angle of inclination (swing), Set by a single knife stroke of the cutting unit *S* = *t* = 76.2 mm. Taking the length of the rocker arm R, we determine the angle of rolling of the rocker arm θ by the formula:

$$\theta = \arccos S/2R_1 = \gamma - 90^0.$$

The condition of the working of the crank is expressed by the following inequalities:

$$r \prec l;\ r + l \prec R_1 + d;\ l - r \succ d - R_1.$$

The vector equation is written in the following form:

$$\vec{r} + \vec{l} + \vec{R}_1 = \vec{d} \qquad (1)$$

where - r-the radius of the crank AB; - l-the length of the connecting rod sun;

R_1- the length of the rocker CD; d- distance between supports A and D.

Projecting equation (1) on the coordinate axes O_X and O_Y, we get:

$$\left.\begin{aligned} r\cos\varphi + l\cos\beta + R_1\cos\gamma = d\cos\alpha \\ r\sin\varphi + l\sin\beta + R_1\sin\gamma = d\sin\alpha \end{aligned}\right\} \qquad (2)$$

where -φ- the angle of rotation of the crank; -β, γ, α respectively, the angles formed by the vectors $\vec{l}, \vec{R}_1, \vec{d}$ with the axis O_X; while $\varphi = 0; d\cos\alpha = l;\ d\sin\alpha = R_1\sin\gamma$.

Moving the point of the rocker rocker CD is determined by:

$$x_1 = R_1\cos\gamma \qquad (3)$$

From the first equation of the system (2), the value of $R_1\cos\gamma$ is substituted into equation (3):

$$x_1 = r\cos\varphi - l\cos\beta + d\cos\alpha \qquad (4)$$

From the second equation of system (2):

$$\sin\beta = \frac{-r\sin\varphi - R_1\sin\gamma + d\sin\alpha}{l},$$

then: $\cos\beta = \frac{\sqrt{l^2 - (-r\sin\varphi - R_1\sin\gamma + d\sin\alpha)^2}}{l}$.

Substituting the value of the expression $\cos\beta$ into equation (4), we get

$$x_1 = -r\cos\varphi - \sqrt{l^2 - (-r\sin\varphi - R_1\sin\gamma + d\sin\alpha)^2} + d\cos\alpha \qquad (5)$$

With sufficient accuracy, we can assume that $R_1\sin\gamma \approx d\sin\alpha$, then we get:

$$x_1 = -r\cos\varphi - \sqrt{l^2 - r^2\sin^2\varphi} + d\cos\alpha \qquad (6)$$

The displacement of point E on the beam is determined by taking into account the ratio K and changing the direction of movement to the opposite side.

The equation of motion of the knife of the cutting apparatus is:

$$x = -\frac{R}{R_1}\left(-r\cos\varphi - \sqrt{l^2 - r^2\sin^2\varphi + d\cos\alpha}\right) \qquad (7)$$

The equations for determining the analogs of the velocity and acceleration of the point *E* will be obtained by a two-fold differentiation of equation (7) along the generalized φ coordinate. Then we get the analytical expressions that determine the speed and acceleration of the blade of the mower-conditioner:

$$V = -\frac{R}{R_1}\omega\left(r\sin\varphi + \frac{r^2\sin 2\varphi}{2\sqrt{l^2 + r^2\sin^2\varphi}}\right) \qquad (8)$$

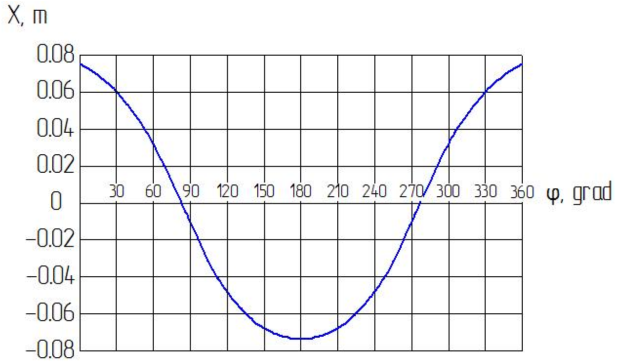

Fig. 2. Graph of the movement of the knife x with double mileage depending on the angle and rotation of the crank φ

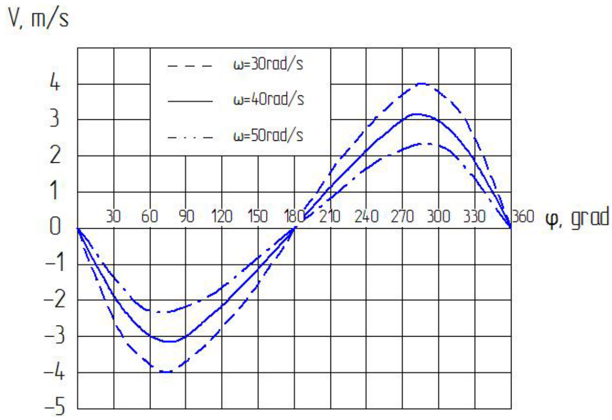

Fig. 3. Graph of the speed of the knife v with double mileage depending on the angle and rotation of the crank φ

$$a = \frac{R}{R_1}\omega^2\left[r\cos\varphi + \frac{r^2}{4}\left(\frac{4\sqrt{(l^2 - r^2\sin^2\omega)}\cos 2\varphi + r^2\sin^2 2\varphi}{\sqrt{(l^2 - r^2\sin^2\varphi)^3}}\right)\right] \qquad (9)$$

At $R = R_1 = D_C$ - the equations describe the speed and acceleration for a knife with a single run, and at $\frac{R}{R_1} = 2$- with a double run of a knife.

Fig. 2 shows a graph of the movement of the knife, depending on the angle of rotation of the crank φ with a double run of the knife.

Figs. 3 and **4** show graphs of changes in the speed and acceleration of the knife with double knife run at various rotational frequencies of the crank shaft.

With increasing speed increases the speed of the knife. With a speed of rad / s, the speed at the beginning of cutting is 2.30 m / s, and at the end of cutting - 1.75 m / s, which is lower than the minimum acceptable value (2.5 m / s). With a frequency of rotation ω = 40 rad / s, the maximum speed of the knife is 3.1 m / s. The maximum speeds in this mechanism are shifted compared with the crank mechanism by 18°…20°. The speeds of the knife at the beginning and at the end of cutting are different and equal, respectively, to 3.05 and

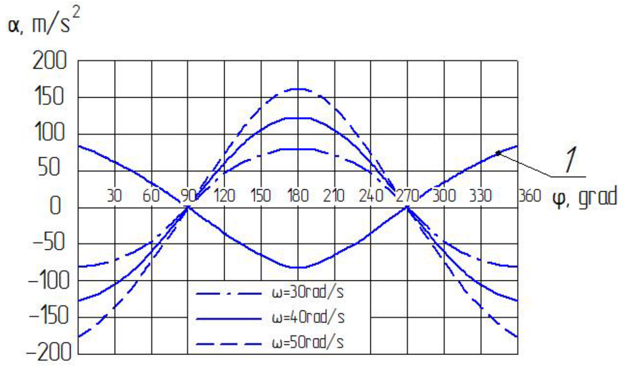

Fig. 4. Graph of the change in acceleration α of the knife with double mileage and (1) the opposite end of the rocker depending on the angle and turning the crank φ

2.6 m / s. The speeds of the forward and reverse moves of the knife are equal to each other. Thus, for the favorable performance of the mowing process of grass, the crank rotation frequency should be not less than 40 rad / s.

Graphs of changes in the acceleration of the knife with a double run depending on the angle of rotation of the crank at different frequencies of rotation are shown in **Fig. 4**.

The figure also shows a graph of the acceleration of the point C of the opposite end of the rocker depending on the angle of rotation of the crank φ. From the graph it can be seen that the knife moves in antiphase to the point C of application of forces to the opposite end of the rocker arm. This will lead to a partial balancing of the inertia force, which will reduce the vibration of the cutting unit.

For the DEFF′D vector contour of the off-axis rocker-slider mechanism, we make up the equation:

$$\bar{l}_{DE} + \bar{l}_n = \bar{x}_F \qquad (10)$$

Projecting it on the x and y axes gives:

$$\bar{l}_{DE} \cdot \cos(180 - \gamma) + \bar{l}_n \cdot cos\,\delta = x_F \qquad (11)$$

where δ is the angle between the positive direction of the *ox* axis and the longitudinal axis of the driver.

Moving the end of the knife head vertically is determined by the formula:

$$\Delta h = R(1 - \cos\theta) \qquad (12)$$

where $\theta = \gamma - 90^0$ is the angle of inclination of the yoke to the vertical axis.

Determination of the Power Required to Drive the Cutting Unit Mower-conditioner

The force of resistance P to the movement of the knife is determined by the formula (Osobov and Vasilyev 1983, Sablikov 1968):

$$P = P_{cp} + P_j + F \qquad (13)$$

where P_{cp} - the average value of the force of resistance to shear, H;

P_j is the inertial force of the knife mass, H;

F - knife friction force, N

The value of the average shear resistance is not the same and is determined by the formulas:

$$\mathrm{P_{cp}} = \mathrm{P^1_{cp}} + \mathrm{P''_{cp}} = \frac{\varepsilon F_{\mathrm{H}_1} \cdot Z}{x_{\mathrm{p}_1}} + \frac{\varepsilon F_{\mathrm{H}_2} \cdot Z}{x_{\mathrm{p}_2}} \qquad (14)$$

where the work expended on cutting the plant - cutting the grass from 1 cm² can be taken

$\varepsilon = 2 - 3\mathrm{H}cm/\mathrm{cm}^2$.

In the normal cutting machine with double knife run $F_{H_1} = 0{,}32LS$ $\mathrm{F}_{H_2} = 0{,}18\mathrm{LS}$- - the knife load area at the first and second fingers, cm2; L - knife feed, 5 ÷ 8 cm; S - knife travel - 15.2 cm; z– number of segments, units;

x_{P_1} and x_{P_2} - moving the knife from the beginning to the end of cutting, respectively, at the middle and extreme fingers.

The inertial force is determined by the mass m_{H} of the knife and the acceleration a_H:

$$P_j = m_{\mathrm{H}} \mathrm{a_H} \qquad (15)$$

The change in inertia force depending on the movement of the knife will change in accordance with the change in the acceleration curve (**Fig. 4**). P_j corresponds to the beginning (φ=0°) and the end of φ=360° of the knife stroke, and at φ=90° and 180° P_j=0.

The force of gravity of the knife of mowers and reapers at a length of 1 m is equal to $G = 20\ldots 22H$, and at a length of 3.0 m, $G = 66H$.

Friction Force

In mowers with a crank-yoke mechanism, the friction force of the knife on the elements of the finger bar consists of the friction force F_1, caused by the force of gravity of the knife, and the force F_2 from the action of the leash:

$$F = F_1 + F_2 \qquad (16)$$

The friction force from the force of gravity of the knife on the elements of the finger bar is equal to (Sablikov 1968):

$$F_1 = G_H f \qquad (17)$$

where G_H is the force of gravity of the knife, H;

f - friction coefficient, *f*=0,25…0,3..

Leverage action:

$$F_2 = \frac{(P_{cp} + P_j + fG_H)tg\delta}{1 - ftg\delta} f \qquad (18)$$

The force required to move the knife P will be equal (Zhortuylov et al. 2017):

$$P = \frac{\varepsilon F_{H_1}.Z}{x_{P_1}} + \frac{\varepsilon F_{H_2}.Z}{x_{P_2}} + m_H a + fG_H + \frac{(P_{cp} + P_j + fG_H)tg\delta}{1 - ftg\delta} f \qquad (19)$$

In the crank mechanism δ– the angle of inclination of the connecting rod to the knife plane varies between 25 and 35⁰ $(tg\delta = 0{,}47 - 0{,}70)$ (Osobov 2010), and in the crank-beam-yoke mechanism, the angle of inclination of the driver to the plane of the knife δ varies between 0-50. It follows that the friction force in the crank-beam mechanism, compared with the crank-connecting rod, is reduced by 5 ÷ 8 times.

Fig.5. Crank-beam mechanism for the drive of cutting device with a double stroke, used in the KP-3,0 mower conditioner

The power required to overcome the forces of resistance of the knife to movement, is determined from the expression (Osobov 2010):

$$N = \frac{P \cdot v_{cp}}{1000}, kW \quad (20)$$

where P is the force of resistance of the knife to movement, H;

v_{cp}- average knife speed, m / s.

Calculations of the power required to drive the mower conditioner drive with a working width of 3.0 m showed the following. The power required to drive a double knife stroke with a crank-beam mechanism when mowing grass is 4.18 kW. The friction force of the knife in the crank-beam mechanism in comparison with the crank connecting rod is reduced by 5.0-8.0 times.

To drive the knife of the cutting apparatus of normal cutting with double knife run, less power is needed by 30-40% than for other apparatuses. This is explained by the fact that in the normal cutting machine with a single knife run (stroke S = 76.2 mm) and the load area is larger than with a double-run knife (Sablikov 1968).

The developed crank-beam mechanism (**Fig. 5**) of the cutting unit drive with a double knife run was used in experimental samples: the KS-2,1ZH mower, the KP-3.0 mower conditioner, which passed production tests with positive results (Zhoruylov et al. 2015).

The energy performance of the KS-2,1ZH mower and the KP-3.0 mower-mower conditioner was determined in field conditions by tensometric method of torque and rotation frequency of the tractor PTO.

The power required for mowing grass with an air-conditioned mower conditioner at a speed of 2.0 m / s is 16.4-17.5 kW, and the idling speed of the cutting unit is 3.1 kW. The mowing capacity was 2.5-2.8 ha / h. As a result of the tests, it was established that on uneven haymaking topography, the technological processes of mowing grass with roll laying are performed reliably and efficiently. Flattening mower has the opportunity to work in conditions of uneven relief of natural and seeded herbs.

CONCLUSION

The method of vector contours obtained analytical equations to determine the analogs of the movement of the knife, speed and acceleration of the movement of the knife with a double stroke.

The parameters of the crank-beam mechanism for the drive of the cutting unit with double knife stroke are justified:

The developed crank-beam drive mechanism of the cutting unit was applied in the KS-2,1Zh mower and the KP-3.0 mower conditioner, which passed production tests with positive results. The use of a new crank-beam mechanism with a double knife stroke reduces the rotational speed of the crank by 1.5 times, increases the knife feed or productivity by 1.6 times, reduces inertial forces by 1.2-1.3 times, respectively, reduces the power consumption of the mowing process herbs and partially reduce vibrations.

ACKNOWLEDGEMENTS

This work is funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan on the budget program 217 “Development of Science”, subprogramme 102 “Grant funding for scientific research.” The crank-beam mechanism is used to drive the cutting unit with double knife run in the mower conditioner used for mechanization of haylage in rolls wrapped with film.

We thank colleagues, employees of the institute, engineering and technical workers who are not the authors of the article, but with their assistance research was conducted.

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