Journal of Engineering and Applied Sciences 12 (14): 3803-3809, 2017
ISSN: 1816-949X

Kinematics of Crank-and-Rocker Mechanism with Flexible Rods of Double-Knife Cutting Unit

Anuarbek Adilsheyev, Omirserik Zhortuylov, Vladimir Golikov,
Toktar Abilzhanuly and Murat Suranchiev
Kazakh Scientific Research Institute of Mechanization and Electrification of Agriculture,
Almaty, Kazakhstan

Abstract: A new crank-and-rocker mechanism with flexible rods is proposed in a stressed closed circuit for the drive of the double-knife cutting unit of harvesting machines. The drive of the double-knife cutting unit is carried out by one mechanism. The use of flexible links makes it possible to reduce the weight and material consumption of the mechanism. Due to the presence of flexible links, the mechanism does not require high precision in the manufacture of parts it is not sensitive to deformation of the frame which increases the reliability of the mechanism. Analytic expressions are obtained for determining the movement, speed and acceleration of cutting unit.

Key words: Double-knife cutting unit, crank-and-rocker mechanism, closed circuit, flexible rods, kinematics, movement, speed and acceleration of knives

INTRODUCTION

The state and level of livestock development are directly dependent on feed production, on the volume and quality of harvested fodder. For harvesting high-quality hay in conditions of dry hot climate of Kazakhstan and Central Asia, harvesting should be carried out in a limited agrotechnical terms which requires high-efficiency fodder harvesters.

In the design of modern fodder harvesters for harvesting grasses a wide application, along with rotary machines has finger-bar cutting units. The development of finger-bar cutting units is carried out in two main directions: improving the technological process of cutting grass and improving the drive mechanisms of the knife (Klenin *et al*., 2008).

The first direction is based on the theory of cutting stems of grasses and cereals by finger-bar type cutting machines where the conditions of pinching the stems in the cutting pair, stems cutting speed, longitudinal and transverse bends of the stems during cutting, the relationship of the cutting process to the structural elements of the cutting unit (Bosoy, 1967; Kariafojski and Karwowski, 1976; Srivastava *et al*., 2006; Miu, 2015).

To convert the rotational motion of the drive shaft into a reciprocating motion of the cutting knife unit, various mechanisms are used that differ in the kinematic scheme and in the design. The most widespread use for the drive of cutting knife unit is eccentric crank mechanisms. Currently, foreign scientists pay a lot of attention to the study of the cutting unit with a eccentric crank mechanisms (Guarnieri *et al*., 2007; Rajabipour *et al*., 2007; Geonea *et al*., 2008). As a result of these studies, the movement, speed and acceleration dependence of rotation knife angle of the crank shaft are obtained. In finger-bar cutting units with reciprocating motion of the knife, there are large alternating inertial forces which load the links of the mechanism and reduce the operational reliability of the cutting unit.

In the grass headers of fodder harvesting machines, double-knife finger-bar cutting units are used in which two knives move in opposite directions which balances the inertial forces of the knives. Studies of double-knife cutting units are mainly aimed at improving existing and creating new drive mechanisms (Rustamov, 1981; Turbin and Drozdov, 1976). In China, Shen *et al*. (2016) scientists are working on a new rocker linkage mechanism for the double-knife of the header. In this research, Chitu and Ilea (2016) kinematics and dynamics of a double-knife cutting unit of a central-tube cutting machine is considered. The research of V.E. Bakteyeva is devoted to an investigation of the crank-and-rocker mechanism with the gear sector which provides double knives for the cutting unit movement in opposite directions (Bakcheev, 1991). However, the open gears used in the constructions of this mechanism have low

Corresponding Author: Anuarbek Adilsheyev, Kazakh Scientific Research Institute of Mechanization and Electrification of Agriculture, Almaty, Kazakhstan

operational reliability. In grass harvesters headers and mower-conditioners, the two knives are driven by two mechanisms of swash plates, separate for each knife and mounted on the sidewall of the header platform. The drive crankshafts of the mechanisms are interconnected by three intermediate shafts mounted on four supports. At the ends of the crankshafts there are swash plates connected by means of a vibratory shaft, a connecting rod and a suspension bracket with the ends of the knives. The drive is structurally complex and metal-consuming as it consists of two independent mechanisms connected by long shafts (Korotkevich, 1991).

As a result of studies on double-knife cutting unit with two mechanisms with a swash plate it was established (Afanasyev *et al*., 1983) that the left and right knives operate at an antiphase displacement for 360 on average which causes dynamic loading of the drive and vibration of the frame and a reduction in the reliability of the header in general. In order to fully balance the inertial loads in the cutting unit, it is advisable to use a symmetrical drive. In addition, the reliability of the swash plate mechanism is ensured when the rotation axes of its three links of the crank shaft, washer and fork intersect at the same point which is possible with high-precision manufacturing of parts (Kotov and Chuprinin, 2011). Nonobservance of these requirements leads to a rapid wear and breakdown of the parts of the mechanism.

In the considered articulated-linkage mechanisms, during operation the links are loaded alternately by tensile and compressive forces. With a considerable length of connecting rods there is a threat of losing longitudinal stability under the action of compressive forces. To ensure longitudinal stability, the shapes and dimensions of the connecting rod cross-section is developed and complicated. At the same time, the mass is increased and as a consequence, inertial loads on the links and kinematic pairs. Variables in the direction of the load in mechanisms with gaps cause vibration and noise, accelerate the wear of the hinge elements. In mechanisms with rigid links as a result of deformations of the frame base as well as inaccuracies in manufacturing and assembly, additional loads arise which increase wear in the kinematic pairs and reduce the efficiency (Reshetov, 1979; Tahmassebpour, 2016).

The most promising technology for the drive of the cutting unit of harvesters is self-aligning mechanisms with flexible links in a prestressed closed circuit (Atafar *et al*., 2013). A feature of these mechanisms is that the flexible links form a closed circuit. The presence of such circuit causes a number of features common to this kind of mechanisms and can serve as a characteristic feature that distinguishes it from the widespread articulated mechanisms. A necessary condition for the flexibility of mechanisms with a closed circuit is the ability of some links of the circuit to sufficient elastic deformations and the geometric parameters of the circuit can be chosen in such a way that sufficient movements of the mechanism are ensured with small relative deformations of the links. When assembling the mechanism in a closed circuit, pre-tension of the flexible links must be created so that tensile forces are always maintained during operation. In these mechanisms, the transfer of motion is carried out by flexible links experiencing only tensile stresses. This makes it possible to significantly reduce metal consumption and weight, simplify the design in comparison with mechanisms in which the requirements for the longitudinal stability of the links force a development and complicated shape of the cross section.

MATERIALS AND METHODS

Theoretical studies to determine the movement of knives, driven back and forth by a crank-and-rocker mechanism with flexible rods were carried out using the analytical method of kinematic calculation, based on the closed nature of the circuit formed by the links. Speed and acceleration of knives of the cutting unit are determined by methods of theoretical mechanics.

In experimental studies, a specially designed slide-wire gauge mounted on a fixed finger bar was used to record the movement of the knives. The movable element of the slide-wire gauge was connected to the reciprocating knife of the cutting unit. The movements of the movable element of the slide-wire gauge were recorded with a strain gauge ZET 017-T8 station.

RESULTS AND DISCUSSION

A grass harvester with a double-knife cutting unit in Kazakhstan Scientific Research Institute of Mechanization and Electrification of Agriculture under the budget program 217 MES RK for 2015-2017 is developed in which the transformation of the rotational motion of the drive shaft into reciprocating motion of the knives is carried out by a crank-and-rocker mechanism with flexible rods in a stressed closed circuit.

The mechanism of the double-knife cutting unit drive (Fig. 1) consists of leading crank shaft 1, connecting rod 2, right 3 and left 4 rocker arms connected by cross flexible rods 5 and 6. The rocker arms 3 and 4 are pivotally connected by connecting links 7 and 8, respectively with the right 9 and the left 10 knives. The right knife 9 of the cutting unit is driven by a crank-and-rocker mechanism

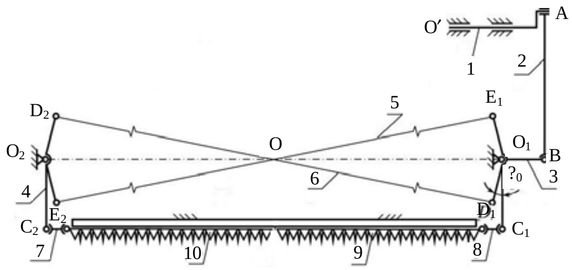

Fig. 1: Double-knife cutting unit drive mechanism

consisting of crank shaft 1, connecting rod 2, left rocker arm 3 and a connecting link 8. The left knife 3 is driven by rocker 4 connected via flexible rods to 6 and 7 to the right rocker 3. Two blades perform vibrational movement towards each other which provides balancing of inertia forces in the cutting unit.

Arms $E_1O_1D_1$ of right rocker and arms $E_2O_2D_2$ of left rocker are connected to flexible rods 5 and 6 forming a closed circuit $E_1O_1D_1D_2O_2$ E_2. A necessary condition for the mobility of the closed circuit of the mechanism is the ability of flexible rods 5 and 6 to sufficient flexible deformations, since in the case of stiff rods, the mobility of the closed circuit $E_1O_1D_1D_2O_2E_2$ is zero:

$$W = 3n - 2P_5 - P_4 = 3.4 - 2.6 - 0 = 0 \tag{1}$$

Where:

n = Number of movable links

P_4, P_5 = Number of kinetics pairs of 4 and 5 classes

In the crank-and-rocker mechanism with crossed flexible rods to ensure the movement of the blades strictly in antiphase in closed circuit $E_1O_1D_1D_2O_2E_2$, the distance between the axes of the rocker arms d should be equal to the length of the flexible rods, i.e., O_1 O_2 = D_1 D_2 = E_1 E_2 (Adilsheyev *et al*., 2016).

To determine the angle of arms deflection connected to flexible links from the arms O_1C_1 and O_2C_2. Let us consider the isosceles triangle OO_1D_1 in which $D_1O = OO_1 = d/2$, $O_1D_1 = R_2$. The angle γ_0 is determined by the expression:

$$\gamma_0 = 90^0\text{-}\arccos\frac{R_2}{d} \tag{2}$$

When assembling the mechanism in closed circuit, pre-tension of the flexible links must be created so that tensile forces are always maintained during operation. Pre-tension provides shock-free operation of the mechanism due to one-sided contact of kinematic pairs. Flexible links which take only tensile forces can be made

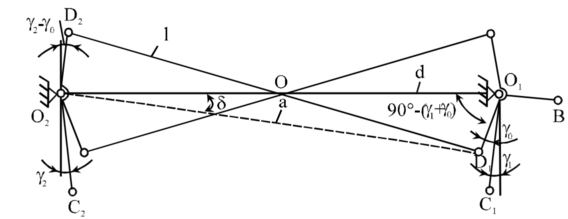

Fig. 2: Closed circuit $O_1D_1D_2O_2$

of steel rope. The use of flexible links makes it possible to reduce the weight and material consumption of the mechanism. Due to the presence of flexible links, these mechanisms do not require high accuracy of manufacturing and are insensitive to deformation of the frame.

The movement, speed and acceleration of the right knife are determined in the work (Adilcheev and Zhortuylov, 2015) depending on the angle of crank shaft rotation:

$$\begin{aligned} x_1 &= -r.\cos\varphi + a_0\sin^2\varphi \\ v_1 &= r\omega.\sin\omega t + a_0\omega\sin 2\omega t \\ a_1 &= r\omega^2\cos\omega t + 2a_0\omega^2\cos 2\omega t \end{aligned} \tag{3}$$

Where:

R/R_1r_k = Relative crank radius

$a_0 = Rr_k^2/2R_1l_0$ = Parameter that depends on the geometric parameters of the mechanism

$\varphi = \omega t$ = Angle of crank shaft rotation

r_k = Crank radius O'A

l_0 = Crank length AB

R_1 = Arm length O_1B connected to crank

R = Arm length O_1C_1 and O_2C_2 connected with knife

Rocking angle γ_1 of the right rocker from its average position is determined by Eq. 4:

$$\gamma_1 \ \ \arcsin\frac{(r.\cos\varphi\text{-}a_0\sin^2\varphi)}{R} \tag{4}$$

To determine the kinematic parameters of the left knife, let us consider separately closed circuit $O_1D_1D_2O_2$ (Fig. 2). During the deflection of O_1C_1 of the right rocker to the left to angle γ_1 from its middle position, the arm O_2N_2 of the left rocker will turn to the right to the angle γ_2. Then, the displacement of the left knife, driven by the left rocker is determined by Eq. 5:

$$x_2 = R\sin\gamma_2 \tag{5}$$

Turn angle γ_2 of the left rocker is:

$$\gamma_2 = \theta\text{-}\delta\text{-}\arccos\frac{R_2}{d} \quad (6)$$

To determine angle θ let us consider triangle $D_1O_2D_2$. From this triangle by the cosine theorem we get:

$$l^2 = R_2^2+a^2-2R_2a\cos\theta \quad (7)$$

From this expression we find:

$$\theta = \arccos\frac{R_2^2+a^2-l^2}{2R_2a} \quad (8)$$

Distance a us determined from the triangle $O_1D_1O_2$:

$$\begin{aligned} a^2 &= R_2^2 + d^2-2R_2d\cos[90-(\gamma_1+\gamma_0)] \\ &= R_2^2+d^2-2R_2d\sin(\gamma_1+\gamma_0) \end{aligned} \quad (9)$$

Inserting Eq. 9 into Eq. 8 considering that d = l, we get:

$$\theta = \arccos\frac{R_2\text{-}d\sin(\gamma_1+\gamma_0)}{\sqrt{R_2^2+d^2-2R_2d\sin(\gamma_1+\gamma_0)}} \quad (10)$$

Angle δ is determined from the triangle $O_1D_1O_2$ and with $a>R_2$, $\delta<90°\text{-}(\gamma_1+\gamma_0)$:

$$\delta = \arcsin\frac{R_2\cos(\gamma_1+\gamma_0)}{\sqrt{R_2^2+d^2-2R_2d\sin(\gamma_1+\gamma_0)}} \quad (11)$$

Substituents Eq. 10 and 11 into Eq. 6, we get the formula for determining of left knife movement:

$$x_2 = R\sin\left[\begin{array}{l}\arccos\dfrac{R_2\text{-}d\sin(\gamma_1+\gamma_0)}{\sqrt{R_2^2+d^2-2R_2d\sin(\gamma_1+\gamma_0)}}\text{-} \\ \arcsin\dfrac{R_2\cos(\gamma_1+\gamma_0)}{\sqrt{R_2^2+d^2-2R_2d\sin(\gamma_1+\gamma_0)}}\text{ - }\arccos\dfrac{R_2}{d}\end{array}\right] \quad (12)$$

To study the dynamics of the crank-and-rocker mechanism with flexible rods, the movement of the left knife can be represented in the following form:

$$x_2 = r\cos\phi+a_0\sin^2\phi \quad (13)$$

The reliability of the obtained analytical expressions was verified by experimental studies on the laboratory unit shown in Fig. 3.

The laboratory unit has a common frame on which the double-knife cutting device with the crank-and-rocker mechanism with flexible links is installed. The drive of the double-knife cutting unit is carried out by the electric motor connected to the crank shaft which is connected to the right rocker by means of the connecting rod. The rocking motion of the right rocker arm is transferred to the left rocker arm by crossed flexible rods. The rocker arms rocking in antiphase are connected with flexible joints to the knives by connecting links.

Fig. 3: Laboratory unit for the study of the mechanism operation

Fig. 4: Slide-wire gauge

The movement of the cutting knife unit is registered by the slide-wire gauge (Fig. 4). The slide-wire gauge is mounted with brackets on a fixed finger block of the cutting unit and the movable element is fixed on a bronze bushing, sliding along the guide. The bronze bushing is moved by a fork connected with a bracket with a knife.

This construction ensures continuous contact of the movable element with the slide-wire which ensures reliable operation of the gauge. The movements of the slide-wire gauge element were recorded with a strain gauge ZET 017-T8.

Only the left knife in experimental studies was recorded by slide-wire gauge, driven by the crossed flexible rods, since the right knife is reciprocated by the rigid links of the crank-and-rocker mechanism.

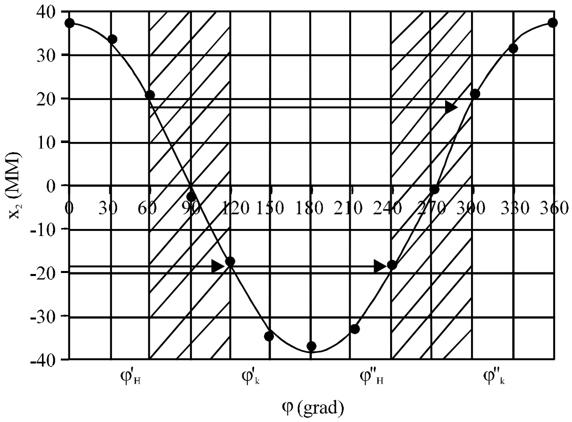

Fig. 5: Left knife movement chart

The results of experiments on the law of motion clarification of the left knife, driven by the rocker through the crossed flexible rods are shown in Fig. 5. The solid lines correspond to theoretical dependencies and the points to the experimental dependencies. Deviations of experimental data from theoretical data do not exceed 1.5%. Thus, it can be concluded that the theoretical dependences determine the movement of the knives with a sufficiently high accuracy.

It is established, Adilsheyev *et al*. (2016) that the minimum knife speed for a qualitative cut of plants by the cutting unit must correspond to Eq. 14:

$$v_{P\min} \geq v_T \tag{14}$$

where, v_T is technological cutting speed, equal to grasses 2.15 m/sec. To determine the cutting stroke of the knife, corresponding to the beginning and the end of the cutting, we build the position of the segment with respect to the cross bar (Fig. 6). The movement of the knife, corresponding to the cutting process is calculated by Eq. 15:

$$x_P = h(tg\varepsilon + tg\mu) \tag{15}$$

Where:

ε = Angle between the cutting edge of the segment and the direction of motion

μ = Angle between the edge of cross bar and the direction of motion

For Segment 1 (GOST 158-74) with size h = 0.055 m, ε = 28°40' and cross bar μ = 7°40'. Inserting these values into Eq. 12, we get x_p = 0.037 m. The cutting stroke of the knife before the start of cutting is:

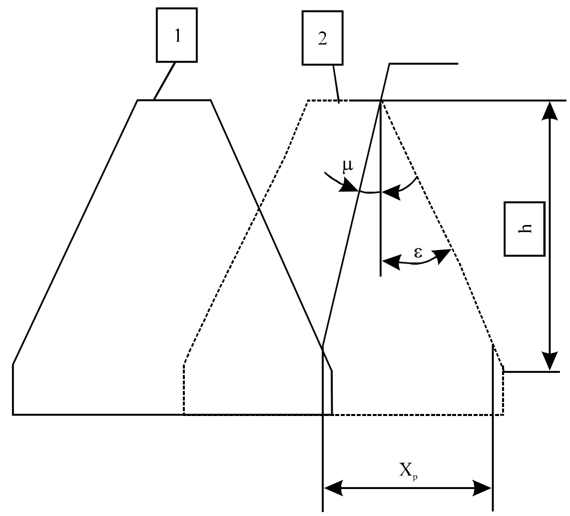

Fig. 6: The position of the knife segment at the begning (1) and at the end (2) of cutting

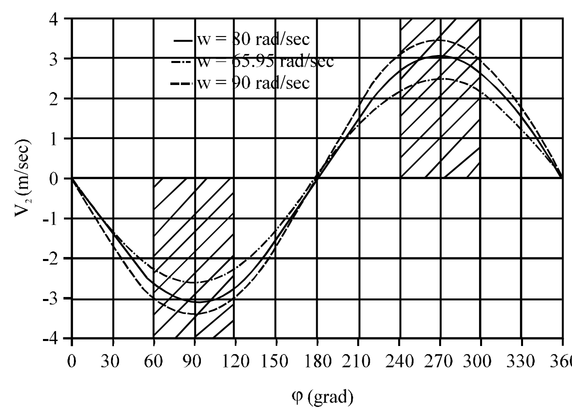

Fig. 7: Charts of the knife movement speed

$$x_k = \frac{x_{max} - x_P}{2} \tag{16}$$

For the cutting unit of normal cutting (x_{max} = 76 mm), the stroke of the cutting knife, calculated by Eq. 16 is equal x_k = 0.0195 m using the movement chart (Fig. 5) of the knife, we find the angles of the crank shaft corresponding to the beginning and the end of the cutting with the straight path of the knife φ'_k = 60.3° and φ'_k = 118.62° and during back stroke φ_k = 241.6° and φ''_k = 299.85°.

Figure 7 shows a chart with the speed of the left knife at different speeds of the crank shaft. Kinematic parameters are determined with the following geometric dimensions of the mechanism: the radius of the crank r_k = 19 mm, arm length R = 240 mm, R_1 = 120 mm, R_2 = 120 mm, crank length l_0 = 800 mm distances between

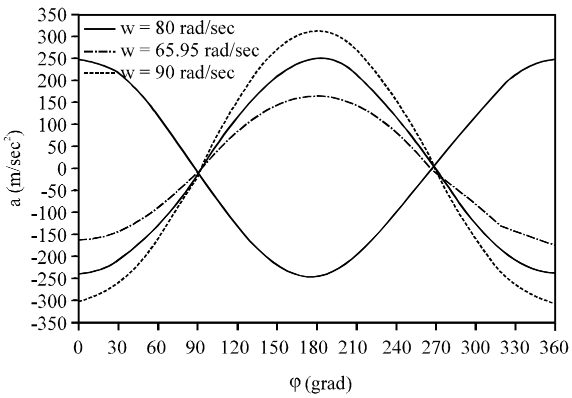

Fig. 8: Charts of the changing knife acceleration

the rocker supports d = 3000 mm. The cutting zone is shown by dashed lines. For high-quality execution of the technological process, the cutting speed should be not <2.15 m/sec. This value of the knife speed in the cutting zone is achieved at the speed of the crank shaft rotation w = 65,95 rad/sec. Thus, the rotational speed of the crank shaft which ensures a qualitative cutting of the plants should not be <65,95 rad/sec.

From the acceleration chart of the right and left knives at a speed w = 80 rad/sec, depending on the angle of the crank (Fig. 8) it is seen that both knives move in antiphase and the inertia forces of the knives are balanced. This leads to a decrease in dynamic loads in the elements of the mechanism.

In the crank-and-rocker mechanism with crossed flexible rods in the prestressed closed circuit with the length of flexible rods equal to the distance between the axes of the rocker arms (l = d) the right and left knives perform reciprocating motion strictly in antiphase.

The results of theoretical and experimental studies show the reliability of the obtained analytical expressions for determining the kinematic parameters of the cutting unit. These formulas allow further dynamic analysis of the mechanism for different sizes of rods and determine the optimal dynamic parameters and operating modes of the mechanism.

CONCLUSION

The most promising drive of double-knife finger-bar cutting machines is a crank-and-rocker mechanism with crossed flexible rods in a prestressed closed circuit. The results of laboratory studies confirmed its operability. The use of flexible rods made it possible to reduce the weight and metal consumption of the mechanism by almost 4 times compared to mechanisms with swash plates of grass harvesters.

Formulas for determination of movement, speed and acceleration of knives for the double-knife cutting unit with the crank-and-rocker mechanism and flexible rods are obtained. The analytical expressions obtained as a result of theoretical studies for determining the kinematic characteristics of the mechanism determine the movement of the knives with a sufficiently high accuracy. The discrepancies between the calculated and experimental values do not exceed 1.5%.

As a result of the kinematic analysis, it is established that in the crank and beam mechanism with a length of flexible links equal to the distance between the axes of the rocker arms, the knives perform oscillatory motion strictly in antiphase.

The obtained formulas allow further dynamic analysis of the mechanism for different sizes of rods; determine the optimal dynamic parameters and operating modes of the mechanism.

REFERENCES

Adilsheyev, A., O. Zhortuylov, M. Suranchiev and R. Akbuzauova, 2016. The determination of the kinematics parameters of a double knife cutting vehicle of grass reaping machine drive mechanisms. Proceedings of the 4th Scientific Congress on Agricultural Machinery Volume 1, July 22-25, 2016, Bulgarian Publishing Companies, Varna, Bulgaria, pp: 45-46.

Afanasyev, N.I., V.A. Dyachenko and E.P. Sorokin, 1983. Harvesting Mechanisms of Self-Propelling Machines. Uradzhai Publisher, Minsk, Belarus, Pages: 136.

Atafar, A., M. Shahrabi and M. Esfahani, 2013. Evaluation of university performance using BSC and ANP. Decis. Sci. Lett., 2: 305-311.

Bakcheev, V.E., 1991. Harvesting machines with double-knife cutting unit: Optimization of parameters and calculation of the drive by Johnson method. Tractors Agric. Mach., 11: 17-19.

Bosoy, E.S., 1967. Cutting Units for Harvesting Machines. American Society of Mechanical Engineers, New York, USA., Pages: 167.

Chitu, N. and R. Ilea, 2016. The dynamics of the operating mechanism of the cutting apparatus with two knives from mowing machine CDC 1, 5. Res. J. Agric. Sci., 48: 204-211.

Geonea, I.D., N. Dumitru and G. Catrina, 2008. The kinematics'analyse of an eccentric mechanism of a mower machine. Fascicle Manage. Technol. Eng., 7: 293-300.

Guarnieri, A., C. Maglioni and G. Molari, 2007. Dynamic analysis of reciprocating single-blade cutter bars. Trans. ASABE., 50: 755-764.

Kariafojski, C.Z. and T. Karwowski, 1976. ?utting Blade and Stalk Materials. In: Agricultural Machines: Theory and Construction, Bernacki, H. (Ed.). National Science Foundation, Washington, USA., pp: 48-120.

Klenin, N.I., S.M. Kiselev and A.G. Levshin, 2008. Agricultural Machinery. Kolos Publication, Moscow, Russia, Pages: 816.

Korotkevich, A.V., 1991. Technologies and Machines for Harvesting Forages from Grasses and Silage Crops: Training Manual. Uradzhai Publisher, Minnesota, USA., Pages: 383.

Kotov, A.V. and Y.V. Chuprinin, 2011. Vector analysis of spatial lever mechanisms. Tractors Agric. Mach., 12: 33-38.

Miu, P., 2015. Combine Harvesters: Thery, Modeling and Design. CRC Press, Boca Raton, Florida, USA., ISBN:9781482282375, Pages: 460.

Rajabipour, A., M. Ayazi, F. Khoshnam, H. Mobli and M. Ghasemi, 2007. Dynamic analysis of pitman and wobble shaft drive mechanisms: Consideration of the harvesting losses in the combine platform. J. Agric. Technol., 3: 173-181.

Reshetov, L.N., 1979. Self-Aligning Mechanisms. American Society of Mechanical Engineers, New York, USA., Pages: 334.

Rustamov, S.I., 1981. Physical and Mechanical Properties of Plants and Improvement of Cutting Units for Harvesting Machines. Donetsk National Medical University, Donetsk, Ukraine, Pages: 172.

Shen, C., X. Li, B. Zhang, K. Tian and J. Huang *et al.*, 2016. Bench experiment and analysis on ramie stalk cutting. Trans. Chin. Soc. Agric. Eng., 32: 68-76.

Srivastava, A.K., C.E. Goering, R.P. Rohrbach and D.R. Buckmaster, 2006. Hay and Forage Harvesting. In: Engineering Principles of Agricultural Machines, Joseph, S. (Ed.). ASABE, Michigan, pp: 325-402.

Tahmassebpour, M., 2016. Methods, algorithms of capacity calculation and increase throughput in wireless sensor networks base of zigbee: A survey. Indian J. Sci. Technol., Vol. 9, 10.17485/ijst/2016/v9i26/97259.

Turbin, B.I. and V.N. Drozdov, 1976. The Reduction of Vibrations and Noise in Agricultural Machines. American Society of Mechanical Engineers, New York, USA., Pages: 223.

Adilcheev, A. and O. Zhortuylov, 2015. Study of Mechanism Kinematic with Flexible Elastic Links of Double Cutter Bar Grass Reaper. Bulgarian Publishing Companies, Bulgaria,.