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KINEMATICS OF THE CONNECTING ROD-CRANK MECHANISM

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Abstract

The purpose of this work is to determine and analyze the laws of motion (velocities and accelerations) of the components of the cutting mechanisms in order to evaluate and optimize their performance, precision and durability. The present work aims to carry out a detailed kinematic study of the connecting rod-crank mechanism, having as its main objective the determination of the position, velocity and acceleration equations for the translation element (piston) as a function of the geometric parameters (length of the connecting rod and crank) and the angular velocity.

The results obtained will serve as a basis for the analysis of the performances and for the formulation of constructive optimization proposals in specific applications, such as agricultural machinery. From the analysis of the kinematic parameters of the connecting rod-crank mechanism, the following can be formulated:

The kinematic parameters show that in the case of agricultural machinery (mowers), the obtained speed profile allows the choice of an optimal operating regime, ensuring a sufficiently high cutting speed at the moment of impact with the plant, while minimizing excessive dynamic loads when reversing the movement.

Key words: kinematic parameters, mechanism, connecting rod-crank

INTRODUCTION

Mechanisms are the heart of any machine, and their study is the basis of modern mechanical engineering. (Aungurence N., et.al.,1997;). Of these, the connecting rod-crank mechanism (also known as the piston-crank mechanism) is undoubtedly one of the most widespread and fundamental. (Derpsch R. 2001, Feier David Saida, et.al., 2020). It performs the essential transformation from a continuous rotational motion (of the crank) to a reciprocating rectilinear translational motion (of the piston/slider) and vice versa. (Popa D. et.al., 2015).

Its applications are ubiquitous, from internal combustion engines (where it generates the main power) and piston compressors, to pumps and various drive mechanisms in the manufacturing and agricultural industries. (Mateoc-Sîrb Nicoleta et. al., 2024).

Kinematics studies the movement of rigid points and bodies without taking into account the forces that produce it. (M.A Drăgan, et. al., 2024; F Mladin, et. al., 2023). Therefore, the kinematic analysis of this mechanism is crucial for:

- understanding the subsequent dynamics of the system (velocities and accelerations are needed to calculate inertia forces);
-optimal design of machines, ensuring performance, durability and a minimum level of vibration. (Ilea R., 2017).

The connecting rod-crank mechanism is an essential system in internal combustion engines, used to convert the reciprocating motion of the piston into rotary motion, which can then be used to power various mechanisms or energy generators. This mechanism mainly consists of two main components: the connecting rod and the crank. (Goga Ana–Maria, 2016).

The connecting rod connects the piston to the crank and transmits the force from the piston to the crank, allowing the conversion of linear motion into rotary motion. The crank, on the other hand, is a wheel or shaft with an eccentric edge that receives the motion from the connecting rod and converts it into continuous rotation. (Duma Copcea Anișoara, et. al.,2024).

The operation of the connecting rod-crank mechanism is based on the engine's working cycle, where the piston moves alternately inside the cylinder, driven by the combustion of the air-fuel mixture. The smooth movement of the piston is converted into continuous rotary motion of the shaft by the connecting rod and crank, allowing the engine to operate efficiently.

This mechanism is appreciated for its simplicity and reliability in industrial and automotive applications, being the foundation of many types of conventional internal combustion engines.

Some authors emphasize the importance of the connecting rod-crank mechanism in internal combustion engines, pointing out that it converts the reciprocating motion of the piston into continuous rotation of the crankshaft. They explain that this mechanism ensures efficient power transmission and precise control of piston movement. (Duma Copcea Anișoara, et. al.,2024; Mazăre Veaceslav, et. al.,2024).

MATERIALS AND METHODS

The knife drive mechanism is of the crank-rod type.

The cutting device (figure 1) consists of a knife, fingers, guide plates, pressure plates. The cutting of plants is carried out by shearing by two distinct elements: the cutting blades of the knife and the counter-cutting blades of the fingers. The cutting blades (plates) are mounted on a support bar which together form the knife of the cutting device. The knife has a translational (linear-alternative) movement.

Figure 1. The cutting device of the Finger bar Mower 1.6

The fingers of the cutting device serve to separate the mass of stems in the area of action of the cutting device into narrow strips, in order to facilitate the cutting process. They are fixed to the support bar with countersunk head screws. When properly mounted, the tips of all fingers should be on the same line. Counter-cutting blades (counter-knives) are mounted on the fingers. The tip of the finger is sharp and curved upwards, which makes it easier to penetrate between the plants and prevents it from entering the ground on uneven terrain.

The knife is the movable part of the cutting device and consists of a steel bar, of rectangular section, to which the blades or cutting plates are attached by two rivets. The bar is placed at one end in connection with the drive mechanism. The blades or cutting inserts have the shape of an isosceles triangle with cut-off tips (figure 2).

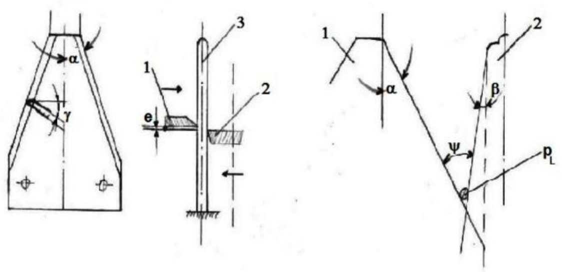

Figure 2 The shearing process of the cutting blade

1-cutting blade; 2-counter-cutting plate; 3-plant subject to cutting; γ – sharpening angle of the cutting blade; β,α – angle of the cutting blade edge, respectively of the counter-cutting plate edge, with the direction of advance; e – vertical clearance of the cutting blade relative to the counter-cutting plate; ψ - angle between the cutting edges of the blade and the counter-cutting blade; p - plant.

The edges of the cutting blades are sharpened at an angle of γ=19º-23º and form an angle of α=30º-50º with the direction of travel. In order for the cutting to be done with minimal effort and without breaking the plants, the cutting edges must be well sharpened, and the clearance between the cutting blade and the counter-cutting plate, in the vertical plane, must not exceed 0.3-0.5 mm. The shearing force decreases with the reduction of the cutting blade sharpening angle, the thickness of the cutting edge and the increase of the

angle that the cutting edges make with the direction of travel.
During the work process, the plants grouped into strips by the fingers are cut by passing the cutting edge of the blade over the edge of the counter-cutting plate.
Mowing grassy forage plants with minimal losses requires good sharpening of the knife as well as correct adjustment of the cutting device. The play that must exist in the knife guides and between the cutting blades should be a maximum of 0.5 mm. When the play is smaller or larger, the pressure plates must be adjusted by hitting them with a hammer. The lateral play of the knife is eliminated by moving the guide plates that are mounted under the pressure plates.
On the cutting device, the distance between the cutting blades of the knife and the counter-cutting blades of the fingers (0.2 – 0.5 mm) and the knife stroke are adjusted: The knife stroke is adjusted by adding or removing adjustment washers to the knife head. The adjustment is correct when the cutting blades of the knife overlap the counter-cutting blades of the fingers at the end of the stroke.

RESULTS AND DISCUSSIONS

The kinematic study of the connecting rod-crank mechanism consists of establishing the equations of the displacement, velocity and acceleration of the knife.
These equations are determined under the assumption that the angular velocity of the crank drive shaft is constant($\omega = constant$).
The determinations were made for the knife drive mechanism of a mechanical mower with fingers and knife. The mower's cutting device is of the single-stroke type characterized by $S = p = 76{,}2\ mm$, S where is the knife stroke (3 inces) and the pitch of the fingers.
For the kinematic study of the crank-rod mechanism, the kinematic diagram in figure 3 was represented.

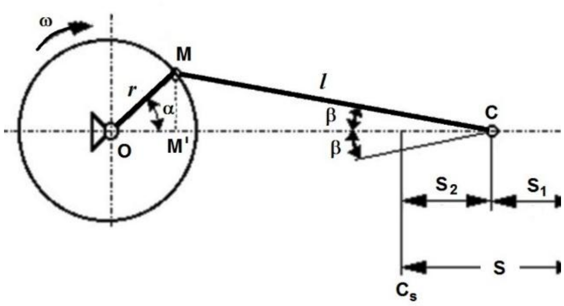

Figure 3. Kinematic diagram of the connecting rod-crank mechanism

The drive shaft of the connecting rod-crank mechanism performs a rotational movement around point *O* with constant angular velocity. The angular displacement of the shaft is obtained by integrating the relation $\omega = d\alpha / dt$. All crank points $OM = r$ are subjected to a centripetal acceleration, the acceleration of the crank *M* being $a_M = r \cdot \omega^2$.
Knowing the knife stroke $S = 76{,}2\ mm = 0{,}0762\ m$, constructive ratio between the radius of the crank and the length of the connecting rod($\lambda = r / l$) şi taking into account the fact that $S = 2 \cdot r$, the radius of the crank can be determined $S = 38{,}1\ mm = 0{,}0381\ m$ and the length of the connecting rod.
The parameters of the motion are: the space S (the knife stroke), the velocity v and the acceleration a. In the following, these kinematic parameters will be analyzed.
Knife stroke. The knife moves between the two dead centers: right dead center C_d și punctul mort din stânga C_s. From figure 1 it follows: $S = OO^I - OC$, respectively:

$$S = r + l - r \cdot cos\,\alpha - l \cdot cos\,\beta = r \cdot (1 - cos\,\alpha) + l \cdot (1 - cos\,\beta) = S_1 + S_2$$

where $S_1 = r \cdot (1 - cos\,\alpha);\quad S_2 = l \cdot (1 - cos\,\beta)$.
To express the angle β, from Δ OMM' and Δ CMM' result:

$$MM^I = r \cdot sin\,\alpha = l \cdot sin\,\beta\ ;$$

$$\sin\beta = \frac{r}{l} \cdot \sin\alpha = \lambda \cdot \sin\alpha .$$

Taking into account that

$sin^2\alpha = \frac{1-cos2\alpha}{2}$ and $cos2\alpha = 1 - 2\cdot sin^2\alpha$

, expanding Newton's binomial we obtain:

$$\left[1-\frac{\lambda^2}{2}\cdot(1-cos2\alpha)\right]^{\frac{1}{2}} = \lambda - \frac{1}{2}\cdot\left[\frac{\lambda^2}{2}\cdot(1-cos2\alpha)\right] = 1-\frac{\lambda^2}{4}\cdot(1-cos2\alpha$$

$$\Rightarrow \lambda - cos\beta = \frac{\lambda^2}{4}\cdot(1-cos2\alpha)$$

$$S_2 = l\cdot(1-cos\beta) = l\cdot\frac{\lambda^2}{4}\cdot(1-cos2\alpha) = \frac{\lambda\cdot r}{4}\cdot(1-cos2\alpha)$$

So the knife race $S = S_1 + S_2$ it will be:

$$S = r\cdot(1-\cos\alpha) + \frac{\lambda\cdot r}{4}\cdot(1-\cos 2\alpha).$$

The knife movement (knife stroke) is done at one complete rotation of the crank. The calculation was performed every 20 degrees. The results are summarized in Table 1. Figure 4 shows the knife movement diagram.

Table 1. Knife travel

α °	S_1 (mm)	S_2 (mm)	$S = S_1+S_2$ (mm)
0	0.000	0.000	0.000
20	2.804	0.876	3.680
40	10.879	3.093	13.972
60	23.250	5.615	28.865
80	38.425	7.261	45.686
100	54.575	7.261	61.835
120	69.750	5.615	75.365
140	82.121	3.093	85.214
160	90.196	0.876	91.071
180	93.000	0.000	93.000
200	90.196	0.876	91.071
220	82.121	3.093	85.214
240	69.750	5.615	75.365
260	54.575	7.261	61.835
280	38.425	7.261	45.686
300	23.250	5.615	28.865
320	10.879	3.093	13.972
340	2.804	0.876	3.680
360	0.000	0.000	0.000

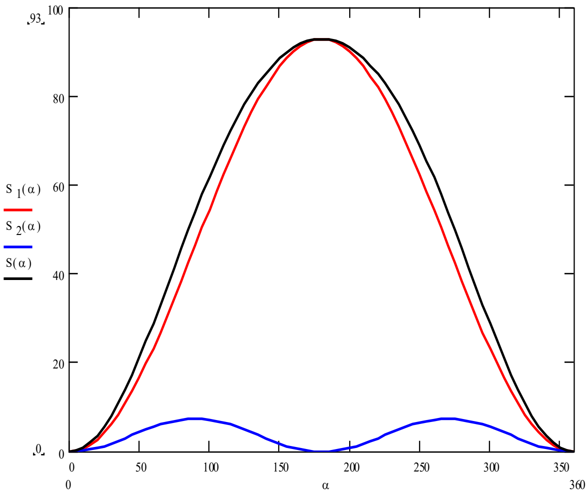

Figure 4 Knife displacement diagram

Knife speed. The knife speed is obtained by deriving the expression for knife displacement:

$$v = \frac{dS}{d\alpha} = \dot{s};$$

$$s = r(1-cos\alpha) + \frac{\lambda\cdot r}{4}\cdot(1-cos2\alpha); \dot{s} = r\cdot sin\alpha\cdot\frac{d\alpha}{dt} + \frac{\lambda\cdot r}{4}\cdot 2sin2\alpha\cdot\frac{d\alpha}{dt}$$

Taking into account that $\omega = d\alpha/dt$ and that $v = \omega\cdot r$, from the above relationship it follows:

$$v = r\cdot\omega sin\alpha + \frac{\lambda\cdot r}{2}\cdot\omega sin2\alpha = v_1 + v_2.$$

Calculate the knife speed for one complete rotation of the crank, $\alpha \in (0^\circ ... 360^\circ)$, every 20 degrees.

The results are summarized in Table 2.

The knife speed diagram is shown in figure 5.

Table 2. Knife speed

α °	v_1 (m/s)	v_2 (m/s)	$v = v_1+v_2$ (m/s)
0	0.000	0.000	0.000
20	9.993	3.024	13.016
40	18.780	4.632	23.413
60	25.303	4.074	29.376
80	28.773	1.609	30.382
100	28.773	-1.609	27.164
120	25.303	-4.074	21.229
140	18.780	-4.632	14.148
160	9.993	-3.024	6.969
180	0.000	0.000	0.000
200	-9.993	3.024	-6.969
220	-18.780	4.632	-14.148
240	-25.303	4.074	-21.229
260	-28.773	1.609	-27.164
280	-28.773	-1.609	-30.382
300	-25.303	-4.074	-29.376
320	-18.780	-4.632	-23.413
340	-9.993	-3.024	-13.016
360	0.000	0.000	0.000

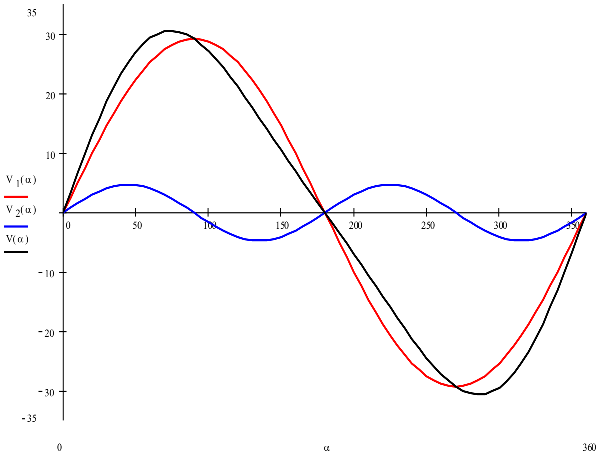

Figure 5 Knife speed diagram

Knife acceleration. The acceleration is obtained by deriving the expression for the knife speed:

$$a = r \cdot \omega^2 \cdot cos\alpha + \lambda \cdot r \cdot \omega^2 \cdot cos 2\alpha .$$

Analogously to the speed, the piston acceleration is calculated for a complete rotation of the crank, every 20 degrees. The results are summarized in table 3. and the piston acceleration diagram is presented in figure 6.

Table 3. Knife acceleration

α °	a_1 (m/s^2)	a_2 (m/s^2)	a = a_1+a_2 (m/s^2)
0	1.753x10^5	5.645 x10^4	2.317 x10^5
20	1.647 x10^5	4.324 x10^4	2.080 x10^5
40	1.343 x10^5	9.802 x10^3	1.441 x10^5
60	8.765 x10^4	-2.822 x10^4	5.943 x10^4
80	3.044 x10^4	-5.304 x10^4	-2.260 x10^4
100	-3.044 x10^4	-5.304 x10^4	-8.348 x10^4
120	-8.765 x10^4	-2.822 x10^4	-1.159 x10^5
140	-1.343 x10^5	9.802 x10^3	-1.245 x10^5
160	-1.647 x10^5	4.324 x10^4	-1.215 x10^5
180	-1.753 x10^5	5.645 x10^4	-1.189 x10^5
200	-1.647 x10^5	4.324 x10^4	-1.215 x10^5
220	-1.343 x10^5	9.802 x10^4	-1.245 x10^5
240	-8.765 x10^4	-2.822 x10^4	-1.159 x10^5
260	-3.044 x10^4	-5.304 x10^4	-8.348 x10^4
280	3.044 x10^5	-5.304 x10^4	-2.260 x10^4
300	8.765 x10^5	-2.822 x10^4	5.943 x10^4
320	1.343 x10^5	9.802 x10^3	1.441 x10^5
340	1.647 x10^5	4.324 x10^4	2.080 x10^5
360	1.753 x10^5	5.645 x10^4	2.317 x10^5

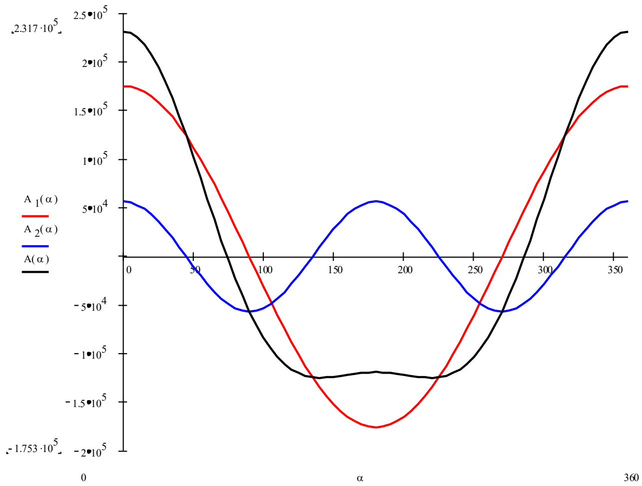

Figure 6 Knife acceleration diagram

CONCLUSIONS

The studies conducted focus on the kinematics of the mechanisms of the cutting devices used in the construction of agricultural harvesting machines. Those mechanisms that are mainly used in the harvesting of strawy cereals and hay forages were analyzed.

The kinematic parameters analyzed were the space, speed and acceleration of the knives of the cutting devices.

Based on the kinematic parameters of the mechanisms, the following can be distinguished:

The connecting rod-crank mechanism for driving cutting devices with fingers and knife is recommended to be of the spatial type, to allow frontal mounting and copying of the unevenness of the terrain so that the cutting height of the cornfield is constant.

The driving mechanism of the cutting devices with two knives from mechanical mowers, of the connecting rod-crank-rocker type, allows the harvesting of fodder at a low cutting height, of the cornfields tangled and fallen by the wind.

For optimal harvesting conditions, working speeds between 7-9 km/h are recommended.

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