Feed Rate and the Pinch of the Cutting Mechanism with Double Strokes Knives

Djema M.A\textsuperscript{1}, Zhortuylov O\textsuperscript{2} & Saidi.Dj\textsuperscript{3}

\textsuperscript{1} Laboratoire Fiabilité des Equipements Pétroliers &Matériaux (LFEPM)
M’hamed Bougara University. Boumerdes, Algeria
\textsuperscript{2}, Kazakh Scientific Research Institute of Mechanization and Electrification of Agriculture Polytechnic national schools

\textbf{Abstract:} The improved machine productivity, while maintaining optimum product quality at reduced cost, is a goal shared by manufacturers and consumers. This rule is valid in the field of agricultural machinery, where specifically, the issue of improving the productivity of the cutting mechanism of mowing-machine is a hot topic.

This paper considers a study to improve feed and pinch of the mowing-machine cutting mechanism focusing on determining the maximum value one of the functional parameters, which is the knife stroke of the cutting mechanism, by developing an analytical method of calculation, consolidated and verified by a specially designed software, but to achieve it, a new patented cutting mechanism is proposed.

\section{1. Introduction}
Fields natural herbs occupy large areas of low performance, that is why mowing machines cutting devices with the segment finger type are widely used, since they do not crush plants and consume less power, than other cutting mechanisms, that the power consumed for cutting one meter of the vegetal band is from 2.2 to 3.6 kilowatts against 10.5 to 14.7 kilowatts for the rotary mower cutting mechanism [01].

The agricultural mower is an agricultural machine for mowing grass and cereals by the cutter bar mechanism under the shear principle. The cutter bars device consists of one movable bar and of one support bar [02]. The movable bar consists of triangular segments forming knives, and animated by a rapid reciprocating linear motion, which is obtained from a rotary motion provided by the tractor's PTO via Cardin transmissions and belts. The support bar is equipped with triangular segments that must divide the grass into small clumps and used against blade for shearing. The two bars are held in contact by oscillating guides.

\section{2. The problem analysis}
When mowing, stems of certain plants, mainly of herbs and cereals, failures of the cutting mechanism and clogging of the knife with the grass and soil occur frequently, therefore the choice of a double stroke bar cutting mechanism as technical solution is very current and practical hence the importance of this work is to find the maximum stroke of the knives of the new mechanism. Therefore, the elongation of the stroke of knives leads to the pinch expansion of the cutting area, thus the quantity of grass mowed increases proportionally with respect to the extended value of the stroke of the knives, which will lead to the increase the productivity of the cutting mechanism of the mowing machine.

In conventional mowers, the attempts to improve the performance of the cutting mechanism through the extension of the radius of the eccentric or the shaft rotation speed, have led to the increase of the stroke of the blades to 76.2 mm and 84 mm instead of 38.1 mm and 50.8 mm respectively [04]. These performances has led to an increase of the dynamic inertial loads, that negatively affect the increased cutting speed, and on taking herbs of knife, consequently the productivity of the mowing mechanism is limited or reduced, with this the inclination angle of the connecting rod increases, which leads to an increase of the vertical components of the forces causing a growing of the frictional forces on the oscillating guides [03].

To minimize such dynamic loads, it is necessary to improve the drive of the cutter bar, so as to reduce the frictional forces and vibration of the cutting device.

Thus improving productivity of the mower cutting mechanism is to increase the pinch of knives, the translational speed of the cutter bar with reduction of dynamic loads on the blades of knives through the crossing to cutting mechanism with a larger pinch of knives, Therefore a new drive mechanism of the cutter bar with double stroke of the knife is adopted [10].
3. Drive mechanism of the mower cutter bar

The new mechanism is designed for mowing natural and seeded grasses, as well as possible the herbs that grow on the slopes, the banks of canals and dams, rice fields, ditches and green median bands of highways [10]. The drive mechanism of cutter bar of the double stroke knife, as shown in figure 1, comprises a crank 4 through the axle 5 drives the pulley 6 on which the two flexible elements 8 and 9 slide in against direction, which the upper end of each is attached to the support plate 1, while at the other end is connected driven element- cutter bar with Knives 7. The flexible elements 8, 9 are made from metallic cables and are tensioned by the guiding idler pulley 2 and 3 respectively [05].

The use of flexible elements under form of metallic cable reduces the weight of mechanism [11]. due to the flexible elements; this mechanism does not require high precision manufacturing sensitive components to deformation of the base frame.

Figure 1. Drive mechanism double stroke knives

4. Analytical formulation

The special feature of this patented mechanism is that the double knife switch is reached by the crank radius which is four times less than the stroke (pitch) knife [07]. In the following, the most influencing parameters on the productivity of knives double stroke of the cutting mechanism are determined.

Determining the knives trajectory of the cutting bar X as a function of the crank rotation angle [10]:

First let’s find L the length of the flexible element between the point A to O’

\[ L = AB + B\hat{C} + CD + D\hat{E} + EO' \]  

(1)

Where AB, CD, EO’ – lengths of the straight segments of the flexible elements;

\[ B\hat{C}, D\hat{E} \] - Arc length of the flexible elements.

Length of right segment AB is determined from the triangle ABO1:

\[ AB = \sqrt{AO_1^2 - BO_1^2} \]  

(2)

From the triangle ΔAKO1:

\[ AO_1^2 = KO_1^2 + AK^2 = (a + r \cdot \cos \phi)^2 + (h_1 - r \cdot \sin \phi)^2 \]  

(3)

Substituting expression (3) in (2) and considering that BO1 = R, we obtain:

\[ AB = \sqrt{(a + r \cdot \cos \phi)^2 + (h_1 - r \cdot \sin \phi)^2 - R^2} \]  

(4)

From the triangle O2MO1, where MO1 = CD and MO2 = 2R, is defined the length of the straight segment CD of the flexible element:

\[ CD = \sqrt{QO_1^2 - MO_2^2} = \sqrt{(b + r \cdot \cos \phi)^2 + (h_2 + r \cdot \sin \phi)^2 - 4R^2} \]  

(5)

Length of the arc BC equal:

\[ B\hat{C} = \frac{\pi R}{180} \cdot (\alpha_1 + \alpha_2) \]  

(6)

Length of the arc DE equal:

\[ D\hat{E} = \frac{\pi R}{180} \cdot (\alpha_2 + 90º) \]  

(7)

Substituting expressions (4) and (7) in (1), while considering that EO’= b, we obtain:

\[ L = \sqrt{(a + r \cdot \cos \phi)^2 + (h_1 - r \cdot \sin \phi)^2 - R^2} + \sqrt{(b + r \cdot \cos \phi)^2 + (h_2 + r \cdot \sin \phi)^2 - 4R^2} + \frac{\pi R}{180} \cdot (\alpha_1 + 2\alpha_2 + 90º) + b \]  

(8)

Inclination angle of the flexible element relative to the vertical \( \alpha_1 \) is determined from the triangles \( \Delta ABO_1 \) and \( \Delta AKO_1 \), where:

Inclination angle of the flexible element relative to the vertical \( \alpha_1 \) is determined from the triangles \( \Delta ABO_1 \) and \( \Delta AKO_1 \), where:

\[ \tan \alpha_1 = \frac{BO_1}{AB} = \frac{R}{\sqrt{(a + r \cdot \cos \phi)^2 + (h_1 - r \cdot \sin \phi)^2 - R^2}} \]  

(9)

\[ \tan \alpha_1 = \frac{KO_1}{AK} = \frac{a + r \cdot \cos \phi}{h_1 - r \cdot \sin \phi} \]

Inclination angle \( \alpha_1 \) equal the sum of angles \( \alpha_1^1 \) and \( \alpha_1^2 \):

\[ \alpha_1 = \alpha_1^1 + \alpha_1^2 \]

Imperial Journal of Interdisciplinary Research (IJIR)  
Page 297
\( \alpha_1 = \arctg \frac{R}{\sqrt{(a + r \cdot \cos \phi)^2 + (h_i - r \cdot \sin \phi)^2} - R^2} + \arctg \frac{a + r \cdot \cos \phi}{h_i - \sin \phi} \) \hspace{1cm} (9)

Inclination angle \( \alpha_2 \) is defined by projecting the closed contour OO1CDO2O on the O'X and O'Y axis:

\[ -2R \cdot \cos \alpha_2 + CD \cdot \sin \alpha_2 - r \cdot \cos \varphi = b; \]
\[ 2R \cdot \sin \alpha_2 + CD \cdot \cos \alpha_2 - r \cdot \sin \varphi = h_2. \]

Solving the system of equations (10), we obtain:

\[ \alpha_2 = \arctg \frac{(b + r) \cdot \sqrt{(b + r)^2 + h_2^2 - 4R^2} + 2R \cdot h_2}{h_2 \cdot \sqrt{(b + r)^2 + h_2^2 - 4R^2} - 2R(b + r)} \] \hspace{1cm} (11)

If the angle value of crank rotation \( \varphi = 0^\circ \), the knife occupies the extreme left position. By turning the crank of an angle \( \varphi \), the knife trajectory is determined by the formula:

\[ X = - (L - L_0), \]

Where \( L_0 \)- length of the flexible element at \( \varphi = 90^\circ \).

Determination stroke of knives is determined by the formula:

\[ S = 2(L_1 - L_2), \] \hspace{1cm} (14)

Where \( L_1 \)- length of the flexible element at \( \varphi = 0^\circ \);

\[ L_2 \]- length of the flexible element at \( \varphi = 180^\circ \).

Considering that the knives are located in the two extreme positions at \( \varphi = 0^\circ \) and \( \varphi = 180^\circ \) relatively thus:

\[ L_1 = \sqrt{(a + r)^2 + h_1^2 - R^2} + \sqrt{(b + r)^2 + h_1^2 - 4R^2} + \frac{\pi R}{180^\circ} (\alpha_1' + 2\alpha_2' + 90^\circ) + b \]

Where \( \alpha_1', \alpha_2' \)- inclination angle of the flexible element at \( \varphi=0^\circ \).

5. Determining the feed rate and the pinch of the cutting mechanism with double strokes knives

The cutting occurs at a variable speed, namely, cutting speed at the beginning and the end are not equal. The end cut speed \( V_{H_k}'' \) is low at the extreme blade of the knife. Due to the low cutting speed, it may be that the cut could be unsatisfactory and creates a clogging of the cutting mechanism. For adequate performance of these devices, a clearance adjusting cutting the pair of the cutting segments is necessary.

On the basis of the conditions of shear plants at minimum cutting speed \( V_{H_k}'' \) = 2, 15 m/s, the rotation crank speed desired is defined [11]:

\[ n = \frac{V_{H_k}''}{S}, \] \hspace{1cm} (18)

When switching from the existent knife stroke of cutting mechanism to the double stroke, the gear ratio is determined by the equation[9]:

\[ \alpha_4' = \arctg \frac{R}{\sqrt{(a + r)^2 + h_1^2 - R^2} + \arctg \frac{a + r}{h_1}} \]
\[ \alpha_4'' = \arctg \frac{(b + r) \cdot \sqrt{(b + r)^2 + h_2^2 - 4R^2} + 2R \cdot h_2}{h_2 \cdot \sqrt{(b + r)^2 + h_2^2 - 4R^2} - 2R(b + r)} \]
In order that the quality work of the cutting mechanism with double stroke is similar to that single stroke, it is necessary to comply with the condition of buckling:

\[
\frac{\alpha_2}{\alpha_1} = \frac{m_2/30}{m_1/30} = \frac{n_2}{n_1} = 0.5
\]  

(19)

Where \( \alpha_2 \) and \( \alpha_1 \) are respectively the angular velocities of the crank and the crank shaft.

The relationship between the angular velocities becomes:

\[
\frac{\alpha_2}{\alpha_1} = \frac{a_1}{a_2} = \frac{A_2}{A_1}
\]

(20)

Where \( A_1 \) - coefficient of the grass cutting height of simple stroke; \( A_2 \) - coefficient of the grass cutting height of double stroke. 

We have \( A_1 = 1.25 \) and \( A_2 = 0.78 \) 

Thus, the feed of the cutting mechanism with double stroke can be increased 1.6 times.

The use of the double stroke of the knife, by doubling the radius of the crank, reduces the angular velocity of the crank shaft without reducing the cutting speed, from time that the acceleration of the moving masses is proportional to the crank radius and the angular velocity squared of crank shaft [06].

The relationship between the angular velocity becomes:

\[
\frac{\alpha_2}{\alpha_1} = \frac{0.78}{1.25} = 0.62
\]

(21)

Thus, the feed of the cutting mechanism with double stroke can be increased 1.6 times.

The use of the double stroke of the knife, by doubling the radius of the crank, reduces the angular velocity of the crank shaft without reducing the cutting speed, from time that the acceleration of the moving masses is proportional to the crank radius and the angular velocity squared of crank shaft [06]. 

When switching from the existent knife stroke of cutting mechanism to the double stroke, the angular velocity and the inertia force are reduced. Reduction inertial forces of the double stroke knife is characterized by relations [09]:

\[
P_2 = \frac{m_2 \omega_2^2 S}{2}
\]

(22)

Where:

- \( P_2 \) – inertia force of knife double stroke, N;
- \( P_1 \) – inertia force of knife simple stroke, N;
- \( m_1 \) – weight of Knife Single stroke, Kg;
- \( m_2 \) – weight of Knife double stroke, Kg;

With \( m_1 = m_2 \) the equation (22) takes the following form:

\[
P_2 = 2 \left( \frac{\omega_2}{\omega_1} \right)^2
\]

(23)

The double stroke of knife (\( S = 152.4 \) mm) is determined with a crank radius \( r = 42.3 \) mm, and a curvature radius of the flexible element \( r_c = 76.2 \) mm, therefore four times and two times smaller than the stroke of the knives respectively.

The proposed mechanism is devoid of any rigid element, which is why the force, which causes the knife movement, acts on along its longitudinal axis and so the friction force is eliminated, because of the inclination of the connecting rod, reducing the required power for the knife stroke.

It follows that with the same inertial forces, the pinch width of cutting mechanism with knives double stroke compared to the punch width of the knives

\[
\frac{\omega_2}{\omega_1} = 0.5
\]

With \( \frac{P_2}{P_1} = 0.5 \) 

(24)

So the pinch width \( l_2 \) of knives double stroke:

\[
l_2 = \frac{1}{l_1} \left( \frac{\omega_1}{\omega_2} \right)^2 = 2l_1
\]

(25)

Results and discussion

The stroke of the knife was calculated by software according to different geometrical parameters of the mechanism as shown in figure 2. The results of the calculation based on the analysis of the kinematic parameters are defined the optimal geometrical parameters as follows:

- crank radius \( r = 42.3 \) mm;
- radius of the pulley \( R = 42.8 \) mm;
- distance \( a = 200 \) mm;
- distance \( B = 150 \) mm;
- \( h_1 = 159 \) mm;
- \( h_2 = 150 \) mm;
- \( S = 152.4 \) mm (calculated by expression (17)).

Figure 2. the knife stroke diagram
simple stroke is two times greater \((P_2 = 0.5 P_1; \ l_2 = 2 \ l_1)\).

**Conclusion:**

The use of the new mechanism allows improving the performance and productivity of the mower cutting mechanism that result as follows:

- Increase of knife stroke until \(S = 152.4\ mm\), led to an increase in productivity of cutting mechanism with double stroke as:
  - The feed to 1.6 times.
  - The pinch width of knives double stroke is two times greater \((l_2 = 2 \ l_1)\) than of knives simple stroke
  - The Minimum Crank speed rotation of the knife double stroke is \(n_2 = 420 \text{ min}^{-1}\), while the one corresponding to a single stroke \(n_1 = 840 \text{ min}^{-1}\) and is manifested by a low rotational speed of the PTO which is less than \(540 \frac{r}{\text{min.}}\).

6. NOMENCLATURE

- \(r\) - Crank radius;
- \(R\) - Radius of the pulley (radius of the pulleys are identical);
- \(B\) - Distance between the crank axis and the guiding pulley axis (tensioning);
- \(a\) - distance from the axis crank and the fixing point \(A\) of the flexible element on the support \(1\);
- \(h_1\) - distance between point \(A\) and the rotation axis of the crank \(4\);
- \(h_2\) - distance between the guiding pulley rotation axis (2 or 3) and the rotation axis of the crank \(4\);
- \(\alpha_1\) and \(\alpha_2\) - inclination angles of the flexible element (8 and 9 respectively) relative to the vertical;
- \(\varphi\) - crank rotation angle

7. References