Theoretical Researches Concerning Constructive Forms of the Cutting Edges of the Knives Used on the Rotating Cutting Devices for Vine Pruning

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Abstract

In the paper the authors present a geometrical description of a smooth-curved-spinning knives which are used for vine pruning or for other purposes (hedges, orchards etc) and study the way in which the rotating and fixed knives are operating upon the shoots (or boughs). Based on the geometrical description of the fixed and mobile edges, the authors developed a full automatic calculus programme which settles up the rules for the shoot’s motion between the knives and determines the conditions in which the cutting process occurs. The research concerning the geometry of rotative knives scissors type and the original automatic calculus programme, make possible the study of the dynamics of cutting the wine shoots and other vegetable boughs. The calculus programme make possible the visualisation of the cutting process. The calculus relations and the programme allow the analysis of knives with different cutting edges, with the purpose to determine those which can assure the best and safest cutting and forces required

INTRODUCTION

The objective of this study was to determine the way the knives act upon the vegetal stems, and particularly upon the vine shoots. During their period of biological rest vine shoots and other vegetal boughs may be cut with spinning devices. Theoretic and experimental researches concerning this topic were carried on in Technical University Iasi, Romania (Filipescu I., 1998). Knowing the equations of the curves that determine the shape of the two types of cutting edges (Boboc V., 1998; Filipescu I., 1998) we have studied and shall study the shoot motion between the two cutting edges before the cutting process starts. The goal is to determine the shape for the cutting edges, in order to avoid that shoots of different diameters to slip away from the cutting area without being cut. In the study the stems are considered isotropic materials.
CONSTRUCTIVE FORMS OF THE CUTTING EDGES OF THE KNIVES

1. Description of the rotating cutting device
The study has been achieved on a smooth-curved-spinning knives device (Fig 1; Boboc; 1998). Knives are set radial on two superposed disks, between which there is a clearing of 0.1 - 0.15 mm. One of the disks is fixed and the other one rotates. On the fixed disk (the lower one in Fig.1) are “fixed” knives, 10 units, mounted only in the working area. On the spinning disk we have mounted equidistant circumscribed “mobile” knives. The fixed and the mobile knives have different pitches. The cutting edges of the mobile knives are in motion towards the fixed knives cutting edges and achieve, finally, the motion and the cutting of shoots (stems) that are pushed in the cutting interspace during the advancing of the device. The agrotechnical considerations had imposed diameters for the disk of 400 mm; the working area width, considering the height of the knives, is 504 mm.

2. Geometrical features of the cutting edge
To define the curves of the two cutting edges, fig. 2, we had to adopt 2nd degree equations with the following shapes:
- for the fixed cutting edge AB:
  \[ y(x) = a_F \cdot x^2 + b_F \cdot x + c_F \]  (1)
- for the mobile cutting edge CD:
  \[ y(x) = a_M \cdot x^2 + b_M \cdot x + c_M \]  (2)
The axis system in which these equations are defined is the same for both cutting edges.
Considering that the number of pairs of working units on the disk’s circumference is 20, it results that the central angle for two neighboring knives is:
\[ \gamma_B = \frac{2\pi}{20} \text{ rad} = \frac{360}{20} = 18^\circ \].

Fig. 1. Rotating cutting device

Fig. 2. Mobile cutting edge in the original position

Fig. 3. Mobile cutting edge rotated from the original position
In Fig. 2 the CD mobile cutting edge is shown in the original position.

Curves AB and CD can take several shapes when the following parameters are varying:
- for the AB fixed curve the angle $\gamma_A$ which determines the position of the point A on the internal circle and the angle $\varepsilon_A$ between the radius OA and the tangent A to the curve;
- for the CD mobile curve: the angle $\gamma_D$ corresponding to the point D on the external circle and the angle $\varepsilon_C$ between the radius OC and the tangent C to the curve.

The positive values of angles $\varepsilon_A$ and $\varepsilon_C$ are those shown in Fig. 2; these angles can also be negative.

3. Equation of the fixed cutting edge
Coordinates of the points A and B, at the ends of the fixed cutting edge are:

$$\begin{cases} x_A = R_i \cdot \cos \gamma_A, \\ y_A = R_i \cdot \sin \gamma_A, \\ x_B = R_e \cdot \cos \gamma_B, \\ y_B = R_e \cdot \sin \gamma_B. \end{cases} \quad (3)$$

To calculate coefficients $a_F$, $b_F$, $c_F$ in the fixed cutting edge equation, the following conditions are assumed:
- the curve has to pass through point A:
  $$y_A = a_F \cdot x_A^2 + b_F \cdot x_A + c_F; \quad (4)$$
- the curve has to pass through point B:
  $$y_A = a_F \cdot x_B^2 + b_F \cdot x_B + c_F; \quad (5)$$
- the tangent to the curve in A forms the angle $(\gamma_A + \varepsilon_A)$ to the Ox axis:
  $$\tan(\gamma_A + \varepsilon_A) = 2a_F \cdot x_A + b_F. \quad (6)$$

Solving the system (4), (5), (6) results:

$$\begin{cases} a_F = \frac{(y_B - y_A) - (x_B - x_A) \cdot \tan(\gamma_A + \varepsilon_A)}{(x_B - x_A)^2}, \\ b_F = \tan(\gamma_A + \varepsilon_A) - 2a_F \cdot x_A, \\ c_F = y_A - a_F \cdot x_A^2 - b_F \cdot x_A. \end{cases} \quad (7)$$

4. Equation of the mobile cutting edge
In Fig. 3 the mobile cutting edge is shown when it is rotated with an angle $\alpha$ referred to its original position. Coordinates C and D, at the ends of the cutting edge are:

$$\begin{cases} x_C = R_i \cdot \cos \alpha, \\ y_C = R_i \cdot \sin \alpha, \\ x_D = R_e \cdot \cos(\alpha + \gamma_D), \\ y_D = R_e \cdot \sin(\alpha + \gamma_D). \end{cases} \quad (8)$$

Assuming some similar conditions as the ones in the case of the fixed cutting edge we shall have the system:

$$\begin{cases} y_C = a_M \cdot x_C^2 + b_M \cdot x_C + c_M, \\ y_D = a_M \cdot x_D^2 + b_M \cdot x_D + c_M, \\ \tan(\alpha + \varepsilon_C) = 2 \cdot a_M \cdot x_C + b_M. \end{cases} \quad (9)$$

which has as solution:
\[
\begin{align*}
  a_M &= \frac{(y_D - y_C) - (x_D - x_C) \cdot \tan(\alpha + \varepsilon_C)}{(x_D - x_C)^2}, \\
  b_M &= \tan(\alpha + \varepsilon_C) - 2 \cdot a_M \cdot x_C, \\
  c_M &= y_C - a_M \cdot x_C^2 - b_M \cdot x_C.
\end{align*}
\]

On the basis of the relations presented above we have developed a calculus programme in which we can introduce different values for the parameters \( \gamma_A \), \( \gamma_B \), \( \gamma_D \), \( \varepsilon_A \), \( \varepsilon_C \), \( R_i \), \( R_e \). The programme calculates the coefficients of the fixed curve (three values) and sets of three values each for the mobile curve coefficients (for given values of the spinning angle \( \alpha \)). The programme allows representing the curves and the graphical reproduction of the intersection of the two cutting edges.

As an example, for \( R_i = 200 \text{ mm}, R_e = 252 \text{ mm}, \gamma_B = 18^\circ, \gamma_D = 8^\circ, \gamma_A = 2^\circ, \varepsilon_A = 10^\circ, \varepsilon_C = -35^\circ \), the following coefficients have been obtained:
- for the fixed cutting edge: \( a_F = 0.0210884 \), \( b_F = -8.028348 \), \( c_F = 790.6805 \);
- for the mobile cutting edge: values in Table 1.

For these values the cutting edges are shown in Fig. 4 a, b, c, d.

<table>
<thead>
<tr>
<th>Table 1. Coefficients of the mobile cutting edge equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha )</td>
</tr>
<tr>
<td>0°</td>
</tr>
<tr>
<td>8°</td>
</tr>
<tr>
<td>10°</td>
</tr>
<tr>
<td>12°</td>
</tr>
</tbody>
</table>

**Fig. 4. Different positions of the mobile cutting edge referring to the fixed cutting edge**

**SHOOT MOTION BETWEEN THE CUTTING EDGES**

1. A study of the shoot motion in the pre-cutting stage

We assume as known: \( R_t \) – the shoot’s radius, \( \mu \) - the rubbing coefficient between shoot and cutting edge.

We also assume that:
- shoot has circular shape;
- shoots are considered isotropic materials;
- when shoot is in motion along the cutting edge, the cutting edge does not penetrate the shoot (the shoot circular shape is preserved during motion).
An automatic calculus programme has been created as to visualise the shoot’s motion between the two cutting edges. The programme allows alterations of the parameters of the shape of the two cutting edges till results the final shape. Within the programme, calculus is completed in several stages:
- determining the original position of the shoot;
- determining the rotating angle for the mobile cutting edge till the contact with the shoot (with the shoot in its original position);
- determining the rotating angle for the mobile cutting edge up to a random position of the shoot between cutting edges;
- analysing the balance of the shoot at a random moment and determining the resultant forces acting upon it.

1.1. State the original position of the shoot

We assumed that the original position (Fig. 5) is the one when the shoot is tangent at the fixed cutting edge and to the internal circle of radius $R_i$. The tangence point with the fixed cutting edge is $P_1$; the common tangent for the cutting edge and the $R_t$ radius circle forms the $\beta_1$ angle with the Ox axis.

Assuming as known the fixed cutting edge equation, we shall have:

$$\tan \beta_1 = 2a_F \cdot x_{P_1} + b_F .$$

(11)

The $O_{t_1}$ center of the $R_t$ radius circle has the coordinates:

$$x_{O_{t_1}} = x_{P_1} + R_t \sin \beta_1,$$

(12)

$$y_{O_{t_1}} = y_{P_1} - R_t \cos \beta_1 .$$

(13)

Fig. 5. Original position of the shoot referring to the fixed cutting edge

Due to the fact that $P_1$ is on the fixed cutting edge, a relation between its coordinates is:

$$y_{P_1} = a_F \cdot x_{P_1}^2 + b_F \cdot x_{P_1} + c_F .$$

(14)

The distance from point $O_{t_1}$ to the rotation center $O$ has to be equal to $(R_i + R_t)$, which means that:

$$x_{O_{t_1}}^2 + y_{O_{t_1}}^2 = (R_i + R_t)^2 .$$

(15)
Equations (11)...(15) are creating a system with 5 unknown quantities: \(x_{p_1}, y_{p_1}, x_{O_1}, y_{O_1}, \beta_1\). A sequence of the programme has the mission to solve this system and to find all the parameters which describe the original position of the shoot.

1.2. Calculation of the rotating angle for the mobile cutting edge up to the contact with shoot

We shall name this angle \(\alpha_1\) (Fig. 6). We shall name \(Q_1\) the tangent point between the mobile cutting edge and the shoot in its original position (as shown above).

The tangent to the mobile cutting edge forms the angle \(\gamma_1\) to the 0x axis:

\[tg \gamma_1 = 2a_M \cdot x_{Q_1} + b_M .\]

(16)

Between the coordinates of point \(Q_1\) we have the relation:

\[y_{Q_1} = a_M \cdot x_{Q_1}^2 + b_M \cdot x_{Q_1} + c_M .\]

(17)

In the relations above, \(a_M, b_M\) and \(c_M\) there are functions of the rotating angle of the mobile cutting edge.

The distance between points \(O_{tt}\) and \(O_1\) is equal to the radius of the shoot, then:

\[(x_{O_{tt}} - x_{Q_1})^2 + (y_{O_{tt}} - y_{Q_1})^2 = R_t^2 .\]

(18)

Having as basis Fig. 6 we can write the following geometrical relation:

\[y_{O_{tt}} = y_{Q_1} \cdot \frac{x_{Q_1} - x_{O_{tt}}}{tg \gamma_1} .\]

(19)

The unknown values \(x_{O_1}, y_{O_1}, \alpha_1, \gamma_1\) are determined then by solving the system made by equations (16)...(19).
1.3. Calculation of the rotating angle of the mobile cutting edge for a random position of the shoot between cutting edges

In fig. 7 the mobile cutting edge in the current position is shown; it is rotated with an undefined angle $\alpha$; the $R_t$ radius shoot is in a tangent position to both cutting edges, in points P and Q respectively.

![Fig. 7. The mobile cutting edge, rotated, tangent at the shoot](image)

The tangents’ angles in P and Q made with axis 0x are $\beta$ and $\gamma$, considering the equation of the mobile curve (with coefficients $a_M, b_M, c_M$ variable on an $\alpha$ basis), we shall have:

\[ y_Q = a_M \cdot x_Q^2 + b_M \cdot x_Q + c_M, \quad (20) \]
\[ \tan \gamma = 2a_M \cdot x_Q + b_M. \quad (21) \]

and for point P on the fixed curve:

\[ y_P = a_F \cdot x_P^2 + b_F \cdot x_P + c_F, \quad (22) \]
\[ \tan \beta = 2a_F \cdot x_P + b_F. \quad (23) \]

From geometrical considerations (Fig. 7), result the following relations:

\[ x_{Ot} = x_Q - R_t \sin \gamma, \quad (24) \]
\[ y_{Ot} = y_Q + R_t \cos \gamma, \quad (25) \]
\[ x_P = x_{Ot} - R_t \sin \beta, \quad (26) \]
\[ y_P = y_{Ot} + R_t \cos \beta. \quad (27) \]

Thus we shall obtain an eight equations system (20)...(27), having eight unknown quantities: angles $\beta$ and $\gamma$ and the coordinates of points P, Q and Qt. The system is to be solved automatically with our programme, and this for each position of the mobile cutting edge (for each value of the $\alpha$ angle). Editing the graph of each position we shall visualise the motion of the shoot between the cutting edges when the mobile cutting edge rotates.

1.4. Calculation of the resulting forces which act upon the shoot

Fig. 8 is showing the normal forces $N_1$ and $N_2$ and the friction forces $F_1$ and $F_2$, which are acting upon the shoot. Normal forces are oriented on the normal directions, the friction
ones on tangent directions in points of contact P and Q. The following is a random position of the mobile cutting edge.

The equilibrium conditions for the shoot are expressed as two force projection equations, towards axis 0x and 0y, and one moment equation referring to the center of the shoot:

\[-N_1 \cos \beta - F_1 \sin \beta + N_2 \cos \gamma - F_2 \sin \gamma = 0\]  

\[N_1 \sin \beta - F_1 \cos \beta - N_2 \sin \gamma - F_2 \cos \gamma = 0\]  

\[F_1 = F_2\]  

\[\frac{1}{\mu_1} \sin \beta - \frac{1}{\mu_2} \sin \gamma - \cos \beta - \cos \gamma \geq 0\]  

If \(\mu_1\) and \(\mu_2\) are the rubbing coefficients between the shoot and the fixed cutting edge between the shoots and the mobile cutting edge, respectively, then:

\[F_1 = \mu_1 N_1, F_2 = \mu_2 N_2\]  

Relation (18) becomes:

\[\mu_1 N_1 = \mu_2 N_2\]  

Figure 9 shows the polygon of the forces that act upon the shoot. If resultant R is null (closed polygon) the shoot has the tendency to approach the cutting position and the cutting process starts. If the polygon is open, the shoot has the tendency to move to the exterior/interior, depending on the resultant direction.

Within the calculus programme, the motion trend has been determined, studying if the horizontal projection of the resultant is oriented towards exterior or interior.

Hence the condition:

\[\frac{1}{\mu_1} \sin \beta - \frac{1}{\mu_2} \sin \gamma - \cos \beta - \cos \gamma >\leq 0\]  

in which for the symbol “>” there occurs a motion to the exterior, for the symbol “=“ there occurs the balance of forces and for the symbol “<” there occurs a motion towards the interior.
2. Using the calculus programme to study the motion of the shoot
The study concerns the shoot motion for several shapes of cutting edges (obtained for several sets of values for $\gamma_A$, $\epsilon_A$, $\gamma_C$, $\epsilon_C$) for different values of the shoot radius $R_t$, and for different friction coefficients. The programme showed that the optimal shape is the one given by: $\gamma_A = 8^\circ$, $\epsilon_A = 10^\circ$, $\gamma_C = 2^\circ$, $\epsilon_C = -35^\circ$. For this shape the cutting edges are shown in Fig. 10.

![Fig.10. Constructive shape for the cutting edges of the knives](image)

Table 2. Coordinates of several points on the fixed cutting edge

<table>
<thead>
<tr>
<th>Point</th>
<th>$x$ (mm)</th>
<th>$y$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>198.05</td>
<td>27.83</td>
</tr>
<tr>
<td>1</td>
<td>206</td>
<td>31.74</td>
</tr>
<tr>
<td>2</td>
<td>212</td>
<td>36.46</td>
</tr>
<tr>
<td>3</td>
<td>220</td>
<td>45.12</td>
</tr>
<tr>
<td>4</td>
<td>228</td>
<td>56.47</td>
</tr>
<tr>
<td>5</td>
<td>234</td>
<td>66.76</td>
</tr>
<tr>
<td>B</td>
<td>239.66</td>
<td>77.87</td>
</tr>
</tbody>
</table>

Table 3. Coordinates of several points on the mobile cutting edge

<table>
<thead>
<tr>
<th>Point</th>
<th>$x$ (mm)</th>
<th>$y$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>200</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>210</td>
<td>-5.32</td>
</tr>
<tr>
<td>2</td>
<td>220</td>
<td>-7.29</td>
</tr>
<tr>
<td>3</td>
<td>228</td>
<td>-6.45</td>
</tr>
<tr>
<td>4</td>
<td>236</td>
<td>-3.46</td>
</tr>
<tr>
<td>5</td>
<td>244</td>
<td>1.67</td>
</tr>
<tr>
<td>D</td>
<td>251.84</td>
<td>8.79</td>
</tr>
</tbody>
</table>

For the practical construction of the two types of knives we have created, on computer, the optimal geometrical shape, for each cutting edge, using the x,y coordinates of points from Tables 2 and 3.

CONCLUSIONS AND FUTURE WORK
The results from this paper will be used to establish the shape of the cutting edges of the knives. Using an original automatic calculus programme we can study: the movement of the vine stem (and different boughs) between cutting edges, forces acting on it and the equilibrium conditions. Knowing the equations of the curves that determine the shape of
the two types of cutting edges (Boboc V., 1998; Filipescu I., 1998) we can study the shoot motion between the two cutting edges before the cutting process starts. The goal is to determine the shape for the cutting edges in order to avoid that shoots (considered isotropic materials) of different diameters to slip away from the cutting area without being cut. The researches will continue with experimental researches for energy consumption in the cutting process; on a laboratory stand will be measured the cutting forces, will be plotted force-displacement diagrams for the vine shoots, with different diameters, provided by different varieties of vineyards and for different boughs from orchards (apple trees, pear trees, plum trees etc).

**Literature Cited**


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**Recherches théoriques sur la forme des arrêtes tranchantes de couteaux utilisés dans les tailleuses rotatives viticoles**

**Mots clés**: Arrêtes tranchantes fixes/mobiles, équations, efforts de coupe, dynamique de la coupe

**Résumé**

Les auteurs de la publication présentent une description géométrique des lames courbées des couteaux utilisés pour la taille de la vigne mais aussi dans d’autres applications (haies, vergers, etc.). Ils étudient la manière avec laquelle les lames rotatives fixes et mobiles opèrent sur les sarments et les pousses.

Sur la base d’une description géométrique des couteaux fixes et mobiles, les auteurs ont développé un programme de calcul des mouvements de sarments entre les lames qui détermine les conditions dans lesquelles le phénomène de coupe se produit.

Les recherches sur la géométrie des lames rotatives du type sécateur ainsi que le module de calcul informatique permettent l’étude de la dynamique de la coupe des sarments ou d’autres végétaux.

Le module de calcul rend possible la visualisation du procédé de coupe. Les relations ainsi calculées par le programme permettent l’analyse de différentes formes de lames, avec comme objectif de déterminer celles qui peuvent assurer la meilleure et la plus sûre des coupes tout en optimisant les efforts mis en jeux.