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DESIGN OF RIGID MEMORY FOR THE EQUIPMENT TO OPEN AND INTERRUPT WATER FURROWS

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In the case of agricultural machines for soil cultivation, their working parts are controlled by the operator, or if repetitive operations are required, a rigid memory may be used during the work.

In this paper, a design of rigid memory is made to send the order to the working parts to make furrows. This rigid memory is made up of a rotating cam and a rotating roller cam follower. The cam - cam follower mechanism has the advantage that it allows the machine's working parts to model the furrow shape as the designer wants.

Keywords: interrupted furrow, rotating cam, cam follower, design.

1. Introduction

In the southern area of Romania, characterized by a temperate continental climate, there is a need to preserve "in-situ" soil moisture due to insufficient rainwater for agriculture. Rainwater collection has the potential to reduce soil erosion and improve the productivity of these areas. Rainwater harvesting is a general term used to describe the collection and concentration of surface leakage for various uses, including for agricultural and domestic use [6].

"In-situ" systems are the simplest and cheapest approaches to harvesting rainwater and can be practiced in many farming systems. Also called water conservation systems, they involve using methods to increase the amount of water stored in the soil profile by capturing or maintaining rainwater [3].

In the case of equipment to open and interrupt water furrows for carrying out the interruption, various mechanisms are used to perform these repetitive movements.

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Interrupted furrow is the result of a mechanical soil work that leaves furrows interrupted by soil mounds, at adjustable intervals, to form small water accumulation basins. During rainfall, excess water is accumulated in these basins so that it can be slowly absorbed by the soil, eliminating the possibility of drying outside the cultivated perimeter. This is particularly important because, during heavy rainfall, the precipitation intensity often exceeds the rate of water infiltration in soil [2].

Fig.1. Continuous and interrupted furrows after rainfall, [2]

An increase in agricultural production per hectare by 20% in agricultural crops, where interrupted furrows are executed, is estimated. This is explained by the infiltration of a larger amount of water to the roots of plants and the reduction of the soil erosion phenomenon.

Fig.2. Device for soil modeling in interrupted furrows DMBC5-0 and the form of the furrows it made, [1]

The device for soil modeling in interrupted furrows for weeding crops, simultaneously on 5 intervals, DMBC5 -0 (Fig. 2) is designed for soil modeling in interrupted furrows for weeding crops sown at 70-80 cm, in order to accumulate rainwater and achieve a uniform distribution of water at the soil surface, on land with a slope of up to 5%, on soils with at least 250 mm high plowing, with light, medium or heavy texture, at a moisture at which the soil does not stick to the active part.

In the case of continuous or interrupted furrows it is intended to obtain as many sections of the furrow as necessary to carry and accumulate as much water as possible.

To increase the efficiency of this equipment (increasing the volume of accumulated water), it is necessary to obtain an optimal shape of the furrow.

Since the cam mechanisms have the great advantage that they can perform particularly complicated transmission functions, in order to obtain an optimal shape of the furrow, a mechanism with rotating cam and rotating roller cam follower is chosen for the equipment in question.

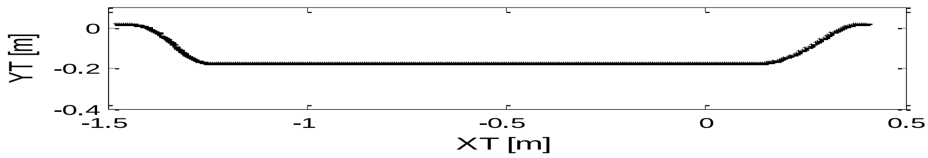

Fig.3. The shape of the furrow obtained by using the cam mechanism, [4]

2. Material and Method

The design of rigid memory to control the working parts involves several phases, namely: choosing the type of control mechanism; establishing transmission functions from cam to cam follower; determining the minimum gauge of the mechanism; the design of the cam profile. Of the different types of cam mechanisms, a mechanism with rotating cam and rotating roller cam follower is chosen for the equipment in question, as shown in the figure.

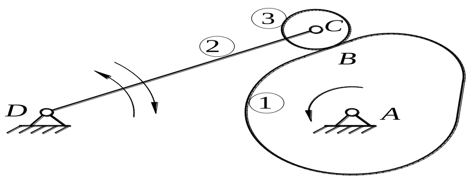

Fig. 4. Mechanism with rotating cam and rotating roller cam follower, [5]

The transmission functions used for the cam follower control are chosen in such a way that the operation of the mechanism is silent, there are no operational shocks, reduced accelerations do not exceed certain limits and lead to the convenient shapes of the furrows. For the present case, transmission functions whose low acceleration diagrams are of sinusoidal and cosine-like form were considered.

Sinusoidal transmission function

Figure 5 shows the variation diagrams of the sinusoidal transmission function.The curve representing reduced acceleration, y'' is composed of two sinusoids connected in the abscissa point $x = u$. Expressions of zero, one and two-order transmission functions are:

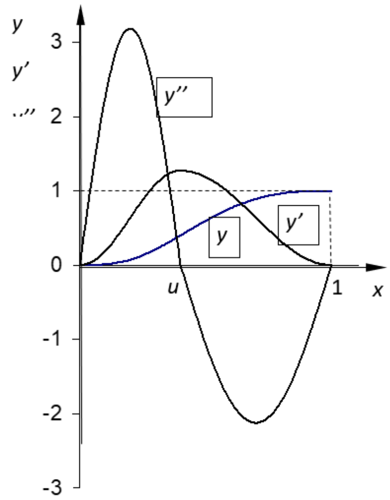

Fig. 5. Variation diagrams of transmission functions y, y', y''

- for $x \in [0, u]$:

$$\begin{aligned} y_1'' &= A\sin(Bx + C); \\ y_1' &= -\frac{A}{B}\cos(Bx + C) + D; \\ y_1 &= -\frac{A}{B^2}\sin(Bx + C) + Dx + E. \end{aligned} \quad (1)$$

- for $x \in [u, 1]$:

$$\begin{aligned} y_2'' &= F\sin(Gx + H); \\ y_2' &= -\frac{F}{G}\cos(Gx + H) + I; \\ y_2 &= -\frac{F}{G^2}\sin(Gx + H) + Ix + J. \end{aligned} \quad , \quad (2)$$

To determine the constants $A, B, C, D, E, F, G, H, I$ and J, a system of 10 nonlinear equations obtained by using the variation diagrams of transmission functions y, y', y'' is solved.

Cosine-like transmission function

The curve representing reduced acceleration, y'', is composed of two cosine curves connected in the abscissa point $x = u$. Expressions of zero, one and two-order transmission functions are:

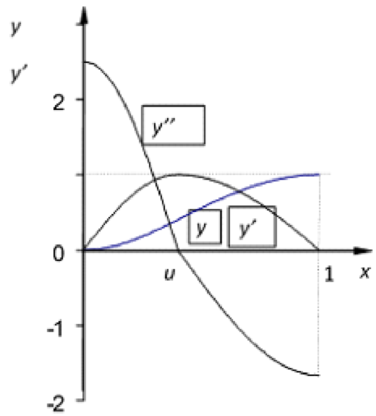

Fig. 6. Variation diagrams of transmission functions y,y',y''

- for $x \in [0,u]$:

$$\begin{aligned} y_1'' &= A\cos(Bx + C); \\ y_1' &= \frac{A}{B}\sin(Bx + C) + D; \\ y_1 &= -\frac{A}{B^2}\cos(Bx + C) + Dx + E. \end{aligned} \tag{3}$$

- for $x \in [u,1]$:

$$\begin{aligned} y_2'' &= F\cos(Gx + H); \\ y_2' &= \frac{F}{G}\sin(Gx + H) + I; \\ y_2 &= -\frac{F}{G^2}\cos(Gx + H) + Ix + J. \end{aligned} \quad , \tag{4}$$

To determine the constants $A, B, C, D, E, F, G, H, I$ and J, a system of 10 nonlinear equations obtained by using the variation diagrams of transmission functions y, y’, y’’ is solved.

Optimizing the dimensions of the mechanism with rotating cam and rotating roller cam follower

Optimizing the dimensions of this mechanism consists in determining the length L of the cam follower and the size of angle ψ_0 so that the allowable pressure angles α_{max} and α_{min} are not exceeded in the operating process of the mechanism. The angle ψ_0 is the angle between the vectors $\overline{BC_0}$ and $\overline{BA}$ (Fig. 6).

If the distance $AB = 1$ is considered, from triangle ABC_0 results

$$r_0 = \sqrt{1 + L^2 - 2L\cos(\psi_0)} \tag{5}$$

And the sizes r_0 and L become dimensionless.

As shown in Fig. 6 and in relation (5), the minimum radius of the cam depends on the cam follower length L and on angle ψ_0.

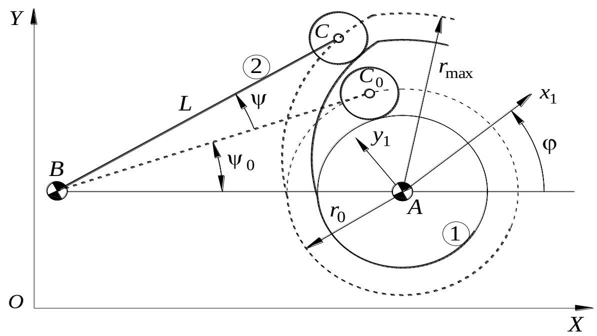

Fig.7. Rotating cam and rotating roller cam follower, with circular active surface.

Minimizing the radius r_0 is done in the presence of limitations that take into account the maximum and minimum values of the allowable pressure angles in the lifting and lowering phases. For the clarity of relations, we will note with ψ_1 the current angle made by the cam follower with its initial position, for the lifting phase, and with ψ_3 the current angle made by the cam follower with its initial position for the lowering phase.

In the lifting phase, the tangent of the pressure angle, α, must be less than or equal to the tangent of the maximum pressure angle α_{max}, namely:

$$\mathbf{g}_1 = \frac{1}{\sin(\psi_0 + \psi_1)}\left[\cos(\psi_0 + \psi_1) - \frac{L}{AB}\left(1 - \frac{d\psi_1}{d\varphi}\right)\right] \le \tan(\alpha_{max}) \cdot \qquad (6)$$

In the lowering phase, the tangent of the pressure angle, α, must be more than or equal to the tangent of the minimum pressure angle α_{min}, namely:

$$\mathbf{g}_2 = \frac{1}{\sin(\psi_0 + \psi_3)}\left[\cos(\psi_0 + \psi_3) - \frac{L}{AB}\left(1 - \frac{d\psi_3}{d\varphi}\right)\right] \ge \tan(\alpha_{min}) \qquad (7)$$

The objective function of the following form is considered:

$$f(L, \psi_0) = 1 + L^2 - 2L\cos(\psi_0) \qquad (8)$$

which must be minimized using the method of Lagrange multipliers.

Given that the mathematical model contains two restrictions, two Lagrange multipliers will be used, namely λ_1 and λ_2. To convert inequalities (6) and (7) into equalities, add the variables w_1 and w_2 (specify that equalities are made for the rotation angles φ_1^* and φ_3^*).

Considering the above, the Lagrange function is:

$$F(L, \psi_0, \varphi_1^*, \varphi_3^*, \lambda_1, \lambda_2, w_1, w_2) = f + \lambda_1(g_1 + w_1^2) + \lambda_2(g_2 + w_2^2) \qquad (9)$$

The minimum of function (9) is obtained from the conditions:

$$\frac{\partial F}{\partial L} = 0;\ \frac{\partial F}{\partial \psi_0} = 0;\ \frac{\partial F}{\partial \varphi_1^*} = 0;\ \frac{\partial F}{\partial \varphi_3^*} = 0;\ \frac{\partial F}{\partial \lambda_1} = 0;\ \frac{\partial F}{\partial \lambda_2} = 0;\ \frac{\partial F}{\partial w_1} = 0;\ \frac{\partial F}{\partial w_2} = 0. \qquad (10)$$

Relationships (10) form a system of 8 nonlinear equations, in the unknowns $L, \psi_0, \varphi_1^*, \varphi_3^*, \lambda_1, \lambda_2, w_1, w_2$, a system that is solved by the gradient method or the Newton-Raphson method.

Design of rotating cam and rotating roller cam follower profile

Figure 8 shows the kinematic scheme of the mechanism with rotating cam and rotating roller cam follower.

The Pelecudi-Sava method is used to design the cam profile [10].

The parametric equations of the cam profile are:

$$\begin{aligned} x_1 &= (XB - XA)\cos\varphi + (YB - YA)\sin\varphi + L\cdot\cos(\theta-\varphi) + \\ &\quad + r[\cos\nu\cdot\cos(\theta-\varphi) - \sin\nu\cdot\sin(\theta-\varphi)]; \\ y_1 &= -(XB - XA)\sin\varphi + (YB - YA)\cos\varphi + L\cdot\sin(\theta-\varphi) + \\ &\quad + r[\cos\nu\cdot\sin(\theta-\varphi) + \cos\nu\cdot\sin(\theta-\varphi)], \end{aligned} \tag{11}$$

where:

$$XA = const, YA = const, \varphi = \varphi(t),\ XB + L\cdot\cos\theta, XB + L\cdot\cos\theta, \theta = \theta(t)$$

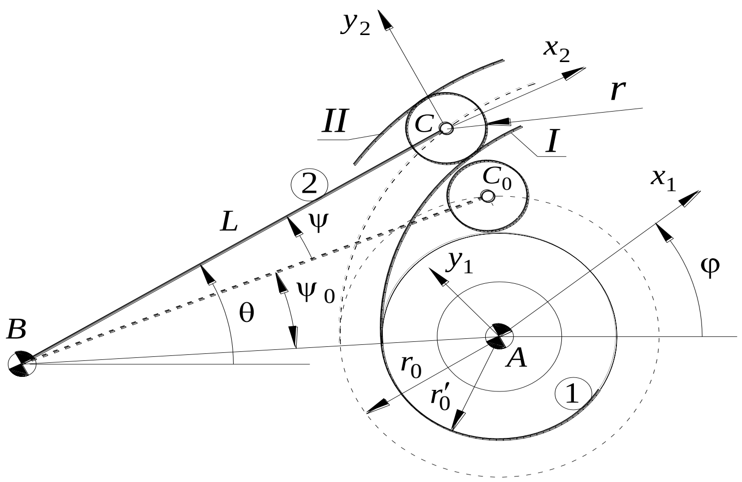

Fig. 8. Kinematic scheme of the mechanism with rotating cam and rotating roller cam follower

The expressions of the trigonometric functions $\cos\nu$ and $\sin\nu$ in the relations (11) are determined by the tangent condition between the cam and the cam follower. Considering the expressions of the parametric equations of the theoretical profile (punctiform cam follower), namely:

$$\begin{aligned} x_{1p} &= (XB - XA)\cos\varphi + (YB - YA)\sin\varphi + L\cdot\cos(\theta-\varphi); \\ y_{1p} &= -(XB - XA)\sin\varphi + (YB - YA)\cos\varphi + L\cdot\sin(\theta-\varphi). \end{aligned} \tag{12}$$

the parametric equations of the two profiles I and II result, having form:

- profile I:

$$x_{1I} = x_{1p} - \frac{r}{\sqrt{A_1^2 + B_1^2}}[A_1 \cdot \cos(\theta - \varphi) - B_1 \cdot \sin(\theta - \varphi)];$$
$$y_{1I} = y_{1p} - \frac{r}{\sqrt{A_1^2 + B_1^2}}[A_1 \cdot \sin(\theta - \varphi) + B_1 \cdot \cos(\theta - \varphi)], \quad (13)$$

- profile II:

$$x_{1II} = x_{1p} + \frac{r}{\sqrt{A_1^2 + B_1^2}}[A_1 \cdot \cos(\theta - \varphi) - B_1 \cdot \sin(\theta - \varphi)];$$
$$y_{1II} = y_{1p} + \frac{r}{\sqrt{A_1^2 + B_1^2}}[A_1 \cdot \sin(\theta - \varphi) + B_1 \cdot \cos(\theta - \varphi)], \quad (14)$$

For the equipment to open and interrupt water furrows, we make the optimal design of the mechanism with rotating cam and rotating roller cam follower, knowing the following data:

- $\psi_{max} = 0.279253$ [rad] ($\psi_{max} = 16$ [grade]) – maximum oscillating angle of the cam follower;
- $\alpha_{max} = 0.785398$ [rad]($\alpha_{max} = 45$ [grade]) – maximum pressure angle;
- $\alpha_{min} = -0.785398$ [rad] ($\alpha_{min} = -45$ [grade]) – minimum pressure angle;
- $\varphi_1 = 0.785398$ [rad] ($\varphi_1 = 45$ [grade]) – cam rotation angle, corresponding to the lifting phase;
- $\varphi_2 = 260$ [rad] – cam rotation angle, corresponding to the superior stationary phase;
- $\varphi_3 = 0.872665$ [rad] ($\varphi_3 = 50$ [grade]) – cam rotation angle, corresponding to the lowering phase;
- $\varphi_4 = 0.0872665$ [rad] ($\varphi_4 = 5$ [grade]) – cam rotation angle, corresponding to the inferior stationary phase;
- lsin – transmission function when lifting;
- lcos – transmission function when lowering;
- $XA = 0$ [mm], $YA = 0$ [mm] – coordinates of cam joint at the base, relative to the fixed OXY coordinate system;
- $XB = -300$ [mm], $YB = -200$ [mm] – coordinates of cam follower joint at the base, relative to the fixed OXY coordinate system;

Figure 9 presents the kinematic scheme of the mechanism resulted after making the design.

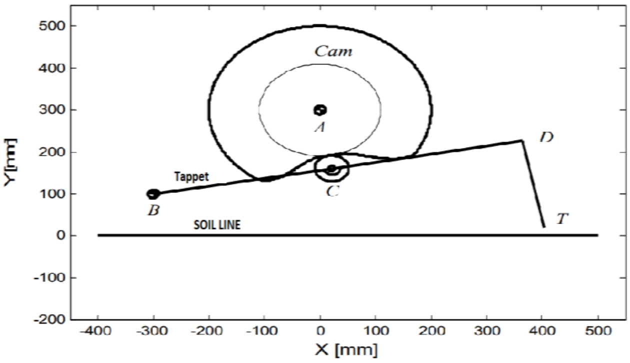

Fig.9. The kinematic scheme of the mechanism resulted after making the design

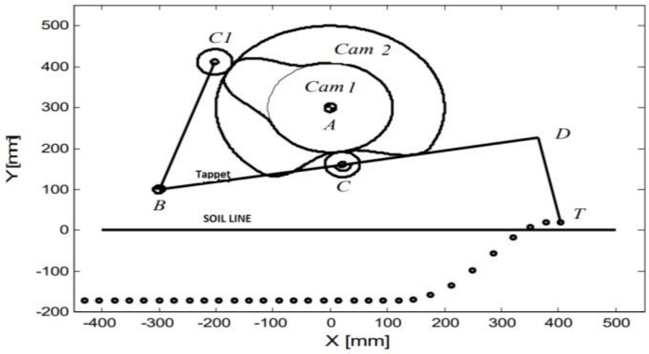

Fig.10. A rotating double cam mechanism can be used

To maintain the permanent contact between the cam and the cam follower, a rotating double cam mechanism can be used, as shown in Figure 10.

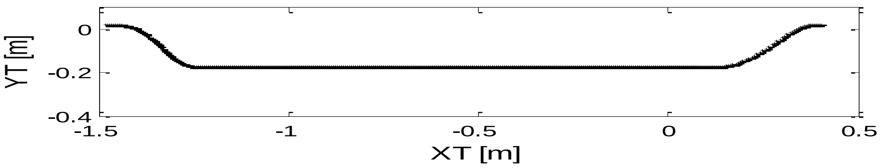

Fig.11 The trajectory of the T-point at a complete rotation of the cam

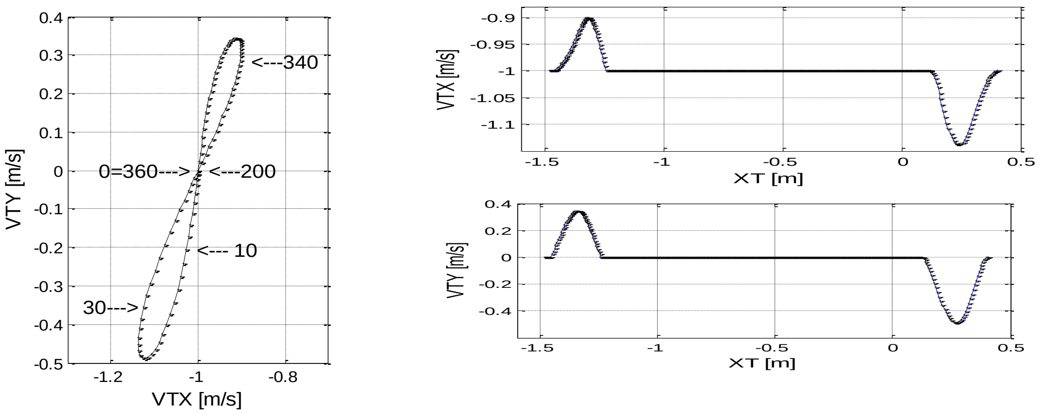

Fig.12 Graphs of T-point velocity

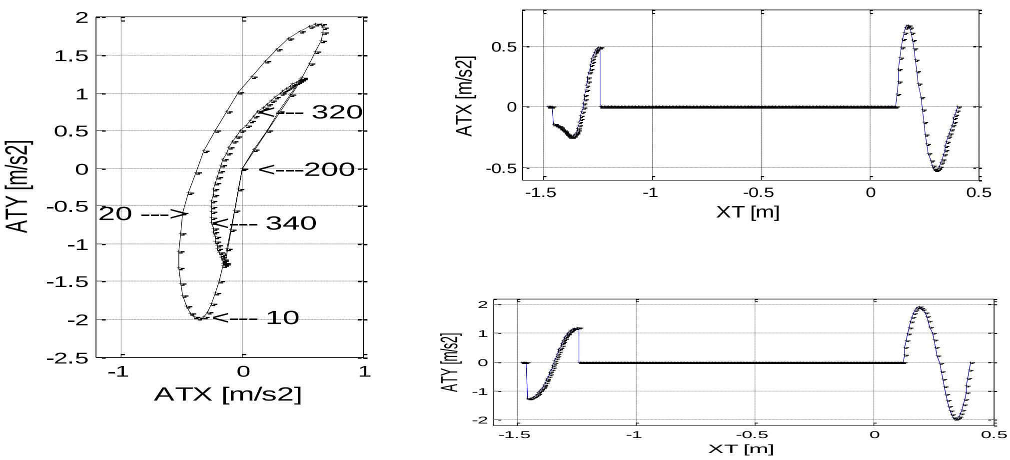

Fig. 13 Graphs of T-point acceleration

Figs. 11, 12, 13 show the travel, velocity and acceleration graphs of the T-point, representing the lower part of the working part.

3. Conclusions

By using the mechanisms with rotating cam and rotating roller cam follower for controlling the working parts constituting the equipment to open and interrupt water furrows, the optimal shape of the furrow and the silent and shock-free operation of the mechanism are obtained. Following the design of the rigid memory, it results: L_cam follower= BC2=327 mm; r_max=198.223 mm; r_min=107.499mm; r_roller = 33 mm;

For the producers owning lands in these areas, the increase of energy consumption for pumping and distributing water leads to an increase in the production price setting pressures on their capacity to produce. For this reason, a series of agricultural equipment has been developed for the compartmentalization of lands in furrows. By making mini dams on the length of the furrow, a more efficient use of the precipitation or sprinkler irrigation water on eroded or lands or with a slope of less than 6^o.

By using this technology, a better soil conservation is achieved, avoiding the occurrence of the erosion phenomenon in the upper part of the slope and of puddles in the lower part.

R E F E R E N C E S

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