THE KINEMATICS OF THE UNIVERSAL REEL

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Abstract: *Reducing grain harvest losses is a primary goal of farmers and implicitly the manufacturers of self-propelled combine harvesters. The combine harvester is destined for grains harvesting of cereals, performs at the same times: the reaping, the threshing, the cleaning of the grains and their collection in an own grain tank. The reaping of the plants consists of cutting them and transporting them to the threshing drum. During the cutting the plants must be supported and directed to the header auger, an operation carried out by the reel. Taking into account the varying conditions that occur at harvest, the reel from the header should be designed so that the losses at harvest are minimal. The reel that best meets this condition is the eccentric reel or the universal reel. For these reasons we have chosen to study a universal reel fitted to the harvest header from the self-propelled combine John Deere S series. The working organs of the reel are elastic fingers from steel or plastic. In order to perform a correct harvesting both the angular velocity and the position of the reel must be within certain parameters so that the elastic fingers bend the plants back so that after cutting they are placed on the header auger. The constructive and functional parameters of the universal reel studied were: the reel diameter, the reel length, the angular velocity of the reel, the elastic finger trajectory, the tangential speed of elastic fingers, the acceleration of elastic fingers, the kinematic index of the reel. In the case of absolute movement, when the reel is rotating and at the same time moving with the working speed of the combine harvester, the trajectory of the elastic fingers of the reel is a cycloid. The kinematic parameters of the reel were determined by the analytical method according to its constructive and functional parameters. The calculations were made for two complete rotations of the reel. Based on the obtained results, the functional parameters of the reel were determined: the length of the cycloid, the time of a complete rotation of the reel and the area covered by the reel to a full rotation. Following the studies carried out, the conclusions and recommendations that are required are established.*

Key words*: harvest header, reel, elastic fingers, trajectory, speed, acceleration*

INTRODUCTION

The harvesting of straw cereals is a particularly important work that must be performed on time and at minimal loss. The losses increase if the harvest is delayed, respectively if the straw cereals pass the phase of full ripe and if combine harvesters do not correspond to the requirements of harvesting because of being morally worn out (AUNGURENCE N., 1994; DĂNILĂ I., 1981; LETOȘNEV M.N., 1959; TONEA CORNELIA, 2003; TOMA D., 1981). A large percentage of grains are lost in the harvesting of recumbent fall wind and overripe fields if harvesting is done with conventional headers equipped with classic reels with paddles. The current modernisations in the construction of the headers of combine harvesters have envisaged the replacement of classical reels with universal reels (NAGHIU AL., 2008; NECULĂIASA V., DĂNILĂ I., 1995; SCRIPNIC V., BABICIU P., 1980; ȘANDRU A., CRISTEA I., 1983).

The reel has the role of holding the plants towards the cutting apparatus, keeping them bent down during cutting. After cutting, the plants fall on the platform of the combine header and are taken over by its transport organs. For the harvesting of both straight and recumbent fall wind plants in good conditions, in the combine harvesters headers, universal or eccentric-type reels are used, a designation given by the kind of mechanism used (DUMA COPCEA ANIȘOARA, MIHUȚ CASIANA, ARSENE O., 2017; DUMA COPCEA ANIȘOARA, ILEA R, POPA D., 2018).

The reaping of the straw cereals with minimal losses requires correct adjustment of the position and speed of the universal reel, depending on the working speed of the combine harvester and on the condition of the crop field (BRÎNDEU L., 1980; ILEA R., 2009; RIPEANU A., 1982; SILAȘ GH., GROȘANU I., 1981). At the modern combine harvesters, these adjustments are made automatically using sensors and hydraulic motors mounted on the combine header platform. (MIHUȚ CASIANA, 2018)

MATERIAL AND METHODS

The studies in this paper were carried out based on the determinations made in the 635R combine headers model that equip the John Deere S series combine harvesters.

The universal reel (Figure 1) is designed to hold the plants towards the cutting apparatus, keeping them bent down during cutting. After cutting, the plants fall on the platform of the combine header and are taken over by its transport organs.

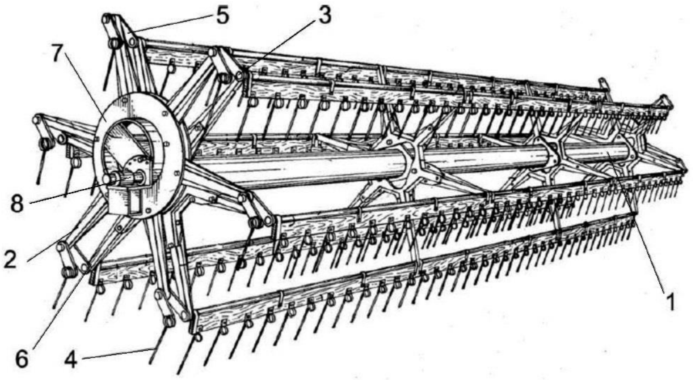

Figure 1. Technological scheme of the universal reel
1-reel tube; 2-arms; 3-axes; 4-elastic fingers; 5-cranks; 6-support arms; 7-rosette; 8-rolls

On the reel tube 1, supported by two bearings, 3-6 rosettes with support arms 2 are mounted rigid. Each rosette has 3-6 support arms. At the outer extremity of the support arms are mounted articulated axes 3 on which elastic fingers 4 of steel or plastic are mounted. At the far right of the reel, axes 3 are fitted with the cranks 5 in the arms 6 of the rosette 7. The rosette is mounted eccentrically to reel tube 1 and rotates on a plate being backed by rolls. During the rotation of the reel, any point on the axes 3 executes two movements: a circular motion around the reel tube and a rotating movement around its axis, so that elastic fingers mounted on the stand bars retain in any position a constant angle towards the ground. Adjusting the tilt of the elastic fingers is done by modifying the position of the rosette 7.

During working, the elastic fingers of the reel perform two movements, namely:

- a plane-parallel movement around the reel tube with tangential velocity $v_p = \omega \cdot R$ (where the reel's radius R is and ω is the angular speed of the reel);
- a rectilinear translation movement with the working speed of the combine v_l .

The absolute speed of the elastic fingers will be:

$$\bar{v}_a = \bar{v}_l + \bar{v}_p \ .$$

Due to the compound of the two movements, the trajectory of a point on the elastic fingers of the reel is a curve called cycloid. The form of cycloid depends on the value of the kinematics index of the reel $\lambda = \frac{v_p}{v_l}$. Depending on the value of the cinematic index, the following cases occur:

- If $\lambda > 1$ plants are tilted backwards (Figure 2a);
- If $\lambda < 1$ plants are tilted forward (Figure 2b);

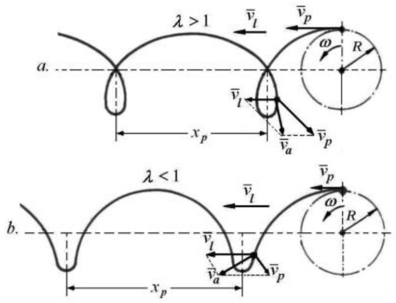

Figure 2. Elastic fingers trajectory

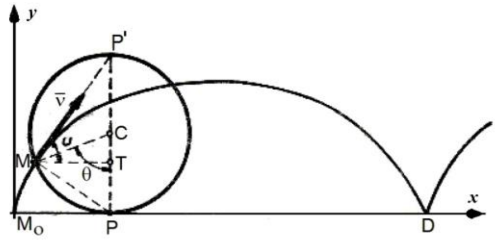

Figure 3. Cycloid

The 635R combine harvester header is characterized by the following constructive and functional parameters: mass of the header, working width of the header, diameter of the reel, diameter of the bars of the fingers, number of elastic fingers, length of the cranks.

The kinetic parameters of the reel (trajectory, speed, acceleration) were determined by the analytical method according to its constructive and functional parameters. For normal working conditions, the following parameters were chosen: working speed of the combine harvester ($v_l = 4{,}5\, km/h = 1{,}25\, m/s$), reel rated speed ($n = 35\, rot/min = 0{,}58\, rot/s$), angular velocity of the reel ($\omega = 3{,}66\, rad/s$), tangential speed of elastic fingers ($v_p = \omega \cdot R = 3{,}66 \cdot 0{,}55 = 2{,}01\, m/s$), kinematics index of the reel ($\lambda = \frac{v_p}{v_l} = \frac{2{,}01}{1{,}25} = 1{,}6$).

Be C a circle of radius R that rolls, without slipping, on a straight D (Figure 3). Point M on the circumference of the circle describes a curve called cycloid. To determine the parametric equations of this curve, we take as the abscissa axis the line D and as the ordinate axis the perpendicular to the line D. Be P the contact point of the circle with the line D; x and y coordinates of point M describing the cycloid are:

$$x = M_0P - MT = R(\theta - sin\theta);\; y = CP - CT = R(1 - cos\theta). \quad (1)$$

These are the parametric equations of the cycloid. The movement of the point on this curve is called cycloidal movement. For the study of the cycloidal movement using equations (1) we need to know the expression of the angle depending on time, that is $\theta = \theta(t)$.

The projection on the axes of the speed of the mobile will be:

$$v_x = R\omega(1 - cos\theta);\; v_y = R\omega sin\theta \text{ , where } \omega = \dot{\theta}.$$

Hence:

$$v = 2R\omega\, sin\frac{\theta}{2}; \quad a = R\omega\sqrt{2(1 - cos\,\theta)}. \quad (2)$$

RESULTS AND DISCUSSIONS

The analytical method was used to determine the trajectory. Taking into account the relationships (1), the cycloid trajectory was generated in Microsoft Excel.

The values of movement parameters (x and y coordinates of the cycloid according to the rotation angle θ) are centralised in Table 1. The generated graph of the cycloid for two revolutions of the reel is shown in Figure 4.

Table 1

Coordinates of cycloid

Nr. crt	**Θ** [grade]	***x*** [m]	***y*** [m]	Nr. crt	**Θ** [grade]	***x*** [m]	***y*** [m/s]
1	0^0	0	0.55	13	360^0	1.98	0.55
2	30^0	0.44	0.48	14	390^0	2.42	0.48
3	60^0	0.81	0.28	15	420^0	2.78	0.28
4	90^0	1.04	0.00	16	450^0	3.02	0.00
5	120^0	1.14	-0.28	17	480^0	3.11	-0.28
6	150^0	1.10	-0.48	18	510^0	3.07	-0.48
7	180^0	0.99	-0.55	19	540^0	2.96	-0.55
8	210^0	0.88	-0.48	20	570^0	2.85	-0.48
9	240^0	0.84	-0.28	21	600^0	2.82	-0.28
10	270^0	0.93	0.00	22	630^0	2.91	0.00
11	300^0	1.17	0.28	23	660^0	3.15	0.28
12	330^0	1.54	0.48	24	690^0	3.51	0.48

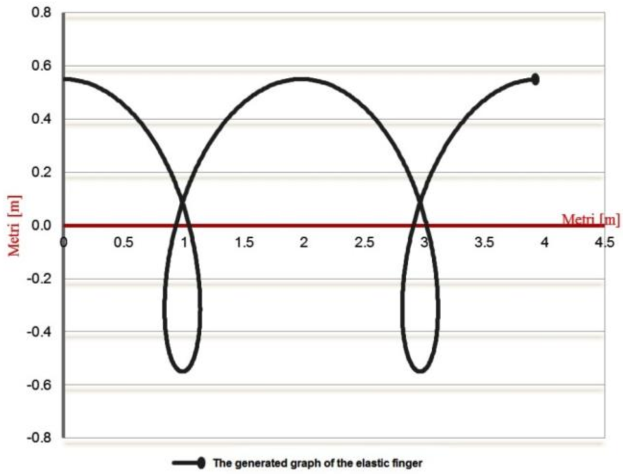

Figure 4. The generated graph of the cycloid

The determination of elastic finger speeds and accelerations was done with the help of relationships (2) for two complete rotation of the reel. Taking into account the constructive and functional parameters of the reel, relations 2 become:

$$v = 2R\omega\, sin\frac{\theta}{2} = 2 \cdot 0{,}55 \cdot 3{,}66\, sin\frac{\theta}{2} = 4{,}026\, sin\frac{\theta}{2} \;;$$

$$a = R\omega\sqrt{2(1-cos\,\theta)} = 0{,}55 \cdot 3{,}66\sqrt{2(1-cos\,\theta)} = 2{,}013\sqrt{2(1-cos\,\theta)}\;.$$

The calculation of elastic finger speeds and accelerations was made every 30 degrees, for two complete rotation of the reel. The values are centralized in Table 2. Based on the values in Table 2, the chart in Figure 5 was generated in Microsoft Excel.

Table 2

Speeds and accelerations of elastic finger

Nr. crt	**Θ** [grade]	**v** [m/s]	**a** [m/s^2]	Nr. crt	**Θ** [grade]	**v** [m/s]	**a** [m/s^2]
1	0^0	0.00	0.00	13	360^0	0.00	0.00
2	30^0	1.04	1.04	14	390^0	-1.04	1.04
3	60^0	2.01	2.01	15	420^0	-2.01	2.01
4	90^0	2.85	2.85	16	450^0	-2.85	2.85
5	120^0	3.49	3.49	17	480^0	-3.49	3.49
6	150^0	3.89	3.89	18	510^0	-3.89	3.89
7	180^0	4.03	4.03	19	540^0	-4.03	4.03
8	210^0	3.89	3.89	20	570^0	-3.89	3.89
9	240^0	3.49	3.49	21	600^0	-3.49	3.49
10	270^0	2.85	2.85	22	630^0	-2.85	2.85
11	300^0	2.01	2.01	23	660^0	-2.01	2.01
12	330^0	1.04	1.04	24	690^0	-1.04	1.04

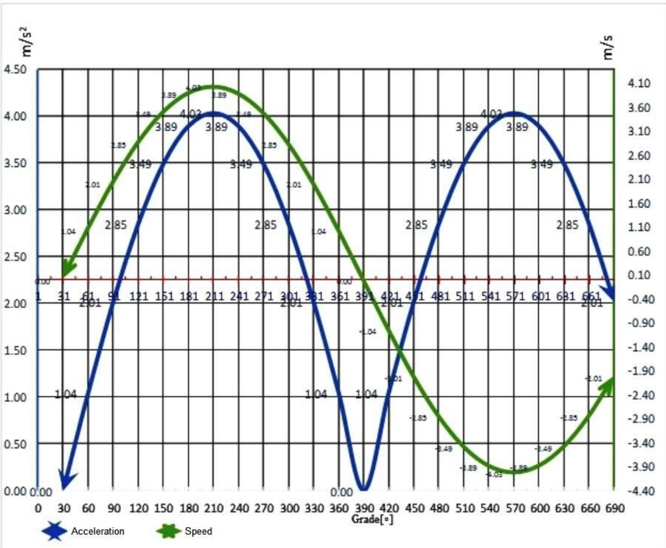

Figure 5. Diagram speed and acceleration of elastic finger

On the basis of the results obtained, the following functional parameters of the reel can be determined: length of the cycloid, time of a complete rotation of the reel, space travelled by the reel during a complete rotation, portion of the field per row of elastic fingers.

CONCLUSIONS

Given that the technique in mechanization of the harvesting works of the straw cereals has advanced a lot lately worldwide, the most important aspect to be addressed is the choice of optimal operating regimes that allow for increased productivity and quality and reduction of losses and costs in mechanized harvesting works. For this reason, a main studied aspect relates to the current state of the reels of the straw cereal harvesting combines. For optimum operation of the reel under varied working conditions, the trajectory of elastic fingers is a cycloid. By studying all types of motion, this cycloid was generated in Microsoft Excel. Given the destination of the reel, it is considered that the type of reel that equips the 635R combine header is well-chosen, since it can ensure the normal folding of plants for all conditions of harvesting of straw cereals.

For a good functioning of the universal reel, the length of the support arms of the elastic fingers shall be equal to the length of the arms of the rosette.

Under normal working conditions (for well-developed fields) the speed of the reel rotates between 25-40 rpm depending on the working speed of the self-propelled combine. The working speed of the combine and the reel speed are automatically adjusted by the electronic control of the combine's onboard computer, depending on the signals received from the electric sensors mounted on the combine.

The efficacy of the work process of the universal reel also results from the specific case being studied. Thus, the working speed chosen (4.5 km/h) we obtained a cycloid with a length of 3.45 m, a space a combine needs for a rotation of the reel (2.12 m), and the portion of the field folded by the elastic fingers of 0.35 m, respectively.

In order to obtain working indices suitable for technological requirements in the case of harvesting straw cereals, on the one hand, and for carrying out a rational load of the universal reel, on the other hand, the recommended working speed is 4-7 km/h.

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