## RESEARCHES ON THE HARVESTING PROCESS OF STRAW CEREALS BY EAR STRIPPING

Vergil Gângu<sup>\*</sup>, Simion Popescu<sup>\*\*</sup>

\* The National Research Institute for Agricultural Machinery (INMA) of Bucharest, Romania \*\* The Transilvania University of Brasov, Romania

Parallel with the constructive evolution all over the world of different types of harvester [3, 4, 5], there were felt the symptoms of functional insufficiencies due to the "saturation" of classical flow sheets. In view of that, the adopted solutions having been imposed, some theoretical and experimental researches were carried out, in order to improve equipment or machines which could assure the harvesting of straw cereals by ear stripping. The researches developed within INMA – Bucharest, have led to a series of significant results finally materialized in a prototype of a header-scraper which, being mounted on a Romanian-manufactured harvester (C 140) has served, by its improving, both as a researching object and as a materialization of the most recent constructive and functional requirements imposed on modern harvesters all over the world.

As a result, both by theoretical consideration of the process, by analyzing the interaction between the field and stripping tool or between the sampled material and the scraper as well as by determining the various subsequent paths, described by the components resulted from these interactions, it was possible to identify the mathematical relations conditioning the correct evolution of the useful product within a suitable mechanical system (Fig. 1) along the period between its taking out of the field (area A) and reception (area C) [1, 2].

The theoretical analysis of the complex process of stripping consists mainly in the identification of the kinematic and dynamic conditions which are imposed on the grain detaching off the ears, on the ears and ear fragments, in area A and their placing on a trajectory (or a trajectory family) within the equipment in area B, so that they could be taken without any losses in area C. As result the process analysis undertakes two distinct parts as follows:

- the study of the proper process of stripping (suitable to the interaction scraper-field in area A);

- the study of displacement of sampled material (on the active surface of the scraper-stripper and then the free movement to area B).



Fig. 1. Working principle of the stripper header

Within the study of the proper stripping process, developed on a physical model faithfully reproducing, from a constructive and functional point of view, the active assembly of a harvesting equipment by ear stripping, one should take into account also the dimensions characteristic of the suitable sizes of a rational construction and influences of the functional peculiarities generated by the practical solutions adopted in performing the mechanical system under the form of equipment. Among them the most important is the "cup" complementary effect, which the assembly geometry of the active area of the stripper offers during work.

It is due to the fact that the active length "b" of the scraper-stripper is only a part, namely the exterior one of an active area, the other part being constituted of the fixing frame (support) "a", the two segments closing up between them an obtuse angle (Fig. 2).



Fig. 2. A mechanical model for the theoretical study of the working process of the stripper header

From the geometrical interpretation of the reciprocal positions characterizing the constructive components, by mathematical sentences suitable to the real conditions for performing the physical model a series of important relations have been obtained being representative for the ear losses stripping process. Thus from the interaction study, being successively imposed an assembly of functional conditions, as that of ground clearance, of integral stripping of useful material and complete taking over the mixture by the scraper-stripper there have resulted the following mathematical relations for the cross section of the active surface "S" and the outer radius  $R_2$ :

$$S = \frac{2\pi h R_2 H_q}{\frac{V_p}{V} Z K_u};$$
(1)

$$R_{2} = \frac{\frac{2K}{Z} - R_{0}(\sin\frac{2\pi}{Z} - \cos\frac{2\pi}{Z} \operatorname{tg}\frac{\gamma}{2})}{\operatorname{tg}\frac{\gamma}{2}} + \sqrt{\left(\frac{\frac{2K}{Z} - R_{0}(\sin\frac{2\pi}{Z} - \cos\frac{2\pi}{Z} \operatorname{tg}\frac{\gamma}{2})}{\operatorname{tg}\frac{\gamma}{2}}\right)^{2}} - R_{0}^{2} \left(\frac{2\sin\frac{2\pi}{Z}}{\operatorname{tg}\frac{\gamma}{2}} - 1\right) (2)$$

where (the values between the parentheses correspond to those chosen for the performing of the experimental model):

h – equipment sinking level into the field (150 < h < 200 mm),

- Vp peripheral speed of the scraper of a length a + b (V = 9-11 m/s),
- V equipment travelling speed (V = 3.5-4.3 m/s),
- Z number of scrapers arranged on the same circumference (Z = 8),
- $K_u$  admission coefficient of the scraper with the sampled material (K = 0.85-0.9),
- $\ddot{K_a}$  aeration coefficient of the sampled material (K = 1,1-1,15),
- K a numerical coefficient (K = 642, for h = 200 mm, and K = 422, for h = 150 mm),
- $\gamma$  inclination angle (in advance) of the scraper to the support (in the conditions of performing the functional model, p = 50).

By knowing the two relations and the significance of the suitable notations, the study of interaction between the scraper-rotor and the field has permitted, by going on, the determining of the formula for calculating the optimum value for the scrapper's (stripper's) total length "l" (l = a + b), as follows:

$$l = \frac{2S - R_0 a \left[\sin \varepsilon_0 - \sin(\varepsilon_0 + \gamma)\right] (1 - \frac{R_0}{R_2}) + a^2 \sin \gamma}{R_0 (1 - \frac{R_0}{R_2}) \sin(\varepsilon_0 + \gamma) + a \sin \gamma}$$
(3)

where:

 $R_0$  – is radius of support drum of the stripping scrapers,

 $\varepsilon_0$  – inclination angle (in advance) of the support to the radial theoretical position,

- $(\varepsilon + \gamma)$  total inclination of the stripping scraper,
- b active length of the proper stripping scraper,
- a active length of the scraper support, calculated by the relation:

$$a = \frac{1}{2} - \frac{(R_2 - R_0)R_0[\sin(\varepsilon_0 + \gamma) - \sin\varepsilon_0]}{2R_2\sin\gamma}$$
(4)

The study of displacing the sampled material marks out for the two distinct stages (displacement on the active surface of the scraper and then freely within the area B - Fig. 2) the forces acting at the same time or successively on the material, being projected on the axes of a Cartesian system with the axes suitably chosen and the center somewhere at the distance "x" from the end of the support, on the active surface of the proper scraper 01.

Taking into consideration the three groups of forces acting in the usual friction conditions on each mass particle "m" from the harvested material (the centrifugal force, the weight and the Coriollis force) it is obtained for the displacing along the scraper, the resultant of the projections on axis O1X (Fig. 2):

$$X = G_x + P_x - f(G_y + P_y + F_{co}),$$
(5)

where, according to the representation in Figure 2:

$$P_x = m\omega^2 [x + R_2 \cos(\gamma + \gamma_1)];$$
(6)

$$P_{y} = m\omega^{2}R_{1}\sin(\gamma + \gamma_{1})$$
<sup>(7)</sup>

$$G_x = G\cos(\omega t + \varepsilon_0 + \gamma) \tag{8}$$

$$G_{\nu} = G\sin(\omega t + \varepsilon_0 + \gamma) \tag{9}$$

$$F_{co} = 2m\omega x \tag{10}$$

Coming back to the relation (5), replacing the expressions (6)-(10), by successive processing the law can be reached of moving the material on the active surface of the scraper:

$$x + C_0 x - \omega^2 x = C_1 + C_2 \cos(\omega t + \psi_1)$$
(11)

where:

$$\begin{split} C_0 &= 2f\omega \,, \\ C_1 &= \omega^2 R_1 \frac{\cos(\gamma + \gamma_1 + \varphi)}{\cos\varphi} \,, \\ C_2 &= \frac{g}{\cos\varphi} \,, \\ \varphi &= arc \, \text{ctg} f \,, \\ \psi_1 &= \varepsilon + \gamma + \varphi \,, \\ f - \text{friction coefficient of the material on the active surface of the stripping-scraper.} \end{split}$$

In the second stage, the material displacement, namely its projection beyond the end of the scraper, begins together with the consuming of the sinking level into the field "h".



Fig. 3. Schema of the material particles trajectories during harvesting

Under the dominant effect of the radial force, depending on the position occupied (x, f, x,) in the assembly of the harvested mass, each particle describes, by moving with a speed between  $V_{\min}$  and  $V_{\max}$  a proper trajectory inscribed into a curve family limited by the extreme parabolas (Fig. 3).

$$Y_{\text{max}} = X_1 \operatorname{tg} \beta_{\text{max}} - \frac{g x_1^2}{2V_{\text{max}}^2 \cos^2 \beta_{\text{max}}}$$
(12)  
$$Y_{\text{min}} = X_2 \operatorname{tg} \beta_{\text{min}} - \frac{g x_2^2}{2V_{\text{min}}^2 \cos^2 \beta_{\text{min}}}$$

The basic condition of setting the trajectory family described between the extreme limits rendered by the relations (12) refers to the "throwing" angle of each particle ( $\mu$ ), which should be suitable to the area horizontal line, always bigger than that of the natural slope ( $\varphi$ ), namely  $\mu \ge \varphi$ .

The main resistance (Fr), faced by the heavy constituents, along the whole period of crossing the area B, calculated on the methodology known in the specialist literature and adapted to the studied case is, as usual, the one opposed by the environmental air, as follows:

$$F_x = K_p q_0 A_0 \frac{V_i^2}{2g},$$
 (13)

where:

- $K_p$  is soaring coefficient,
- $q_0 = \gamma/g air density,$
- $V_i$  initial speed of "throwing" a particle (equal to that one which the mixture constituent has, when it detaches from the stripping scraper),
- $A_0$  mean surface of the cross section of the particle on the direction of displacement,
- g gravitational acceleration.

Assuming that the equipment corresponds from a constructive point of view to the assembly creation of the conditions necessary for consuming the soaring, processes within the area B in the hypotheses of the free throwing of the heavy constituents, it results that the reception area C (Fig. 2) of the scraped material practically covers a space (L) enclosed between:

$$L_{\min} \le L_c \le L_{\max} \tag{14}$$

the extreme limits being, in their turn, calculated as follows:

$$L_{\min} = \frac{V_{\min}^2 \sin 2\beta_{\min}}{g}$$

$$L_{\max} = \frac{V_{\max}^2 \sin 2\beta_{\max}}{g}$$
(15)

The comparative experimental tests performed by C 140 harvester equipped with a mechanical system of ear stripping and a classical header, in order to check the functional and constructive compatibility between a real equipment reproducing the complex process of stripping and the laws governing in the studied range of the interaction between a mathematical model and the field have led, by the results they obtained, to the confirmation of the validity of the theoretical assumptions.

Resulted as a materialization of the numerical values adopted for the main constructive elements conditioning a good operation of the complex stripping process ( $R_2 = 350$  mm; Z = 8;  $\gamma = 50$ ; nscraper = 300 rpm) the functional model has been tested, according to the procedure specific to the cereal harvesting machines in wheat, barley, oats, rice, soya-beans, mustard, etc.

The experimental researches [2] were performed both in INMA-Bucharest area, and in various agricultural units in Romania, according to a program at the stages of which the priority is emphasized given to the dominant cereal crops, as wheat, barley and oats.

The special importance of the sinking depth into the field [4] for ensuring optimum working conditions, theoretically determined to be comprised between the levels 150 and 200 mm, has constituted for the beginning the object of the experimental check, confirming the practical validity of the relation:  $150 \le h \le 200$  (mm), for all the crops where they have worked.

As a result, once theoretically established and practically checked, the value of the sinking level has been maintained constant along all the test period. According to the valid procedure some indexes regarding the quality of performed work, refer to the grain losses on the soil (Pbs), grains which remained into ears or panicle (Ps), losses due to the internal flow sheet of the harvester (Pc) and the total losses of grains (Pt).

The measurements have been performed, by suitable means, for the partial losses, in the area immediately following the pass of the stripping or classical equipment, and for the total ones after passing the harvester.

The resulting systematization of the comparative tests on distinct categories, grouped on the three dominant crops, has made it possible to perform a detailed analysis of the way in which the harvesting process by stripping is influenced by the nature of the crop, the production per hectare and the harvester's driving speed.

The total losses, representing the sum (Pbs + Ps + Pc) can constitute a quality index defining for checking the validity of the theory regarding the stripping process, analyzed comparatively to the classical system of harvesting.

Both the experimental data obtained, for the situation of wheat, barley and oats harvesting by stripping or the classical method have permitted the drawing of a series of important conclusions, generally valid, as follows:

– the domain of the optimum working speeds (DVOL) characteristic of the present day harvesters equipped with a stripping mechanical system is, within the cereal eared crops (wheat and barley) much larger than in the case of the same harvesters equipped with a header. It is, as a rule, much displaced to the segment of the rapid speed steps, covering for wheat the range 5.8-11.4 km/h and for barley 5.6-11.6 km/h, while the total acceptable losses imposed on the harvesters having a usual cutting equipment the optimum domains much narrower (3.52-5.8 km/h - for wheat and 3.6-8.45 km/h - for barley);

- the domain of the optimum working speeds (DVOL) characteristic of the present day harvesters equipped with a stripping mechanical system also in the situation of harvesting the cereal crops with a greater panicle than the same harvesters equipped with a classical header;

– given the various physical – mechanical properties of the panicle to the ears, the optimum working domain in the case of the stripping mechanical system is narrower as compared to that recommendable for ears, covering the segment 4.3-7.5 km/h (for oats). The system having a classical header, in its turn, presents a more narrower DVOL, namely 4.3-6.8 km/h;

– in the perspective of growing the exigencies all over the world regarding the quality working index, by limiting the total losses percentage to 2%, confirmed with the efficiency – making of the harvesting works by increasing the working speed, the stripping mechanical system is liable to a series of constructive improvements, meant to reproduce the same theory referring to the complex stripping process for all the cereal crops, either with an ear, or with a panicle, in the newly imposed conditions, a situation practically impossible to be performed in the case of the present – day harvesters equipped with a classical header.

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## SUMMARY

The paper presents theoretically grounded and experimentally checked by a physical model, the theoretical process aiming at the stripping of the ears or panicles of the straw cereals, their transport and reception in view of the subsequent works within the working process of the harvesting machines for straw cereals.

The large range of problems lying at the basis of clearing up the complex process of harvesting by stripping the straw cereals offers the contemporary scientific research a vast area of investigation with the results which can constitute, by their importance, significant steps on the way of the future evolution of modern harvesters.