STUDIES REGARDING THE OPTIMIZATION OF THE MILLING MACHINES WORKING PROCESS

G. Paraschiv, I. Paunescu, E. Maican, S. Bungescu

***Abstract**: There are two important requirements that should be respected in order to get quality from the milling machines: soil crushing without its pulverization, and a flat bottom of the bed (the crests' height should be less than 10 % from the working depth). In this respect, a great influence has the optimum selection of the milling machine functional parameters and the correct dimensioning of its rotor. Establishing the functional parameters also means to determine the relationship between the soil chip thickness (s) disrupted by a knife and the kinematical index of the machine (λ). In this paper it is determined this relationship and also the height of the crests (h), measured from the bottom of the bed.*

***Key words:** Milling machine, kinematical index, optimisation,.*

INTRODUCTION

Agricultural milling machines are more and more used to completely process the soil. They could be part of some complex machine systems or they can be independently used.

According to some authors, their persistent utilization on the same areas can lead to soil texture destruction. Therefore, a deeper study of the working process of the milling machines is necessary to be made. On the same time, the influence of the machine's kinematical parameters over the quality of the resultant work should be established.

In order to establish the optimal functional parameters of the milling machines also involves calculus of the relation between the soil chip thickness (s) dislocated by the knife and the kinematical index (λ) of the machine.

Coming into the help of the design engineers, this paper presents the calculus of the correlation between λ and s, and also the height of the crests (h), measured from the bottom of the bed.

SOIL CHIP THICKNESS CALCULUS

The thickness s of the soil chip dislocated by the knife is heavily influenced by the milling machine's kinematical index λ. A smaller value of the kinematical index λ means a bigger value of the thickness s.

The problem to be resolved rests in finding the relation between the soil chip thickness s at the surface of the soil and the kinematical parameters of the milling machine.

If Δt is the time interval corresponding to the penetration of the soil by two successive knives, according to figure1 the relation for s is:

$$s = v_m \Delta t = v_m \frac{\Delta\varphi}{\omega} = \frac{2\pi v_m}{z \cdot \omega} \quad (1)$$

where $\Delta\varphi$ the angle between two knives from the same plane and z is is the number of the knives.

If both the denominator and numerator in relation (1) are multiplied by R, the following relation is obtained:

$$s = \frac{2\pi v_m R}{z\omega R} = \frac{2\pi R}{z\lambda} \quad (2)$$

This relation shows that s is in inverse ratio to the kinematical index λ. So, for a given diameter of the milling machine rotor, the thickness can be influenced both by the value of λ and by the number of knives from the same plane (z).

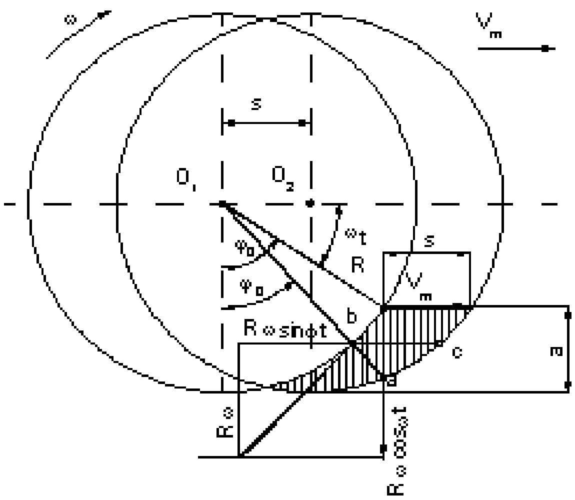

Fig. 1 – The parameters of the milling machine working process

Relation (2) can be transformed as follows:

$$\begin{cases} \dfrac{s}{R} = \dfrac{2\pi}{z\lambda} \\ \lambda = \dfrac{2\pi}{z\dfrac{s}{R}} \end{cases} \tag{3}$$

where equation (3) gives the relation between the kinematic index and *s/R* ratio.

In figure 2, *H* is the intersection point betwwen two cycloids described by points belonging to the cutting edges of two consecutive knives from the same part of a disk [1]. The parametric ecuations describing one of this points' trajectory are:

$$\begin{aligned} x &= v_m t + R\cos\varphi \\ y &= R\sin\varphi \end{aligned} \tag{4}$$

where φ is the angle between the radius corresponding to the point and *Ox* axes.

When $O \equiv O_{\pi/2}$ the radius is vertical, and when $O \equiv O_H$ the radius is backwards inclined with an angle $\varphi_H > \pi/2$.

The position of the rotor's center corresponding to the angle $\varphi = \frac{\pi}{2}$ was denoted with $O_{\pi/2}$. Also, O_h is the position of the rotor's centre when the radius makes an angle φ_H corresponding to the point of intersection *H* between the two cycloids. In this case:

$$x_H = x_{\pi/2} - \frac{s}{2} \tag{5}$$

However:

$$x_{\pi/2} = v_m t_{\pi/2} + R\cos\frac{\pi}{2} = v_m \frac{\pi}{2\omega} = \frac{\pi R}{2\lambda} \tag{6}$$

Finally:

$$x_H = \frac{\pi R}{2\lambda} - \frac{\pi R}{z\lambda} \tag{7}$$

From figure 2: $sin\varphi_H = \frac{R-h}{R}$, which leads to:

$$\varphi_H = k\pi + (-1)^k \arcsin\frac{R-h}{R} \tag{8}$$

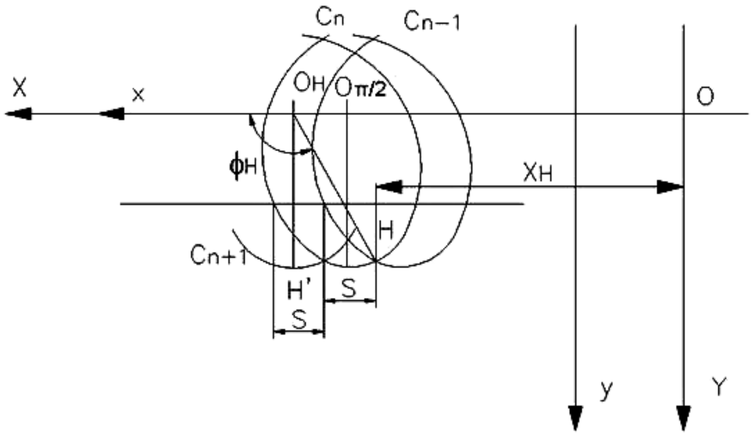

Fig. 2 – The relation between *h*, *z* and *λ*

However, there is another way to express x_H:

$$x_H = v_m t + R\cos\varphi_H, \quad \text{or}$$

$$x_H = v_m\frac{\varphi_H}{\omega} + R\cos\varphi_H = \frac{R\varphi_H}{\lambda} + R\cos\varphi_H \tag{9}$$

From the equations (7) and (8) the kinematical index *λ* is calculated:

$$\lambda = \frac{\frac{\pi}{2} - \frac{\pi}{z} - \arcsin\frac{R-h}{R}}{\sqrt{1-\left(\frac{R-h}{R}\right)^2}} \tag{10}$$

Relation (10) shows the relation between the milling machine kinematical index and the ratio *h/R*, being well known that the soil crests height *h* measured from the bottom of the bed should not exceed *10%* from the maximum working depth.

The two relations expressing the relation between the kinematical index and the ration *s/R*, respectively *h/R*, could be represented in a chart, as in figure 3.

Following, a MathCAD program for chart data is presented. Microcal Origin program was used to represent the chart based on the results from MathCAD.

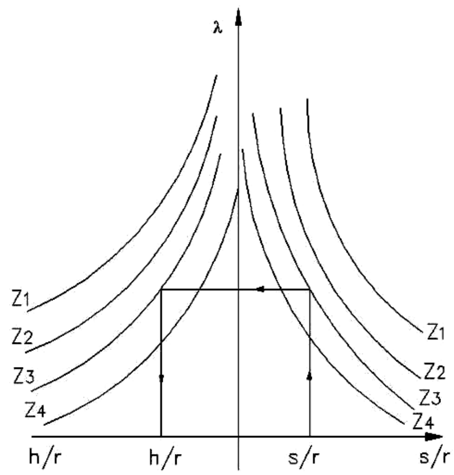

Fig. 3 – Variation of λ *with* h/R *and* s/R

MathCAD program (calculus of the kinematical index λ in relation with h/R)

$$TOL := 1\cdot 10^{-15}$$

$$hr\_m := \begin{pmatrix} -1 & .103 & 0.044 & .024 & .015 & 0.011 \\ .372 & .074 & .032 & .018 & .011 & .008 \\ .313 & .065 & .024 & .016 & .01 & .007 \\ .248 & .054 & .022 & .013 & .008 & .006 \\ .178 & .04 & .018 & .01 & .006 & .004 \end{pmatrix} \qquad z\_m :=$$

$$\lambda0_{i,j} := \lambda\left(hr\_m_{i,j}, z\_m_j\right)$$

$$\lambda1_{i,j} := \lambda\left(hr\_n_{i,j}, z\_m_j\right)$$

$$\lambda2_{i,j} := \lambda\left(hr\_t_{i,j}, z\_m_j\right)$$

$$hr\_n := \begin{pmatrix} -1 & .163 & .067 & .037 & .023 & . \\ -1 & .113 & .048 & .027 & .017 & . \\ .629 & .098 & .042 & .023 & .015 & \\ .421 & .081 & .035 & .019 & .012 & . \\ .275 & .059 & .026 & .014 & .009 & . \end{pmatrix}$$

$$\lambda0 = \begin{pmatrix} 0.76 - 1.814i & 4.589 & 4.585 & 4.615 & 4.646 & 4.544 \\ 5.183 & 5.186 & 5.184 & 5.164 & 5.252 & 5.15 \\ 5.443 & 5.451 & 5.817 & 5.414 & 5.457 & 5.435 \\ 5.858 & 5.864 & 6.027 & 5.891 & 5.98 & 5.789 \\ 6.58 & 6.624 & 6.55 & 6.571 & 6.746 & 6.861 \end{pmatrix}$$

$$hr\_t := \begin{pmatrix} -1 & .273 & .115 & 0.57 & .036 & .025 \\ -1 & .177 & .072 & .04 & .025 & .017 \\ -1 & .122 & .051 & .028 & .018 & .013 \\ .478 & .087 & .037 & .021 & .013 & .009 \\ -1 & .051 & .063 & .035 & .022 & 0.15 \end{pmatrix}$$

$$\lambda1 = \begin{pmatrix} 0.76 - 1.814i & 3.929 & 3.933 & 3.927 & 3.954 & 3.944 \\ 0.76 - 1.814i & 4.441 & 4.437 & 4.412 & 4.428 & 4.394 \\ 4.665 & 4.672 & 4.666 & 4.691 & 4.646 & 4.715 \\ 5.022 & 5.012 & 5.005 & 5.055 & 5.072 & 4.914 \\ 5.664 & 5.662 & 5.631 & 5.715 & 5.697 & 5.789 \end{pmatrix}$$

$$\lambda(hr, z) := \frac{\left(\frac{\pi}{z} - \frac{\pi}{2} - \operatorname{asin}(1 - hr)\right)}{\sqrt{1 - (1 - hr)^2}}$$

$$i := 0..4 \qquad j := 0..5$$

$$\lambda2 = \begin{pmatrix} 0.76 - 1.814i & 3.39 & 3.289 & 2.117 & 3.375 & 3.365 \\ 0.76 - 1.814i & 3.829 & 3.835 & 3.819 & 3.836 & 3.857 \\ 0.76 - 1.814i & 4.324 & 4.339 & 4.352 & 4.333 & 4.262 \\ 4.881 & 4.88 & 4.898 & 4.86 & 4.914 & 4.914 \\ 0.76 - 1.814i & 6 & 4.019 & 4.007 & 4.019 & 2.047 \end{pmatrix}$$

Calculus of the kinematical index λ in relation with *s/R*
(results from the previous section of the program are used to form the matrices below)

$$TOL := 1\cdot 10^{-15}$$

$$sr\_m := \begin{pmatrix} 1.369 & .684 & .456 & .342 & .273 & .228 \\ 1.212 & .606 & .404 & .303 & .242 & .202 \\ 1.154 & .577 & .384 & .288 & .230 & .192 \\ 1.072 & .536 & .357 & .268 & .214 & .178 \\ .95 & .475 & .316 & .237 & .19 & .158 \end{pmatrix} \qquad z\_m := \begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{pmatrix}$$

$$sr\_n := \begin{pmatrix} 1.597 & 0.798 & .532 & .399 & .319 & .266 \\ 1.414 & .707 & .471 & .353 & .282 & .235 \\ 1.346 & .673 & .448 & .336 & .269 & .224 \\ 1.251 & .625 & .417 & .312 & .250 & .208 \\ 1.108 & .554 & .369 & .277 & .221 & .184 \end{pmatrix}$$

$$sr\_t := \begin{pmatrix} 1.854 & .927 & .618 & .463 & .37 & .309 \\ 1.641 & .82 & .547 & .41 & .328 & .273 \\ 1.452 & .726 & .484 & .363 & .29 & .242 \\ 1.287 & .643 & .429 & .321 & .257 & .214 \\ 1.163 & .548 & .382 & .301 & .217 & .154 \end{pmatrix}$$

$$\lambda 0 = \begin{pmatrix} 4.59 & 4.593 & 4.593 & 4.593 & 4.603 & 4.593 \\ 5.184 & 5.184 & 5.184 & 5.184 & 5.193 & 5.184 \\ 5.445 & 5.445 & 5.454 & 5.454 & 5.464 & 5.454 \\ 5.861 & 5.861 & 5.867 & 5.861 & 5.872 & 5.883 \\ 6.614 & 6.614 & 6.628 & 6.628 & 6.614 & 6.628 \end{pmatrix}$$

$$\lambda 1 = \begin{pmatrix} 3.934 & 3.937 & 3.937 & 3.937 & 3.939 & 3.937 \\ 4.444 & 4.444 & 4.447 & 4.45 & 4.456 & 4.456 \\ 4.668 & 4.668 & 4.675 & 4.675 & 4.672 & 4.675 \\ 5.023 & 5.027 & 5.023 & 5.035 & 5.027 & 5.035 \\ 5.671 & 5.671 & 5.676 & 5.671 & 5.686 & 5.691 \end{pmatrix}$$

$$\lambda 2 = \begin{pmatrix} 3.389 & 3.389 & 3.389 & 3.393 & 3.396 & 3.389 \\ 3.829 & 3.831 & 3.829 & 3.831 & 3.831 & 3.836 \\ 4.327 & 4.327 & 4.327 & 4.327 & 4.333 & 4.327 \\ 4.882 & 4.886 & 4.882 & 4.893 & 4.89 & 4.893 \\ 5.403 & 5.733 & 5.483 & 5.219 & 5.791 & 6.8 \end{pmatrix}$$

$$\lambda(sr,z) := 2\cdot\frac{\pi}{z\cdot sr}$$

$$i := 0..4 \qquad j := 0..5$$

$$\lambda 0_{i,j} := \lambda\left(sr\_m_{i,j}, z\_m_j\right)$$

$$\lambda 1_{i,j} := \lambda\left(sr\_n_{i,j}, z\_m_j\right)$$

$$\lambda 2_{i,j} := \lambda\left(sr\_t_{i,j}, z\_m_j\right)$$

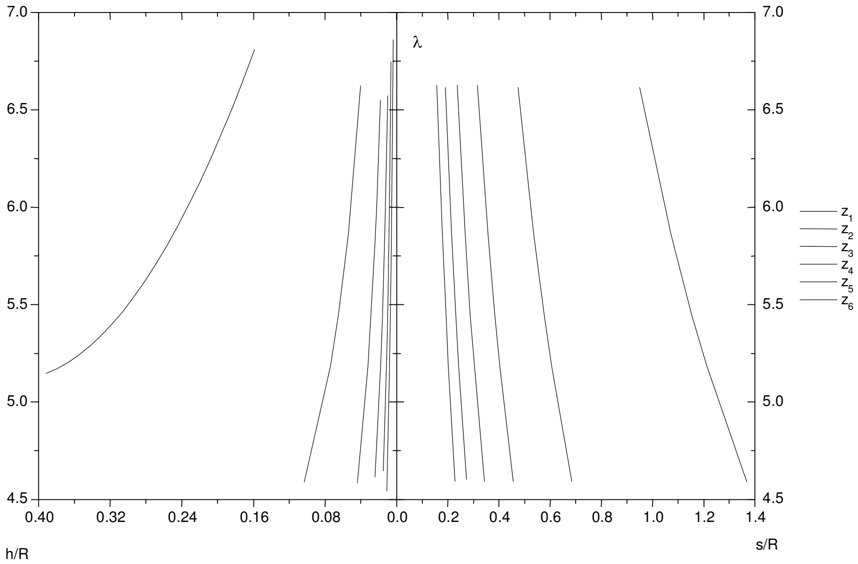

Fig. 4 – Variation of *λ* in relation with *h/R* and *s/R* (machine speed: *v*=4.8 km/h)

CONCLUSIONS

There are two important requirements that should be respected in order to get quality from the working process of the milling machine: soil crushing without its pulverization, and a flat bottom of the bed (the crests' height should be less than 10% reported to the working depth). In this respect, a great influence has the optimum selection of the milling machine functional parameters and the correct dimensioning of its rotor.

The chart presented in this paper puts-out the repetitive work of engineers and makes possible to choose the optimum working regime (*λ*) in correlation with the agro technical demands and the rotor's constructive parameters (*s/R* and *h/R*).

REFERENCES

1. Babiciu, P., et al. 1970. Studiul interdependentei dintre parametrii constructivi si cinematici ai cutitelor frezelor. Revista Studii si Cercetari de Mecanica Agricola, nr.3, vol.4.

3. Paraschiv, G. 2002. Cercetari privind realizarea si verificarea experimentala a unui pachet de programe pentru modelarea, simularea si proiectarea pe calculator a frezelor agricole. Doctoral Thesis. Bucharest.