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OPTIMISING OF LUBRICATION LAYER ON THE TRANSVERSAL STRIP ROUGHNESS

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Solutions of differential equations for smooth surfaces and transversal strip roughness with influence of inertial lubrication forces are analyzed. Ten factors influencing the height of lubricating film at input cross section of metal deformation zone are systemized according to rheological properties of lubricants, kinematics of technological process and geometric characteristics of rolling process. At dressing processes, inertial forces of lubricants have a weak influence on the height of lubrication film at input cross-section of deformation zone. Above the nominal height of lubrication layer the roughness of strip surface also determines the form of lubrication layer in a congruent way, while under the nominal height there is an inversion - concave planes of lubricating layer are transferred into convex ones. A correction of logarithm is presented for the processes of rotary cloning of the solutions of differential equations.

Key words: *Monte-Carlo method, linear regression, Fourier´s development, index of rhythmicity, linear optimization*

Optimiziranje sloja maziva na poprečnu hrapavost trake. Analizirana su riješenja diferencijalnih jednadžbi za glatke površine i poprečnu hrapavost trake sa utjecajem inercijskih sila maziva. Deset faktora koji utječu na visinu mazivoga filma na ulaznom presijeku zone deformacije metala sistematizirani su kroz; reološka svojstva maziva, kinematiku tehnološkoga procesa i geometrijske karakteristike procesa valjanja. Za procese dresiranja inercijske sile maziva imaju slab utjecaj na visinu mazivoga filma na ulaznom presijeku zone deformacije. Iznad nominalne visine sloja maziva hrapavost površine trake određuje formu mazivoga sloja kongruentno dok je ispod nominalne visine inverzija, konkavne plohe mazivoga filma preslikavaju se u konveksne. Za procese rotacijskoga cloniranja riješenja diferencijalnih jednadžbi predstavljena je korekcija algoritma.

Ključne riječi: *metoda Monte-Carlo, linearna regresija, Fourierov razvoj, indeks ritmičnosti, linearno optimiziranje*

INTRODUCTION

In the paper [1] the solutions of differential equations of O. Reynolds for smooth strip and rolls surfaces with an influence of inertial lubrication forces are analyzed.

However, the influence of transversal strip roughness on the lubricating layer on the input cross section of metal deformation zone is left unsolved and upon determining of the index of inertia a correction of the height of lubrication layer in the function of the angle of contact is given.

Notation of Reynolds differential equations for lubrication can be presented in the following form:

$$\frac{\partial p}{\partial x} = \mu \frac{\partial^2 v_x}{\partial y^2}; \quad \frac{\partial p}{\partial y} = 0 \tag{1}$$

$$\frac{\partial p}{\partial z} = \mu \frac{\partial^2 v_z}{\partial y^2}; \quad \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} = 0 \tag{2}$$

where:

μ - dynamic viscosity of lubrication /Pa·s,
x, y, z - coordinates of Descartes system,
p - pressure in lubrication film /Pa,
v_x, v_y, v_z - adequate velocities alongside coordinate axes / (m/s).

Differential equation taking into account the influence of lubricant inertial forces for high strip rolling speeds has the following notation:

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$$\frac{\partial p}{\partial x}=6\mu\frac{v_0+v_R}{\varepsilon^2(x)}+C\mu\frac{1}{\varepsilon^3(x)}+ +x\rho\frac{16(v_0+v_R)^2\varepsilon^2(x)-C^2}{120R\varepsilon^3(x)} \quad (3)$$

$$C=\frac{k}{2}-\sqrt{\frac{k^2}{4}+2(v_0+v_R)\varepsilon_0\left[8(v_0+v_R)\varepsilon_0+3k\right]};$$

$$k=120v\frac{R}{x} \quad (4)$$

where:

$v_0 + v_R$ - moving speed of rolled strip and operating speed of the rolls /(m/s),
R - radius of rolls /m,
$\varepsilon(x)$ - geometric form of lubricating key at input cross-section of metal deformation zone /m,
v - kinematic viscosity /(m^2/s),
ε_0 - height of lubricating film at input cross section of metal deformation zone /m.

Differential equation taking into account strip transversal roughness and longitudinal roughness of rolls assumes the following notation [1]:

$$\left\langle\frac{dp}{dx}\right\rangle=6\mu(v_0+v_R)\left[\left\langle\frac{1}{\varepsilon^2(x_0)}\right\rangle-\frac{\left\langle\frac{1}{\varepsilon_0^2}\right\rangle}{\left\langle\frac{1}{\varepsilon_0^3}\right\rangle}\left\langle\frac{1}{\varepsilon^3(x_0)}\right\rangle\right] \quad (5)$$

where $\langle\ \rangle$ is designation for the operator of mathematic hope.

Random value of strip and rolls roughness at $R_Z = 6\sigma$ according to GOST is

$$\varepsilon(x_0)=\varepsilon_N+\left[\sigma_v(x_0)+\sigma_{tr}(x_0)\right]$$

where:

ε_N - nominal height of lubricant layer when the surfaces of rolls and strip are easily described ($R_Z = 0$).

SOLUTIONS OF DIFFERENTIAL EQUATIONS BY MONTE-CARLO METHOD AND DISCUSSION OF RESULTS

Evaluation of cage rolls rhythmicity

The lubricants viscosity depending on rolling pressure is presented in the form of Baruss formula

$$\mu=\mu_0 e^{\gamma p} \quad (6)$$

where:

μ_0 - dynamic viscosity at atmospheric pressure,
p - rolls pressure on the metal,
γ - piezocoefficient of lubricants viscosity /Pa^{-1}.

If viscosity depends also on t-temperature then is

$$\mu_t=\mu_0 e^{\gamma D}\cdot e^{\frac{-\Theta(t-t_1)}{B-1}} \quad (7)$$

where the coefficients D, B and Θ are defined with rotary viscosymeters.

With disposal of reliable dynamic lubricant viscosities according to (6) and (7), the solutions of differential equations can be presented through technological parameters

$$A=\frac{1-e^{-\gamma p}}{6\mu_0\gamma(v_0+v_R)} \quad (8)$$

The length of lubricating key on a cold-rolled strip according to Figure 1. is determined as:

$$a=R\left[\sqrt{1-\left(\cos\alpha-\frac{\varepsilon_a}{R}+\frac{\varepsilon_a}{R}\right)^2}-\sin\alpha\right] \quad (9)$$

where:

ε_a - lubricant height on the strip.

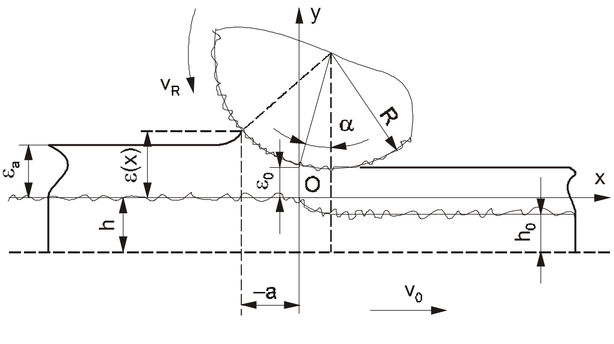

Figure 1. **The scheme of lubricating rolling at transversal strip roughness and longitudinal roll roughness**
Slika 1. **Shema valjanja s mazivima za slučaj poprečne hrapavosti trake i uzdužne hrapavosti valjaka**

The lubricant height in the area of [$-\alpha$; 0] can be approximated by the following polynomial for $R_Z = 0$:

$$\varepsilon(x) \cong \varepsilon_N = \varepsilon_0 - \alpha x + \frac{x^2}{2R} - \alpha \frac{x^3}{2R^2} + \frac{x^4}{8R^3} \tag{10}$$

For the area of cold rolling and even more so for dressing it is enough to approximate $\varepsilon(x)$ by square polynomial.

In the theoretical analysis, cage rolling with 11 roll pairs is assumed inside which technological parameter A decreases linearly from A_0 = 1965512 m^{-1} to A_{10} = 898519 m^{-1} with ΔA = 106700. In this connection is: v_0 = 0,6 v_R m/s, v_R =10 m/s, μ_0 = 0,024 Pa·s, γ = 0,218 E–6 m^2/N, $p\gamma$ = 4,36, ε_a = 0,001 m, R_Z = 6E–6 m, isothermal conditions of technological process t = 20 °C. For the realization of linearity condition according to the technological parameter A there are available five technological values in the equation (8). The guidelines of analysis will move across the singular point in which the discriminate of square expression in (10) equals to zero. Analytical solutions are known for differential equations (1) and (5). Guidelines of the analysis will move through the singular point with the discriminant of square expression in which the discriminant of square expression (10) equals to zero. For the differential equations (1) and (5) analytical solutions are known.

$$\alpha^* = \sqrt[3]{\frac{8}{15RA}} = 1,243\sqrt{\frac{\varepsilon_0^1}{R}}; \quad \varepsilon_0^* = 0,7726\varepsilon_0^1 \tag{11}$$

$$\frac{2048}{\pi^2}A^2\left(\varepsilon_0^1\right)^7 - 16R\left(\varepsilon_0^1\right)^4 -$$

$$-118R\sigma^2\left(\varepsilon_0^1\right)^4 - 182,25118R\sigma^4 = 0$$

$$315AR^3\left(\alpha^*\right)^7 - 168R^2\left(\alpha^*\right)^4 - 1824\sigma^2 = 0$$

$$\varepsilon_0^* = R\frac{\left(\alpha^*\right)^2}{2}; \quad \sigma^2 = \sigma_v^2 + \sigma_{tr}^2 \tag{12}$$

Analytical solutions of differential equation (3) for a singular point cannot be derived therefore they will be sought with Monte-Carlo numerical method.

The Figure 2. shows that the 2nd and 3rd pair of rolls in the cage (the rolls of A_0 are not involved in the analysis of abscissa) are to be corrected because they disturb linear continuity of observed value in angles of contact α = 0,03 rad and α = 0,04 rad according to the solutions of differential equation (5). In the marked area, disturbed harmony of rhytmicity index is characterized by an more intensive decrease of ε_0 in the function of angle of contact α. Such a disharmony depending on angles of contact has a various method of transferring. For the angle α = 0,03 rad it is concave, while for α = 0,04 rad it is convex. On the abscissa of Figure 2., the ordinal number of cage rolls is plotted, however the graphical presentation would not change neither with the plotted ratio of technological parameters. In addition to the graphical method of correcting of disharmonic cage rolls, other criteria and evaluation methods can be developed. The easiest one is regressive evaluation with the regression coefficient.

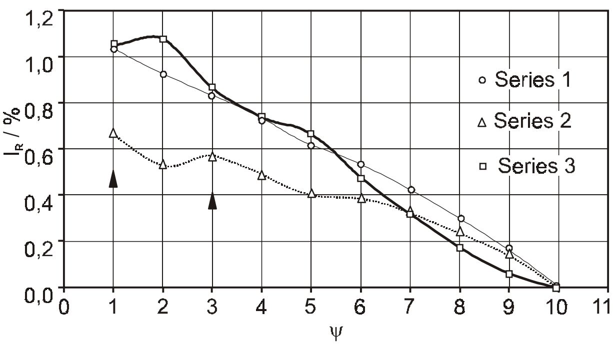

Figure 2. **Deviation of lubricating film height at input cross section of deformation zone in relation to the technological parameter A_{10} = 898519 m^{-1} (10 roll pairs), R = 0,35 m; N - ordinal number of cage rolls. Series 1 - α = 0,02 rad; Series 2 - α = 0,03 rad; Series 3 - α = 0,04 rad. The height of strip lubricant ε_a = 0,0012 m, R_Z = 6E–6 m**

Slika 2. **Odstupanje visine mazivoga filma na ulaznome presjeku zone deformacije u odnosu na tehnološki parametar A_{10} = 898519 m^{-1} (10 para valjaka), R = 0,35 m; N - redni broj valjaka u kavezu. Serija 1 - α = 0,02 rad; serija 2 - α = 0,03 rad; serija 3 - α = 0,04 rad. Visina maziva na traci ε_a = 0,0012 m, R_Z = 6E–6 m**

In the Figure 3. a comparison of the evaluation of cage rhythmicity index for two cases is given. Series-2 presents the cloned cage rolls, and series-2 direct comparison of solutions of differential equation in relation to the 10th cage

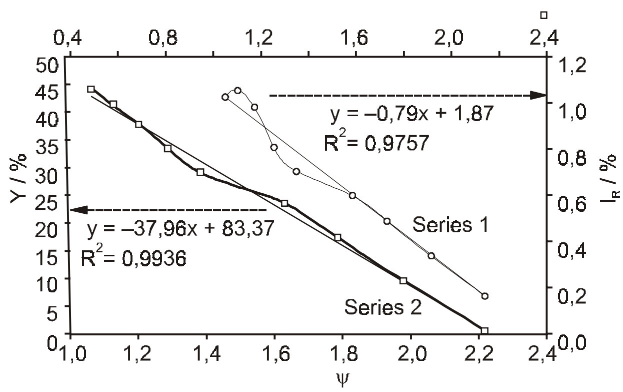

Figure 3. **Putting analysis under differential equation magnifying glass (1). Series 1 - Cloned results (I_R) over singular point (with linear regression) in relation to the roll A_{10}; Series 2 - "Raw results" (Y) with direct comparison of solutions of differential equations (1) for R = 0,2 m, α = 0,03 rad, ε_a = 0,001 m (with linear regression)**

Slika 3. **Dovođenje analize pod povećalo za diferencijalnu jednadžbu (1). Serija 1 - Klonirani rezultati (I_R) preko singularne točke (s linearnom regresijom) u odnosu na valjak A_{10}; serija 2 - "Sirovi rezultati" (Y) s direktnim uspoređivanjem u odnosu na valjak A_{10} rješenja diferencijalne jednadžbe (1) za R = 0,2 m, α = 0,03 rad, ε_a = 0,001 m (s linearnom regresijom)** rolls pair. A careful review of these results indicates the fact that the series-1 more strongly points out those cage rolls which disturb rhythmicity of technological process. So the presentation of the 6 cage rolls picturesquely stands out where series-1 gives larger arguments for its optimization. The third pair of cage rolls could also be optimized. The regressive coefficient in the Figure 3. (R^2) points out a greater disharmony of cage rolls for the cloned results. In this connection the abscissas and ordinates are connected with following relations:

$$X = \frac{A_0}{A_{1-10}} = \Psi; \quad Y = \frac{\varepsilon_0\left(A_{10}\right) - \varepsilon_0\left(A_{1-10}\right)}{\varepsilon_0\left(A_{10}\right)} \% = I_R \qquad (13)$$

Optimization of the process and presentation of tools

The principled scheme is given in the Figure 4. where two methods can be seen.

1. Transfer of the similarity criteria from the calibration A_0 over the guide A_{1-10} in relation to the fixed cage roll A_{10} is performed by hyperbole.
2. Transfer of criteria similarity in the cage is performed by rotary Osnap.

The tools in the Figure 4. are usually connected by the expression (13) in diagram presentations of index rhythmicity I_R /%, which in fact is an ordinate, and the ratio of technological parameters which constitutes the abscissa. For some larger angles of contact linearization by Osnap can be shifted alongside the known values of angles of contact near and near to the aimed angle on which the cloning is performed.

In the Table 1. a review of implementation of Osnap tool for differential equation (1) is shown.

In the examples quoted in the Table 1. you can see that the precision of cloning can be improved by shifting Osnap towards the aimed angle of contact. If the aimed angle is about 0,05 rad there is no need to change Osnap. On the other hand, if the angle of contact is about 0,1 rad, the cloning can be performed in several steps. Upon receiving the results of cloning the first aimed angle about 0,05 rad can be transformed into the front Osnap angle, while the second aimed angle being now in the second stage is 0,1 rad. Furthermore, the precision is also increased if the step of technological parameter is decreased. Here, ΔA = 106700 m^{-1} is large enough. In the Table 2. a selective application of Osnap with a correction on differential equations (1) is provided and especially (3) where one cannot come to any analytical solutions when $\alpha \rightarrow 0$ rad. Correction is performed on rotary cloning by comparing the results with the previous step without rotation on the aimed angle. If the correction is necessary it flows across calibration for $\alpha \rightarrow 0$ rad, because in the next step this rotation value falls out from the algorithm. Ability to be congruent in correction should be achieved for so much digits as the function (10) is developed for. It should be performed in cycles so that the first digit delaying one step behind the congruency is larger than the aimed one and in the next step less.

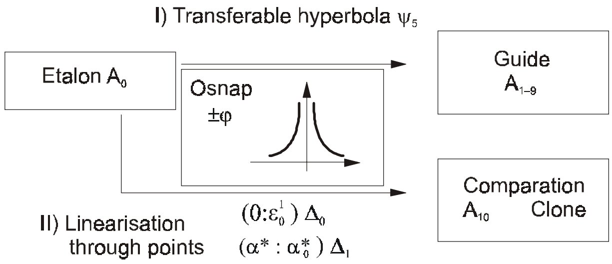

Figure 4. **The tool for defining cage rhythmicity index and cloning**
Slika 4. **Alat za određivanje indeksa ritmičnosti kaveza i kloniranje**

If we, for the conditions of technological process in Table 1., show the ratio φ / φ_0 (tool parameters) for the medium of the class A_6 in the function of index rhythmicity, Figure 5. follows. Very high value of correlation coefficient indicates also to a functional dependency, so the whole analysis which was carried out above the singular point (α^*; ε_0^*) has its justification. The high value of correlation coefficient for the tool of the Figure 4. enables also the estimation of lubricating film when differential equations are difficult to solve in the area of dressing.

Table 1. **A presentation of cloning differential equation (1) in intersection of different angles and shifting of Osnap alongside abscissa; R = 0,2 m, ε_a = 0,0012 m, A_0 = 1 965 512 m^{-1}, R_Z = 0**

Tablica 1. **Prikaz kloniranja diferencijalne jednadžbe (1) u presjeku različitih kuteva i pomicanja Osnapa uzduž apscise; R = 0,2 m, ε_a = 0,0012 m, A_0 = 1 965 512 m^{-1}, R_Z = 0**

Osnap position		Cloned solution (Э)	Method Monte-Carlo (#)
front α	final α	α = 0,052 / rad	α = 0,06 / rad
α = 0,011058 rad	α → 0 rad	ε_0 / m	ε_0 / m
A_2 = 1858812 m^{-1}		5,161 E$^{-6Э}$ / 5,156 E$^{-6\#}$	4,544 E$^{-6Э}$ / 4,538 E$^{-6\#}$
α = 0,05 rad	α = 0,03 rad	α = 0,052 rad	α = 0,06 rad
A_2 = 1858812 m^{-1}		5,153 E$^{-6Э}$ / 5,156 E$^{-6\#}$	4,534 E$^{-6Э}$ / 4,538 E$^{-6\#}$
α = 0,05 rad	α = 0,03 rad	α = 0,06 rad	α = 0,07 rad
A_{10} = 898519 m^{-1}		8,586 E$^{-6Э}$ / 8,597 E$^{-6\#}$	7,500 E$^{-5Э}$ / 7,511 E$^{-6\#}$
α = 0,011058 rad	α → 0 rad	α = 0,06 rad	α = 0,07 rad
A_{10} = 898519 m^{-1}		8,882 E^{6Э} / 8,597 E$^{6\#}$	7,537 E^{5Э} / 7,511 E$^{6\#}$
α = 0,011058 rad	α → 0 rad	α = 0,03 rad	α = 0,05 rad
A_2 = 1858812 m^{-1}		8,014 E^{6Э} / 8,013 E$^{6\#}$	5,340 E^{5Э} / 5,336 E$^{6\#}$

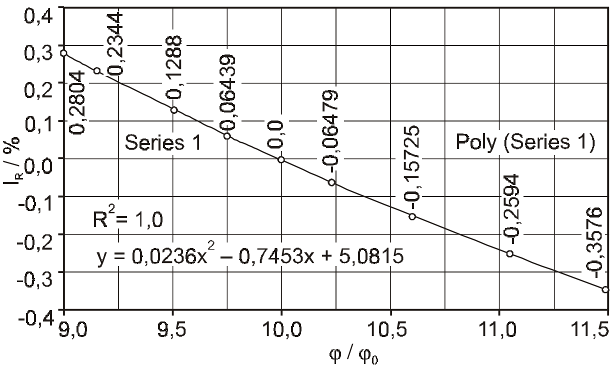

Figure 5. **Index connection of cage rolls rythmicity according to ratio of transferable functions in Figure 4. and the values calculated according to the examples in Table 1. in relation to the mean class of technological parameter A_6**

Slika 5. **Veza indeksa ritmičnosti valjaka u kavezu prema omjeru prenosnih funkcije slike 4. i vrijednostima računatim po primjeru tablici 1. u odnosu na sredinu razreda tehnološkog parametra A_6**

Optimizing of the process can be performed in three already described methods [2]:

- inside constant value of technological parameter,
- through the change of deformation zone geometric characteristic,
- through the change of rheologic characteristics of lubricants and kinematics of technological process.

Table 2. **Correction of rotary cloning**

Tablica 2. **Korekcija rotacijskoga kloniranja**

A / m^{-1}	Differential equation (1)	Differential equation (3)	Note
A_2			
A_3	4,822 E^{-6} / 4,837 E^{-6}	8,564 E^{-6} / 8,561 E^{-6}	ε_a = 0,001 m diff. equ. (3)
A_4	5,144 E^{-6} / 5,166 E^{-6*}	9,101 E^{-6} / 9,092 E^{-6}	R = 0,2 m
A_5	5,512 E^{-6} / 5,529 E^{-6}	9,711 E^{-6} / 9,693 E^{-6}	ε_a = 0,001 m
A_6	5,937 E^{-6} / 5,954 E^{-6}	1,041 E^{-5} / 1,038 E^{-5}	α = 0,06 rad diff. equ. (1)
A_7	6,433 E^{-6} / 6,455 E^{-6}	1,123 E^{-5} / 1,118 E^{-5}	
A_8	7,021 E^{-6} / 7,052 E^{-6*}	1,218 E^{-5} / 1,211 E^{-5}	
A_9	7,729 E^{-6} / 7,762 E^{-6*}	1,133 E^{-5} / 1,321 E^{-5}	
A_{10}	8,597 E^{-6} / 8,610 E^{-6}	1,472 E^{-5} / 1,455 E^{-5}	
Numerator is Monte-Carlo method, denominator is Clone, * is correction			

When the calculations of optimization are connected with the roughness of the surfaces through the differential equation (5) the main criterion of optimization is connected with the height of lubricating film ε_0 by means of which the kind of friction in the deformation zone is determined. At high technological velocities, approaching 100 m/s, it is necessary to make a correction of lubricating film per a differential equation (3).

The influence of strip surface roughness on the shape lubricating film at boundary lubrication

Surface roughness and its influence on the height of lubricating film is defined by differential equation (5). The same characteristics of technological parameters A_0, already set at the beginning of the this work, are used in order to add: R = 0,35 m, α = 0,02 rad, while the transversal strip roughness is R_Z = 12 E–6 m, and the roughness of rolls is described by smoothness. The results obtained by the Monte-Carlo method are presented in the Figure 6. The starting height of lubricating film for R_Z =0 equals ε_0 = 10,102 E–6 m which is a nominal height. The roughness of the surfaces is presented by the following function development

$$f(x)=\begin{cases}-1, & -\pi<x<0\\ 1, & 0<x<\pi\end{cases} \tag{14}$$

including the third member the Fourier's development reads

$$f(x)=\frac{4}{\pi}\left(\sin x+\frac{1}{3}\sin 3x+\frac{1}{5}\sin 5x\right)R_Z \tag{15}$$

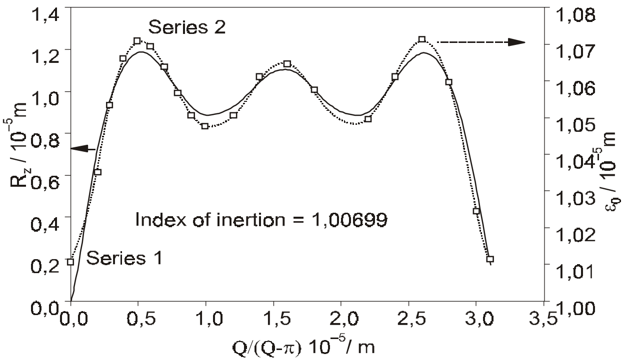

Figure 6. **Presentation of congruency of lubricant film and surface roughness at boundary lubrication. Series 1 - height of lubricant film on the second ordinate /m; Series 2 - roughness of surfaces on the primary ordinate /m**

Slika 6. **Prikaz kongruentnosti visine mazivoga filma i hrapavosti površina kod graničnoga podmazivanja. Serija 1 - visina mazivoga filma na sekundarnoj ordinati /m; serija 2 - hrapavost površina na primarnoj ordinati /m**

It was possible to choose a more natural function for the roughness of surfaces, for example $f(x)=|x|$ in the area $-\pi < x < \pi$, but in that case there would be no attractive congruences.

Figure 7. illustrates it best - the height of roughness slowly declines in relation to the height of lubricating film. The bearing profile of roughness from (0 - π) is devided into 32 classes for an easier application of numeric method Monte-Carlo to differential equation (5). Inertia index, calcu-

lated according to differential equation (3) for the condition in Figure 6. is small and accounts 1,00699. It is explained by the fact that angle of contact is small; α = 0,02 rad, and operating speeds v_0 =6 m/s, v_R = 10 m/s are also small.

Fundamental conclusion based on the Figure 6. could be contracted into one sentence. The roughness of surfaces effects the height of lubricating film and its profile for the cases of lubricating boundary which is an often appearance in metal plastic processing. Figure 7. demonstrates a 3-D presentation of the influence of strip transversal rough-

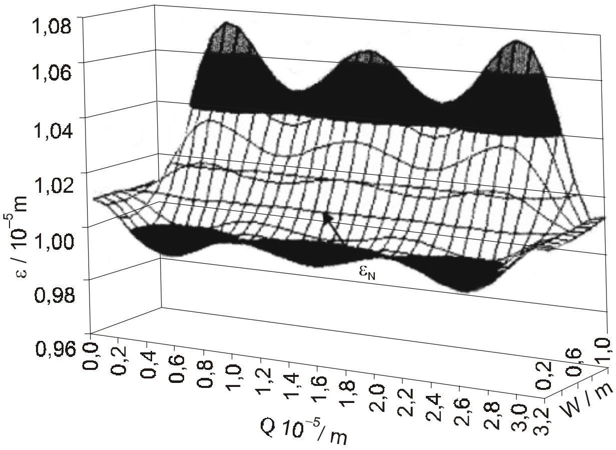

Figure 7. **3-D Presentation of the influence of transversal strip roughness on the height of lubricant film. *Q* - supporting profile of roughness /m, (0,0 - 3,2) × E–6 separated in 32 classes; *W* - roughness /m, R_Z = (0,2 - 1,0) × 12 E–6, separated in 9 classes; ε_0 - height of lubricating film /m, (9,6 - 10,2) × E–6. Ranges of boundary lubrication (10,1 - 10,2) × E–6 /m**

Slika 7. **3-D prikaz utjecaja poprečne hrapavosti trake na visinu mazivoga filma. *Q* - noseći profil hrapavosti /m, (0,0 - 3,2) × E–6, podijeljen u 32 razreda; *W* - hrapavost /m; R_Z = (0,2 - 1,0) × 12 E–6, podijeljena u 9 razreda; ε_0 - visina mazivoga filma /m, (9,6 - 10,2) × E–6. Područje graničnog podmazivanja (10,1 - 10,2) × E–6 /m**

ness on the height of lubricating film. Intensity of roughness, divided into 9 classes, is simulated through the parameter W. A bearing profile of roughness *Q* is divided into 32 classes. The strip surface roughness is supposed to be rather big - R_Z = 12 E–6 m in order to have a more pictorial influence. ε_N designates nominal height of lubricant layer being ε_N = 10,1 E–6 m. Above the nominal height of lubricant layer graphical presentation gives the results from the Figure 6. Under the nominal height it comes to an inversion of graphical presentation because the concave planes transfer into convex planes.

The cause of it is the transfer of stabile hydrodynamic lubrication into a mixed lubrication of insufficient moistened surfaces. Boundary lubricating takes place in ε_N - environment.

CONCLUSION

In an operating calibration for the investigation of strip surface roughness and lubricants inertial forces it has been estimated as follows:

1. Inertial forces of lubricants for small angles of contact and even more so for the processes of dressing at low rolling speeds can be neglected. If the operating speeds are above 50 m/s, calculations according to differential equations (3) should be performed and solutions compared with differential equation (1) and then inertial index estimated.
2. The index of cage rhythmicity calculated by means of the cloning method gives a good insight into hydrodynamic stability of the cage indicating the rolls that should be optimized. Optimizing can be realized through rheological (μ, v, γ, ρ), kinematical (v_R, v_0), constructive (R_Z, R, α, ε_a) features of technological process, as well as rolling pressure p and temperature t.
3. Cloning processes of the solutions of differential equations are carried out by the Osnap tool as much as up to α = 0,05 rad. Osnap is located in singular point and angle of contact $\alpha \to 0$ rad. At higher angles of contact of cold rolling location of Osnap can approach the aimed angle, or the cloning method can be performed stepwise in several interventions alongside α. The correction for rotary cloning is also represented and it achieves good results with numerical method Monte-Carlo.
4. The observed analysis of strip transversal roughness enables a conclusion that the bearing strip roughness profile determines the profile of lubricating film for stable hydrodynamic lubricating. As the strip roughness decreases under the nominal height of lubricating film according to the differential equation (1) the profile of lubricating film behaves inversely.

REFERENCES

[1] D. Ćurčija, I.Mamuzić, Metalugija 44 (2005) 2,113 - 117.
[2] G. L. Kolmogorov, A. E. Kovalev, Izv. V.U.Z.Chernaya Metall (2003) 1, 40 - 42.
[3] S. A. Kuznetsov, S. Y. Semenov, A. I. Vinogradov, A. E. Graber, Proizvod. Prokata, (1999) 7, 26 - 28.