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CALCULATION PROGRAM FOR THE DETERMINATION OF FORCE PARAMETERS IN ROLLING

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Abstract

The article presents a modern approach of the rolling force parameters calculation mode. A numerical C++ simulation of the studied phenomena was performed on this purpose, which made possible an automatic calculation of the concerned parameters by designing an easy to use graphic interface. Also, the program is able to map graphics automatically, illustrating the rolling force parameters variations in different situations.

Keywords

rolling force parameters, numerical simulation, graphic interface

Introduction

For the achievement of the rolling process parameters with an electronic calculation technique, their mathematical description has to be precisely formulated. This can be obtained by the elaboration of proper algorithms.

Most of the times, the algorithm is written under a graphic form of a block-scheme, or under a textual form, in words.

By textual expression of the algorithms are used the mathematical consacrated symbols and expressions that are attended by explanatory text. But, such a writing is hard to understand and too complicated. Therefore, the algorithm's representation under a block-scheme form is usually used.

The essence of the algorithm elaboration consists of choosing and establishing of such specific usage order of the mathematical expressions, that would mandatory lead to the problem solution through any combinations of the initial data.

The algorithm's composition for the general case includes a few steps. Primarily a simple scheme is established, that reflects only the basics of the problem solution and blocks that represent underprogram blocks. Secondly the type of the calculation process is determined in each block and for the whole problem. Finally a detailed scheme of the algorithm is elaborated, which should characterize the hole process calculation without any simplifications.

The calculation algorithm for the parameters of the stabilized rolling process without using the iteration procedure

Initial dates:
R – working cylinders' ray, mm;
h_0 , h_1 – band thickness at the entry and exit from the plastic range, mm;
Δh – absolute reduction, mm;
f – rolling friction coefficient;
ε, ε_{in}, ε_{Σ} - relative, initial and summary reduction;
q_0, q_1 – posterior and anterior unitary bar stretching, N/ mm^2 ;
$\sigma_{c.in}$ – band material yield point in soaked status or after hot-rolling, N/ mm^2 ;
$\sigma_{c0\varepsilon}$, $\sigma_{c1\varepsilon}$, $\sigma_{c.m\varepsilon}$ - band material yield point before and after rolling and their medium value in the plastic range, calculated considering the cold-hardening, N/mm^2;
ξ_0, ξ_1, ξ_m – coefficients that adequately characterise the influence of the posterior, anterior unitary bar stretching and their median value;
m, k – empiric coefficients that characterise the band material hardening intensity;
E_c, E_b – elasticity module of the band and cylinders' material, N/mm^2;
ν_c, ν_b – Poisson's coefficients of the band and cylinders' material;
p_0, p_1 – normal stress ordinates at the elasto-plastic border contact of the material with the cylinders, N/mm^2;
$p_{m.c}$ – normal median contact stress (median pressure), calculated considering the elastic deformation of the band and cylinders, N/mm^2;
I_c, x_1 – arc of contact length and its growth by the plan passing through the cylinders' rotation centers, calculated considering the elastic deformation of the band and cylinders, mm^2;
x_{0b}, x_{1b} – length of contact between the band and cylinders, created because of the band's elastic compression and recovery, mm;
α_c, γ_c – angle of contact between the band and the cylinders and the neutral angle, calculated considering the elastic deformation of the band and cylinders, rad;
F_c – rolling force, calculated considering the stretching and elastic deformation of the band and cylinders, N;
S_a, ψ_c – feed and the coefficient that characterises the position of the resultant application point, calculated considering the elastic deformation of the band and cylinders;
Δ_{0b}, Δ_{1b} – absolute values of the band's compression and recovery elastic defformation, N/mm^2;
M_c – rolling moment, calculated considering the stretching and elastic deformation of the band and cylinders, Nmm;
η- coefficient characterising the position of the normal contact stress' diagram maximum reffered to the band's entry section between the cylinders;
$[\sigma_k]$- permissible contact stress at the working cylinders' contact resistance, N/mm^2.

$$h_1 = h_0 \cdot (1-\varepsilon) \tag{1}$$

$$\Delta h = h_0 \cdot \varepsilon \tag{2}$$

$$\varepsilon_\Sigma = 1-(1-\varepsilon_{in.})(1-\varepsilon) \tag{3}$$

$$\sigma_{c.0\varepsilon} = \sigma_{c.in.} + m(100 \cdot \varepsilon_{in.})^k \tag{4}$$

$$\sigma_{c.1\varepsilon} = \sigma_{c.in.} + m(100 \cdot \varepsilon_{\Sigma.})^k \tag{5}$$

$$\sigma_{c.m.\varepsilon} = \sigma_{c.in.} + \frac{m}{6} \cdot 100^k \left[\varepsilon_{in}^k + \varepsilon_\Sigma^k + 4(0{,}75 \cdot \varepsilon + \varepsilon_{in.} - 0{,}75 \cdot \varepsilon \cdot \varepsilon_{in})^k\right] \tag{6}$$

$$h_m = \frac{1}{2}(h_0 + h_1) \tag{7}$$

$$\xi_{0\varepsilon} = 1 - \frac{q_0}{1{,}15 \cdot \sigma_{co\varepsilon}} \tag{8}$$

$$\xi_{1\varepsilon} = 1 - \frac{q_1}{1{,}15 \cdot \sigma_{c1\varepsilon}} \tag{9}$$

$$\xi_{m.\varepsilon} = \xi_{0\varepsilon}\left(1{,}05 + 0{,}10\frac{\xi_{1\varepsilon}}{\xi_{0\varepsilon}} - 0{,}15\frac{\xi_{0\varepsilon}}{\xi_{1\varepsilon}}\right) \tag{10}$$

$$\Delta_{1b} = \frac{1{,}15 \cdot \sigma_{c.1\varepsilon}}{E_b}\xi_{1\varepsilon} \cdot h_1 \tag{11}$$

$$p_{0\varepsilon} = \frac{1{,}15 \cdot \sigma_{c.0\varepsilon}}{1-\nu_b^2}\xi_{0\varepsilon} \tag{12}$$

$$p_{1\varepsilon} = \frac{1{,}15 \cdot \sigma_{c.1\varepsilon}}{1-\nu_b^2}\xi_{1\varepsilon} \tag{13}$$

$$\frac{x_{1b}}{l_c} = \frac{1}{1+\sqrt{1+\frac{\varepsilon}{1-\varepsilon} \cdot \frac{E_b}{1{,}15 \cdot \sigma_{c.1\varepsilon} \cdot \xi_{1\varepsilon}}}} \tag{14}$$

$$\frac{x_{0b}}{l_c} = \left(1-\frac{x_{1b}}{l_c}\right)\left[1-\sqrt{1-\frac{1{,}15 \cdot \sigma_{c.0\varepsilon} \cdot \xi_{0\varepsilon}}{\varepsilon \cdot E_b + 1{,}15 \cdot \sigma_{c.1\varepsilon} \cdot \xi_{1\varepsilon}(1-\varepsilon)}}\right] \tag{15}$$

$$A = 6 \cdot \frac{1-\nu_c^2}{\pi \cdot E_c} \cdot R\left(1-\frac{x_{1b}}{l_c}\right)\left[4 \cdot \frac{x_{1b}}{l_c}\left(1-\frac{x_{1b}}{l_c}\right)+1\right] \tag{16}$$

$$B = \frac{A\left[\frac{1{,}15}{2(1-\nu_b^2)}\left(\xi_{0\varepsilon} \cdot \sigma_{c.0\varepsilon} \cdot \frac{x_{0b}}{l_c} + \xi_{1\varepsilon} \cdot \sigma_{c.1\varepsilon} \cdot \frac{x_{1b}}{l_c}\right) + \frac{1{,}15 \cdot \sigma_{c.m\varepsilon} \cdot \xi_{m.\varepsilon}}{1-\nu_b^2}\left(1-\frac{x_{0b}}{l_c}-\frac{x_{1b}}{l_c}\right)\right]}{1-2\frac{x_{1b}}{l_c} - \frac{1{,}15 \cdot \sigma_{c.m\varepsilon}}{1-\nu_b^2} \cdot \xi_{m.\varepsilon} \cdot \frac{f \cdot A}{h_m}\left(1-\frac{x_{0b}}{l_c}-\frac{x_{1b}}{l_c}\right)^2} \tag{17}$$

$$C = \frac{R \cdot \Delta h}{1 - 2\frac{x_{1b}}{l_c} - \frac{1{,}15 \cdot \sigma_{c.m\varepsilon}}{1-\nu_b^2} \cdot \xi_{m.\varepsilon} \cdot \frac{f \cdot A}{h_m}\left(1 - \frac{x_{0b}}{l_c} - \frac{x_{1b}}{l_c}\right)^2} \tag{18}$$

$$l_c = B + \sqrt{C + B^2} \tag{19}$$

$$p_{m.c} = \frac{1{,}15}{2\left(1-\nu_b^2\right)}\left(\sigma_{c.0\varepsilon} \cdot \xi_{0\varepsilon} \cdot \frac{x_{0b}}{l_c} + \sigma_{c.1\varepsilon} \cdot \xi_{1\varepsilon} \cdot \frac{x_{1b}}{l_c}\right) + \frac{1{,}15 \cdot \sigma_{c.m\varepsilon}}{1-\nu_b^2}\xi_{m\varepsilon} \cdot \left[1 + \frac{f \cdot l_c}{2 \cdot h_m}\left(1 - \frac{x_{0b}}{l_c} - \frac{x_{1b}}{l_c}\right)\right] \cdot \left(1 - \frac{x_{0b}}{l_c} - \frac{x_{1b}}{l_c}\right) \tag{20}$$

$$\alpha_c = \frac{l_c}{R} \tag{21}$$

$$p_k = 0{,}59\sqrt{\frac{p_{m.c} \cdot l_c \cdot E_c}{R}} \tag{22}$$

$$\alpha_c \le 2f \tag{23}$$

$$p_k \le \left[\sigma_k\right] \tag{24}$$

$$F_c^* = p_{m.c} \cdot l_c \tag{25}$$

$$\frac{x_1}{l_c} = \frac{1}{2}\left(1 - \frac{R \cdot \Delta h}{l_c^2}\right) \tag{26}$$

$$\frac{\gamma_c}{l_c} = \frac{1}{2}\left[1 - \frac{\left(\Delta h + \Delta_{1b}\right)\left(2 - 3\frac{x_{1b}}{l_c}\right)}{4 \cdot f \cdot l_c\left(1 - \frac{x_{1b}}{l_c}\right)^2}\right] + \frac{q_1 \cdot h_1 - q_0 \cdot h_0}{4 \cdot f \cdot p_{m.c} \cdot l_c} - \frac{x_1}{l_c} \tag{27}$$

$$\eta = 1 - \frac{\gamma_c}{\alpha_c} - \frac{x_1}{l_c} \tag{28}$$

$$S_a = \frac{\left(\frac{\gamma_c}{\alpha_c} + \frac{x_1}{l_c} - \frac{x_{1b}}{l_c}\right)^2}{\left(1 - \frac{x_{1b}}{l_c}\right)^2} \cdot \frac{\left(\Delta h + \Delta_{1b}\right)}{h_1} - \frac{\Delta_{1b}}{h_1} \tag{29}$$

$$\psi_c = \frac{1}{6}\left[\frac{p_{0.\varepsilon}}{p_{m.c}}\left(1 - \frac{\gamma_c}{\alpha_c} - \frac{x_1}{l_c}\right)\left(1 - \frac{x_{1b}}{l_c}\right) - \frac{p_{1.\varepsilon}}{p_{m.c}}\left(\frac{\gamma_c}{\alpha_c} + \frac{x_1}{l_c}\right)\left(1 - \frac{x_{0b}}{l_c}\right)\right] + 2\left(1 + \frac{\gamma_c}{\alpha_c} + \frac{x_{1b}}{l_c} - 2 \cdot \frac{x_1}{l_c} - \frac{x_{0b}}{l_c}\right) \tag{30}$$

$$M_c^* = 2 \cdot F_c \cdot \psi_c \cdot l_c + R\left(q_0 \cdot h_0 - q_1 \cdot h_1\right) \tag{31}$$

If conditions 23 and 24 are accomplished, it can be continued with condition 25, if not then STOP.
∗As a remark, F_c and M_c represent the values of the force and moment per length unit of the arc of contact. To obtain information about the total value of these parameters we need to multiply the right-sided part of the relations 25 and 31 by ”b” (the rolled band thickness).

Calculation program and results

The calculation program is performed in C++ programming and runs in Win 32 software (Windows 95, 98, Me, NT4, 2000, XP-Intel processor). As a graphical interface the programe uses the MFC (Microsoft Foundation Classes). Fig. 1 shows the dialog window that opens at startup, and fig. 2 the one for program data input.

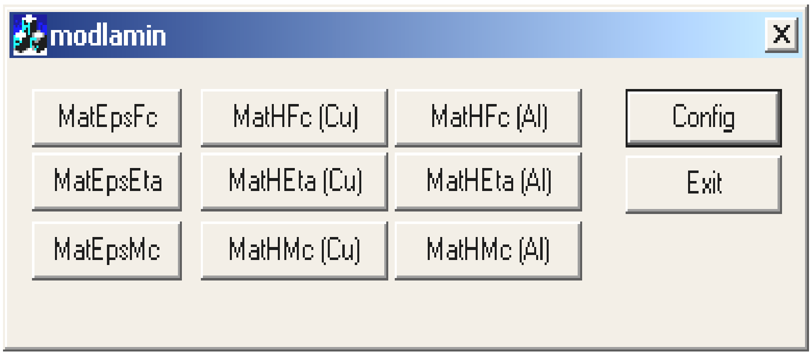

Fig. 1. Main program window

The program was created for the calculation of the force parameters in the aluminum and copper rolling. It also makes possible the plotting of curve sets corresponding to different entry thickness of the band (h_0).

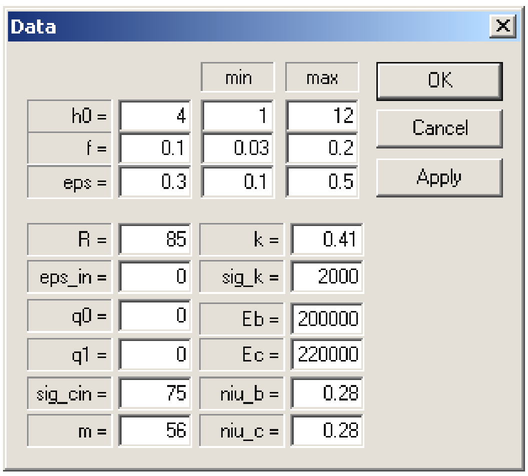

Fig. 2. Data input window

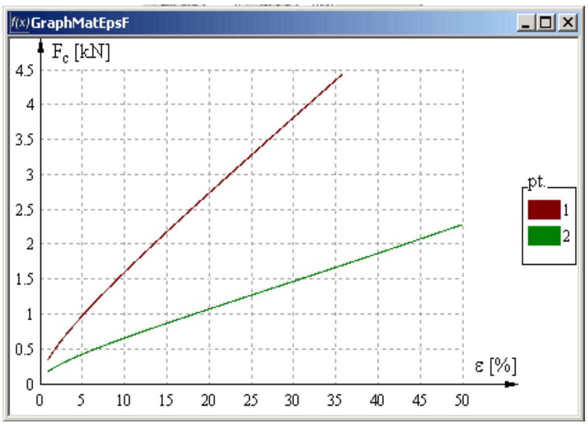

Fig. 3. Rolling force in relation to relative reduction, when rolling Cu (1) and Al (2)

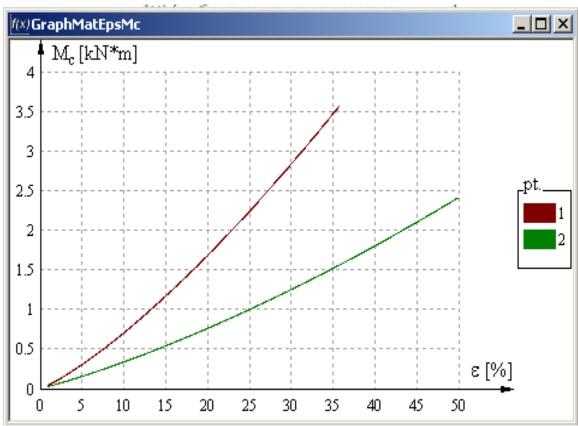

Fig. 4. Rolling moment in relation to relative reduction, when rolling Cu (1) and Al (2)

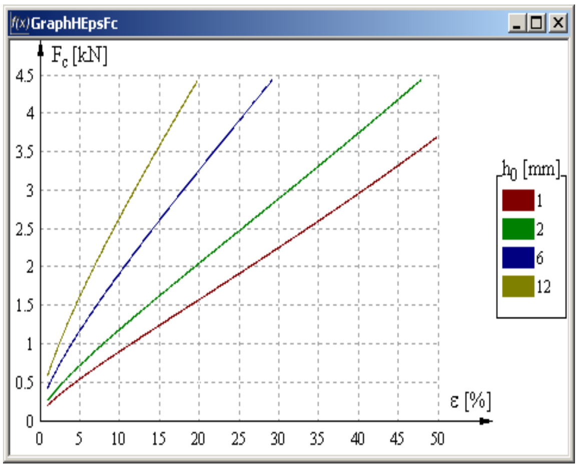

Fig. 5. Rolling force in relation to relative reduction, when rolling Cu, for different entry thickness values of the band

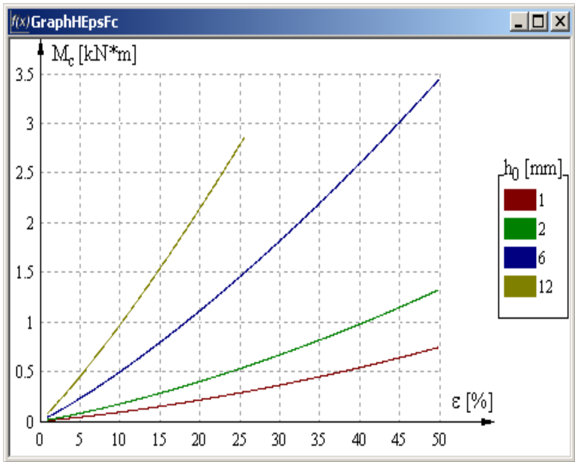

Fig. 6. Rolling moment in relation to relative reduction, when rolling Al, for different entry thickness values of the band

Conclusion

The accomplishment of the automatic calculus for the values of the rolling force parameters presents a series of conveniences related mainly to the facility of real-time visualization of the changes occurring in the pattern of the specific curves with the changes of the input parameter values.

References

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