THE EXPERIENCE OF USING AUTOMATICAL COMPUTER-ASSISTANT ENGINEERING IN DEVELOPING THE WORKING PATTERNS OF PICKLING LINE TANDEM COLD MILL

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Abstract

The developing of working patterns of rolling is very important to create and update a technology of producing steel strips. In addition, it used in estimation a possibility of equipment for producing new gages of steel strip.

We used the invariable method to designing the pattern of rolling, which based in automatical computer-assistant engineering. With help this method we have calculated rational total strain amount and rolling speed with maximum productivity for different kinds of steel grades on PLTCM 2000 (picking line tandem cold mill).

For examples, to produce on PLTCM 2000 low carbon and ultralow carbon steels (DC01-DC04, HC180Y and analogue) with total strain amount about 85 % rational rolling speed calculated about 16.5-17 m·s^{-1}. According to equipment's specification PLTCM, maximum rolling speed not more than 25 m·s^{-1}. The limitation was a picking speed.

To produce HSLA steels (HC260LA, HC300LA, HC340LA and analogue) with total strain amount about 80 % rational cold rolling speed calculated about 16-18.5 m·s^{-1}. According to accounts Cold Roll, during the cold rolling on PLTCM 2000 these grades with total strain amount 75-85 % the limitation was a high-temperature stability of rolling emulsion. To produce HSLA steels with total strain less 75 % the limitation was a picking speed.

To produce HSLA steels (HC420LA, HX420LAD and analogue) rational total strain amount was about 67 - 70 %, cold rolling speed - 13 - 15 m·s^{-1}. To produced high strength steels (HTC980X, HTD1200M and analogue) rational strain amount was about 58 - 63 %, cold rolling speed - 7.5 - 10 m·s^{-1}. In last two examples, limitations were a pickling speed.

Keywords: Invariable method to designing the pattern of rolling, automatical computer-assistant engineering, cold roll, pickling line tandem cold rolling mill, working patter of cold roll

1. INTRODUCTION

The development of the rolling pattern is of high importance at the invention and improvement of technologies as well as estimation of facility performance for the output of new types of flat products. The process units performing simultaneously rolling and other metal treatment processes represent the major challenge for developers. One of such units is the facility combining the continuous turbulent chlorohydric acid pickling unit (PL) and 2000 continuous five-stand tandem cold-rolling mill (TCM 2000). The combined unit (PLTCM 2000) is intended for manufacture of 0.28 - 3.0 mm thick and 850 - 1850 mm wide cold-rolled bands of different grade steels and of different types (LC, HSLA, IF-HSS, BH, DP, CP, TRIP) in coils weighting up to 35 t. Starting stocks for their manufacture are 1.2 - 6.0 mm thick hot-rolled bands. Band speed in the pickling bathes can amount 4.7 m·s^{-1}, maximum rolling speed is 25 m·s^{-1}.

The combination of TCM and PL requires solving a number of tasks related to the matching the operating modes of pickling line and continuous mill. Among them is the mode selection of pickling semi-finished hot-rolled stock and rolling providing execution of unit's operational program with prevention of cold-rolled bands faults [1]. With maximum cost-cast the mentioned tasks can be solved by combination of analysis of actual operating modes of the combined unit with application of automated design engineering to find solutions of their necessary improvement.

1.1. Invariable method to designing the pattern of rolling

In terms of algorithmization, the task of designing a rolling mode may be considered invariably in relation to the type of the rolled section. The peculiarities of rolling sections of particular type are represented in numerical schemes and in variety of limitations used. On the basis of the above concept, the invariant (generalized) algorithm (**Fig.1**) and software structure of automated design engineering of rolling pattern have been developed [2]. Thus represented data system can be used to develop modes of rolling any sections at any rolling mill. The peculiarities of rolling sections of different type and applied equipment (machining system) are taken into consideration in the special mathematical support which can be used not only for implementation of procedures 9 and 10, but also for description of the initial approximation of the rolling modes generated at the beginning of designing by sequential execution of procedures 4 - 8 (**Fig. 1**).

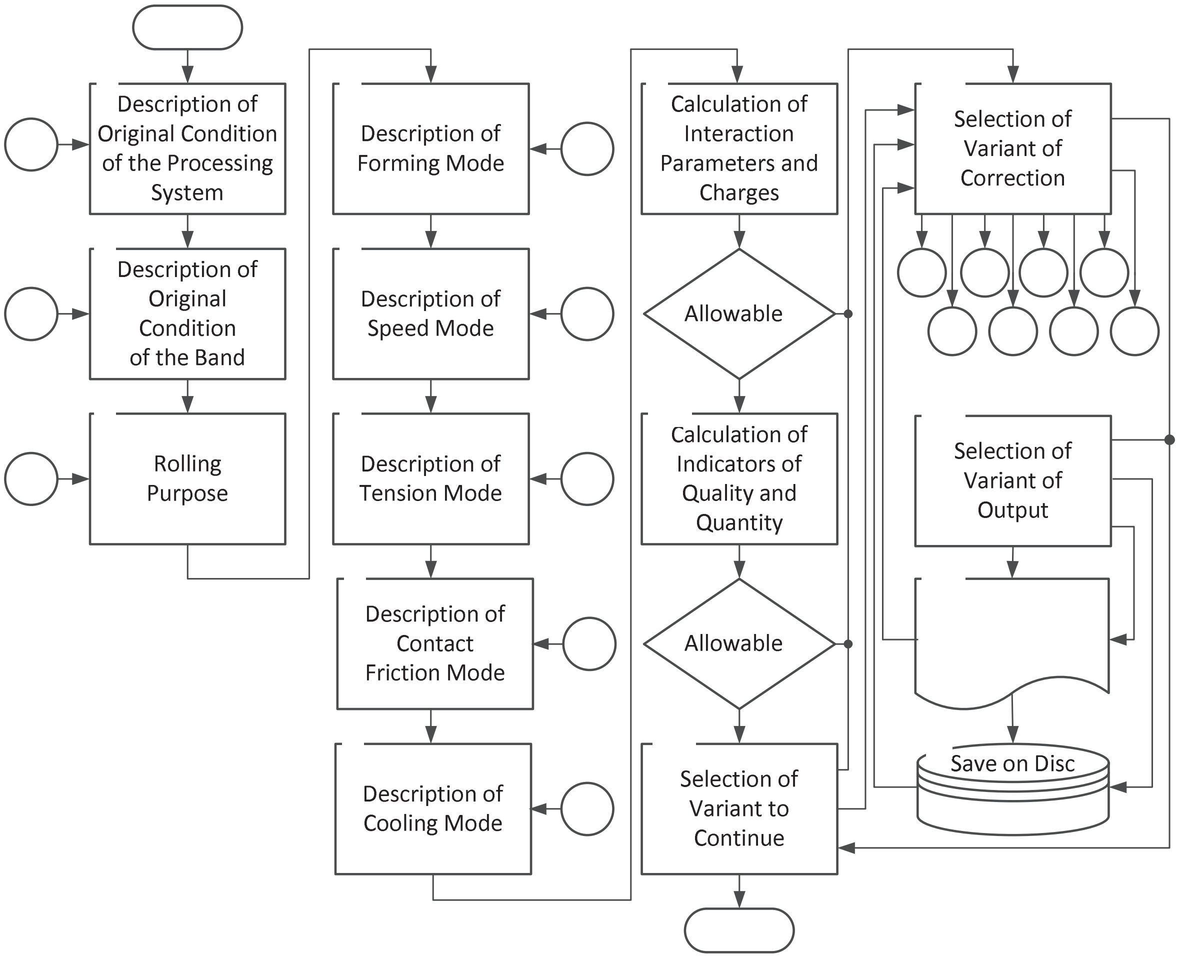

Fig. 1 Generalized Algorithm of the Automated Designing Rolling Modes [2]

On the basis of generalized algorithm the software for automated designing cold-rolling modes, CR CAD [3], has been developed.

1.2. Some features of the model of the process of cold rolling

For the development of rolling modes of steels which deformation peculiarities have not been established yet, the forecast models of yield point of steels with random chemical composition are provided in the software. The yield point of semi-finished hot-rolled stock is calculated in function of chemical composition of steel as well as temperatures at the end of rolling (t_{ert}) and reeling (t_{ct}). Relevant equations for the forecast of yield point achieved with regression analyses of rolling 1640 bands:

$$\sigma_H = 338.1 - 460.5C^* - 4.88\frac{1-Al}{C^*} + 0.182t_{ert} - 0.149t_{ct}; \quad (1)$$

$$\sigma_H = 619.2 + 291.3C^* + 1.495\frac{1-LA^*}{C^*} - 0.323t_{ert} - 0.124t_{ct}; \quad (2)$$

$$\sigma_H = 93.38 + 967.58C^* + 43.34\frac{1-Al}{C^*} - 14.35\frac{1-LA^*}{C^*} - 0.151t_{ert} - 0.017t_{ct}; \quad (3)$$

$$\sigma_H = 658 + 343.3C^* - 254.04\frac{(1-Al)}{C^*} + 216.27\frac{(1-LA^*)}{C^*} + 0.591t_{ert} - 0.99t_{ct}. \quad (4)$$

In (1) - (4) equations $C^* = C + Mn/6 + Si/3$ is carbon equivalent value, %; $LA^* = Ti + Mo + V + Nb$ is total amount of micro-alloying elements, %. Specifications of their applications are represented in **Table 1**.

Comparison of results of approximation of curves of hardening different steel grades with the application of known dependences [4-6] shows that mechanical hardening can be represented best by the power-law relation

Table 1 Specifications of Applications the Equations (1)-(4)

Equation	C^*, %	$\frac{1-LA^*}{C^*}$, %	t_{ert}, °C	t_{ct}, °C
1	0.05-0.12	8.3-18.1	860-890	500-670
2	0.13-0.6	1.5-7.5	830-890	600-680
3	0.5-0.7	1.2-1.8	840-880	600-680
4	0.2-0.5	1.5-4.1	770-860	560-650

$$\sigma_s = C_\sigma \varepsilon^n, \quad (5)$$

which, relying on the results of the conducted study, can be presented as follows [7]:

$$\sigma_s = \left[510.2\ln(\sigma_H) - 2707.9\right]\left(100\frac{H-h}{H}\right)^n; \quad (6)$$

$$n = 0.42 - 0.3C^2 - 0.35Si + 0.19Mn^2 - 3.73S + 33.3P - 1020.45P^2 - 5.07Ni + \\ + 54.62Ni^2 - 2.37Cu + 9.73Cu^2 - 144.14Ti^2 - 9.77Nb \quad (7)$$

Certainty index of approximation of dependence (7) is R^2 =0.906, for dependences (1)-(4) is within 0.796-0.889. These R values are statistically significant with confidence coefficient of 95% [8].

Table 2 Value Range (Numerator) and Sampling Mean (Denominator) of the Friction Coefficient in Stands of TCM 2000

Stand	Rolling Conditions			Friction Coefficient
	Roll Roughness Ra, μm	ε, %	v, m·s^{-1}	
1	0.8-1.2	20-44	2.1-6.5	$\frac{0.050\text{-}0.120}{0.085}$
2, 3, 4	0.8-1.2	19-44	2.5-19.6	$\frac{0.040\text{-}0.080}{0.060}$
5	3.5-5.0	0.5-5.0	7.0-23.0	$\frac{0.038\text{-}0.255}{0.147}$

The procedure of calculation of coefficient of contact friction [9] has been adjusted to PLTCM 2000 conditions, on the basis of its results the ranges of variations of friction coefficient in the TCM mill stands have been established (**Table 2**). The higher friction coefficient in stand 1 compared with stands 2-4 may be explained by the fact that a band is fed into stand 1 immediately from the pickling line without preliminary oiling. The increased friction coefficient in stand 5 is due to the fact that rolling of hardened metal with light draft occurs here. Combined with the model of precast of the yield point related to the steel chemical composition, adjustment of methods of calculation of friction coefficient enables cutting errors when calculating roll pressure from 3.5 MN to 0.78 MN.

1.3. The condition speed agree processes pickling and rolling in the steady state of PLCTM

Coherence of operation of the pickling unit and continuous mill can be achieved by selection the unit speed mode at which band speed at the input of stand v_H equals speed v_{PL} of the band transfer through the pickling bathes, which is determined due to the criteria of the quality scale removal. At the other side, value v_H is specified by rolling speed in the last mill stand $v_{TCM}^{(k)}$ and value of draft of hot-rolled H thick band into the cold-rolled h_k thick one. So, in the steady mode of the combined facility the following condition has to be met:

$$v_H = v_{TCM}^{(k)} \cdot h_k / H = v_{PL} \,. \tag{8}$$

Speed of semi-finished rolled stock $v_{TCM}^{(k)}$ must not exceed some rational value for particular deformation conditions which at first approximation can be found from the formula as per [10] with some adjustments

$$v_{TCM}^{(k)} = k_{cp} \cdot k_\sigma \cdot k_{hb} \cdot v_{\max}^{(k)} \,, \tag{9}$$

where $v_{\max}^{(k)}$ - мmaximum allowable speed of rolling in the last mill stand according to its technical specifications; k_σ - coefficient of impact of the semi-finished rolled stock strength (assumed dependent on the yield point of the hot-rolled band σ_H in accordance with values of **Table 3**);

Table 3 Coefficient of Impact of Semi-finished Rolled Stock on the Speed of Cold Rolling

σ_H , MPa	k_σ
Under 300	1.00
310 - 350	0.95
360 - 400	0.85
410 - 450	0.80
Over 450	0.75

k_{cp} - factor of assurance for process adjustment (if $k_\sigma \cdot k_{hb} \leq 0.9$, then k_{cp} =1.0); k_{hb} - coefficient of impact of the section dimensions, which depend on band thickness and relation of its width b to length of working roll body L_{wr} :

$$k_{hb} = 0.769 \cdot h_k^{-0.3687} \cdot \left(b/L_{wr}\right)^{-0.1015}; \quad (10)$$

The speed of the band travel through the L_{PL} long pickling bath can be calculated by formula

$$v_{PL} = L_{PL}/\tau_{pt}, \quad (11)$$

Table 4 Ranges of Variations in Element Content in the Investigated Steel Grades

Element	Content, %
C	0.005-0.06
Si	0.01-0.14
Mn	0.14-0.73
S	0.006-0.08
P	0.008-0.068
Al	0.036-0.048
Mo	0.002-0.004
Nb	0.001-0.041
V	0.003-0.008
Ti	0.001-0.047

where τ_{pt} - period of scale removal (s) which depends on mass of scale on the band.

To determine scale mass and period of its removal the 2.0 - 3.6 thick samples were used which had been selected from hot-rolled bands of steel with various chemical composition (**Table 4**), having been rolled at temperature of the rolling end t_{ret} = 840-890 °C and reeling t_{ct} = 530-730 °C. For each thickness and grade of steel 9 experiments were carried out, at which parameters of the pickling solutions were varied within the following limits: acid concentration $[HCl]$=44-184 g/l, iron salt concentration $[FeCl_2]$=45-230 g/l, temperature of solution t_{ps}=40 - 80 °C. The total number of observations amounted 81, on the basis of their results the following approximations were constructed:

$$\tau_{pt} = 2.1 \cdot 10^8 \left[HCl\right]^{-2.069} \left[FeCl_2\right]^{1.437} t_{ps}^{-3.757} m_{sc}^{0.727}, \text{ s}; \quad (12)$$

$$m_{sc} = 56.35\left(\frac{t_{кп}}{1000}\right)^2 + 846.7\frac{t_{см}}{1000} - 646.5\left(\frac{t_{см}}{1000}\right)^2 - 2.9\frac{1-LA*}{C*} - 0.133\left(\frac{1-LA*}{C*}\right)^2 - 253.83\,, \quad (13)$$

where m_{sc} - mass of scale on the hot-rolled band, g/m². For relation (12) the confidence coefficient of approximation is R^2 = 0.988, for relation (13) - R^2 = 0.898 providing degree of conformity of the predicted and actual values. These R^2 values are statistically significant with confidence coefficient of 95 % [8].

1.4. Development of a rational combination of total reduction and rolling speed of the TCM2000

The matched speed mode of the combined pickling unit and continuous mill is selected as follows. At the given dimensions and yield period speed v_{PL} is calculated by formula (11), while rational speed $v_{TCM}^{(k)}$ in the last mill stand is established by formula (9). Then speed $v_{TCM}^{(k)}$ on the input of v_H mill corresponding to the achieved value is defined:

$$v_H = v_{TCM}^{(k)}\, h_k / H\,. \quad (14)$$

Further, the values v_H and v_{PL} are compared. If $v_{PL} > v_H$, then the speed mode of the combined unit is limited by rolling speed and, therefore, band speed in the pickling bathes should be decreased to the value

$$v_{PL} = v_{TCM}^{(k)}\, h_k / H\,. \quad (15)$$

Table 4 Specifications of Steels of Various Strength Groups

Strength Group	Steel Grade	C*, %	LA*, %	t_{ret}, °C	t_{ct}, °C	σH, MPa
I	H180Y	0.07	0.08	830	560	306
	08Ю	0.06	0.01	850	670	288
	Ст3сп	0.27	0.01	850	630	352
II	HC260LA	0.14	0.02	830	580	330
	HC300LA	0.15	0.02	820	550	340
	HC340LA	0.22	0.04	820	570	354
III	09Г2С	0.57	0.01	810	580	451
	HX420LAD	0.60	0.06	850	580	448
	DP600	0.26	0.07	850	590	519
IV	HDT1200M	0.47	0.26	870	640	531
	DP1000	0.57	0.02	850	590	552
	HCT980X	0.67	0.20	870	630	642

If $v_{PL} < v_H$, then the speed mode of the combined unit is limited by band speed in the pickling bathes and rolling speed in the last continuous mill stand should be decreased to the value

$$v_{TCM}^{(k)} = v_{PL}\, H / h_k\,. \quad (16)$$

In order to establish rational combinations of the overall reduction and speed of band rolling, the steel grades specified in **Table 4** were selected. With the CR CAD software for automated designing the rolling process of the hot-rolled semi-finished stock with thickness H, from 1.8 to 6 mm, was simulated for each steel grade to establish the maximum reduction during cold-rolling at which conditions of pickling and rolling would fulfil the limit complex. Amongst others no-slip conditions of rollers, deformation metal heating up (max 220 °C), power and mechanical specifications of rolling (force, torque, capacity) and speed v_{PL} were estimated. The total calculation number amounted 120.

The calculation data showed (**Fig. 2**) that reduction up to 85% could be achieved for steel grades of the first strength group (HC180Y, 08Ю, Ст3сп- killed steel), the rational rolling speed being 16.5 -17 m·s^{-1}. Bands of steel of the second strength group (HC260LA, HC300LA, HC340LA) can be rolled with overall reduction to 80 %, rational speed being 16 - 18.5 m·s^{-1}. The specific feature of these strength groups is that within 75 - 85 % reduction range the matched speed mode of PLTCM 2000 unit is defined by rolling speed due to the thermal resistance of lubricating agent. At lower values of overall reduction the matched speed mode is specified by band speed in the pickling bathes. We recommend perform rolling steels belonging to strength group 3 (09Г2С, DP600, HX420LAD) with max 67-70 % overall reduction at speed of 13 - 15 m·s^{-1}; rolling of steel of strength group 4 (HTD1200M, DP1000, HTC980X) - with reduction up to 58-63% at speed of 7.5 - 10 m·s^{-1}. At any overall reduction value of steel grades belonging to the above groups the speed of the combined unit is determined by speed of a band traveling through the pickling bathes.

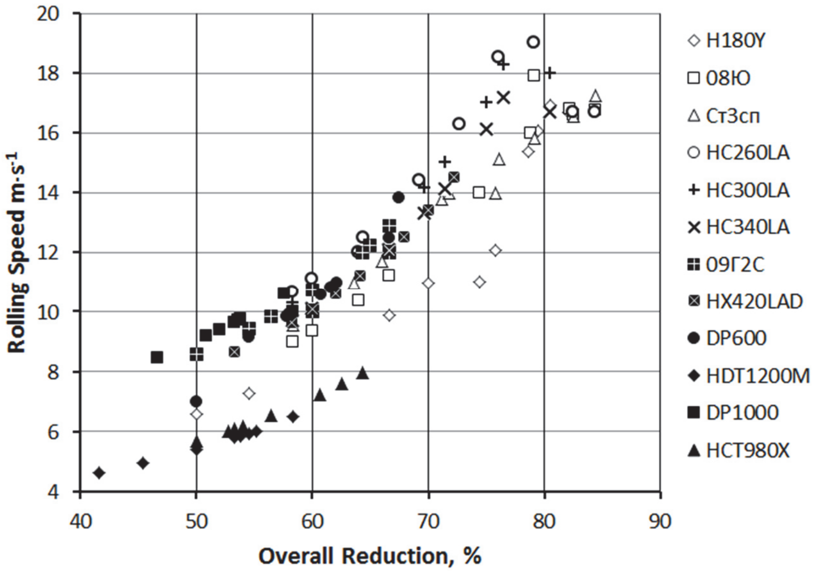

Fig. 2 Rational Combination of the Overall Reduction and Rolling Speed of TCM 2000

CONCLUSION

Thus, the generalized algorithm of automated design engineering of rolling modes has been developed which can be transformed into software of automated design engineering for band cold-rolling modes of various application with the mathematical support. On the basis of this algorithm, the CR CAD software for automated design of band cod-rolling process modes has been developed which specifically provides the forecast of yield point and deformation hardening of steel with random chemical composition. CR CAD software adjustment to the specification of PLTCM 2000 unit provided suitable matching assessed speed modes of the combined unit with actual data as well as reduced errors of calculation of rolling effort to 0.78 MN. With adjusted software variants of PLCTM 2000 modes of rolling bands of various dimensional and grade gauge, as well as rational combinations of overall reduction and speed of rolling of steel grades belonging to various strength groups at TCM 2000 mill stand were established.

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