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Computer Simulation of Pass Schedule on Strip Mills

Yan Xiaoqiang Zou Jiaxiang Gao Yongsheng
Mechanical Engineering College, USTB, Beijing 100083, PRC

ABSTRACT The computer program of the pass schedule setting up is worked out in the paper. The program simulates the whole process of rolling metals in cold rolling condition. It includes the mathematical models of specific deformation energy, tension, coefficients of roll flattening, and of speed effect, deformation efficiency, etc.. On the basis of the limited conditions, entry thickness, exit thickness, rolling speed, tension, rolling force and rolling torque, etc. are calculated.
KEY WORDS strip mills, computer simulation, mathematical models/pass schedule

1 Computer – controlling System of Reversing Strip Mill

1.1 Structure and function of the computer – controlling system

Computer – controlling system of rolling process can raise production efficiency and product quality. The equipments and computer – controlling system of a four high reversing cold mill consist of two computers. One calculates the pass schedule, the other completes parameters of main drive control system, assumes gap value, automatic showing down at defect location and strip end, annealing parameters storage, pass line position adjustment, and sirip classification, etc..

1.2 Technological and power parameters determination

After the operator inputs the coil data and consumer's demand for thickness, surface quality, tolerance and mechanical properties etc., by means of the program, the technological parameters such as entry thickness, exit thickness, rolling speed, tension, roll force, roll power, roll torque and rolling time, and so on, are determined in order to reach the maximum productivity.

2 The Program Characters on the Pass Schedule Setting up

The program diagram is shown in figure 1. The program characters are :

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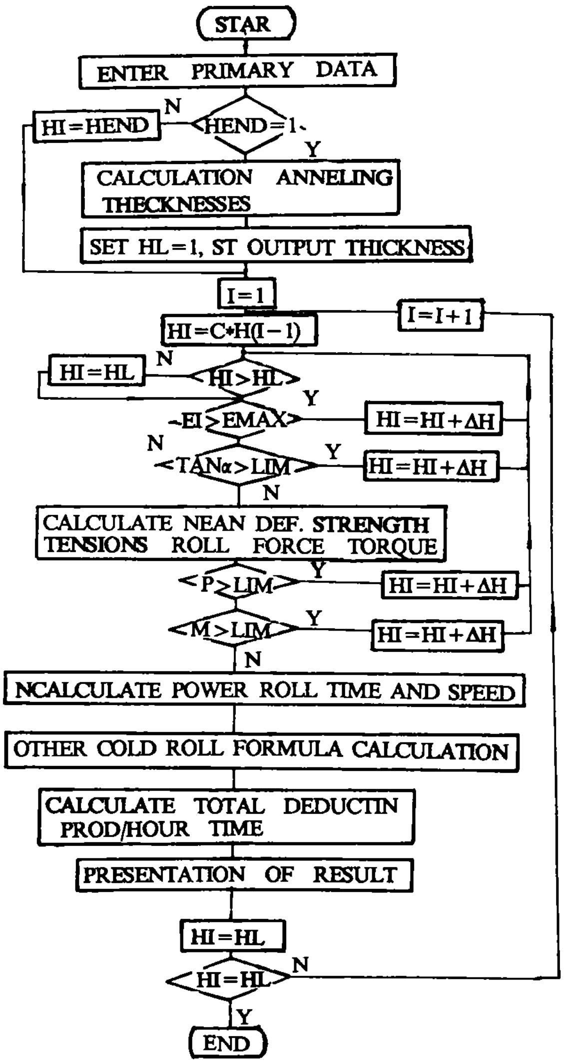

Fig. 1 Program diagram

(1) The program consists of many blocks for the convenience of reading and developing. (2) The program occupies small memory space and calculates quickly. (3) The operator inputs original parameters easily and reads calculated result clearly. (4) The program is flexible. If the parameters are changed, the program can be applied to other four high cold mills. (5) This program can be used to design mills, adjust mills, calculate strength, work out new technology, raise productivity and study control models.

3 Mathematical Models of Rolling Process

3.1 Roll force model P

Because cold rolling process is very complicated, fricative mechanism, deformation law of metals and roll flattening are still not clear, therefore, some formulae are different from scope of application, structure form and calculated precision. To obtain high precision, roll force model adopt unification structure form including Bland – Ford formula, Hill formula and Roberts formula, etc. in cold rolling :

$$P = K_F \cdot F_T \cdot F_A \cdot L \cdot B \cdot F_V / N_F$$

where, K_F – mean pure deformation resistance (N/mm^2); F_T – coefficient of tension influence; F_A – coefficient of roll flattening; L – arc length (mm); B – strip width (mm); F_V – coefficient of speed effect; N_F – deformation efficiency.

The formula is very simple, and not only reflects main influence factors but also separates these factors clearly. So the formula structure is easy to programme and use statistical data. K_F, N_F, F_V and F_A are the statistical models. F_T is theoritical solution in the simulation program.

3.2 Pure deformation resistance model K_F

By using rolling – drawing method, the metals pure deformation resistance in cold rolling is gotten on MTS – 809 materials test machine. Figures 2 and 3 show two examples of pure deformation resistance curves of T2 (pure copper) and H65 (brass).

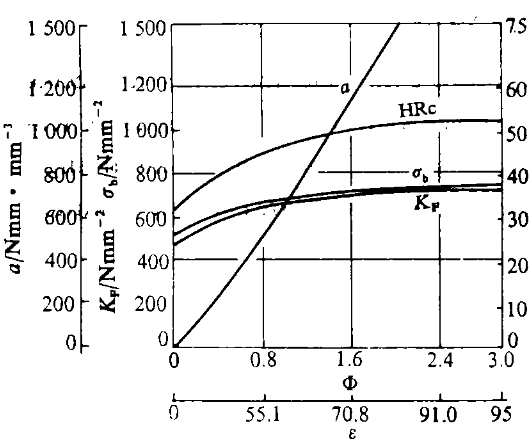

Fig. 2 Pure deformtion resistance strength hardness

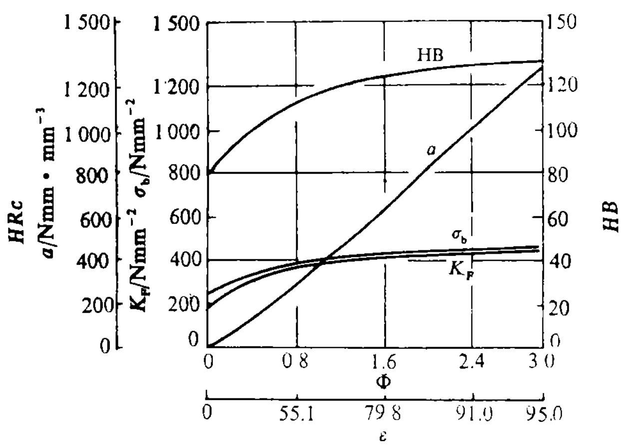

Fig. 3 Pure deformation resistance strength hardness

Mean pure deformation resistance K_F is calculated by means of specific pure deformation energy. Mean pure deformation energy of the "i" th pass is:

$$a_l = a_i - a_{i-1} \int_{\Phi_{i-1}}^{\Phi_i} K_f \, d\Phi = K_{F_i} (\Phi_i - \Phi_{i-1})$$

Thus, the "i" th pass mean pure deformation resistance is:

$$K_{fi} = (a_i - a_{i-1})/(\Phi_i - \Phi_{i-1})$$

where a_i, a_{i-1} – pure deformation energy from first pass to the "i"th pass , "$i-1$"th pass; Φ_i, Φ_{i-1} – logarithmic deformation from first pass to the "i"th pass, "$i-1$" th pass.

3.3 Tension influence coefficient model F_T

If tension is considered, deformation strengths:

Entry side $\quad K_W^+ = (k_h h_\theta/h)e^\mu a_\alpha (1 - \sigma_h/k_h)$

Exit side $\quad K_W^- = (k_H h_\theta/H)e^\mu (a_\alpha - a_\theta)(1 - \sigma_H/k_H)$

In particuar, when no front back tensions are applied:

$$K_W^+ = (k_h h_\theta/h)e^\mu a_\theta$$

$$K_W^- = (k_h h_h/H)e^\mu (a_\alpha - a_\theta)$$

where k_h, k_H – exit, entry deformation resistance (N/mm^2); h_θ – rolled piece thichness in any position of rolling area (mm); μ – friction coefficient between rolled piece and roll; σ_h, σ_H – specific front tension, bace tension (N/mm^2); R' – roll flattening radius (mm); α, θ – arc of contace, central angle in any position of rolling area; h, H – exit, entry thickness (mm).

$$a_\theta = 2(R'/h)^{1/2} \mathrm{arctg}[(R'/h)^{1/2}\theta]$$

$$a_\alpha = 2(R'/h)^{1/2} \mathrm{arctg}[(R'/h)^{1/2}\alpha]$$

From the above equations when tension is applied, entry side and exit side specific deformation strength reduce separately $(1 - \sigma_h/k_h)$ times and $(1 - \sigma_H/k_H)$ times as tension is applied. If specific front tension and back tension are similar and neutral angle is constant, revision coefficient of the whole deformation area to deformation strength is:

$$F_T = (1 - \sigma_h - k_h)\gamma/\alpha + (1 - \sigma_H/k_H)(\gamma/\alpha)$$

where, γ – neutral angle; α – arc of contact.

When $k_h = k_H \approx k_F$ equals to k_F and γ/α to 0.5, tension influence coefficient model is :

$$F_T = 1 - (\sigma_h + \sigma_H)/(2k_F)$$

3.4 Deformation effciency model N_F

Because friction between roll and rolled piece, and internal shearing stress produce energy loss in rolling process, the deformation efficiency N_F of a pass is defined as

$$N_F = A_0 / A$$

where, A_0 — pure deformation energy; A — total deformation energy (include pure deformation energy and energy loss).

Specific pure deformation energy is calculated by means of pure deformation resistance curve through integration. Total deformation energy is measured value in rolling process. Figure 4 shows deformation efficiency curve.

3.5 Speed Effect coefficient F_v

Because the lubrication condition changes with the rolling speed, to forecast accurately, roll seperation force needs to revise force formula. Figure 5 shows the speed coefficient curve of a four high reversing cold mill.

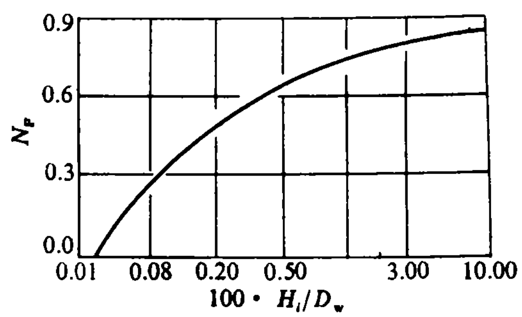

Fig. 4 Deformation efficiency

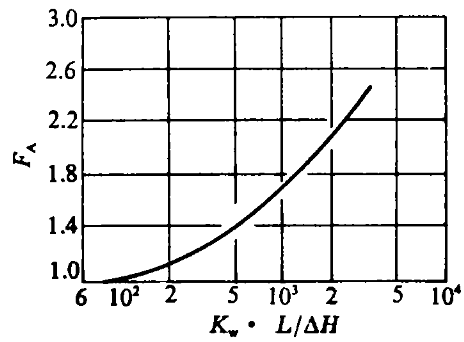

Fig. 5 Speed coefficient

4 Simulation Effect

Tables 1 and 2 show simulating results of rolling T2 and H65.

Maximum difference between the calculation result of the program and measured value is less than 10%, proving the high precision of the roll seperating.

Table 1 Simulation result of each pass for T2 (pure copper)

No	H /mm	h /mm	ε /%	σ_H /N • mm^{-2}	σ_b /N • mm^{-2}	K_F /N • mm^{-2}	K_W /N • m^{-2}	V /m • min^{-1}	P /k N	P_1 /k N	δ /%
1	12.4	9.20	26	0	0	313.1	417.4	104	11 294	10 665	5.57
2	9.20	6.70	27	28	0	399.9	532.6	104	12 485	11 717	6.15
3	6.70	4.57	32	42	28	439.6	577.8	116	12 362	11 432	7.52
4	4.57	2.75	40	69	42	456.7	626.4	133	11 881	11 736	1.22
5	2.75	1.51	45	78	69	456.8	715.3	176	10 149	9 836	3.08
6	1.51	0.83	45	68	78	457.4	819.0	270	8 034	8 161	−0.02
7	0.83	0.62	25	78	68	457.5	1 008	450	5 596	5 454	2.54

Table 2 Simulation result of each pass for H65 (brass)

No	H /mm	h /mm	ε /%	σ_H /N·mm^{-2}	σ_h /N·mm^{-2}	K_F /N·mm^{-2}	K_W /N·m	V m·mm	P /kN	P_1 /kN	δ /%
1	12.4	9.5	23	0	0	570.0	728.9	104	12 480	11 858	4.98
2	9.5	7.10	25	0	0	672.5	886.0	104	13 716	12 937	5.68
3	7.10	5.05	29	61	0	733.0	954.1	115	13 505	12 599	6.71
4	5.05	3.30	35	93	61	764.7	1 000.0	134	12 719	11 667	8.27
5	3.30	2.48	25	55	93	774.9	1 012.0	245	9 135	8 604	5.81

板带轧机 轧制规程计算机仿真

闫晓强　邹家祥　高永生

北京科技大学机械工程学院，北京　100083

摘 要　编制了轧制规程计算程序，该程序模拟了在冷轧条件下的整个轧制过程，包括单位变形能数学模型、张力数学模型、轧辊压扁系数数学模型、速度影响系数数学模型、变形效率数学模型等．根据极限条件，计算出入口厚度、出口厚度、轧制速度、张力、轧制力、轧制力矩等．

关键词　板带轧机，轧制规程，计算机仿真，数学模型

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