研 究 速 報

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ON THE OPTIMUM A.G.C. SYSTEM FOR COLD TANDEM MILL

コールドタンデムミルの最適制御系について

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1. Introduction

Recently, studies on the characteristics of cold tandem mill have developed and many useful results have been obtained and have contributed and have contributed effectively to actual works.

Generally speaking, however, these proposed methods are carried out by use of much store capacity of digital computer.

Therefore, in the case of small deviations from the stationary rolling state, it is effective to adopt the method of analysis through analog simulation. In this study, we propose the method that is convenient to analize the characteristics of cold tandem mill with automatic control system. Then, we simulate the actual system by use of analog computer and show their results.

2. Superiority of analog simulation

Superiorities of analog simulation to digital simulation are summarized as follows:

(1) Since we consider the condition of stationary rolling state, the coefficient of mathematical equation can be assumed to be constant.

(2) We have higher speed and easiness of repeated computation.

(3) We easily introduce every kind of control system.

(4) Our main object is to have the qualitative tendency of control effect rather than the quantitative accuracy of control effect.

(5) We easily construct other pass schedule by changing the setting values of potentio meter.

(6) We can observe the responses of the simulated system directly by oscillo paper and appreciate the effect of control system easily.

3. Simulated model

The model we simulate is the 5 stands cold tandem mill illustrated in Fig. 1.

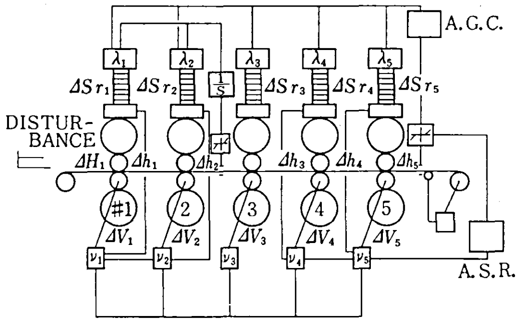

Fig. 1 Usual pattern of A.C. system for tanden cold mill

Table 1 Notations

P	Rolling force
L	Distance between two adjacent stands
f	Forward slip ratio
ϵ	Backward slip ratio
V	Velocity of the neutral point of the material
V_f	Velocity of the material at the exit of roll
V_b	Velocity of the material at the entry of roll
H	Incoming strip thickness
h	Outgoing strip thickness
t_f	Forward tension
t_p	Backward tension
S_r	Roll gap setting

The rolling parameters are summarized on table 1.

As we consider the small deviation from the stationary rolling state, rolling variables we treat have the deviated values of these parameters from the stationary rolling state.

Now, we consider the mathematical equation of

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simulated system. In our discussion, the effect of oil film thickness in back up roll bearing and that of flow stress of the material are neglected.

Therefore, the deviation of the out-going strip thickness is linearly dependent on the deviations of roll spacing and rolling force as follows:

$$\Delta h_i=\left(\frac{\partial h}{\partial S_r}\right)_i\cdot\Delta S_{ri}+\left(\frac{\partial h}{\partial P}\right)_i\cdot\Delta P_i \qquad (1)$$

The rolling force of $\sharp i$ stand is given as follows:

$$P_i=P_i(H_i,\ h_i,\ t_{ti},\ t_{bi}) \qquad (2)$$

Two adjacent stands are combined with the propagation of the deviation strip thickness and the equiliblium relation of inter-stand tension as follows:

$$\Delta H_{i+1}(t)=\Delta h_i\left(t-\frac{L}{V_{fi}}\right) \qquad (3)$$

$$H_{i+1}\cdot t_{bi+1}=h_i\cdot t_{fi} \qquad (4)$$

Neglecting the effect of droop properties of mill motor, the deviations of speeds of the material are given by

$$\Delta V_{fi}=V_i\frac{\partial f_i}{\partial H_i}\Delta H_i+V_i\frac{\partial f_i}{\partial h_i}\Delta h_i+(1+f_i)\Delta V_i \qquad (5)$$

$$\Delta V_{bi}=V_i\frac{\partial f_i}{\partial H_i}\Delta H_i+V_i\frac{\partial \epsilon_i}{\partial h_i}\Delta h_i+(1+\epsilon_i)\Delta V_i \qquad (6)$$

The deviation of inter-stand tension is induced from the deviations of incoming and outgoing strip speeds between two adjacent stands as follows:

$$\Delta t_{fi}=\frac{E}{L}\int_0^t(\Delta V_{bi+1}-\Delta V_{fi})dt \qquad (7)$$

Those described above are the mathematical models for our simulation and are summarized in Fig. 2.

4. Analog simulation of 5 stands

The structure of simulated blocks is made such as illustrated in Fig. 2. Constants set on analog computer are computed by digital computer with regard to fundamental pass schedule. We adopt the pass schedule presented on table 2. The disturbance for this system is the thickness deviation, ΔH_1.

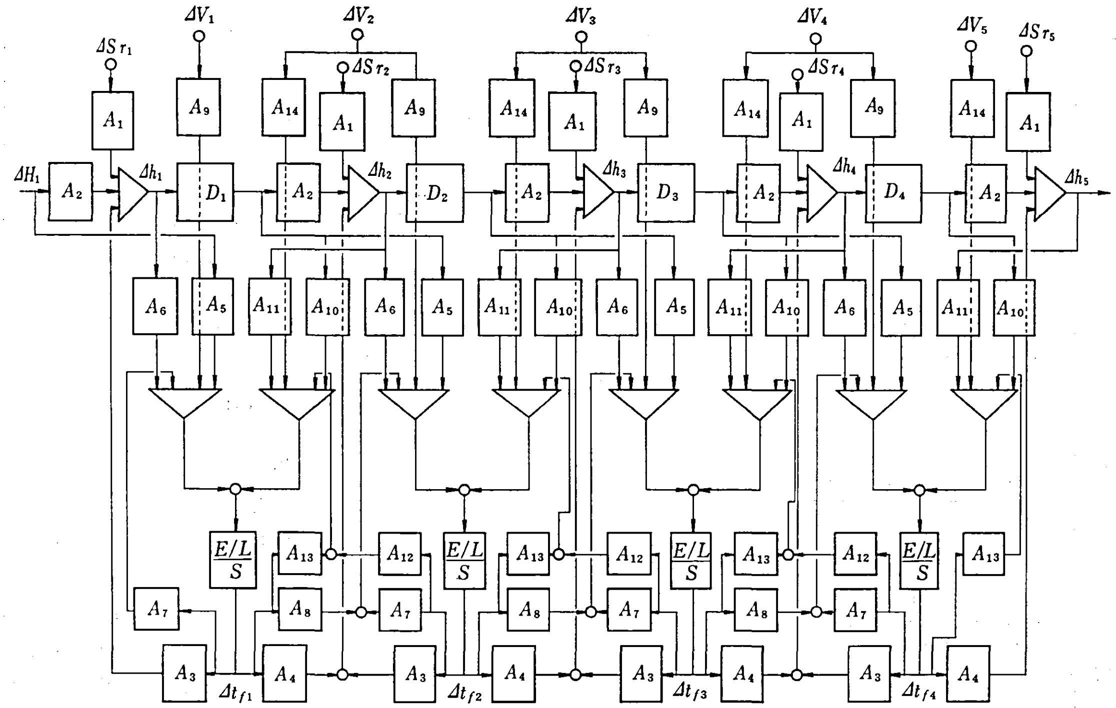

Fig. 2 Simulated block

Table 2 Fundamental pass schedule

		# 1	2	3	4	5
H	mm	3.2	2.64	2.10	1.67	1.34
h	mm	2.64	2.10	1.67	1.34	1.21
r	%	17.5	20.4	20.4	19.7	9.7
V	m/s	5.96	7.54	9.47	11.7	13.1
μ		0.05	0.05	0.05	0.05	0.05
t_f	kg/m²	12.0	12.8	16.1	16.1	4.5
t_b	〃	2.0	12.0	12.8	16.1	16.1
P	t.	504.5	580.1	605.3	598.9	505.5
G	t. m.	825.2	7323.1	5811.7	5892.4	5445.8
f		0.018	0.023	0.028	0.031	0.019
ϵ		−0.159	−0.185	−0.182	−0.172	−0.079
B	mm	775	775	775	775	775

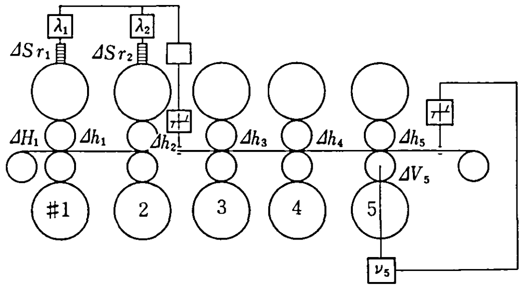

Fig. 4 System S.

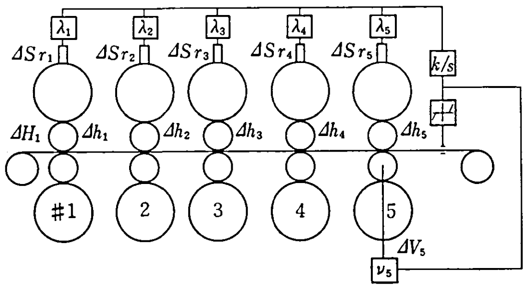

Fig. 5 System S₂ (monitor A. G. C.)

This disturbance is the step one. In Fig. 3, responses of the deviation of outgoing thickness, Δh_i's and those of foward tensions Δt_{fi}'s in the case of disturbance ΔH_1 are presented. The A. G. C. system we treat is classified into three fundamental types s_1, s_2 and s_3.

These are illustrated in Fig.'s 4 to 6.

The practical A.G.C. system is to be constructed with these three fundamental A. G. C. systems. In these Fig.'s λ_i and ν_i are called the arranged ratios of gains of A. G. C. and A. S. R. system for each stand. The inter-relations of λ_i and ν_i are defined by

$$\sum_{i=1}^{5}|\lambda_i|=1 \qquad (8)$$

$$\sum_{i=1}^{5}|\nu_i|=1\,; \ (i\neq 3) \qquad (9)$$

In these equations, we define the signs of λ_i and ν_i as follows: $\lambda_i>0$ means closing of roll gap and $\lambda_i<0$ means widening of roll gap. And $\nu_i>0$ means accele ration and $\lambda_i<0$ means deceleration of #i stand. In our simulation, we

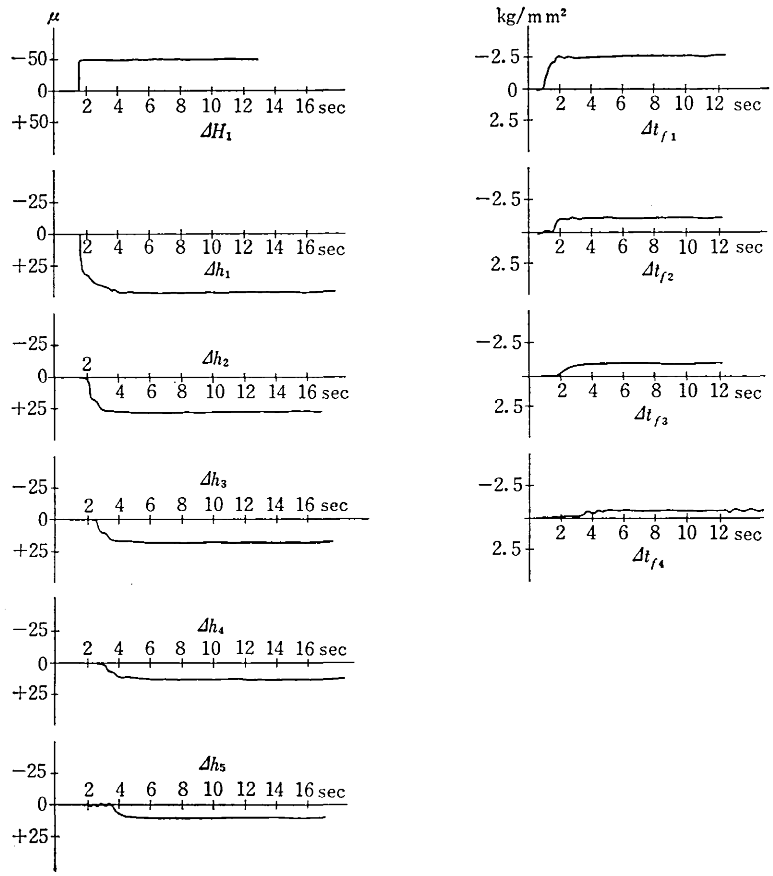

Fig. 3 RESPONSE of the System without A. G. C.

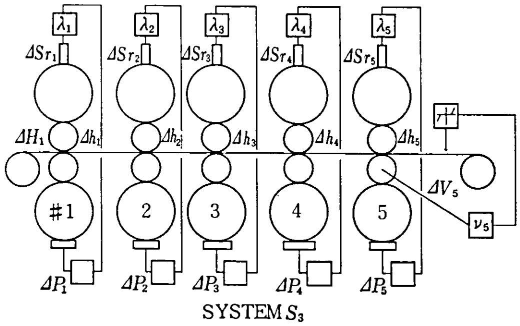

Fig. 6　System S_3 (roll force A. G. C.)

Table 3　Arrangement of λ_i and ν_i.

	B_1	B_2	B_3	B_4	B_5
λ_1					1
λ_2		0		1	
λ_3			1		
λ_4		1		0	
λ_5	1				

	D_1	D_2	D_3	D_4	D_5
ν_1	1				
ν_2		1		0	
ν_3			—		
ν_4		0		1	
ν_5					1

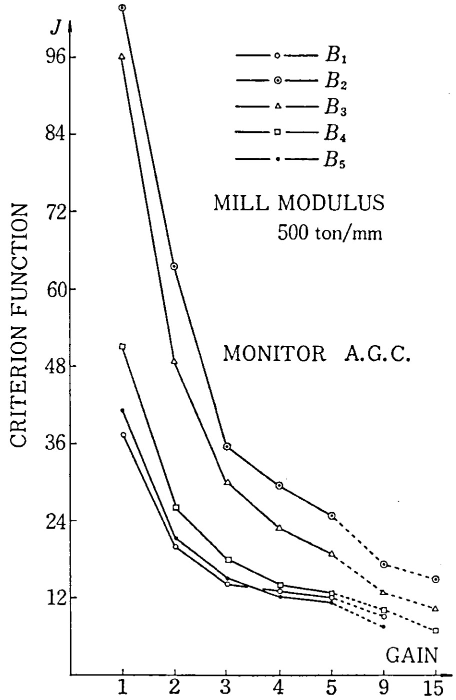

Fig. 7　Influence of gain

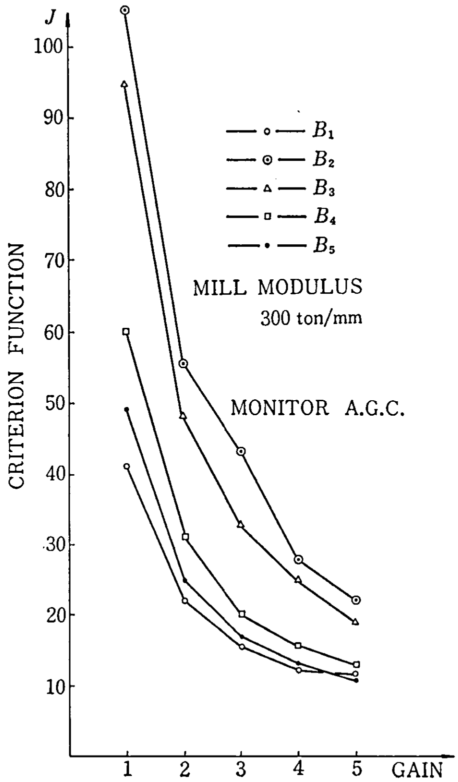

Fig. 8　Influence of gain

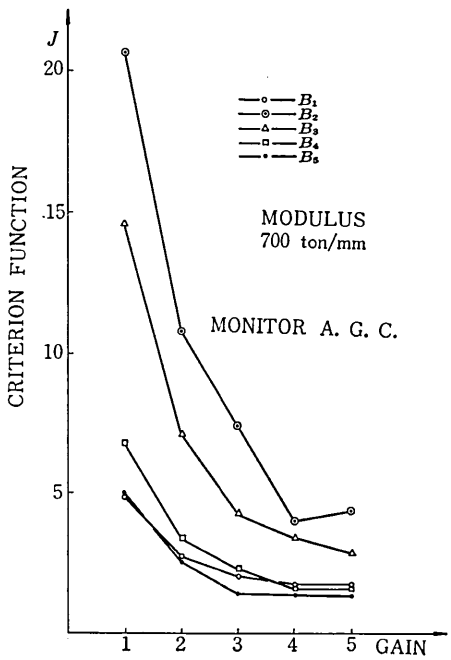

Fig. 9　Influence of gain

experience by use of the combination of λ_i and ν_i as pesented on table 3.

5. Results of simulation

The results of simulations are analized by the following criterion function which estimates the effect of control system.

The criterion function is called J and defined by

$$J=\int_0^t |m(t)|dt \qquad (10)$$

the integral of $|m(t)|$ with respect to time.

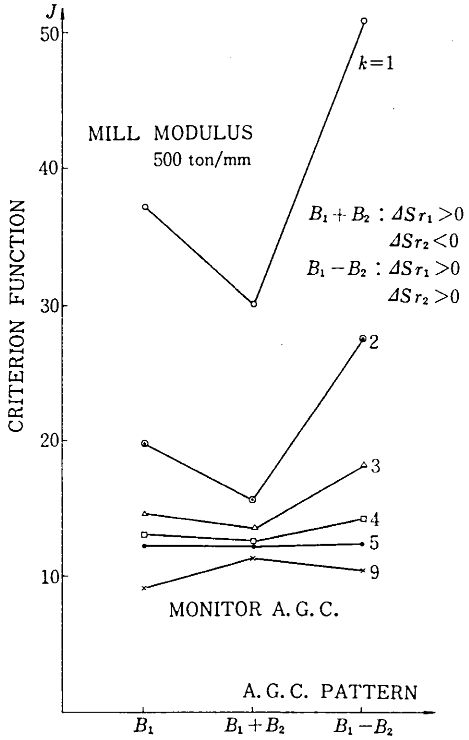

Fig. 10 Influence of A.G.C.

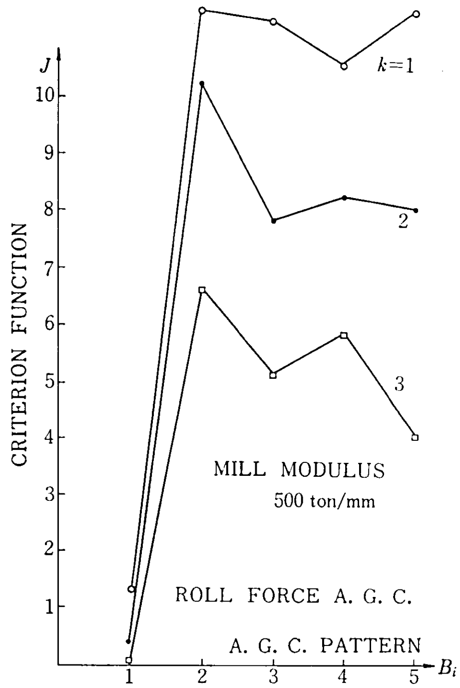

Fig. 12 Influence of A.G.C.

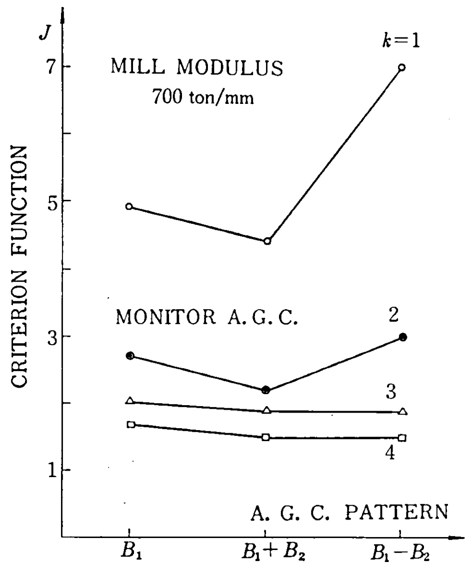

Fig. 12 Influence of A.G.C.

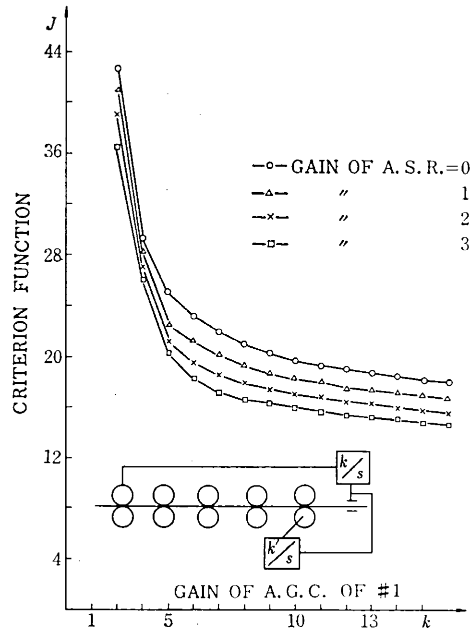

Fig. 13 Influence of gain

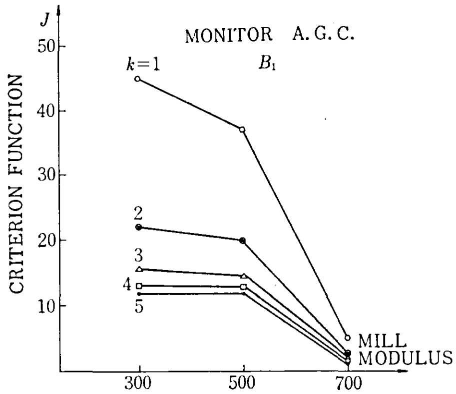

Fig. 14 Influence of mill modulus

In Fig.'s 7 to 9, the influence of gain is illustrated.

In Fig.'s 10 to 12, the influence of A. G. C. patterns are illustrated. In Fig.'s 13 and 14, other results of our simulations are presented.

6. Conclusions

From the discussions described above, we can conclude the characteristics of control system of 5 stands cold tandem mill in the case of small disturbance from the stationary rolling state.

Our conclusions are given as follows:

(1) There exists optimum gain of integrator.

(2) It is desirable to make mill modulus as large as possible.

(3) For s_2, screw down of #1 or #5 is desirable and for s_3, screw down of #1 is desirable.

(4) In our simulation, for #2 and #4, it is desirable to widen the roll gap.

(5) For small gain, the A. G. C. pattern of closing #1 roll gap and widening #2 roll gap is superior to that of closing those two roll gaps.

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Reference

Kamata et al: J of JSTP, Vol. 10, No. 96, 1969

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