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A STUDY ON THE OPTIMUM A.G.C. SYSTEM FOR HOT TANDEM MILL

ホットタンデムミルの最適 A.G.C. 系について

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1. Introduction

Generally speaking, the automatic control systems of tandem rolling mill are designed on the basis of experimental suggestion and not on theoretical analysis. Therefore, it is worthwhile to discuss theoretically the optimum control system.

For the first step of our studies, in this paper, we consider the control system of hot tandem mill in the case of small disturbances. The method of analysis adopted here is as follows: we consider the problem of optimum control system by analog simulation. Here, rolling condition of hot tandem mill is considered in the case of 3 stands. In the stationary rolling state of hot tandem mill, we can assume the following properties: the effect of change in rolling velocity on rolling condition occurs separately in up-stream side and in down-stream side from the pivotal stand.

Therefore, here, we can reduce the problem of multi stands hot tandem mill to 3 stands in down-stream side including pivotal stand in the case of small disturbances. Then, for the purpose of the development of the conclusions based on the above discussion to the usual tandem mill, we simulate the system of 5 stands and compare its results with those of 3 stands.

2. Simulated model

The system we simulate is the one shown in Fig. 1. This is the mill system consisting of 3 stands.

The rolling parameters of this system are presented 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.

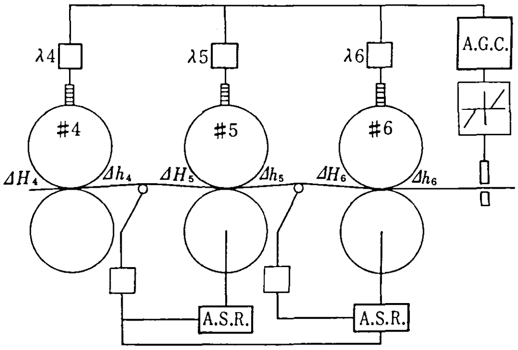

Fig. 1 Simulation Model.

Table 1-1

NOTATION 1

G	Rolling torque
P	Rolling load
L	Distance between two
f	Forward slip
$\in$	Backward slip
V	Velocity
V_f	Velocity of the material at the exit of roll
V_b	Velocity of the material at the entry of roll

Table 1-2

NOTATION 2

H	Thickness of the material at the entry to roll bite
h	Thickness of the material at the exit from roll bite
r	Reduction ratio of the material in rolling
T	Temperature of the material
b	Width of the material
K	Mill modulus
S_r	Roll gap setting

Table 1-3

NOTATION 3

i	Suffix designating rolling stand at location (i)
M_p	This is called plastic coefficient
$T^{(i)}$	Time constant of screw-down motor at ♯i stand
α	Loop angle of the material between adjacent stands
Δ	Operator designating small deviation from stationary state

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Now, we consider the mathematical equation of simulated system. In our discussion, the effect of the change of the thickness of oil film in back-up roll bearing and that of flow stress of the material on the deviation of out-going strip thickness are neglected. Therefore, the deviation of the outgoing thickness of strip is linearly dependent on the deviation of roll spacing and that of incoming strip thickness as follows:

$$\Delta h_i=\frac{1+\epsilon_i}{1+f_i}\Delta H_i+\frac{K_i}{K_i+Mp_i}\Delta Sr_i.$$

Two adjacent stands are combined with the propagation of the deviation of strip thickness and given by

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

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

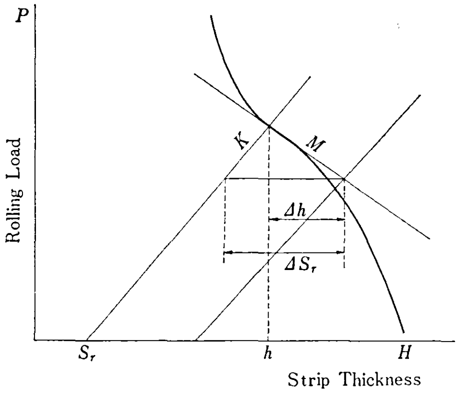
$$\Delta V_{fi}=\frac{\partial f_i}{\partial H_i}\Delta H_i+\frac{\partial f_i}{\partial h_i}\Delta h_i+(1+f_i)\Delta V_i,$$

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

The deviation of loop angle of the material between two adjacent stands is described by the deviation of the velocity of the material and given by

$$\Delta\alpha_i=\frac{\sin^2\alpha_i}{L\cos\alpha_i}\int_0^t(\Delta V_{bi+1}-\Delta V_{fi})dt.$$

Schematic Diagram of Rolling Condition



Interstand Relation

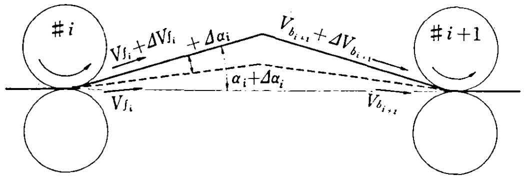


Fig. 2 Fundamental Relation.

These described above are the mathematical models of our simulation and are shown in Fig. 2.

3. Analog simulation of 3 stands

The structure of simulated blocks is made such as illustrated in Fig. 3. Constants set on analog computer are computed by digital computer with regard to fundamental pass schedules.

We adopt two fundamental pass schedules called A and B. On Table 2 and 3, these pass schedules are presented. Data of 3 stands from ♯4 to ♯6 are used for simulation.

The disturbance for this system is the thickness deviation, ΔH_4, and this is classified into three types: step disturbance, parabolic disturbance and taper disturbance. These three kinds of disturbances are shown in Fig. 4.

The A. G. C. system is that of integral control and the kinds of gains and time constants are classified as presented on Table

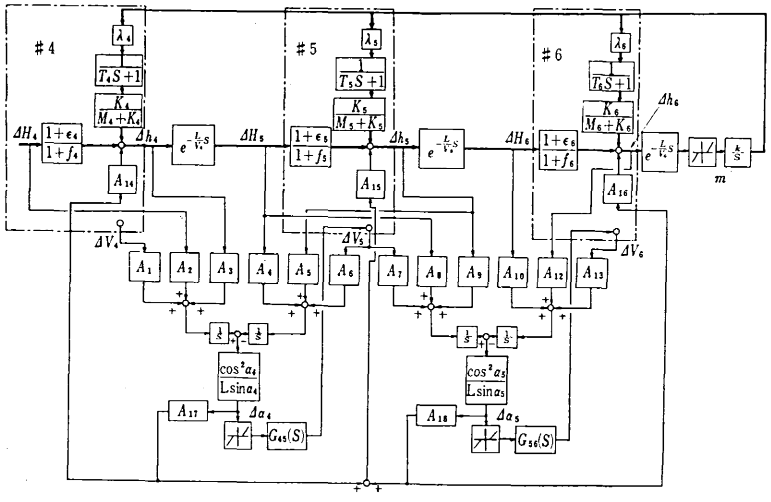


Fig. 3 Simulation Block.

Table 2 Pass schedule A

	♯ 1	♯ 2	♯ 3	♯ 4	♯ 5	♯ 6
H mm	26.0	16.9	11.83	7.69	4.99	3.49
h mm	16.9	11.83	7.69	4.99	3.49	3.26
r%	35	30	35	35	30	6.59
T°C	974	954	920	900	870	850
V m/s	1.63	2.35	3.56	5.46	7.9	9.0
K t/mm	500	500	500	500	500	500
b mm	946	946	946	946	946	946

Table 3 Pass schedule B

	♯ 1	♯ 2	♯ 3	♯ 4	♯ 5	♯ 6
H mm	23.0	13.8	8.97	5.56	3.44	2.13
h mm	13.8	8.97	5.56	3.44	2.13	1.98
r%	40	35	38	38	38	7.0
T°C	985	950	920	890	860	830
V m/s	1.19	1.83	2.96	4.76	7.67	9.0
K t/mm	500	500	500	500	500	500
b mm	988	988	988	988	988	988

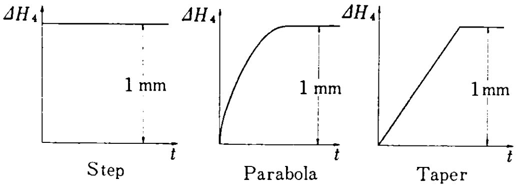


Fig. 4 Three Kinds of Disturbances.

4 and 5. λ_i in Fig. 1 is called the arranged ratio of gains of A. G. C. system for each stand. The inter-relation of λ_i's is defined by

$$\sum_{i=1}^{N} \lambda_i = 1. \quad (\lambda_i > 0)$$

In analog simulation, we experience by use of the combination of λ_i's as presented on Table 6.

Table 4 Arrangement of Time Constants
TIME CONSTANTS

	C_1	C_2	C_3	C_4	C_5
$T^{(i)}$	10^{sec}	0.1	0.1	0	3

Table 5 Arrangement of Gains
GAINS OF A.G.C.

	G_0	G_1	G_2	G_3	G_4	G_5	G_6
Gain	0.9	1	10	100	20	40	5

4. Results of simulation

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

Table 6 Arrangement of Rambda

	B_1	B_2	B_3	B_4	B_5	B_6
λ_4	0	0	1	0	0.5	0.5
λ_5	0	1	0	0.5	0	0.5
λ_6	1	0	0	0.5	0.5	0

The criterion function is called J and defined by

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

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

In Fig.'s 5, 6 and 7, some examples of the simulated results are shown. These are the results of simulation by use of fundamental pass schedule A with step disturbance.

In Fig. 8, the simulated results by use of fundamental pass schedule B with step disturbance are shown. In Fig. 9, the simulated results by use of fundamental pass schedule A with taper disturbance are shown. In Fig.'s 10 and 11, the influences of mill modulus on control effects are shown.

From these results, it is apparent that the qualitative tendencies of control effects are same with regard to several disturbances and fundamental pass schedules. But, with respect to mill modulus, the tendency of control effect is influenced not

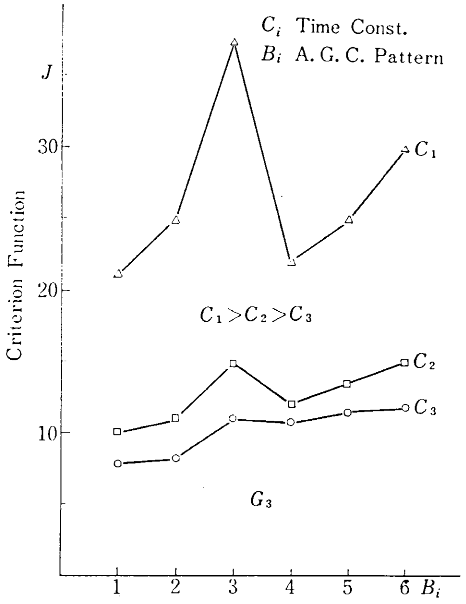


Fig. 5 Influence of A.G.C. Pattern.
(B_i shows A. G. C. pattern.)

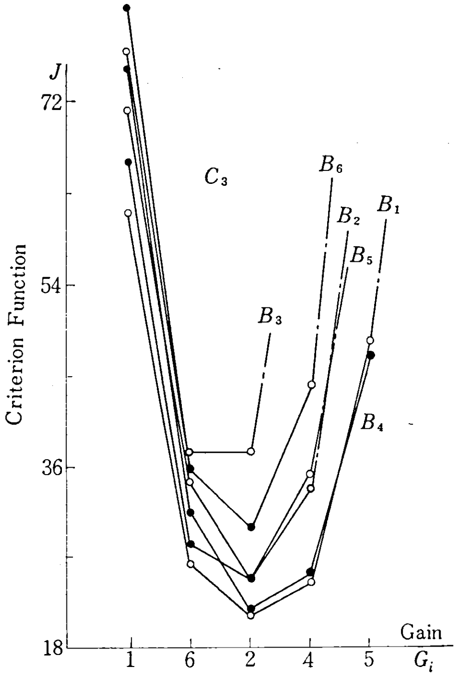


Fig. 6 Influence of Gain.

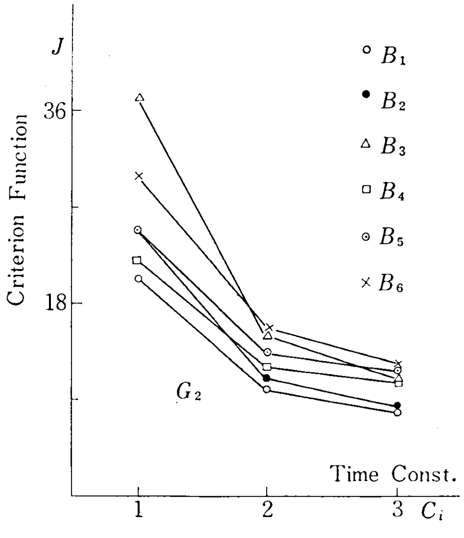


Fig. 7 Influence of Time Constant.

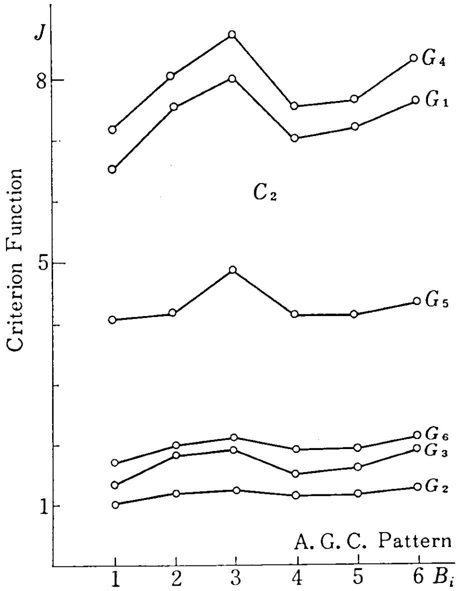


Fig. 8 Influence of A.G.C. Pattern.

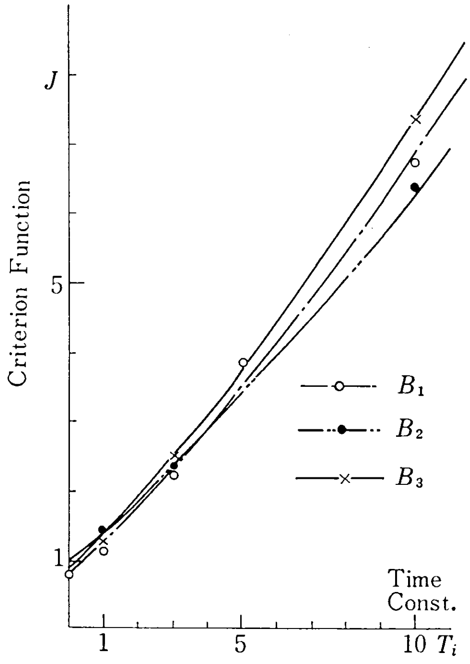


Fig. 9 Influence of Time Constant.

Table 7 Combination of Lambda

	D_1	D_2	D_3	D_4	D_5
λ_1	0	0	0	0	1
λ_2	0	0	0	1	0
λ_3	0	0	1	0	0
λ_4	0	1	0	0	0
λ_5	1	0	0	0	0

only by mill modulus but also by the derivative of rolling force with respect to strip thickness. These tendencies are shown in Fig.'s 12 and 13. Finally for the purpose of the development of our results, we simulated the case of 5 stands with the combination of λ_i's as presented on Table 7. The simulated results in this case are shown in Fig. 14. The same tendency of control effect is appreciated also in this case.

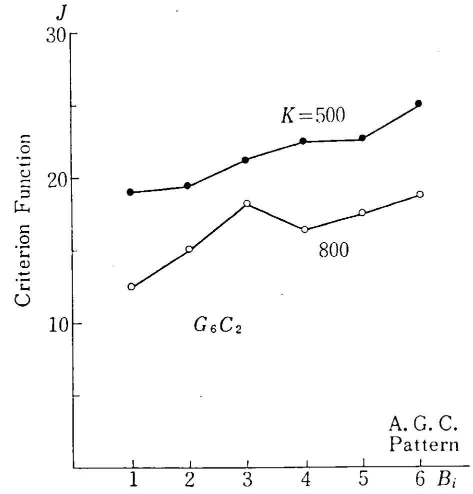


Fig. 10 Influence of A.G.C. Pattern.

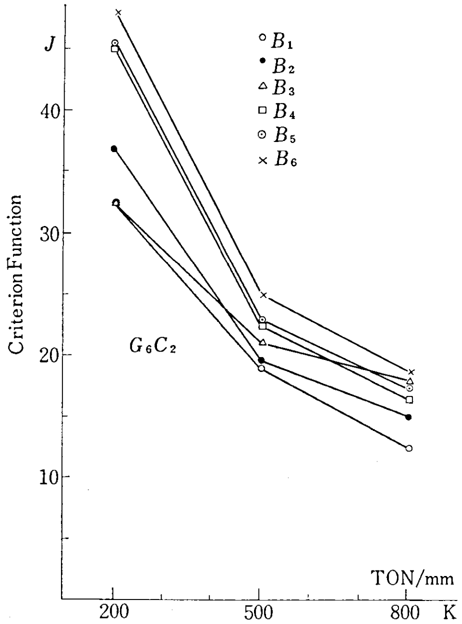


Fig. 11 Influence of Mill Modulus.

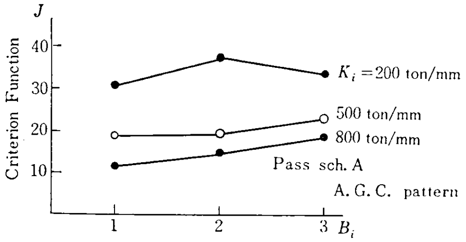


Fig. 12 Influence of Mill Modulus.

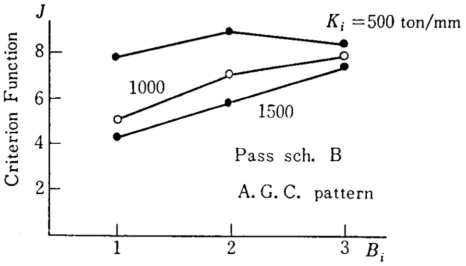


Fig. 13 Influence of Mill Modulus.

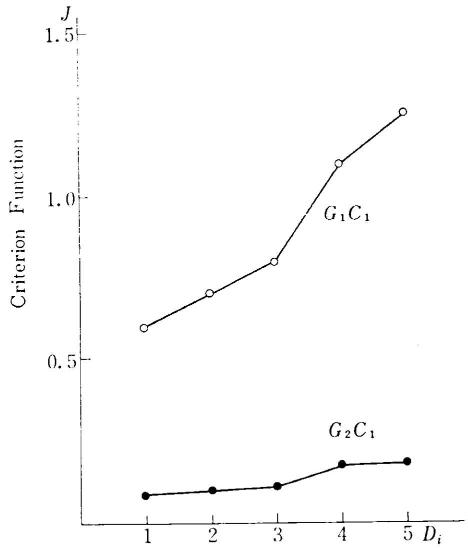


Fig. 14 Influence of A.G.C. Pattern.
(D_i shows the combination of Lamda)

5. Conclusion

From the discussions described above, we can conclude the characteristics of control system in the case of small deviation from the stationary rolling state.

Our conclusions are given as follows:

(1) It is desirable to have shorter delay time of screw-down motion of each stand.

(2) There exists optimum gain of integrator.

(3) It is desirable to have higher mill modulus.

(4) The best policy of feed-back control is that of pattern B_1. That is we must feed back to the final stand.

(5) The effect of A.G.C. system is influenced not only by mill modulus but also by the derivative of rolling force with respect to strip thickness.

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6. References

1) Nishimura et al: J. of JSTP, Vol. 4, No. 27, 1963
2) Hiraoka: 18th conference of JSTP, 1967
3) Kamata et al: J. of JSTP, Vol. 9, No. 90, 1968