JSW for CAL

CONFIDENTIAL

Outline for Strip Temperature Control

Contents

June , 2013

Steel Plantech

1. Outline

1.1 Overview

A basic factor determining the quality of strip on its annealing is the temperature history of the annealing process. For the continuous annealing furnace, the temperature history as determined by strip temperature at the delivery of each furnace section is called the heat pattern. This heat pattern is given as one of manufacturing specifications.

The principal object of the dynamic strip temperature control system is to keep the strip temperature at the delivery of each furnace section to a proper heat pattern by controlling the line speed, furnace temperature, etc. so as to allow the strip size change and to ensure that the maximum line speed is maintained within of several restrictions (ex. furnace capacity).

The dynamic strip temperature control system covers seven (6) furnace sections, namely; Pre-heating, Radiant tube heating, Radiant tube soaking, Slow cooling , Rapid cooling (Gas jet cooling) , Over aging

i) Pre-heating section
ii) Heating section
iii) Soaking section
iv) Slow cooling section
v) Rapid cooling section
vi) Over aging section

1.2 Abbreviation definition

Abbreviations used in this document are as follows.

1) Furnace section

i) PHS (Pre Heating Section)
ii) HS (Heating Section)
iii) SS (Soaking Section)
iv) SCS (Slow cooling Section)
v) RCS (Rapid cooling Section)
vi) OAS (Over aging section)
vii) FCS (Final Cooling section)

2) Line facility

i) POR	:Pay - off reel
ii) WDR	: welding machine
iii) ELP	:Entry Looper
iv) DLP	:Delivery Looper
v) SPM	:Skin pass Mill
vi) SHR	:Delivery shear
vii) TR	: Tension reel
viii) L2	: process computer(Level 2)
ix) DCS	:Instrumentation DCS
x) PLC	:Electric PLC

1.3 Line specification

1) Main specification

i) Line speed

(a) Entry Speed : 30 to 580 mpm

(b) Furnace Speed : 30 to 430 mpm

(c) Delivery Speed : 30 to 630 mpm

ii) Looper length

(a) Entry Looper : 1260 m

(b) Delivery Looper : 1368 m

2) Strip

i) Thickness : 0.35 to 2.3 mm

ii) Width : 800 to 1870 mm (Entry Coil= Delivery Coil)

3) Entry Coil (Charging coil)

i) Outer diameter : 2600 mm (Max.) 700mm (Min.)

ii) Inner Diameter : 508 / 610 mm

iii) Weight : 50 ton (Max.)

4) Delivery Coil

i) Outer diameter : 2200 mm (Max.) 700mm (Min.)

ii) Inner Diameter : 508 / 610 mm

iii) Weight : 30 ton (Max.)
5 ton (Min)

5) Zone arrangement and Pass length

Zone arrangement and Pass length are shown as Fig. 1-1

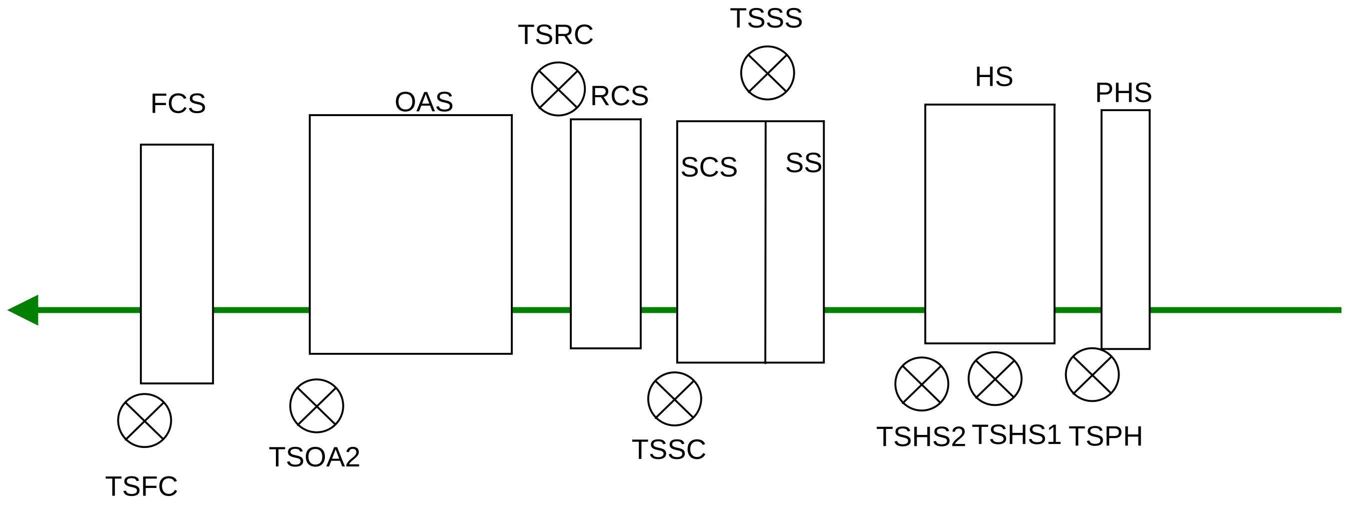


Fig. 1-1 Zone arrangement and Pass length

Section	Equipment	Zone	Pass	Pass length [m]
PHS	Exhaust gas	4	4(8)	109
HS	Radiant Tube	8	22(44)	596
SS	Radiant Tube	2	7(14)	194
SCS	Cooler & heater	4	5(10)	146
RCS	Cooler & heater	4	1(4)	44
OAS	Cooler & heater	4	25	667
FCS	Cooler	6	5(10)	-

< Table 1-1 >

6) Pass arrangement of HS

i) Definition:

(a) Pass No.

(b) Roll No.

(c) Pass arrangement of furnace section

Refer to Figure and Table

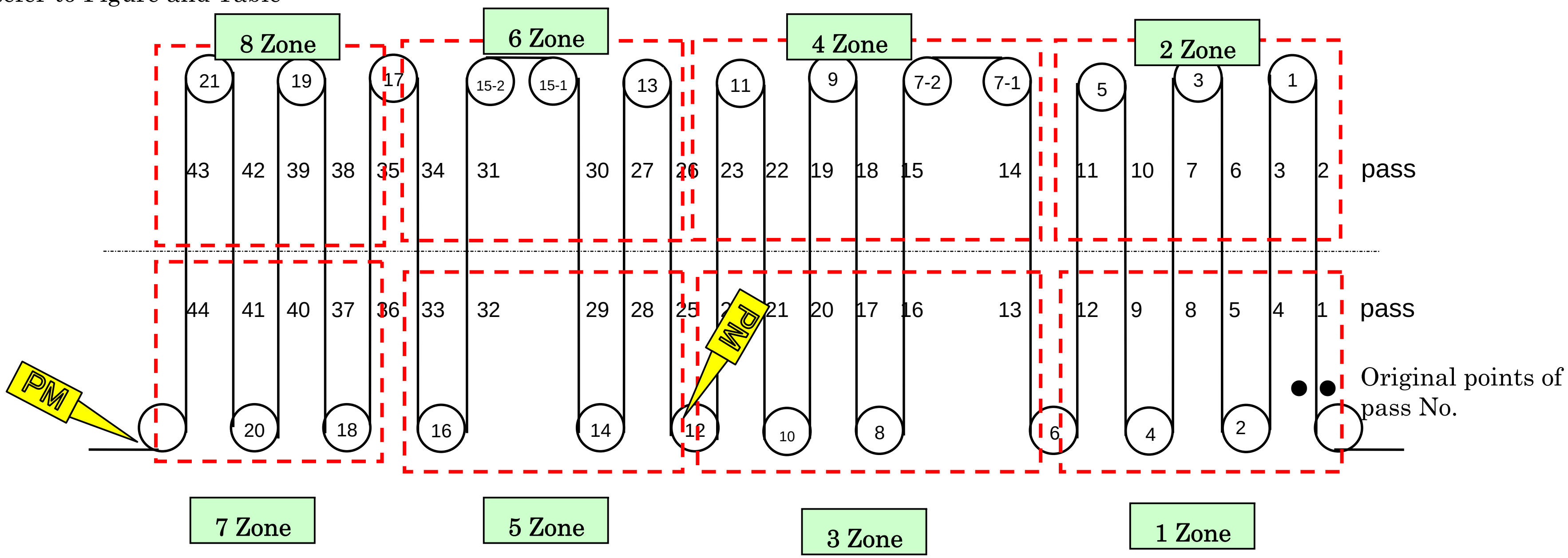


Fig. 1-2 HS Zone arrangement

ii) Pass Position

(a) Dps···Distance from original point to pass start position [m]

(b) Dpe···Distance from original point to pass end position [m]

iii) Variables

(a) Strip temperature (TS) [℃]

(b) Roll temperature (TR) [℃]

(c) Furnace temperature (TF) [℃]

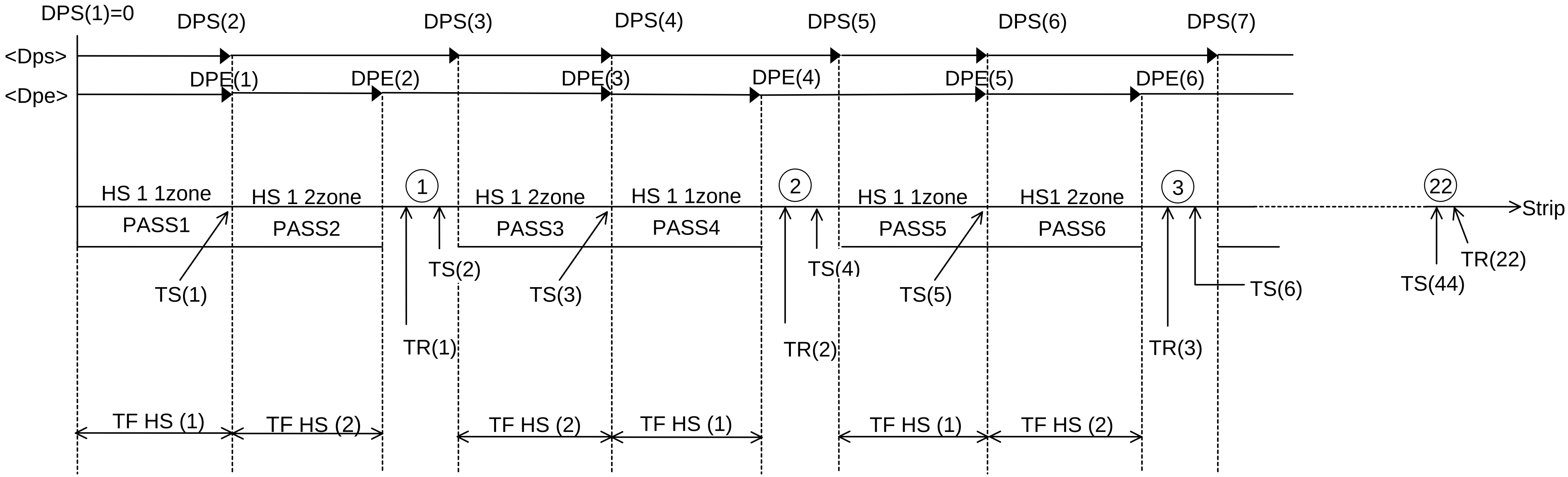


Fig. 1-3　HS Pass arrangement

Zone	Pass	Zone	Pass
1 (HS)	1,4,5,8,9,12	5 (HS)	25,28,29,32,33
2 (HS)	2,3,6,7,10,11	6 (HS)	26,27,30,31,34
3 (HS)	13,16,17,20,21,24	7 (HS)	36,37,40,41,44
4 (HS)	14,15,18,19,22,23	8 (HS)	35,38,39,42,43

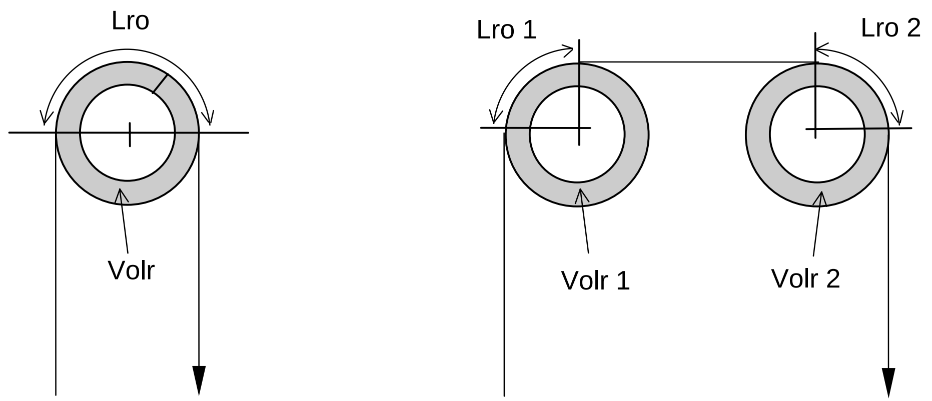
< Table 1-2 >

The Pass No. and Zone No. are serial number in HS. But HS1 section is 1~ 24 pass and HS2 section is 25 ~ 44 pass. They are separated and independent in the strip temperature control.

< Table 1-3 > HS Pass and Roll arrangement

Pass No. (Roll No.)		1	2	3	4	5	6	7-1,2	8	9	10	------	21
Pass	Dps	DPS (2)	DPS (4)	DPS (6)	DPS (8)	DPS (10)	DPS (12)	DPS (14)	DPS (16)	DPS (18)	DPS (20)	------	DPS (42)
	Dpe	DPE (2)	DPE (4)	DPE (6)	DPE (8)	DPE (10)	DPE (12)	DPE (14)	DPE (16)	DPE (18)	DPE (20)	------	DPE (42)
Roll	Volr	VOLR (1)	VOLR (2)	VOLR (3)	VOLR (4)	VOLR (5)	VOLR (6)	VOLR (7)	VOLR (8)	VOLR (9)	VOLR (10)	------	VOLR (21)
	Lro	LRO (1)	LRO (2)	LRO (3)	LRO (4)	LRO (5)	LRO (6)	LRO (7)	LRO (8)	LRO (9)	LRO (10)	------	LRO (21)
	Rhor	RHOR (1)	RHOR (2)	RHOR (3)	RHOR (4)	RHOR (5)	RHOR (6)	RHOR (7)	RHOR (8)	RHOR (9)	RHOR (10)	------	RHOR (21)
HS zone No. (ZN)													

Note
Volr [m^3] Roll shell volume(= wall thickness* width *circumferential length)
Lro [m] Roll and strip contact length
Rhor [kg/m^3] Roll density



Lro = Lro1 + Lro2
Volr = Volr1 + Volr2

< Case 1> < Case 2>

Fig. 1-4 Hearth roll

7) Pass arrangement of SS

i) Definition:

(a) Pass No.

(b) Roll No.

(c) Pass arrangement of furnace section

Refer to right figure and Table

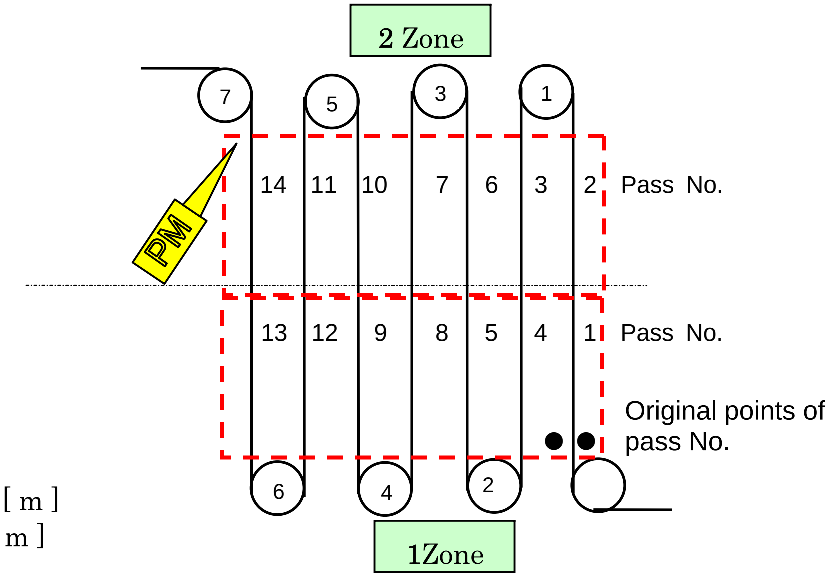


Fig. 1-5 SS zone

ii) Pass Position

(a) Dps···Distance from original point to pass start position [m]

(b) Dpe···Distance from original point to pass end position [m]

iii) Variables

(a) Strip temperature (TS) [℃]

(b) Roll temperature (TR) [℃]

(c) Furnace temperature (TF) [℃]

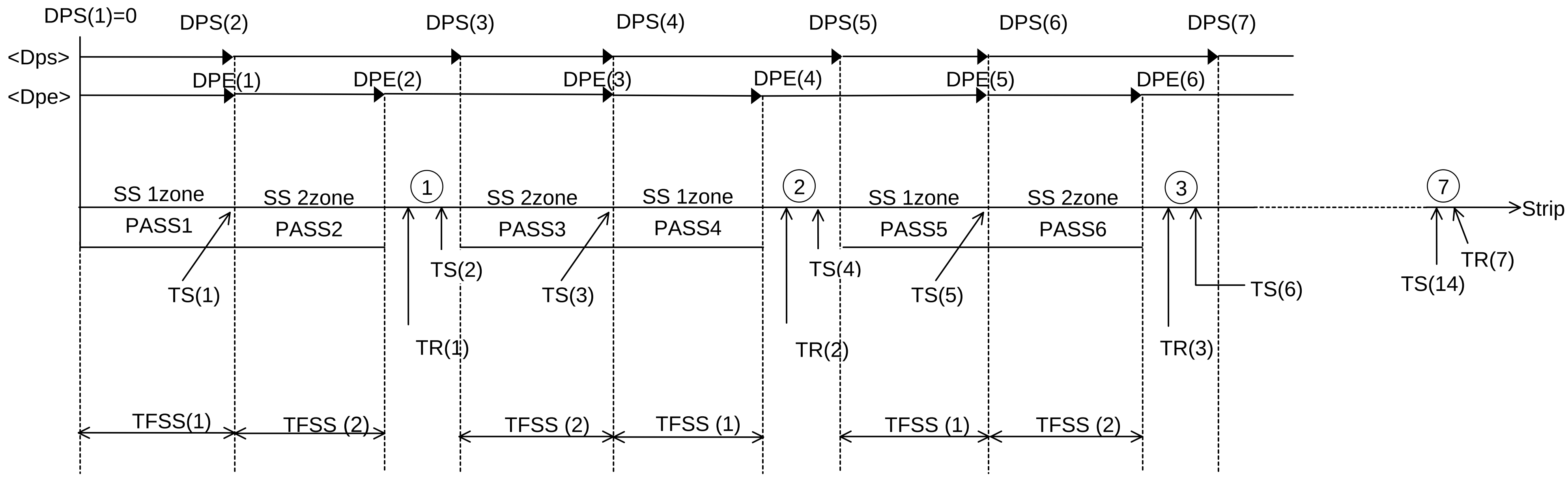


Fig. 1-6 SS Pass arrangement

< Table 1-4 >

Zone	Pass
1 (SS)	1,4,5,8,9,12,13
2 (SS)	2,3,6,7,10,11,14

8) Pass arrangement of SCS

i) Definition:

(a) Pass No.

(b) Roll No.

(c) Pass arrangement of furnace section

Refer to Figure and Table

Gas jet nozzle

Furnace temp.

ii) Pass Position

(a) Dps···Distance from original point to pass start position [m]

(b) Dpe···Distance from original point to pass end position [m]

iii) Variables

(a) Strip temperature (TS) [℃]

(b) Furnace temperature (TF) [℃]

(c) Cooling gas presure (PG) [mmH2O]

(d) Cooling gas temperature (TG) [℃]

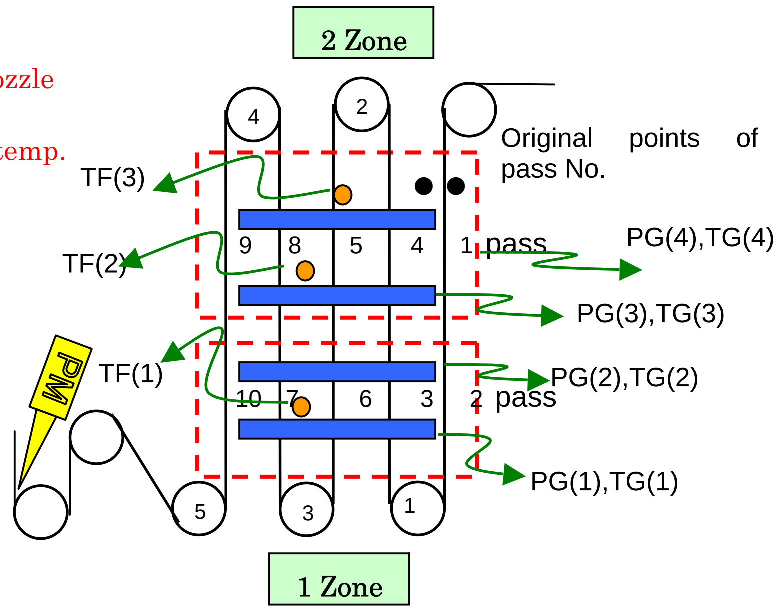


Fig. 1-7 SCS Zone arrangement

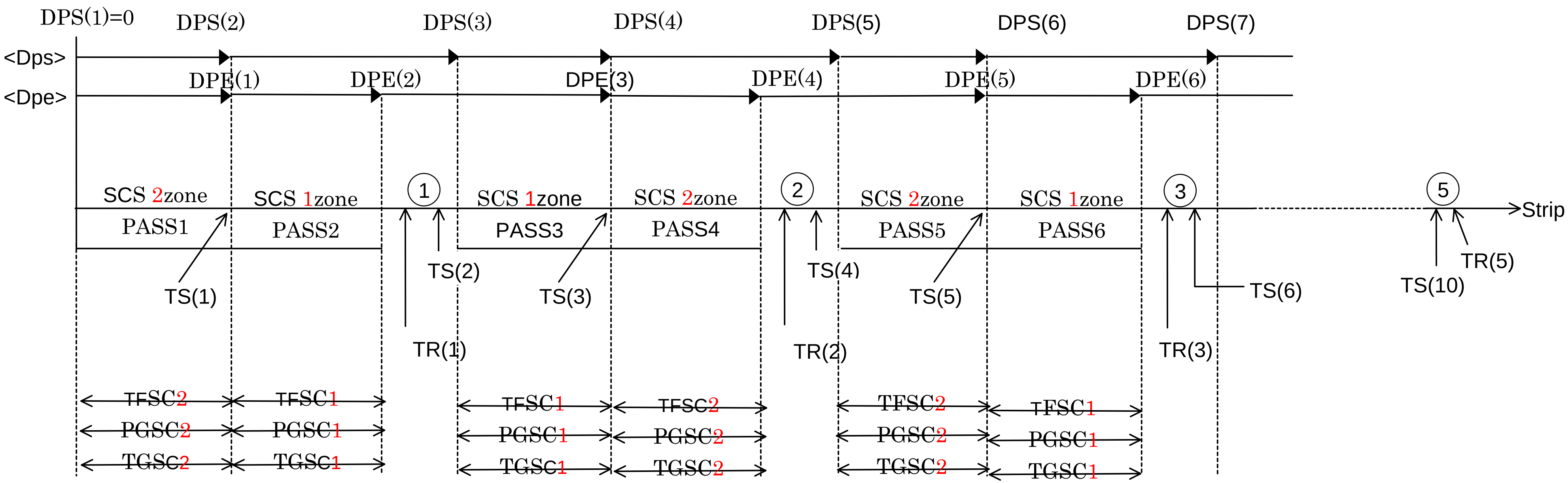


Fig. 1-8 SCS Pass arrangement

< Table 1-5 >

Zone	Pass
1 (SCS)	2,3,6,7,10
2 (SCS)	1,4,5,8,9

TFSC1= TF(1)
TFSC2= (TF(2) +TF(3))/2
PGSC1= (PG(1)+ PG(２))/2
PGSC2= (PG(3)+ PG(4))/2
TGSC1= (TG(1)+ TG(２))/2
TGSC2= (TG(3)+ TG(4))/2

9) Pass arrangement of RCS

i) Definision :

(a) Pass No.

(b) Pass arrangement of cooling section

Refer to Figure and Table

< Table 1-6 >

Pass No.	Cooling zone
1	1
2	2
3	3
4	4

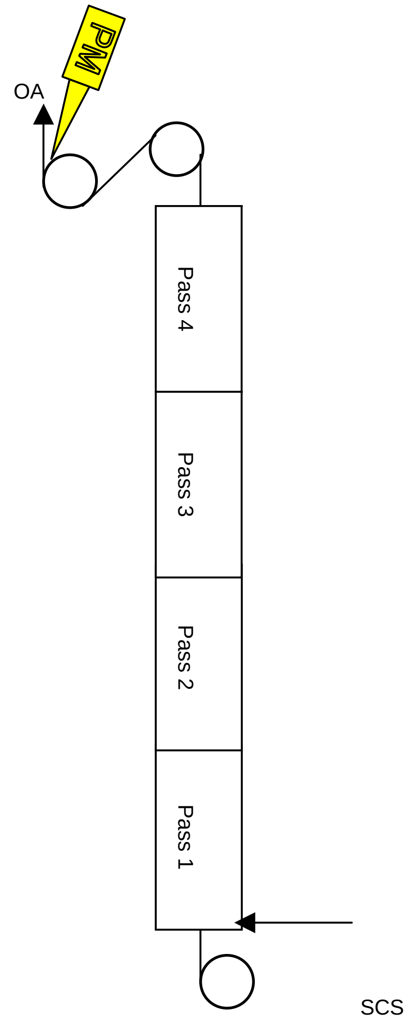


Fig. 1-9 RCS Zone arrangement

ii) Pass Position

(a) Dps···Distance from original point to pass start position [m]

(b) Dpe···Distance from original point to pass end position [m]

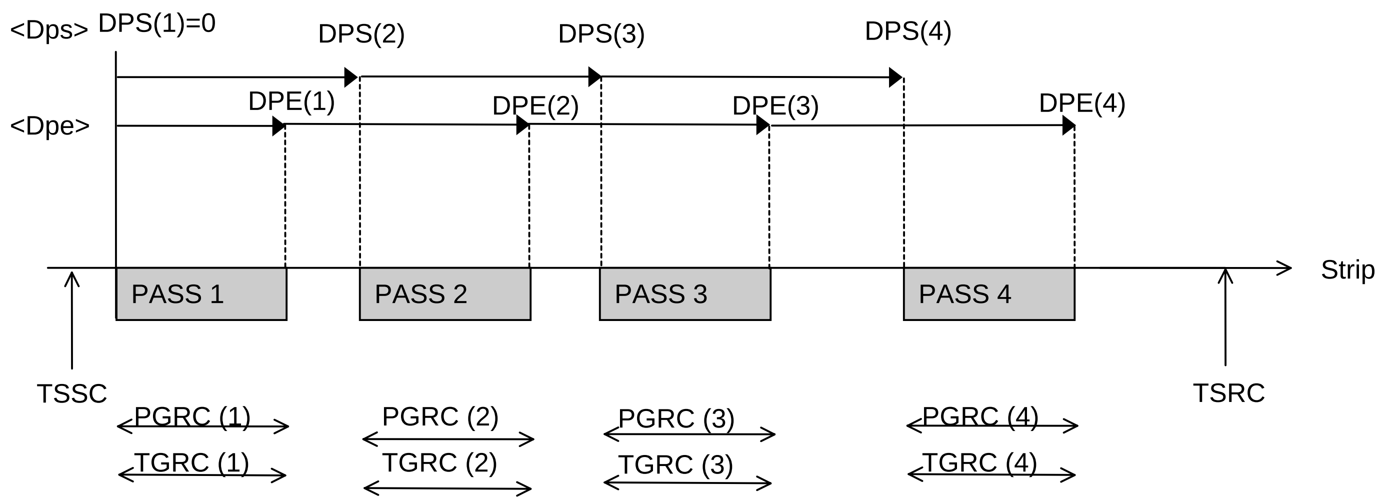


Fig. 1-10 RCS Pass arrangement

iii) Variables

(a) Strip temperature (TS) [℃]

(b) Cooling gas presure (PG) [mmH2O]

(c) Cooling gas temperature (TG) [℃]

(d) Furnace temperature (TF) [℃]

< Table 1-7 >

Pass No.	1	2	3	4
Dps [m]	DPS (1)	DPS (2)	DPS (3)	DPS (4)
Dpe [m]	DPE (1)	DPE (2)	DPE (3)	DPE (4)

10) Pass arrangement of OAS

i) Definition:

(a) Pass No.

(b) Zone No.

(c) Pass arrangement of furnace zone and cooling zone
Refer to Figure and Table

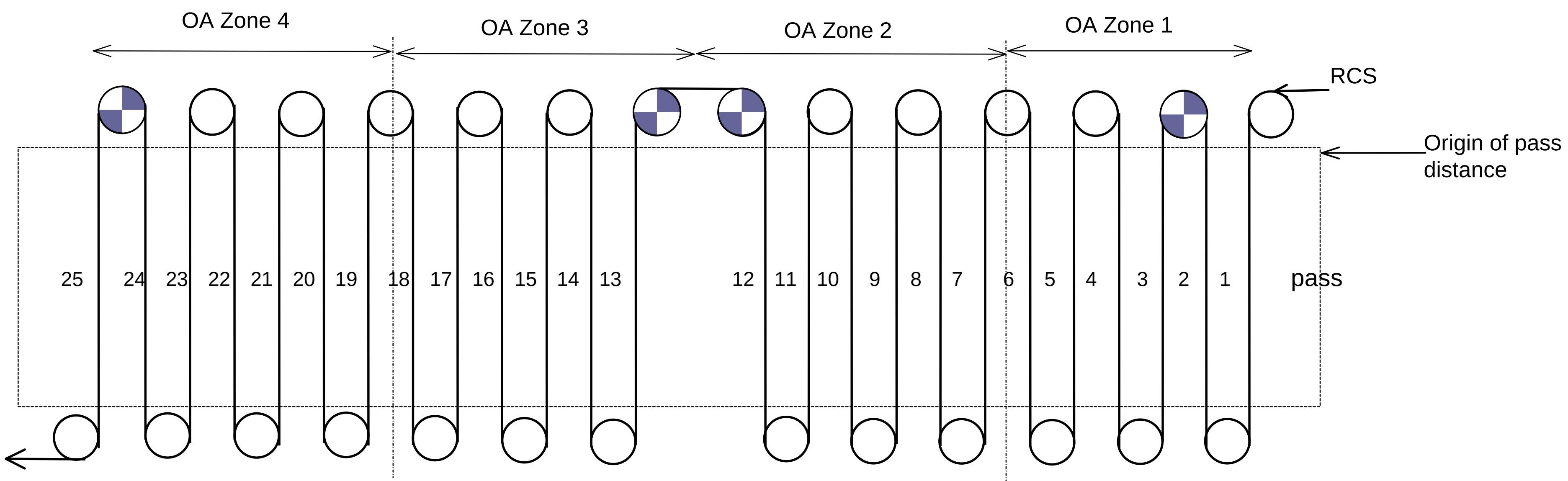


Fig. 1-11 OAS Zone arrangement

ii) Pass Position

(a) Dps···Distance from original point to pass start position [m]

(b) Dpe···Distance from original point to pass end position [m]

< Table 1- 8 >

Pass No	Zone No
1, 2, 3, 4, 5, 6	Zone 1
7, 8,9, 10, 11, 12	Zone 2
13, 14, 15, 16, 17,18	Zone 3
19,20,21,22,23,24,25	Zone 4

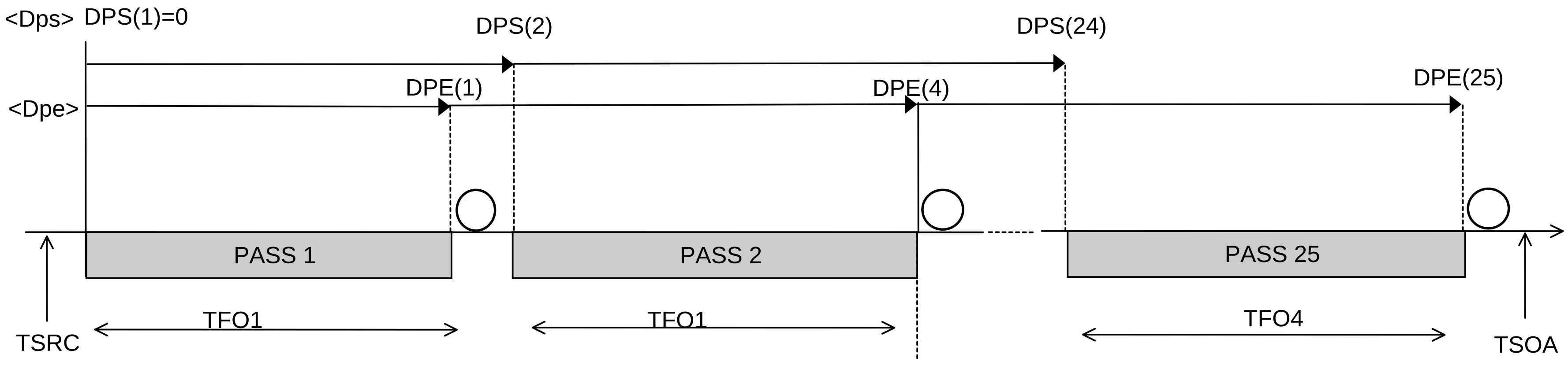


Fig. 1-12 OAS Pass arrangement

iii) Variables

(a) Furnace temperature (TF) [℃]

(b) Cooling gas presure (PG) [mmH2O]

(c) Cooling gas temperature (TG) [℃]

Pass No.	1	2	3	4	----	24	25
Dps [m]	DPS (1)	DPS (2)	DPS (3)	DPS (4)	----	DPS (24)	DPS (25)
Dpe [m]	DPE (1)	DPE (2)	DPE (3)	DPE (4)	----	DPE (24)	DPE (25)
Zone No. ZN [-]					----		

< Table 1-9 >

1.4 Heat cycle Table

Strip temperature target on Heat cycle shows Fig. 1-13 and Table 1-10.

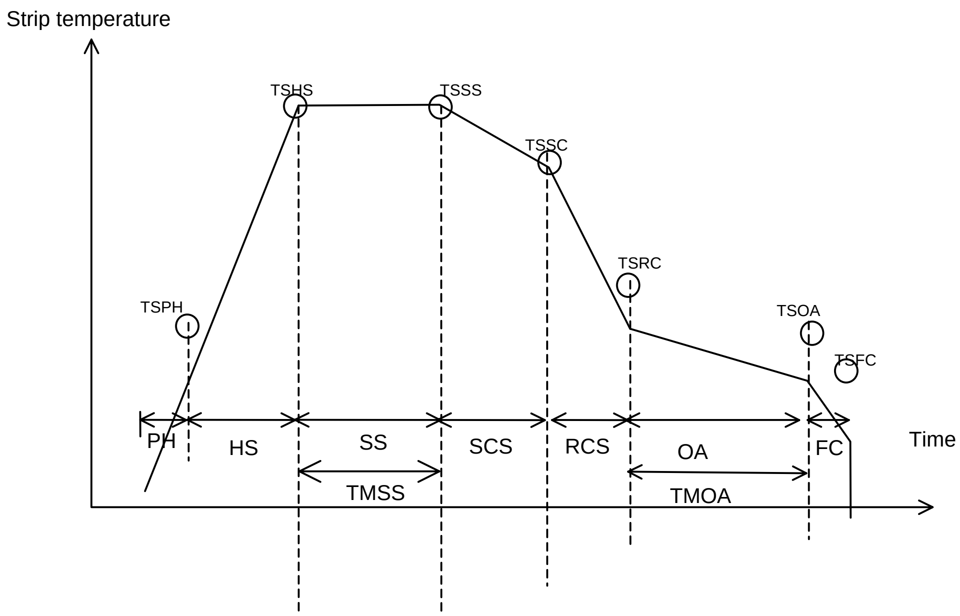


Fig. 1-13 Strip temperature target on Heat cycle

Annealing Number	Heat cycle name		PHS Entrance	PHS exit	HS1	HS2	SS	SCS	RCS	OAS	FCS	WCS	Soaking time	OA time	Max T/Hr
1	CR-LC-CQ	Upper			550	730	730	670	460	460	150				
		Target	20	200	530	710	710	650	430	430	120		>20	>90	
		Lower			510	690	690	630	400	400	90				
2	CR-LC-CQ	Upper			560	740	740	670	460	460	150				
		Target	20	200	540	720	720	650	430	430	120		>20	>90	
		Lower			520	700	700	630	400	400	90				
3	CR-LC-CQ	Upper			570	750	750	680	460	460	150				
		Target	20	200	550	730	730	650	430	430	120		>20	>90	
		Lower			530	710	710	630	400	400	90				
4	CR-LC-DQ	Upper			600	760	760	690	460	460	150				
		Target	20	200	580	740	740	670	430	430	120		>20	>120	
		Lower			560	720	720	650	400	400	90				
5	CR-LC-DQ	Upper			610	770	770	690	460	460	150				
		Target	20	200	590	750	750	670	430	430	120		>20	>120	
		Lower			570	730	730	650	400	400	90				
6	CR-LC-DQ	Upper			610	780	780	690	460	460	150				
		Target	20	200	590	760	760	670	430	430	120		>20	>120	
		Lower			570	740	740	650	400	400	90				
7	CR-LC-DDQ	Upper			610	780	780	690	460	460	150				
		Target	20	200	590	760	760	670	430	430	120		>20	>120	
		Lower			570	740	740	650	400	400	90				
8	CR-LC-DDQ	Upper			620	790	790	690	460	460	150				
		Target	20	200	600	770	770	670	430	430	120		>20	>120	
		Lower			580	750	750	650	400	400	90				
9	CR-LC-DDQ	Upper			630	800	800	700	460	460	150				
		Target	20	200	610	780	780	680	430	430	120		>20	>120	
		Lower			590	760	760	660	400	400	90				
10	CR-IF-ULC-DDQ	Upper			650	800	800				150				
		Target	20	200	630	780	780	650	430	430	120		>20	-	
		Lower			610	760	760				90				

< Table 1-10-a > Heat cycle table (Low)

Annealing Number	Heat cycle name		PHS Entrance	PHS exit	HS1	HS2	SS	SCS	RCS	OAS	FCS	WCS	Soaking time	OA time	Max T/Hr
11	CR-LC-HSS-440	Upper			660	810	810	670	460	460	150				
		Target	20	200	640	790	790	650	430	430	120		>20	-	
		Lower			620	770	770	630	400	400	90				
12	CR-LC-HSS-440	Upper			670	820	820	670	460	460	150				
		Target	20	200	650	800	800	650	430	430	120		>20	-	
		Lower			630	780	780	630	400	400	90				
13	CR-LC-HSS-440	Upper			680	830	830	670	460	460	150				
		Target	20	200	660	810	810	650	430	430	120		>20	-	
		Lower			640	790	790	630	400	400	90				
14	CR-LC-HSS-590	Upper			690	840	840	670	430	430	150				
		Target	20	200	670	820	820	650	400	400	120		>20	-	
		Lower			650	800	800	630	370	370	90				
15	CR-LC-HSS-590	Upper			690	850	850	670	430	430	150				
		Target	20	200	670	830	830	650	400	400	120		>20	-	
		Lower			650	810	810	630	370	370	90				
16	CR-LC-HSS-590	Upper			700	860	860	680	430	430	150				
		Target	20	200	680	840	840	660	400	400	120		>20	-	
		Lower			660	820	820	640	370	370	90				
17	CR-DP-HSS-590	Upper			690	840	840	720	330	330	150				
	CR-DP-HSS-780	Target	20	200	670	820	820	700	300	300	120		>20	-	
		Lower			650	800	800	680	270	270	90				
18	CR-DP-HSS-780	Upper			695	840	840	720	330	330	150				
		Target	20	200	675	830	830	700	300	300	120		>20	-	
		Lower			655	800	800	680	270	270	90				
19	CR-DP-HSS-980	Upper			695	845	845	720	330	330	150				
		Target	20	200	675	825	825	700	300	300	120		>20	-	
		Lower			655	805	805	680	270	270	90				
20	CR-DP-HSS-980	Upper			700	850	850	720	330	330	150				
		Target	20	200	680	830	830	700	300	300	120		>20	-	
		Lower			660	810	810	680	270	270	90				

< Table 1-10-b > Heat cycle table (Middle)

Annealing Number	Heat cycle name		PHS Entrance	PHS exit	HS1	HS2	SS	SCS	RCS	OAS	FCS	WCS	Soaking time	OA time	Max T/Hr
21	CR-IF-ULC-EDDQ	Upper			690	840	840	-	-	-	150				
		Target	20	200	670	820	820	650	430	430	120		>20	-	
		Lower			650	800	800	-	-	-	90				
22	CR-IF-ULC-EDDQ	Upper			700	850	850	-	-	-	150				
		Target	20	200	680	830	830	650	430	430	120		>20	-	
		Lower			660	810	810	-	-	-	90				
23	CR-IF-ULC-EDDQ	Upper			710	860	860	-	-	-	150				
		Target	20	200	690	840	840	650	430	430	120		>20	-	
		Lower			670	820	820	-	-	-	90				
24	CR-IF-ULC-SEDDQ	Upper			710	850	850	-	-	-	150				
		Target	20	200	700	840	840	650	430	430	120		>20	-	
		Lower			690	830	830	-	-	-	90				
25	CR-IF-ULC-SEDDQ	Upper			710	860	860	-	-	-	150				
		Target	20	200	700	850	850	650	430	430	120		>20	-	
		Lower			690	840	840	-	-	-	90				
26	CR-IF-ULC-SEDDQ	Upper			720	870	870	-	-	-	150				
		Target	20	200	710	860	860	650	430	430	120		>20	-	
		Lower			700	850	850	-	-	-	90				
27	CR-IF-BH-HS-340	Upper			720	870	870	820	530	530	150				
		Target	20	200	700	850	850	800	500	500	120		>20	-	
		Lower			680	830	830	780	470	470	90				
28	CR-IF-BH-HS-340 CR-IF-ULC-HSS-440	Upper			730	880	880	820	530	530	150				
		Target	20	200	710	860	860	800	500	500	120		>20	-	
		Lower			690	840	840	780	470	470	90				
29	CR-IF-ULC-HSS-440	Upper			680	830	830	-	-	-	150				
		Target	20	200	660	810	810	800	430	430	120		>20	-	
		Lower			640	790	790	-	-	-	90				
30	CR-IF-ULC-HSS-440	Upper			690	840	840	-	-	-	150				
		Target	20	200	670	820	820	800	430	430	120		>20	-	
		Lower			650	800	800	-	-	-	90				

< Table 1-10-c > Heat cycle table (High)

1.5 I/F with the other system

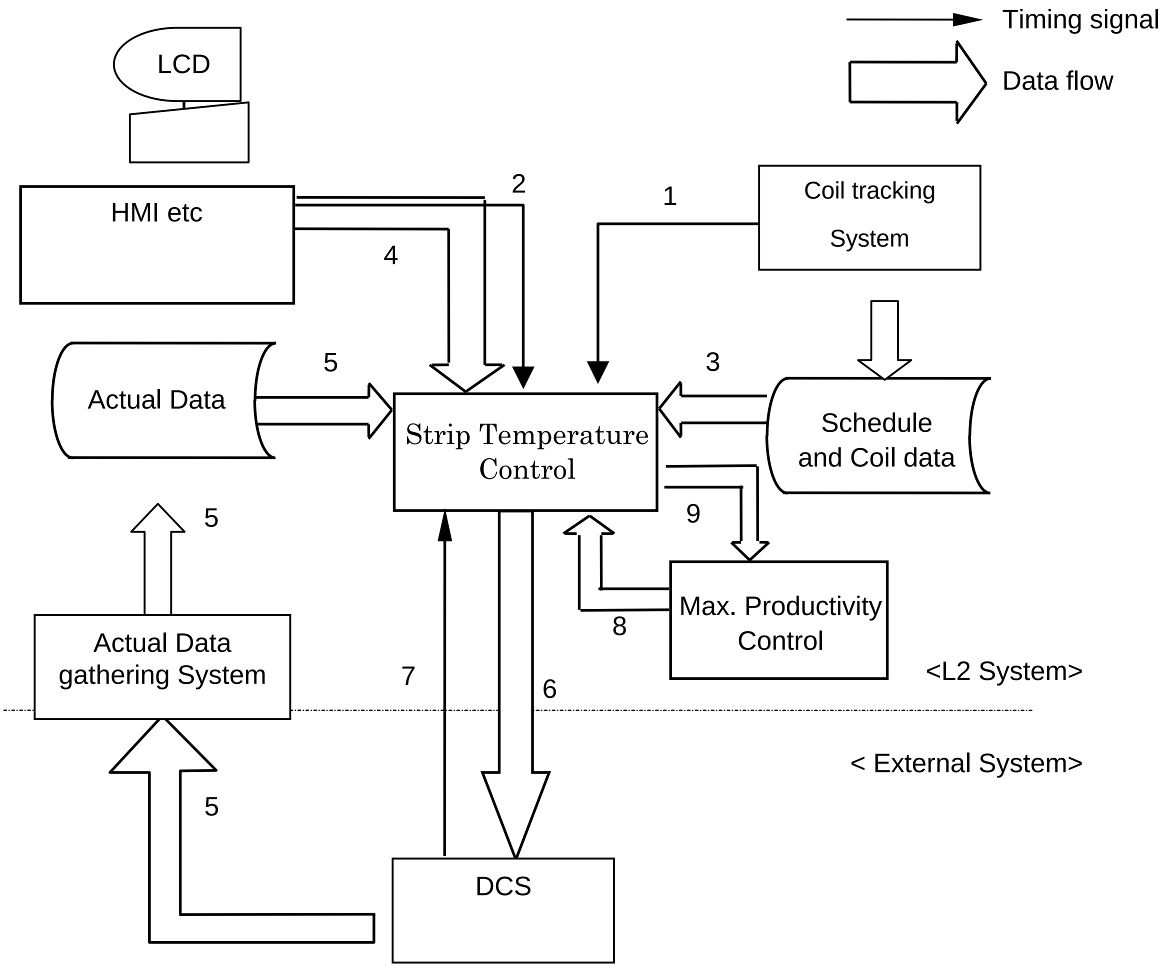
1) Overview

i) Strip temperature control System interfaces the following system.

(a) L2 other function

(b) DCS

The relationship with the other systems shows Fig. 1-14.



1. Coil Tracking
2. Operator input timing
3. Scheduled Coil data
4. Operator input etc
5. Process data
6. Set point
7. L2 mode ON/OFF
8. Speed change condition, speed reference
9. Center speed changing value (within 20mpm)

Fig. 1-14 Relationship between Strip temperature control and the other system

2) L2 other function

i) Coil Tracking signal

Coils and Welding points in CAL are traced by Tracking System. Coil Tracking System transmits Coil Tracking data with additional information to Strip temperature control System.

ii) Charging Schedule and Coil data

Strip temperature control System refers to Coil data of each tracking zone and Coil Charging Schedule.

iii) Operator input data

Operator input data are transmitted to Strip temperature control System via HMI.

iv) Actual process data

Actual process data is gathered by periodical data gathering system and stocked to the actual data file. Strip temperature control System can use the data anytime.

3) Instrumentation and Electrical control System

i) Instrumentation (DCS)

L2 send the control mode to DCS according to the control status and furnace condition. The control mode is prepared for each section. DCS change the control loops according to the instruction form Level-2.

(a) Strip temperature mode

L2 sets the strip target temperature to DCS. DCS control the strip temperature using strip temperature TIC, furnace temperature TIC, air – gas flow rate FIC, gas pressure PIC, and damper open / close control. And DCS has strip temperature control mode independent of Level-2.

(b) Furnace temperature mode

DCS uses the furnace temperature TIC base on the level-2 set value same as strip temperature mode. If operation mode is not Level-2, operators set the target temperature.

(c) Other mode

Manual setting is available for each TIC, PIC, FIC loop in DCS except Level-2 mode.

(d) Neutral mode (N mode)

Strip temperature control is changed to manual operation in this mod and each manipulated value is kept. This mode is used only tentatively on the transient condition.

ii) Electrical control System

(a) Weld point tracking

(b) Line speed and tension control

2. Strip temperature control System Overview

2.1 System Overview

Strip temperature control System has main four functions and auxiliary some functions.

1) Stable annealing control
2) Size change control (same Heat cycle)
3) Heat cycle change control
4) Periodical processing
   i) Strip temperature data gathering
   ii) Actual trip temperature monitoring, Furnace temperature correction
   iii) Stable condition discriminant
   iv) Model Parameter adaptive

The relation between main four functions and auxiliary some functions are sown as Fig. 2-1

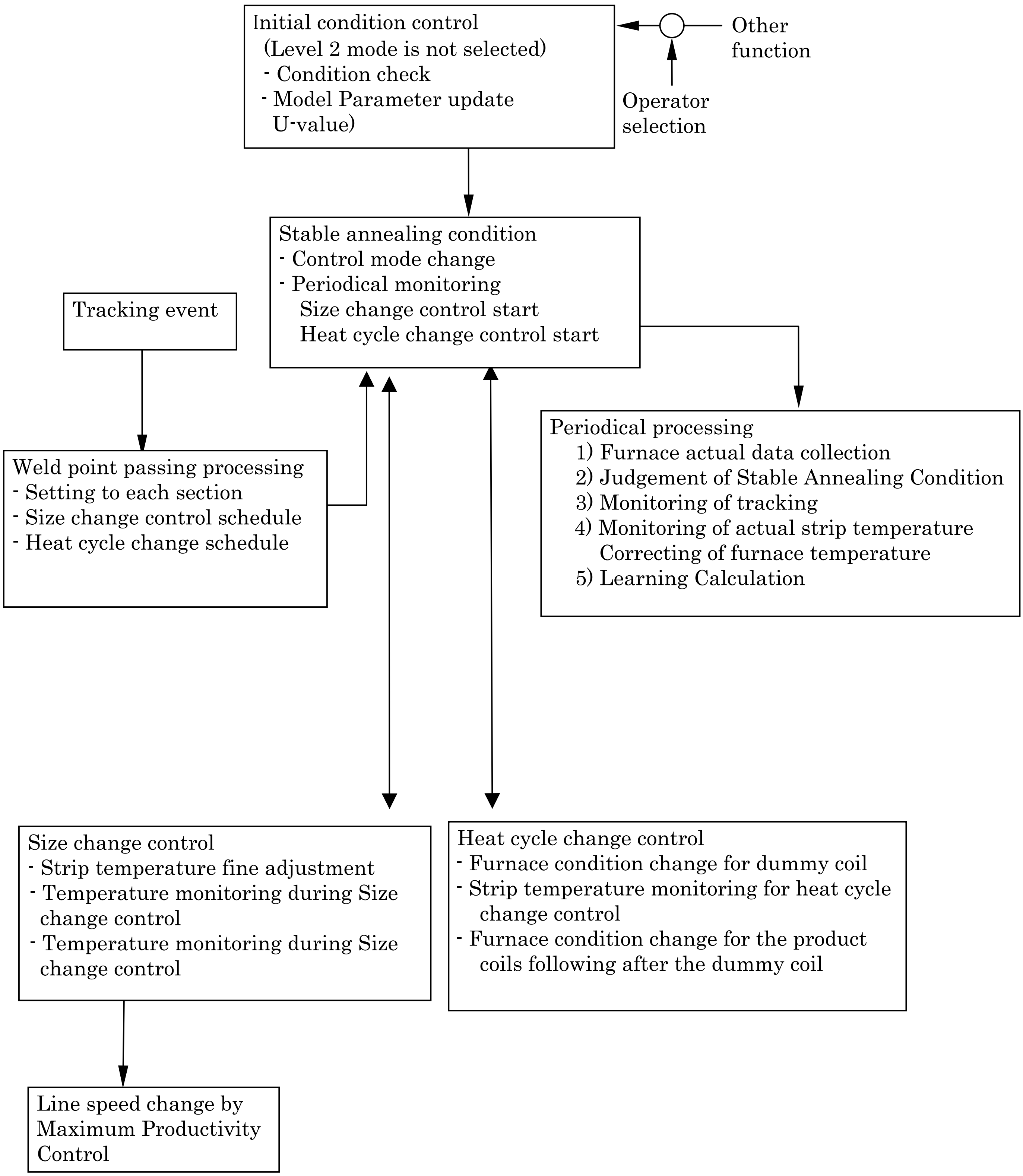


Fig. 2-1 Concept of Strip temperature control

2.2 Stable annealing condition

Each strip temperature of each section delivery during the stable annealing condition is monitored in the periodical interval and the following functions are executed.

1) Model Parameter update

If the strip temperature and furnace temperature is stable and within the temperature tolerance, Mathematical Model Parameters are updated. As a result, the heat transfer Mathematical Model represents the actual heat transfer phenomena precisely.

2.3 Size change control

This function is applied to the Size change point of the present coil and next coil, which does not include the heat cycle change.

1) Speed change during Size change control

Size change control has the two cases in which the furnace Speed is used and not used. If Speed change is available for the furnace condition, it is used for the Size change control.

When the both target temperature of the Previous and next coil is same, $v1 \cdot h1 = v2 \cdot h2$ is essentially hold.

v1:Previous coil Speed h1:Previous coil Thickness

v2:Next coil Speed h2:Next coil Thickness

If the furnace sped is used for the control, the size change control is executed at rapid response without the furnace condition change. But Speed operation has the influence to all section strip temperature and it is related to the Maximum Productivity Control. So the speed range for strip size change is limited within 20mpm.

2) Strip temperature fine adjustment before Size change control

While Size change point passes the furnace, the steep strip temperature change appears. This is called as Strip temperature jump, and this change cannot be reduced by any control. Therefore, this Strip temperature is controlled to shift to plus and minus against the target temperature. This control is Strip temperature fine adjustment and the target temperature is the transient temperature for the control in order to keep the temperature of the weld point neighborhood within the allowance range. Within the Heat cycle. Size change. In the case of speed use, the strip temperature adjustment is not necessary for the size change as later discussion.

3) Strip temperature monitoring at Size change control

This is the auxiliary function for Size change control. The strip temperature is normally within the allowance of temperature. But sometimes it is out of range due to a furnace disturbance. The strip temperature of each section delivery is monitored during Size change control, and if the temperature is out of range,the furnace temperature is corrected.

4) Control mode change at Size change control

When Operation mode is Auto., the control mode is furnace mode or neutral mode during Size change control. When the Size change control is finished, the control mode becomes to strip temperature mode. If operation mode is Semi- Auto, operators select the control mode.

2.4 Heat cycle change control

Each Heat cycle has the target temperature and the tolerance temperature for each section. When Heat cycle change is requested in Auto Mode, this control is always executed.

1) Strip temperature fine adjustment before Heat cycle change control

The target temperature of the previous coil is different from the next coil in Heat cycle change. Therefore, the temperature of the weld point = Heat cycle change point may be out of range. But normally the temperature tolerance of nearby coils (previous and next coil has common rage of temperature. So the target temperature is common temperature, which satisfies both heats cycle tolerance of nearby coils. The temperature fine adjustment is executed before the heat change point comes to the section delivery. Then the furnace speed is not used.

2) Furnace condition change for dummy coil

Dummy coils or low-grade coils are used for Heat cycle change control. When the head of dummy coils or low-grade coils come to the section delivery, the furnace temperature is set for the next product coil. And also, the target strip temperature of dummy coil is calculated for next product coil.

3) Strip temperature monitoring during Heat cycle change control

Actual strip temperature is monitored during Heat cycle change control, and if the temperature is out of range, the furnace temperature is corrected. When the Heat cycle change control is finished in Auto mode, the control mode becomes to the strip temperature mode.

2.5 Communication for Maximum Productivity Control

1) Interface items From Maximum Productivity Control to Strip temperature control

target Center speed, Acc. and Dec. rate, Acc prohibition ON/OFF

* Strip temperature control System judge the speed usage for the temperature control according to Center speed control mode (L1/L2), Acc prohibition ON/OFF.

(Refer top Table 2-1.)

(Speed can be used only in Size change control for HS. Refer 6.3 HS Size change control)

2) Interface items from Strip temperature control to Maximum Productivity Control

Center speed changing value(within 20mpm), Acc. and Dec. rate

* The target speed decided by Maximum Productivity Control includes the speed change from strip temperature control.

＜Table2-1 HS Size change control method>

Center speed Control mode	Only Speed	Acceleration prohibition ON/OFF	Speed Acc/ Dec	Method of heat cycle change
L1	-	-	-	Strip temperature fine adjustment
L2	○	OFF	-	only Speed
L2	○	ON	Deceleration	only Speed
L2	○	ON	Acceleration	Strip temperature fine adjustment
L2	×	OFF	-	Speed+Strip temperature fine adjustment
L2	×	ON	Deceleration	Speed+Strip temperature fine adjustment
L2	×	ON	Acceleration	Strip temperature fine adjustment

3. Mathematical Model

3.1 Overview

Strip temperature control System employs Mathematical Model based on the heat transfer theory. The target strip temperature of HS (Heating section), SS (Soaking section), SCS(Slow Cooling Section) , RCS (Rapid Cooling section) and furnace temperature of HS, SS are sent to DCS. And Strip temperature control System achieves the Strip temperature control with speed change closely concerned to Maximum Productivity Control. Mathematical Model used in this control is shown as Chapter 3.2 Mathematical Model. Each Mathematical Model is represented as difference equations and Model Parameter U is used in each model. This Model Parameter are updated when the furnace condition is judged as stable.

Model Parameter update is called as long-term error correction. Model Parameter update is slowly leaned to avoid a calculation runaway. Model parameters are calculated using actual strip temperature, actual furnace temperature, actual line speed and so on. And comparing the calculated value and actual vale of the strip temperature, the error is reflected to the next furnace target temperature.

3.2 Mathematical Model

Section	Model formula	Parameter
HS	$RHO \cdot H \cdot \frac{dQts}{dt}$ $= 2 \cdot U \cdot Ufs \cdot \sigma \cdot \left[(TF+273)^4 - (TS+273)^4 \right]$	Qts[Kcal/kg] Strip heat content TS[℃] Strip temperature t [h] Time H [m] Strip thickness RHO[kg/m^3] Strip density U [-] Model updating parameter σ [kcal/hm^2k^4] Stefan-Boltzmann constant Ufs[-] heat transfer coefficient TF[℃] Furnace temperature
SS	$TS = U \cdot TF$	TS [℃] Strip temperature TF [℃] Furnace temperature U [-] Model updating parameter
SCS	$RHO \cdot H \cdot \frac{dQts}{dt}$ $= 2 \cdot U \cdot \left[U1 \cdot C1 \cdot P^{C2} \cdot \left(\frac{C3}{TG+273} \right)^{C4} \cdot (TG - TS) \right.$ $+ U2 \cdot C5 \cdot \sigma \cdot ((TF+273)^4 - (TS+273)^4)$ $\left. + U3 \cdot C6 \cdot (TF - TS) \right]$	RHO[kg/m^3] Strip density H [m] Strip thickness Qts[Kcal/kg] Strip heat content t [h] Time U [-] Model updating parameter U1～U3 [-] heat transfer coefficient P [mmH_2O] coolant gas pressure TG[℃] coolant gas temperature TF[℃] Furnace temperature σ [kcal/m^2hk^4] Stefan-Boltzmann constant C1～C6 [-] Constant

Section	Model formula	Parameter
RCS	$RHO \cdot H \cdot \frac{dQts}{dt}$ $= 2 \cdot U \cdot [\ U1 \cdot C1 \cdot P^{C2} \cdot \left(\frac{C3}{TG + 273} \right)^{C4} \cdot (TG - TS)\ ]$	RHO[kg/m³] Strip density H [m] Strip thickness Qts[Kcal/kg] Strip heat content t [h] Time U [-] Model updating parameter U1 [-] heat transfer coefficient P [mmH_2O] coolant gas pressure TG[℃] coolant gas temperature C1～C4 [-] Constant
OAS	$RHO \cdot H \cdot \frac{dQts}{dt}$ $= 2 \cdot U \cdot Ufs \cdot \sigma \cdot [\ (TF + 273)^4 - (TS + 273)^4\ ]$	Qts[Kcal/kg] Strip heat content TS[℃] Strip temperature t [h] Time H [m] Strip thickness RHO[kg/m³] Strip density U [-] Model updating parameter σ [kcal/hm²k⁴] Stefan-Boltzmann constant Ufs[-] heat transfer coefficient TF[℃] Furnace temperature
Roll Heat transfer	$TSout = TR(i) - (TR(i) - TSin) \cdot e^{-\alpha}$ $\quad i = RNPX$ $where, \quad \alpha = [UR \cdot LPO(i)/(V \cdot 60)]/[*Cs(TSin) \cdot (H/1000) \cdot Rho]$	Qts[Kcal/kg] Strip heat content TSin[℃] Strip temperature; Entry of Roll Tsout [℃] Strip temperature; Delivery of Roll H[m] Strip thickness RHO[kg/m³] Strip density UR[-] heat transfer coefficient LPO[m] Roll contact length V[m] Line speed RNPX Roll No. TR [℃] Roll temperature

4. Control mode

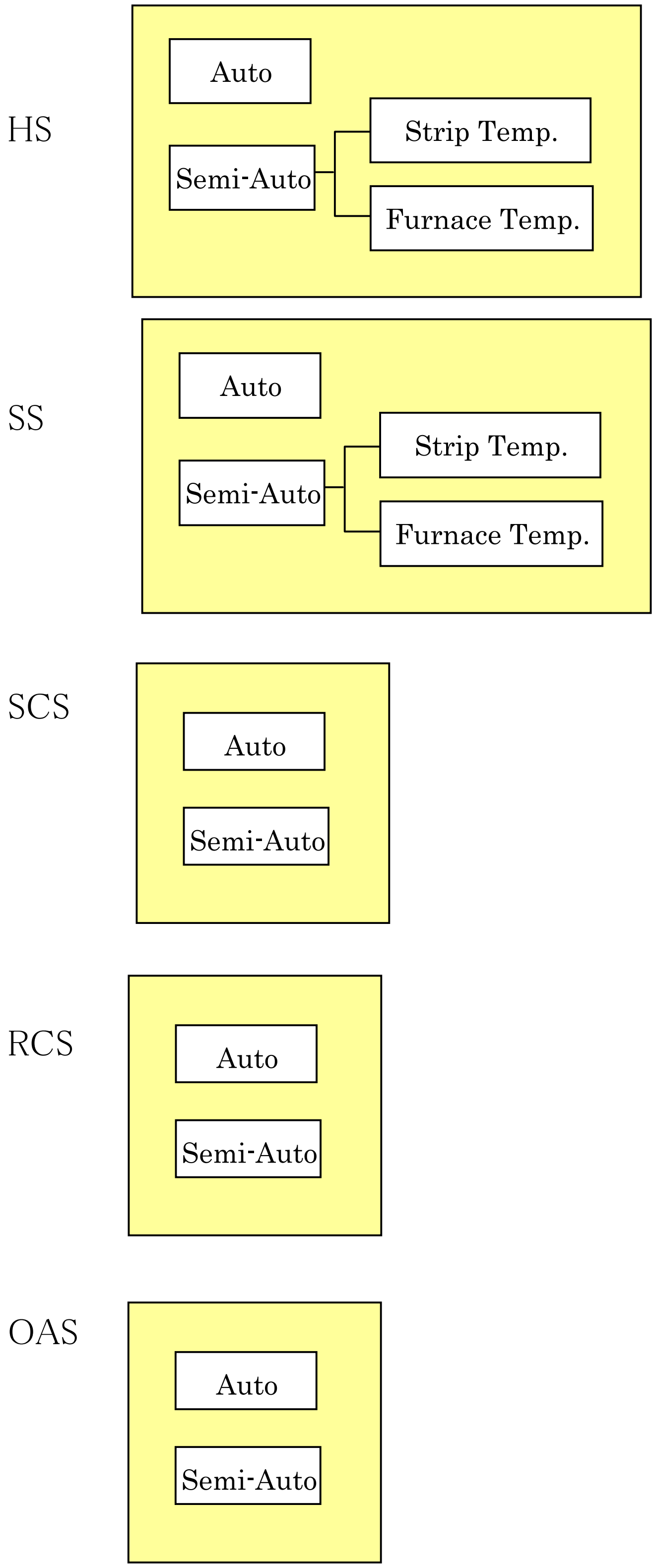


Fig.4-1 Control mode switch

4.1 Auto Mode

Auto Mode can work against Size change control and Heat cycle change control.
HS, SS; Control mode (furnace or strip temperature) is automatically changed.

4.2 Semi-Auto Mode

Semi-Auto Mode can't work against Size change control and Heat cycle change control.
At Semi-Auto Mode, Strip temperature control basically sets strip temperature on Heat cycle table.
HS, SS; Control mode (furnace or strip temperature) is manually changed.

4.3 Neutral Mode

At Neutral Mode, each manipulated value is kept in DCS.
Neutral Mode is used only at Size change control with speed.

4.4 HS

1) Auto mode; Furnace Temperature mode is selected at Size change control or Heat cycle change control. Strip Temperature mode is selected during Stable annealing. This changing is automatically. Size change control and Heat cycle change control carry out Strip temperature fine adjustment.
2) Semi-Auto mode; Operator selects Strip Temperature mode or Furnace Temperature mode. At Strip Temperature mode, the strip temperature is set target value on Heat cycle table. Semi-Auto Mode can't work against Size change control and Heat cycle change control.
3) Monitoring of actual strip temperature is always done and if strip temperature is abnormal, alarm is issued. Correcting of furnace temperature is done if Furnace Temperature mode is chosen.

4.5 SS

Basically, same as HS.

4.6 SCS, RCS, OAS

Each section has Auto mode and Semi-Auto mode. And about control mode, there is only Strip Temperature mode. Semi-Auto Mode can't work against Size change control and Heat cycle change control. Setting strip temperature target is done when welding point goes through the exit of each section.

5. Manual intervention

5.1 Overview

Manual intervention has the following process.

1) Setting strip temperature target

5.2 Strip temperature target

1) Heat cycle Table data is normally used to set Strip temperature target. But operator can change Strip temperature target using Manual intervention function temporarily.
2) Setting strip temperature target is reset to the original data on Heat cycle Table when Heat cycle changing point or Size changing point goes through the exit of each furnace section.

6. Size change control

6.1 Overview

In this chapter, Size change control without Heat cycle change is explained. Size change control with Heat cycle change is treated as Heat cycle change control.

Size change means changing thickness, not width. Because main heat transfer of radiant tube furnace (HS and SS) is radiation heat transfer and amount of heat transferred is same against width direction. If Strip Temperature target is same and thickness is different, target furnace temperature is different. So in this case, furnace temperature is changed, when Size change point (CAL welding point) passes at HS delivery. But time constant of furnace is very big, therefore off temperature might appear like Fig.6-1.

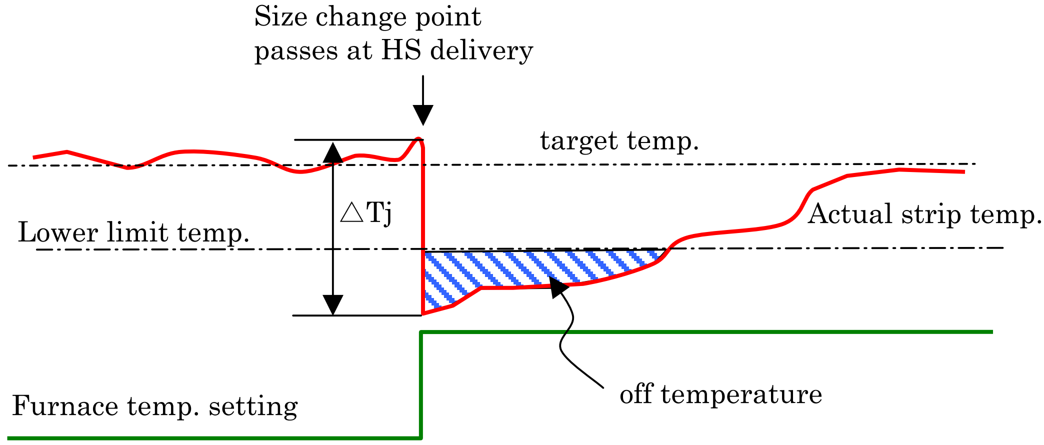


Fig. 6-1 Size change control without Strip temperature fine adjustment

Difference of thickness causes Strip temperature jump and Strip temperature jump cannot be reduced. But before Size change point comes to HS delivery, it is possible to modify furnace temperature to decrease off temperature. This control is defined “Strip temperature fine adjustment”.

Size change control with Strip temperature fine adjustment is shown at Fig.6-2.

Size change control is executed at Auto mode.

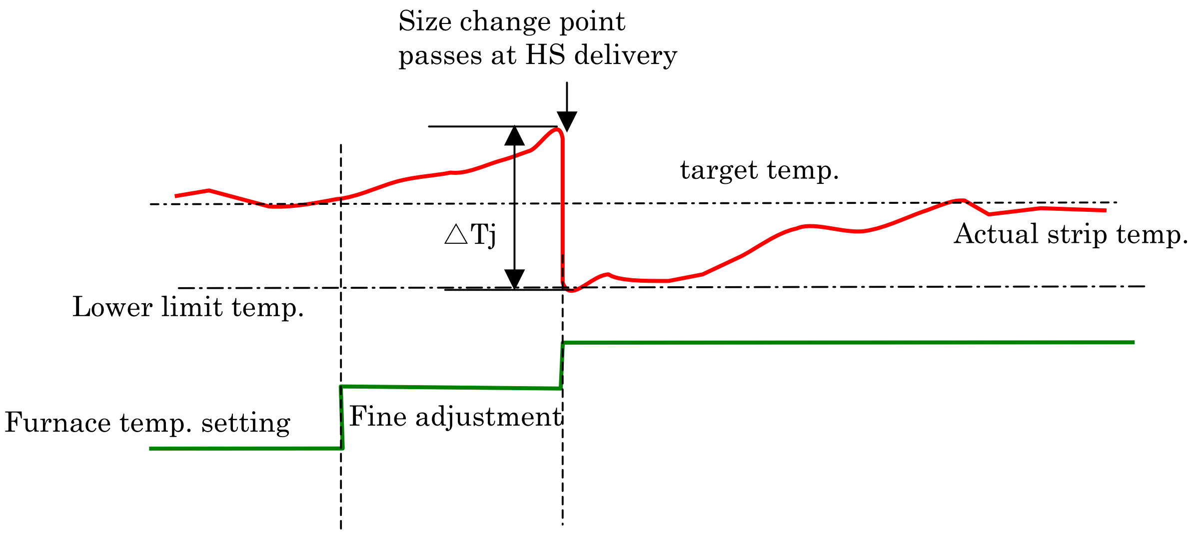


Fig. 6-2 Size change control with Strip temperature fine adjustment

Regarding the mathematical model of SS, SS Strip temperature jump does not occur and HS Strip temperature jump becomes small by roll heat transfer at SS delivery. But HS Strip temperature jump may remain, therefore Strip temperature jump is calculated same as HS and Strip temperature fine adjustment is executed at Auto mode in SS.

At Cooling section（SCS, RCS, OAS）, direction of Strip temperature jump is opposite to HS Strip temperature jump. HS Strip temperature jump is bigger than cooling section Strip temperature jump. Because HS Strip temperature difference from HS Entry to HS Delivery is bigger than cooling section's difference. As a result, Strip temperature jump may remain. Strip temperature jump is calculated same as HS and Strip temperature fine adjustment is executed at Auto mode in the cooling section.

6.2 Size change condition

1) In case there is only one Size change point from Welder to HS delivery, Size change control is executed. In case there are several Size change points from Welder to HS delivery, Size change whose control status comes earlier is executed. (Refer to 6.6 Plan for Size change control)

2) Maximum Size change rate (HR01) is the following.

$$\left|\frac{H1 - H2}{H1}\right| \geq HR01 \ \text{(Constant data)}$$

H1 : Previous coil thickness
H2 : Next coil thickness
Because amount of Size change is big in this case, off temperature might occur. If off temperature appears, alarm is issued.
If Size change rate is HR01 and more, Alarm is issued and Size change control is executed.

3) Minimum Size change rate (HR02) is the following.

$$\left|\frac{H1 - H2}{H1}\right| \leq HR02 \ \text{(Constant data)}$$

If Size change rate is HR02 or less, Size change control is not executed.

Fig.6-1~6-8 show several patterns of Size change control.

6.3 Size change control for HS

HS Size change control has three control method;

1:furnace speed changing

2:furnace speed changing + Strip temperature fine adjustment

3:Strip temperature fine adjustment

HS Size change control uses furnace speed (1 or 2) if possible. At same furnace temperature and same strip temperature, the following equation is basically held.

v1 * h1 = v2 * h2

v1:Previous coil speed h1:Previous coil thickness

v2:Next coil speed h2:Next coil thickness

Size change control can be executed without changing furnace temperature. But furnace speed is common to all furnace section and the influence may be big. In addition, Maximum Productivity Control sets up the target of furnace speed. Therefore furnace speed changing is executed within 20 mpm of changing amount at L2 mode of furnace speed. HS Speed changing timing is the following. (Refer to Fig.6-3)

T1: Size change point passes at HS Entry

T2: Size change point passes at HS Delivery

T3: The point which passed at HS Entry at T2 passes at HS Delivery

1)【CASE-1】furnace speed changing without Strip temperature fine adjustment

In case v1-v2= v1(1-h1/ h2) is 20 mpm or less, Size change control can be done by furnace speed changing only (refer to Fig.6-3) . Basically, Strip temperature jump is divided into plus and minus from target strip temperature equally. Therefore Strip temperature fine adjustment doesn't be required.

Neutral Mode (N-mode) ; In case of only furnace speed changing, Strip temperature control is not done during Size change control.

At N-mode, actual strip temperarure is monitored, but furnace temperature is not corrected.

(a) Procedure

① Calculation of Strip temperature jump (Refer to 6.6 Plan for Size change control and 6.8 Calculation of Strip temperature jump)

② Timing of furnace speed changing and amount of furnace speed changing

Start timing of furnace speed changing (T1) : Size change point passes at HS Entry

End timing of furnace speed changing (T2) : Size change point passes at HS Delivery

Acc. and Dec. rate is the following.

$\alpha = -(v1^2 - v2^2)/Lhs/2$

$\triangle v = v1(1 - h1/h2)$

③ Size change point passes at HS Delivery

Furnace speed changing is finished.

(b) Status of HS Size change control

① ON : X-WPD passing length of Next coil = 0 (T1)

② OFF : X-WPD passing length of Next coil = Lhs * 2 (T3)

(c) Control mode during Size change control; N-mode

(d) Monitoring of actual strip temperature and Furnace temperature Correction

Monitoring of actual strip temperature during Size change control is same method during Stable annealing. When off temperature (out of Heat cycle limit) occurs, alarm is issued. Furnace temperature is not corrected.

Refer to 9. Periodical processing and 10. Monitoring of actual strip temperature

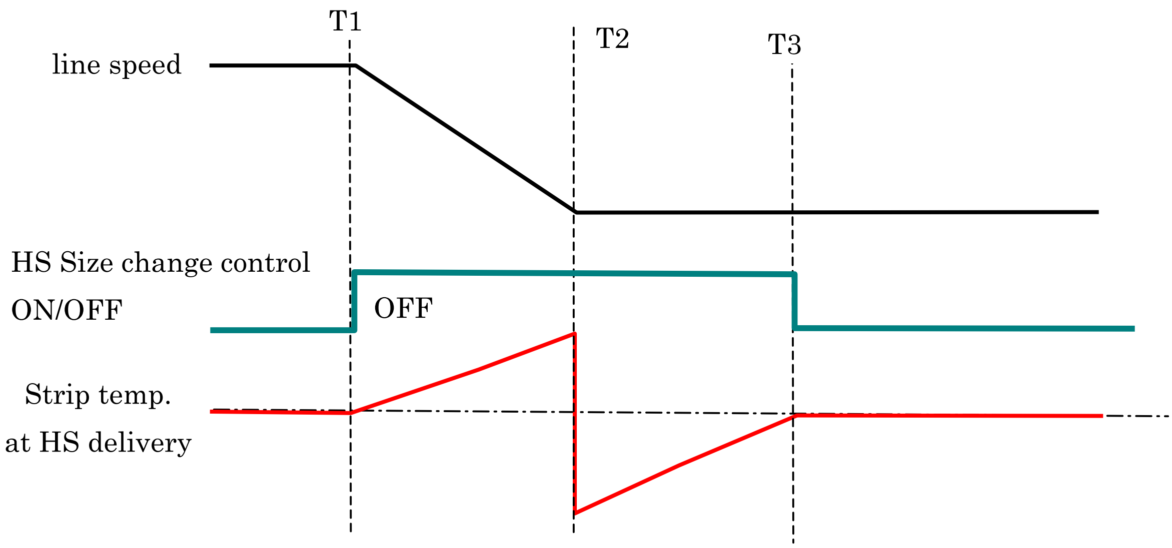


Fig.6-3 HS Size change control using furnace speed: Thin→Thick

In case of “HS Size change control using furnace speed: Thin→Thick”, Size change control raises Strip temperature at HS delivery during reducing speed (T1 ~ T2). And Strip temperature jump appears when Size change point passes at HS Delivery. Then strip temperature rises again because the strip which passes at HS delivery at the time from T2 to T3 has been decelerated at HS section. Thus Strip temperature jump mostly shifts to plus and minus against the target temperature.

2) 【CASE-2】furnace speed changing + Strip temperature fine adjustment

In case of "Thin→Thick" Size change control and amount of furnace speed changing "v1-v2= v1(1-h1/ h2)" is more than 20mpm, this condition shows Fig. 6-4. Using speed only, strip temperature of next coil is low (Red line in Fig. 6-4). Thus, Strip temperature fine adjustment is executed to compensate for this shortage defined "△Tss". During Size change control, Actual strip temperature monitoring is executed and furnace temperature is corrected if necessary.

(a) Procedure

① Calculation of Strip temperature jump (Refer to 6.6 Plan for Size change control and 6.8 Calculation of Strip temperature jump)

② Tail temperature of Previous coil at using only furnace speed (-20mpm); Tsa is calculated.

The target of Strip temperature fine adjustment ; Tsta=Tst1-△Tj/2

In this case, Tsta＞Tsa. Because the speed manipulated value is limted to 20 mpm.

shortage of using furnace speed; △Tss＝Tsta-Tsa

Strip temperature fine adjustment rises temperature whose amount is △Tss.

Therefore, target of Strip temperature fine adjustment is Tstas=Tst1+△Tss. Furnace speed of next coil is v 1-20mpm.

(Size change control Schedule)

Tf : Furnace temp. target of Previous coil
Tst1 : strip temp. target of Previous coil
△Tj : Strip temperature jump from Previous coil to Next coil
Tsa : tail temp. of Previous coil at using only furnace speed (-20mpm)
Tsta : target of "furnace speed changing + Strip temperature fine adjustment"
△Tss : shortage of using furnace speed (=Tsta-Tsa)
Tstas : target of Strip temperature fine adjustment

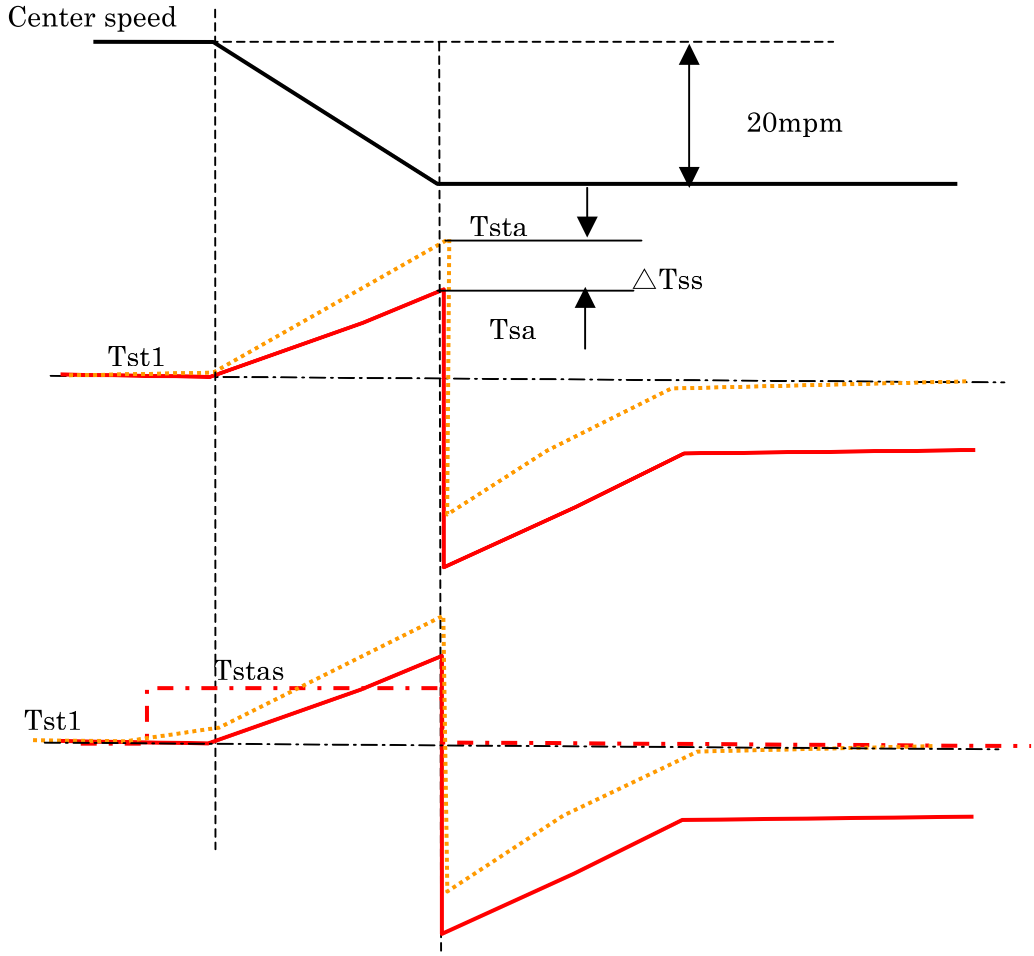


Fig. 6-4 HS Size change control using speed and Strip temp. fine adjustment: Thin→Thick

③ Start timing of Strip temperature fine adjustment（Size change control Schedule）

Start timing of Strip temperature fine adjustment is △tm(necessary period to rise temperarure △Tss) before Size change point comes to HS Delivery. △tm is obtained by furnace response table (rising temperature).

$\triangle tm=\triangle Tss / CS$

$Ly= \triangle tm * Va$

CS :Furnace response speed(Rising temperature ,Dropping temperature in Table)

Va :Actual speed

Ly :necessary transport distance for Strip temperature fine adjustment

Start timing of Strip temperature fine adjustment is the following.

X-WPD passing length of Next coil =-(Ly-Lhs)

* It is necessary for Ly to satisfy “Ly <= Previous coil”.

When Size change point passes at HS delivery, Strip temperature fine adjustment is reset.

④ Timing of furnace speed changing and amount of furnace speed changing

Same as CASE-1. Amount of furnace speed changing is 20mpm (fixed value).

Start timing of furnace speed changing（T1）：Size change point passes at HS Entry

End timing of furnace speed changing (T2)：Size change point passes at HS Delivery

Acc. and Dec. rate is the following.

$\alpha = -(v1^2-v2^2)/Lhs/2$

$= -20(v1-10)/Lhs$ 　(In case, v2=v1-20)

$\triangle v=\pm 20$

Acc. and Dec. time is the following.

$tac=2*Lhs/(v1+v2)= Lhs/(v1-10)$ (min)

⑤ Size change point passes at HS Delivery

If control mode is Furnace temperature, Furnace temperature is changed to next coil furnace temperature. Furnace speed changing and Strip temperature fine adjustment are finished.

(b) Status of HS Size change control

① ON :Start timing of Strip temperature fine adjustment

X-WPD passing length of Next coil = -(Ly-Lhs)

② OFF :When the second sampling timing comes after Size change point passes the HS Delivery, Tsac is defined as Strip temperature Actual and △Tasz is as △Tasz = Tsac -Tst2. At Size change control, Tst1=Tst2. When the weld point (= Size change point) comes to HS Delivery, Strip temperature is chaged and the change value of strip temperature is △Tasz. If △Tasz is plus value, Strip temperature is corrected to the dropping temperature direction, and if it is mainus value, the temperaure is to rising temperature dorection. The time until the strip temperature is chaged to the target, is estimated same as Size change control start time, in this during, Actual strip temperature monitoring is executed and furnace temperature is corrected.

$Lz = \triangle Tasz /CS*Va$

CS :Furnace response speed(Rising temperature ,Dropping temperature in Table)

Va:Actual speed

Lz :necessary transport distance for △Tasz change

Therefre, when the X-WPD passing length of next coil becomes Lhs+Lz, HS Size change control Status turns to OFF.

* It is necessary for Lz to satisfy “Lz <= Next coil”.

(c) Monitoring of actual strip temperature and Furnace temperature Correction

Refer to 9. Periodical processing and 10. Monitoring of actual strip temperature

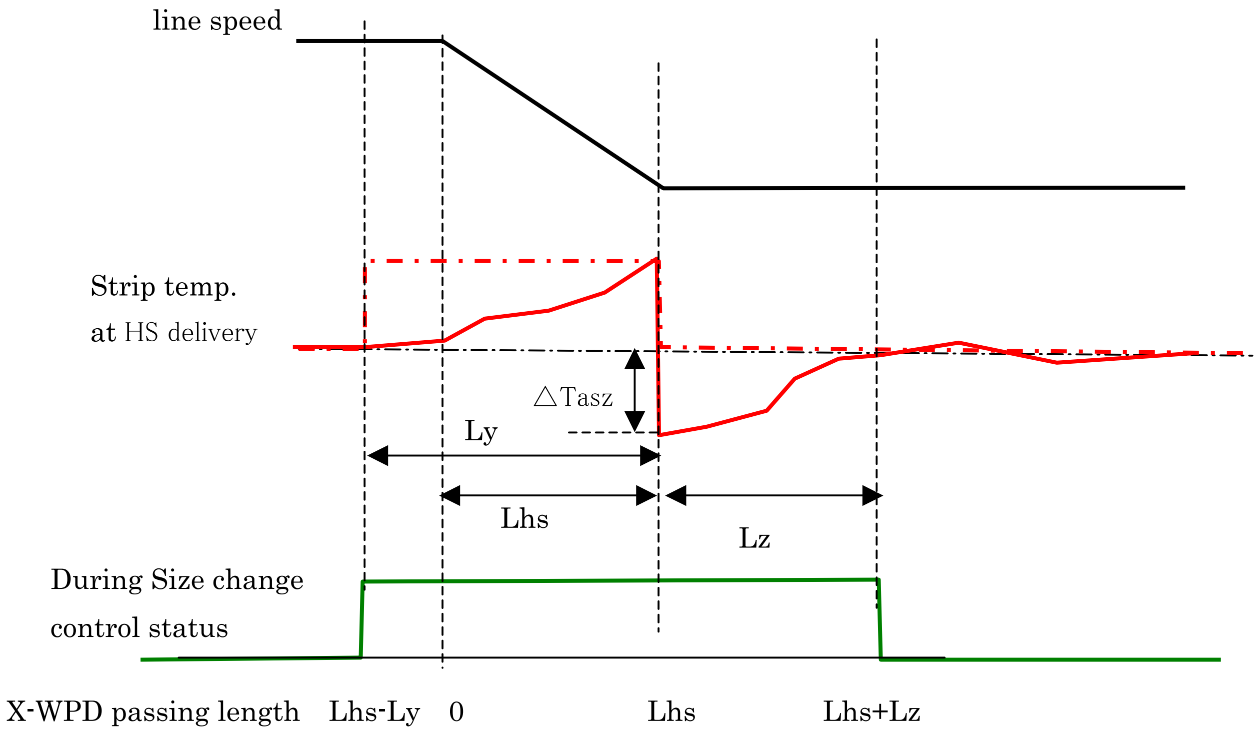


Fig. 6-5 HS Size change control using speed and Strip temp. fine adjustment: Thin→Thick

3) 【CASE-3】Strip temperature fine adjustment without furnace speed changing

In case of furnace speed mode is L1 or Acceleration prohibition, Strip temperature fine adjustment without furnace speed changing is chosen at Size change control. Basically, same as CASE-2.

(a) Procedure

① Calculation of Strip temperature jump（Refer to 6.6 Plan for Size change control and 6.8 Calculation of Strip temperature jump）

② The target of Strip temperature fine adjustment ; Tam=Tst1-△Tj/2

③ Start timing of Strip temperature fine adjustment （Size change control Schedule）

Strip temperature change value is △Tj/2. Start timing of Strip temperature fine adjustment is △tm(necessary period to rise temperarure △Tj/2) before Size change point comes to HS Delivery. △tm is obtained by furnace response table (rising temperature).

△tm=△Tj / 2 /CS

Ly= △tm* Va

CS :Furnace response speed(Rising temperature ,Dropping temperature in Table)

Va :Actual speed

Ly :necessary transport distance for Strip temperature fine adjustment

Start timing of Strip temperature fine adjustment is the following.

X-WPD passing length of Next coil =-（Ly-Lhs）

* It is necessary for Ly to satisfy “Ly <= Previous coil”.

④ Size change point passes at HS Delivery

If mode is Furnace temperature, Furnace temperature is changed to next coil furnace temperature. Strip temperature fine adjustment is finished.

(b) Status of HS Size change control

① ON :Start timing of Strip temperature fine adjustment

X-WPD passing length of Next coil = -（Ly-Lhs）

② OFF :When the second sampling timing comes after Size change point passes the HS Delivery, Tsac is defined as Strip temperature Actual and △Tasz is as △Tasz = Tsac -Tst2. At Size change control, Tst1=Tst2. When the weld point (= Size change point) comes to HS Delivery, Strip temperature is chaged and the change value of strip temperature is △Tasz. If △Tasz is plus value, Strip temperature is corrected to the dropping temperature direction, and if it is mainus value, the temperaure is to rising temperature dorection. The time until the strip temperature is chaged to the target, is estimated same as Size change control start time, in this during, Actual strip temperature monitoring is executed and furnace temperature is corrected.

Lz = △Tasz /CS*Va

CS :Furnace response speed(Rising temperature ,Dropping temperature in Table)

Va:Actual speed

Lz :necessary transport distance for △Tasz change

Therefre, when the X-WPD passing length of next coil becomes Lhs+Lz, HS Size change control Status turns to OFF.

* It is necessary for Lz to satisfy “Lz <= Next coil”.

(c) Monitoring of actual strip temperature and Furnace temperature Correction

Refer to 9. Periodical processing and 10. Monitoring of actual strip temperature

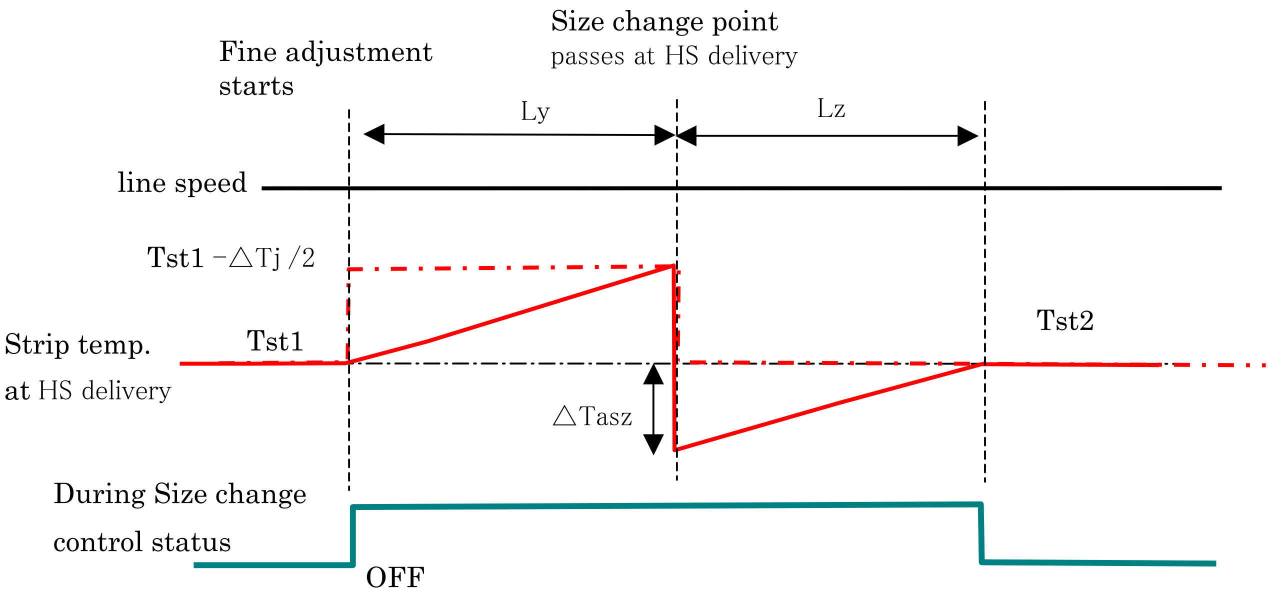


Fig. 6-6 HS Size change control using Strip temp. fine adjustment: Thin→Thick

6.4 Size change control for SS

Regarding the mathematical model of SS, SS Strip temperature jump is nothing. But actually, HS Strip temperature jump may remain. Basically, same as HS CASE-3.

(a) Procedure

① Calculation of Strip temperature jump（Refer to 6.6 Plan for Size change control and 6.8 Calculation of Strip temperature jump）

② The target of Strip temperature fine adjustment ; Tam=Tst1-△Tj/2

③ Start timing of Strip temperature fine adjustment（Size change control Schedule）

Strip temperature change value is △Tj/2. Start timing of Strip temperature fine adjustment is △tm(necessary period to rise temperarure △Tj/2) before Size change point comes to SS Delivery. △tm is obtained by furnace response table (rising temperature).

△tm=△Tj / 2 /CS

Ly= △tm* Va

CS :Furnace response speed(Rising temperature ,Dropping temperature in Table)

Va:Actual speed

Ly :necessary transport distance for Strip temperature fine adjustment

Start timing of Strip temperature fine adjustment is the following.

X-WPD passing length of Next coil =-(Ly-Lhs-Lss)

* It is necessary for Ly to satisfy “Ly <= Previous coil”.

④ Size change point passes at SS Delivery

If mode is Furnace temperature, Furnace temperature is changed to next coil furnace temperature. Strip temperature fine adjustment is finished.

(b) Status of SS Size change control

ON :Start timing of Strip temperature fine adjustment

X-WPD passing length of Next coil = -(Ly-Lhs-Lss)

OFF :When the second sampling timing comes after Size change point passes the SS Delivery, Tsac is defined as Strip temperature Actual and △Tasz is as △Tasz = Tsac -Tst2. At Size change control, Tst1=Tst2. When the weld point (= Size change point) comes to SS Delivery, Strip temperature is chaged and the change value of strip temperature is △Tasz. If △Tasz is plus value, Strip temperature is corrected to the dropping temperature direction, and if it is mainus value, the temperaure is to rising temperature dorection. The time until the strip temperature is chaged to the target, is estimated same as Size change control start time, in this during, Actual strip temperature monitoring is executed and furnace temperature is corrected.

Lz = △Tasz /CS*Va

CS :Furnace response speed(Rising temperature ,Dropping temperature in Table)

Va:Actual speed

Lz :necessary transport distance for △Tasz change

Therefre, when the X-WPD passing length of next coil becomes Lhs+Lss+Lz, SS Size change control Status turns to OFF.

* It is necessary for Lz to satisfy “Lz <= Next coil”.

(c) Monitoring of actual strip temperature and Furnace temperature Correction

Refer to 9. Periodical processing and 10. Monitoring of actual strip temperature

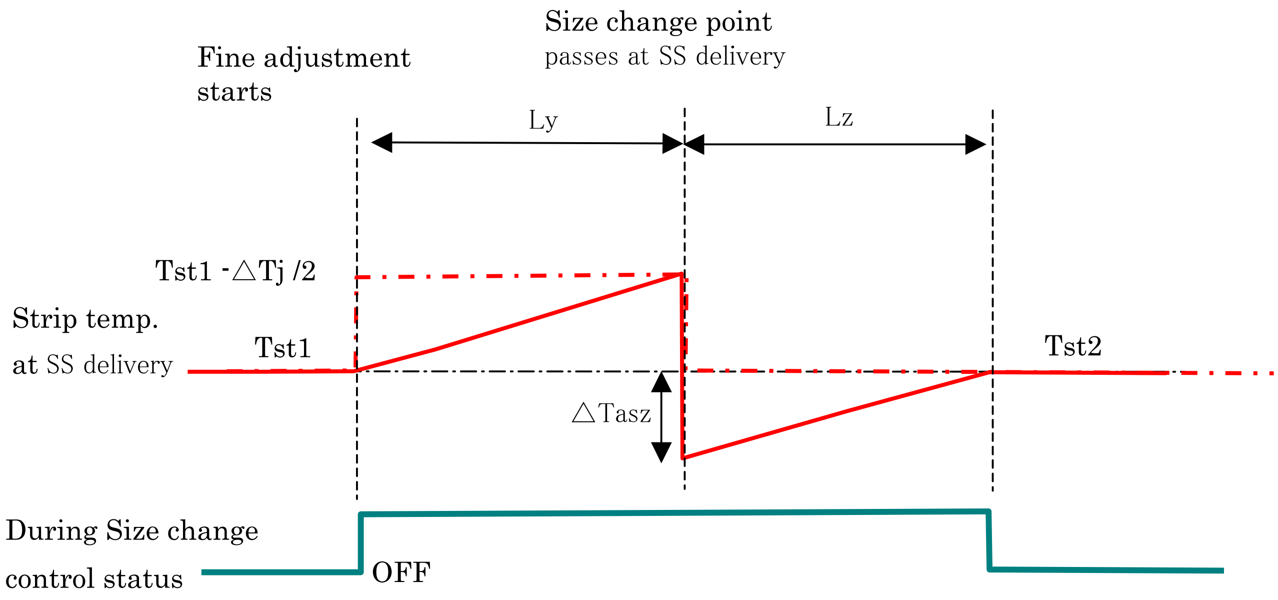


Fig. 6-7 SS Size change control using Strip tempe. fine adjustment: Thin→Thick

6.5 Size change control for SCS, RCS and OAS

The case of RCS is shown as follows.

(Basically, same as SS. But control mode is fixed at strip temperature mode. Actual strip temperature monitoring is executed. But furnace temperature is not corrected, because there is only strip temperature mode.

SCS and OAS are omitted, because of same as RCS.)

(a) Procedure

① Calculation of Strip temperature jump (Refer to 6.6 Plan for Size change control and 6.8 Calculation of Strip temperature jump)

② The target of Strip temperature fine adjustment ; Tam=Tst1-△Tj/2

③ Start timing of Strip temperature fine adjustment (Size change control Schedule)

Strip temperature change value is △Tj/2. Start timing of Strip temperature fine adjustment is △tm(necessary period to rise temperarure △Tj/2) before Size change point comes to RCS Delivery. △tm is obtained by furnace response table (rising temperature).

△tm=△Tj / 2 /CS

Ly= △tm* Va

CS :Furnace response speed(Rising temperature ,Dropping temperature in Table)

Va :Actual speed

Ly :necessary transport distance for Strip temperature fine adjustment

Start timing of Strip temperature fine adjustment is the following.

X-WPD passing length of Next coil =-(Ly-Lhs-Lss-Lsc-Lrc)

* It is necessary for Ly to satisfy "Ly <= Previous coil".

④ Size change point passes at RCS Delivery

Strip temperature fine adjustment is finished.

(b) Status of RCS Size change control

ON :Start timing of Strip temperature fine adjustment

X-WPD passing length of Next coil = -(Ly-Lhs-Lss-Lsc-Lrc)

OFF :When the second sampling timing comes after Size change point passes the RCS Delivery, Tsac is defined as Strip temperature Actual and △Tasz is as △Tasz = Tsac -Tst2. At Size change control, Tst1=Tst2. When the weld point (= Size change point) comes to RCS Delivery, Strip temperature is chaged and the change value of strip temperature is △Tasz. If △Tasz is plus value, Strip temperature is corrected to the dropping temperature direction, and if it is mainus value, the temperaure is to rising temperature dorection. The time until the strip temperature is chaged to the target, is estimated same as Size change control start time, in this during, Actual strip temperature monitoring is executed. But furnace temperature is not corrected.

Lz = △Tasz /CS*Va

CS :Furnace response speed(Rising temperature ,Dropping temperature in Table)

Va:Actual speed

Lz :necessary transport distance for △Tasz change

Therefre, when the X-WPD passing length of next coil becomes Lhs+Lss+ Lsc+Lrc +Lz, RCS Size change control Status turns to OFF.

* It is necessary for Lz to satisfy "Lz <= Next coil".

(c) Monitoring of actual strip temperature and Furnace temperature Correction

Refer to 9. Periodical processing and 10. Monitoring of actual strip temperature

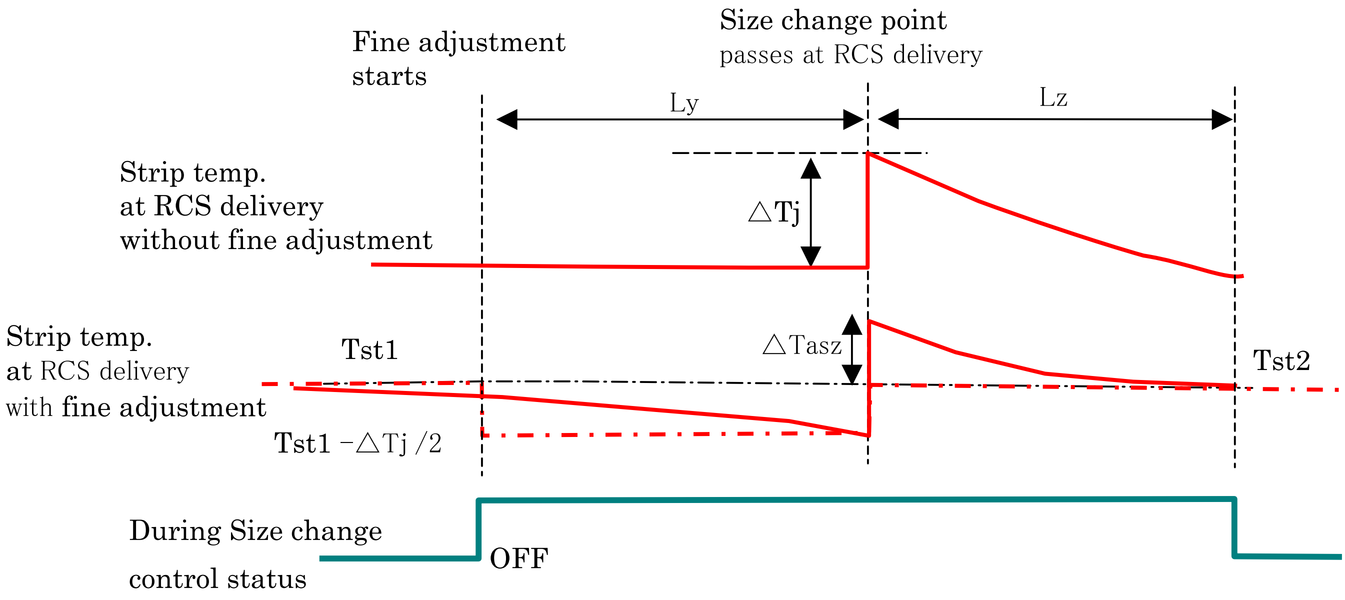


Fig. 6-8 RCS Size change control using Strip temp. fine adjustment: Thin→Thick

6.6 Size change control Schedule

The reasons of executing the plan for Size change control are the following.

- Size change control must be done before delivery side of target section.
- Size change control timing is not constant.

1) Calculation timing of the plan for Size change control

i) The plan for Size change control is always executed until Size change WP passes HS Entry.

2) Target of Size change point

Target coils of the plan for Size change control are 1~10 coils including the coils which pass Line. If target ten coils have Size change welding point, the following i), ii) are calculated.

* In case Size change control or Heat cycle change control are overlapped, coming later control is executed. (Refer to Fig. 6-9,Fig. 6-9A)

i) Strip temperature jump (Refer to 6.8 Calculation of Strip temperature jump)

ii) Size change control method and timing of starting Size change control

There are three Size change control method.

1:furnace speed changing

2:furnace speed changing + Strip temperature fine adjustment

3:Strip temperature fine adjustment

About 2 and 3, timing of starting Size change control is calculated at each section.

*Using furnace speed (2 and 3) is only HS section.

(About HS Size change control method, refer to Table2-1 HS Size change control.)

Timing of starting Strip temperature fine adjustment is calculated by using X-WPD passing length of next coil. (Refer to 9.5 Furnace Tracking processing)

Using only furnace speed, furnace speed changes from HS Entry to HS delivery.

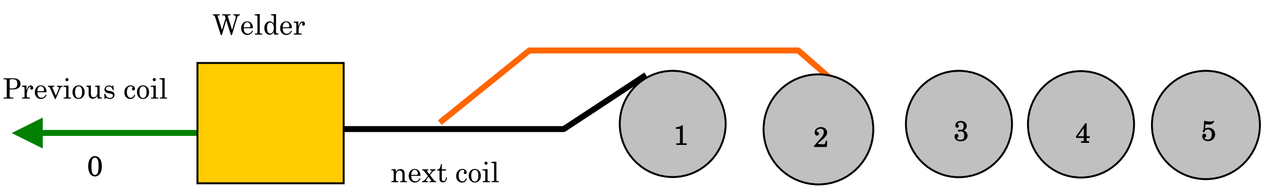


Fig. 6-9 The target coil at Entry side for Size change control

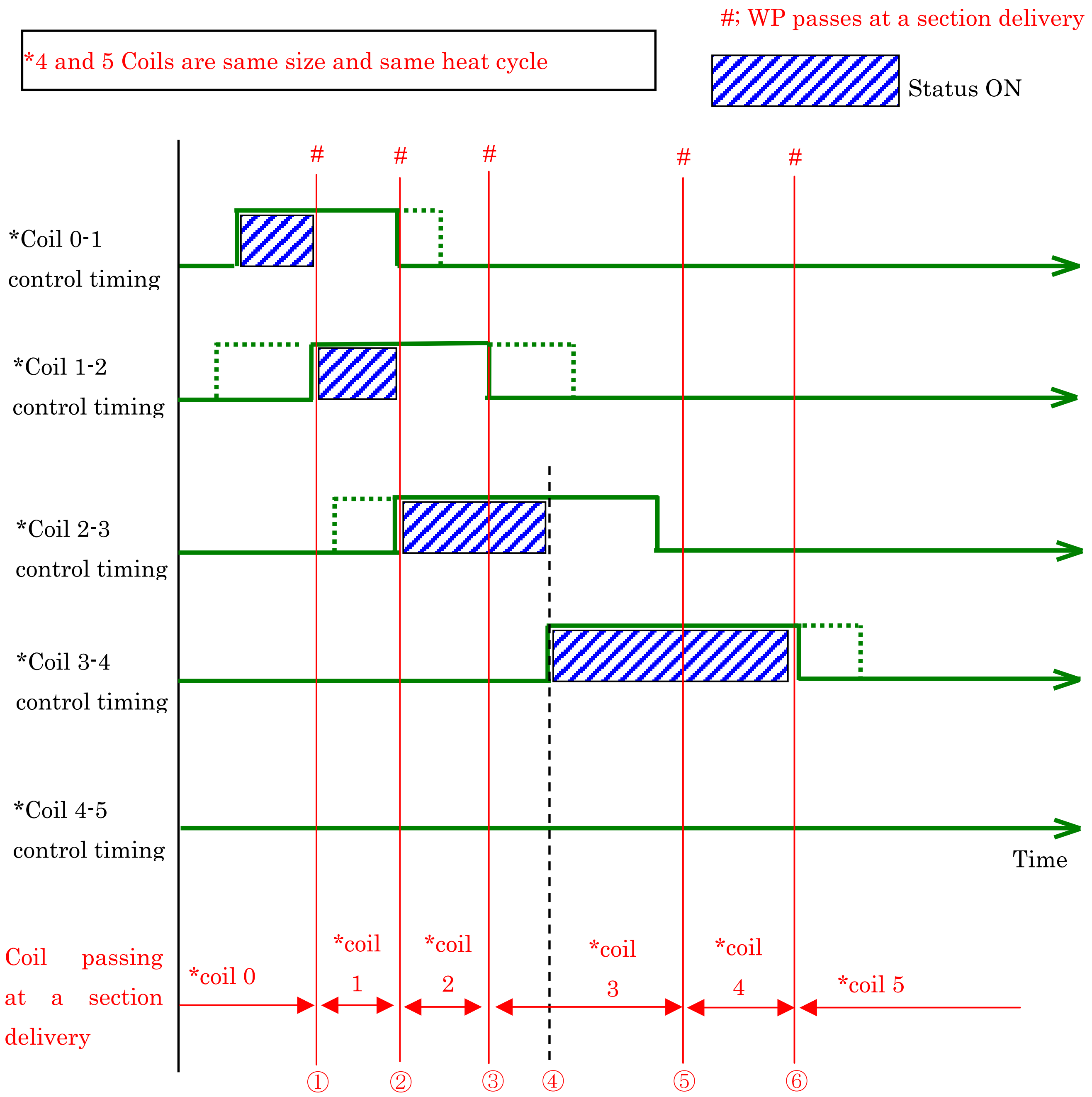


Fig. 6-9A Ex) Judgement in case some Size change control (or Heat cycle change control) are overlapped. (*Coil No.; Refer to Fig. 6-9)

< About Fig. 6-9A >

-Dotted lines stand for the condition without the restrictions of “Ly <= Previous coil” or “Lz <= Next coil”.

-Solid line such as the tail of Coil 3-4 control timing stands for the condition including the restrictions of “Ly <= Previous coil” or “Lz <= Next coil”.

-Control timing is as follows.

A; Coil 0-1 control starts.

B; At ① timing, coming later control (Coil 1-2 control) is executed.

C; At ② timing, coming later control (Coil 2-3 control) is executed.

D; At ④ timing, coming later control (Coil 3-4 control) is executed.

E; At ⑥ timing, Coil 3-4 control is finished.

Control mode changing timing

Auto mode ; When Size change control or Heat cycle change control finished, control status changes Stable annealing. And at that time, control mode changes Furnace Temperature control to Strip Temperature control about HS and SS.

Size change control status is ON during Size change control and Heat cycle change control status is ON during Heat cycle change control.

Basically, L2 Strip temperature control is feedforward control and poor at feedback control. (DCS controls using feedback during Stable annealing.)

<Size change control using furnace speed>

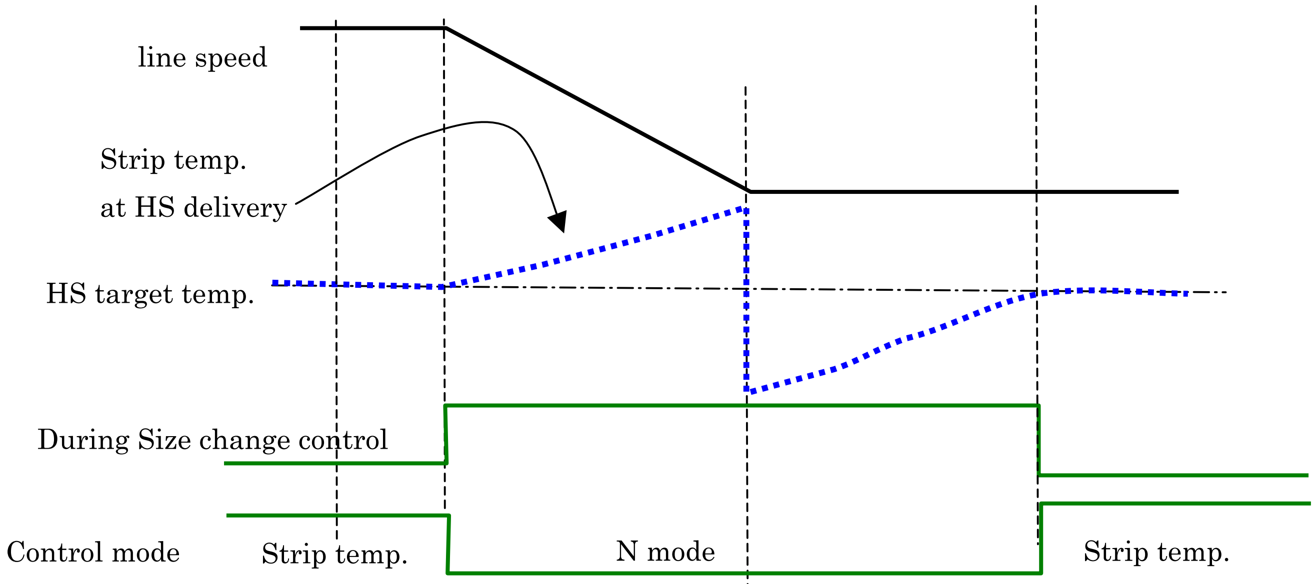


Fig. 6-10 Control mode for Size change control using speed: Thin→Thick

<Size change control using furnace speed and Strip temperature fine adjustment>

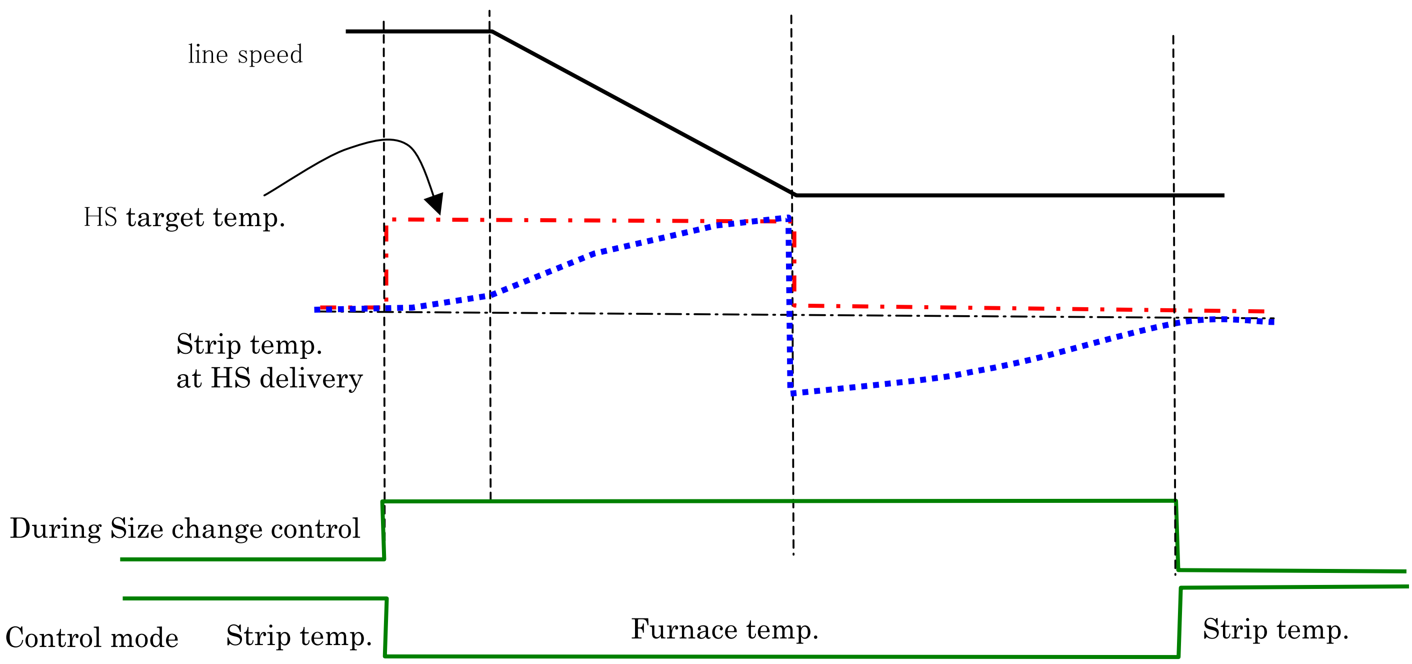


Fig. 6-11 Control mode for Size change control
using speed and Strip temperature fine adjustment: Thin→Thick

6.7 Calculation of Strip temperature jump

1) HS Strip temperature jump calculation

i) Calculation of target furnace temperature which makes the strip temperature of Previous coil target temperature

Strip Temperature at HS Entry : Target Temperature at PHS
(Refer to Table 1-10 Heat cycle Table)
Strip Temperature at HS Delivery : Target Temperature at HS (defined as "TSP")
(Heat cycle Table or Set value by operator)
Line speed : Actual center line speed
H1 : Thickness of Previous coil

ii) Calculation of target strip temperature of Next coil at HS delivery

Strip Temperature at HS Entry : Target Temperature at PHS (Refer to Table 1-10 Heat cycle Table)
line speed : Same as i)
Furnace temperature : Same as i)

iii) Strip temperature jump is the following.

TSDV = TSS – TSP
TSDV : Strip temperature jump
TSP : Strip Temperature of previous coil
TSS : Strip Temperature of next coil

2) SS Strip temperature jump calculation

Regarding the mathematical model of SS, SS Strip temperature jump is nothing. But actually, HS Strip temperature jump may remain. Decreasing rate for HS Strip temperature jump is defined and Strip temperature jump at SS Delivery is used decreasing rate.

i) Calculation of target strip temperature at SS delivery

Strip Temp. of previous coil at SS Delivery (TSP) : Target Temperature at HS
Strip Temp. of next coil at SS Delivery (TSS) : TSP + [TSDV * decreasing rate]
Strip temperature jump : TSDV * decreasing rate
(There is a decreasing rate every Heat cycle Table.)

3) SCS Strip temperature jump calculation

i) Calculation of target gas pressure which makes the strip temperature of Previous coil target temperature

Strip Temperature at SCS Entry : Target Temperature at SS
Strip Temperature at SCS Delivery : Target Temperature at SCS (defined as "TSP")
(Heat cycle Table or Set value by operator)
Line speed : Actual center line speed
Furnace Temperature : Actual Furnace Temperature
Gas Temperature : Actual Gas Temperature
H1 : Thickness of Previous coil

ii) Calculation of target strip temperature of Next coil at SCS delivery

Strip Temp. at SCS Entry :Strip Temp. of next coil at SS Delivery (TSS of 2))
Line speed : Same as i)
Furnace temperature : Same as i)

iii) Strip temperature jump is the following.

TSDV = TSS – TSP
TSDV : Strip temperature jump
TSP : Strip Temperature of previous coil
TSS : Strip Temperature of next coil

4) RCS Strip temperature jump calculation

Same as SCS.

Strip Temperature at RCS Entry : Target Temperature at SCS

Strip Temperature at RCS Delivery : Target Temperature at RCS (defined as "TSP")
(Heat cycle Table or Set value by operator)

Furnace Temperature : Actual Furnace Temperature

Gas Temperature : Actual Gas Temperature

5) OAS Strip temperature jump calculation

Basically, same as HS.

i) Calculation of target furnace temperature which makes the strip temperature of Previous coil target temperature

Strip Temperature at OAS Entry : Target Temperature at RCS
(Refer to Table 1-10 Heat cycle Table)

Strip Temperature at OAS Delivery : Target Temperature at OAS (defined as "TSP")
(Heat cycle Table or Set value by operator)

Line speed : Actual center line speed

H1 : Thickness of Previous coil

ii) Calculation of target strip temperature of Next coil at OAS delivery

Strip Temperature at OAS Entry : Strip Temperature of next coil at RCS Delivery (calculation value of 4))

Line speed : Same as i)

Furnace temperature : Same as i)

iii) Strip temperature jump is the following.

TSDV = TSS – TSP

TSDV : Strip temperature jump

TSP : Strip Temperature of previous coil

TSS : Strip Temperature of next coil

7. Heat cycle change control

7.1 Overview

A wide variety of steel product passes into the CAL. And each kind of steel grade has the annealing process, which is defined by Heat cycle Table shown at Table 1.3-1.

1) Each Heat cycle has a target temperature and the tolerance of temperature. Heat cycle change control changes the furnace condition and controls the strip temperature to be the target, which is instructed by heat cycle of the coil or manual input. The furnace speed shall be not changed in the Heat cycle change control.

2) The Heat cycles of the neighboring coils dose not have so big difference of temperature. That is, the tolerance range of strip temperature of the current coil overlaps with the next coil tolerance range. (Refer to the below figure)

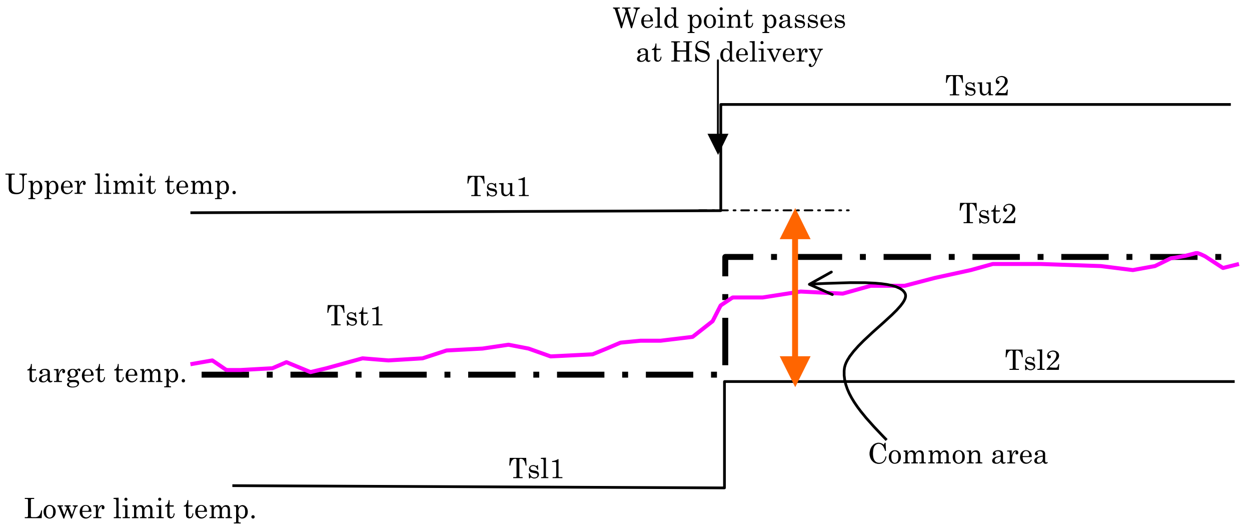


Fig.7-1 Heat cycle change control

3) The target strip temperate before WP points passing the section delivery is the overlap range of both coils in Heat cycle change control, so the strip temperature adjustment is executed.

4) If the heat cycles of the neighboring coils have a big difference of temperature, the dummy coils or low-grade product coils are often charged into the normal product coils. The number of Dummy coils in Heat cycle change is decided by operators or Level-3. During dummy coils or low-grade coils passing the furnace, the furnace condition shall be available for the next product coil so it stops the off-temperature of the product coils. Heat cycle change control executes the following functions.

Tst1 : previous coil target temperature (Heat cycle Table)
Tst2 : next coil target temperature (Heat cycle Table)
Tsu1 : previous coil upper temperature (Heat cycle Table)
Tsu2 : next coil upper temperature (Heat cycle Table)
Tsl1 : previous coil lower temperature (Heat cycle Table)
Tsl2 : next coil lower temperature(Heat cycle Table)

7.2 Example of Heat cycle change control

1) Heat cycle change control with no Size change

i) Heat cycle: Low temperature → High temperature

The target of Strip temperature fine adjustment(Tsti)=(previous coil upper temperature + next coil lower temperature)/2

=(Tsu1 +Tsl2) / 2

If next coil lower temperature > Previous coil upper temperature, the target temperature shall be the next coil lower temperature.

(That means the lower temperature is guaranteed.)

Tsti= Tsl2

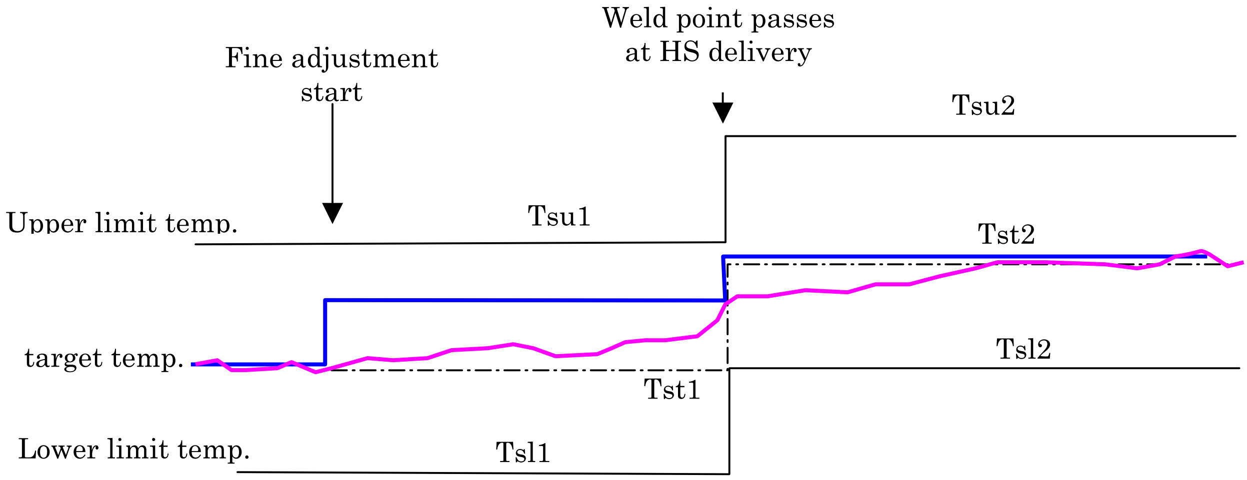


Fig.7-2 Heat cycle change control without Size change: LOW→HIGH

ii) Heat cycle: High temperature → Low temperature

The target of Strip temperature fine adjustment(Tsti)= (previous coil lower temperature + next coil upper temperature)/2

=(Tsl1 + Tsu2) / 2

If the next coil upper temperature < Previous coil lower temperature, the target temperature shall be the previous coil lower temperature.(the lower temperature is guaranteed.)

Tsti= Tsl1

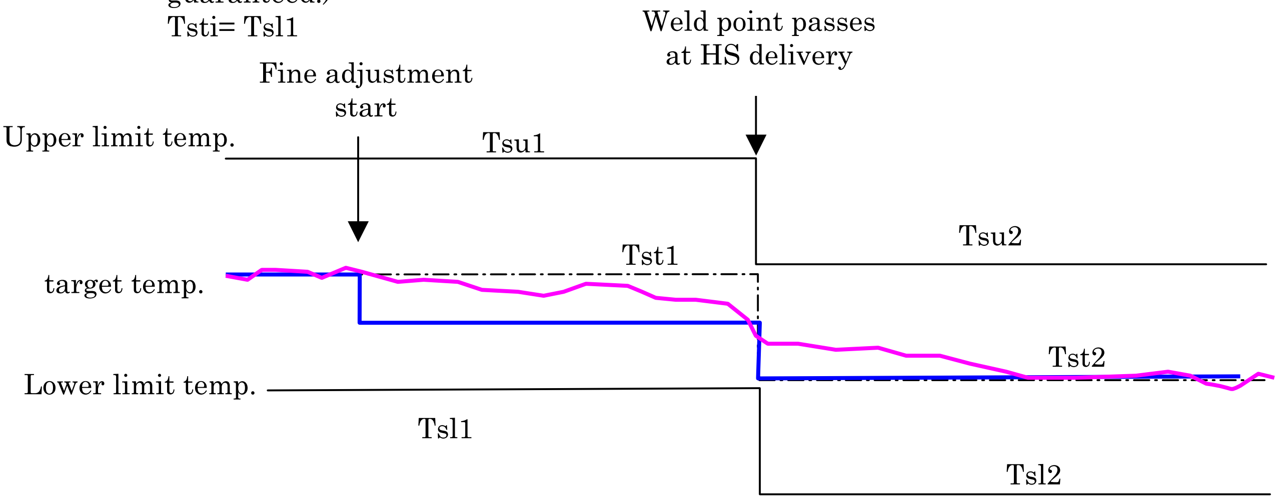


Fig.7-3 Heat cycle change control without Size change: HIGH→LOW

2) Heat cycle change control with Size change

i) Heat cycle: LOW→HIGH, Thickness: Thin→Thick

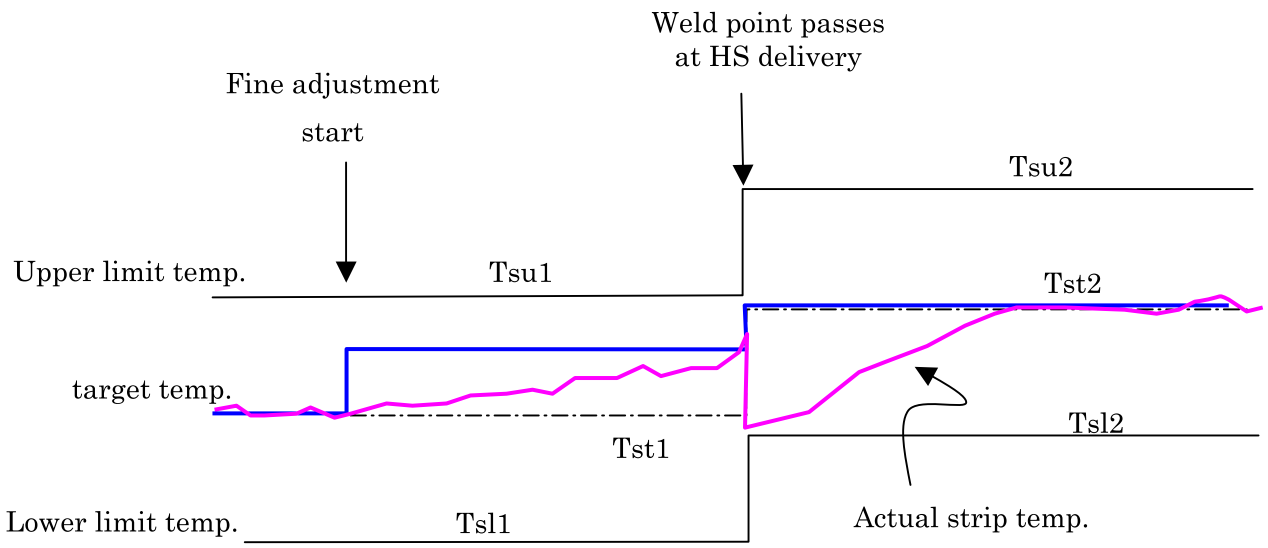


Fig.7-4 Heat cycle change control with Size change: LOW→HIGH, Thin→Thick

Strip target temperature for Heat cycle change control is the intermediated value of the neighboring temperature tolerance added with half of Strip temperature jump.
That is, Strip temperature jump is defined as △Tj (next coil – previous coil), so
The target of Strip temperature fine adjustment (Tsti)=(previous coil upper temperature + next coil lower temperature)/2-Strip temperature jump /2
=(Tsu1 + Tsl2) / 2-△Tj/2 (△Tj/2; Minus value)

If next coil lower temperature > previous coil upper temperature,
Tsti= Tsl2-△Tj/2

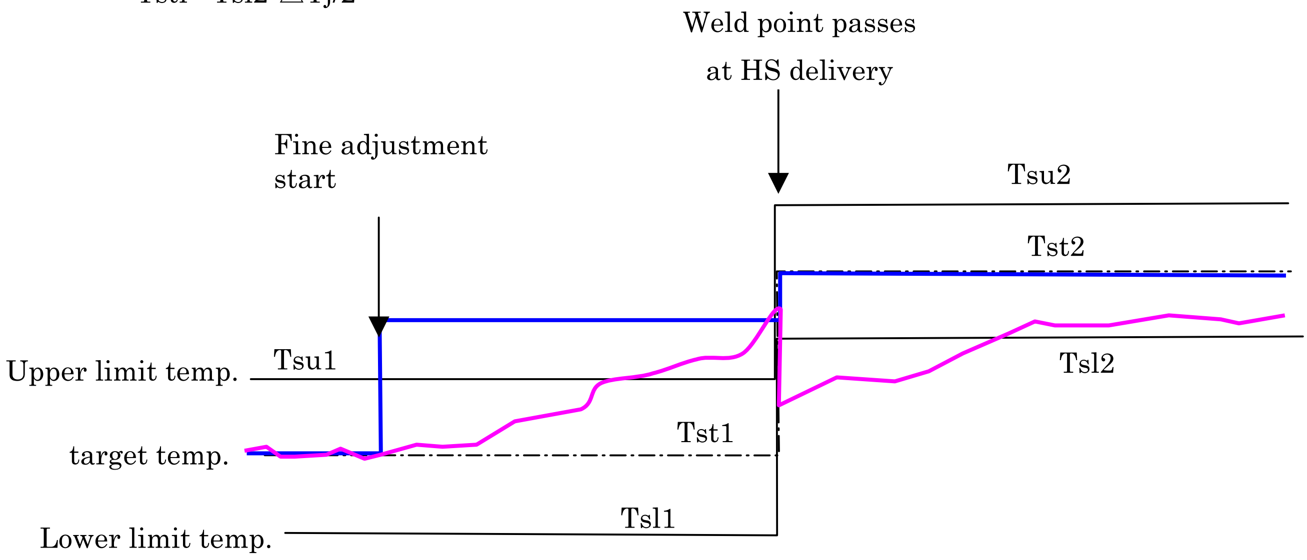


Fig.7-5 Bigger Heat cycle change control with Size change: LOW→HIGH, Thin→Thick

ii) Heat cycle: LOW→HIGH, Thickness: Thick→Thin

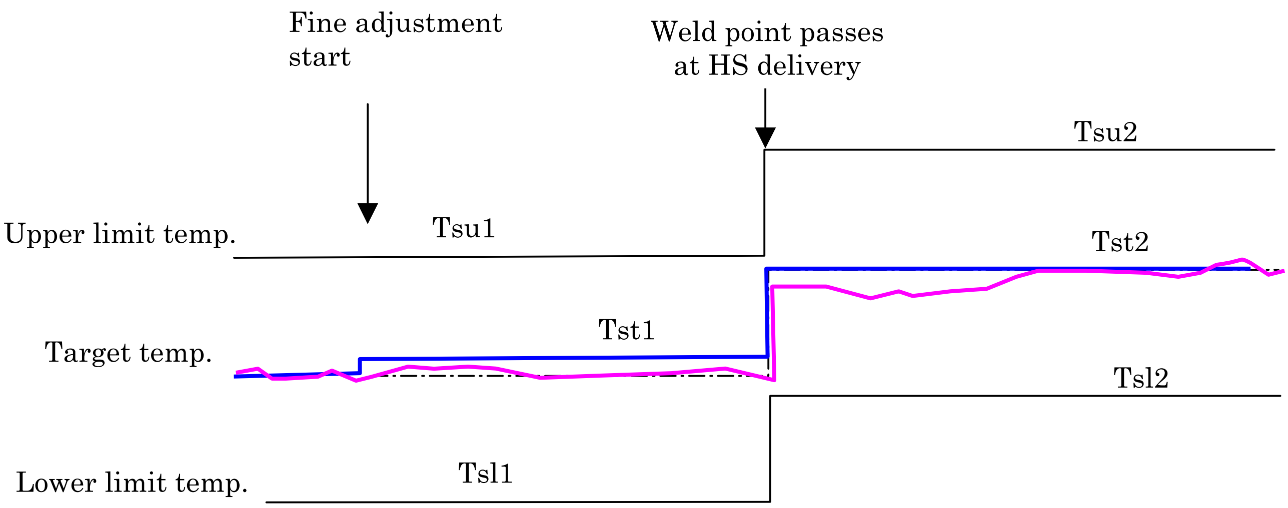


Fig.7-6 Heat cycle change control with Size change: LOW→HIGH, Thick→Thin

Strip target temperature for Heat cycle change control is the intermediated value of the neighboring temperature tolerance added with half of Strip temperature jump.
That is, Strip temperature jump is defined as $\triangle$Tj (next coil – previous coil) , then
The target of Strip temperature fine adjustment (Tsti)=(previous coil upper temperature + next coil lower temperature)/2-Strip temperature jump /2

=(Tsu1 + Tsl2) / 2-$\triangle$Tj/2 ($\triangle$Tj is Plus value)

If next coil lower temperature > previous coil upper temperature,
Tsti= Tsl2-$\triangle$Tj/2

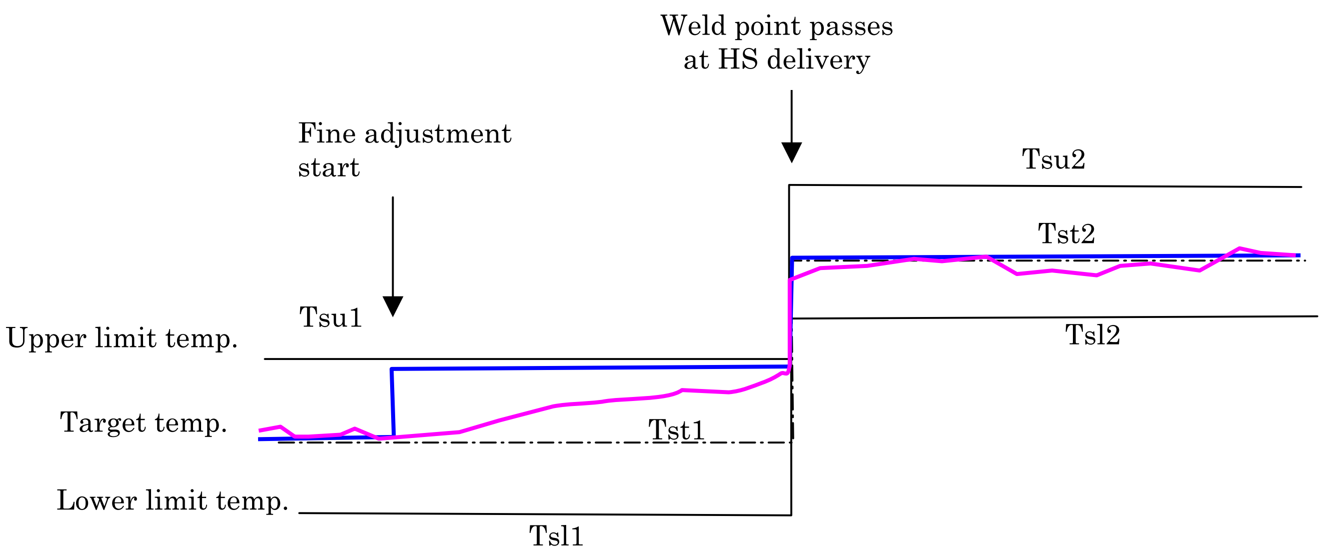


Fig.7-7 Bigger Heat cycle change control with Size change: LOW→HIGH, Thick→Thin

iii) Heat cycle :HIGH→LOW, Thickness: Thin→Thick

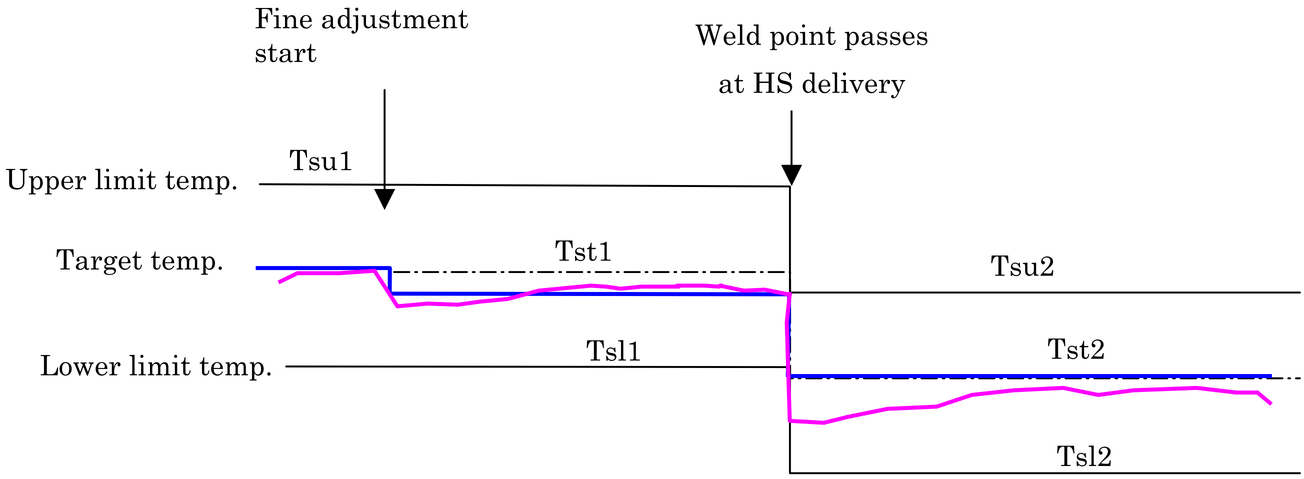


Fig.7-8 Heat cycle change control with Size change: HIGH→LOW, Thin→Thick

Strip temperature jump :△Tj (next coil – previous coil) is ,
Tsti=(Tsl1 +Tsu2)/2 -△Tj/2 (△Tj: Minus value)

If previous coil lower temperature > next coil upper temperature,
Tsti= Tsl1-△Tj/2

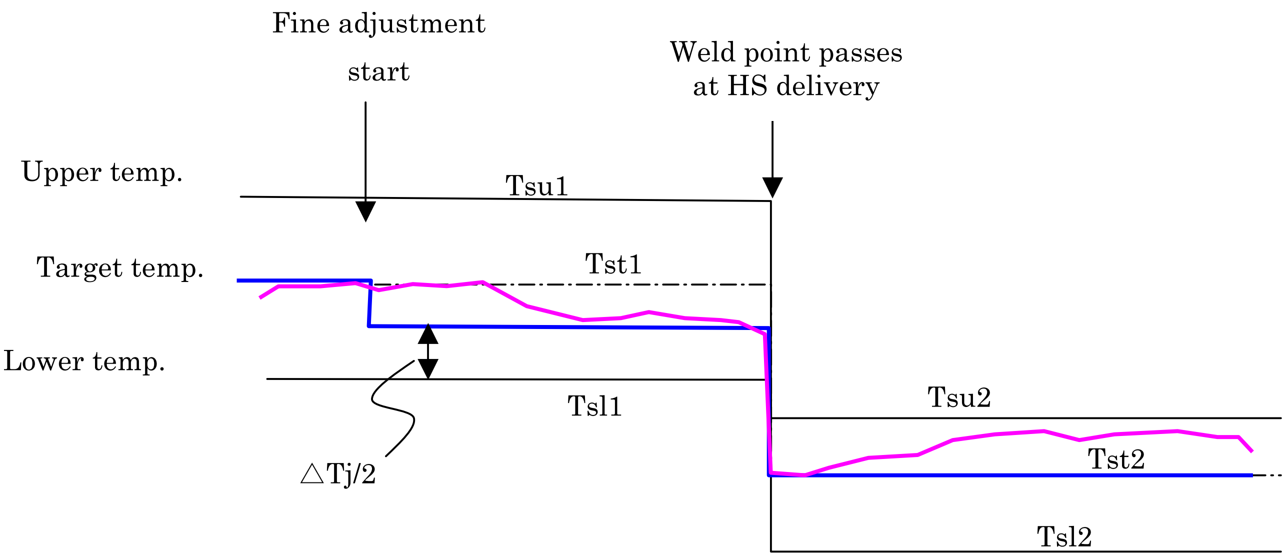


Fig.7-9 Bigger Heat cycle change control with Size change: HIGH→LOW, Thin→Thick

iv) Heat cycle: HIGH→LOW, Thickness: Thick→Thin

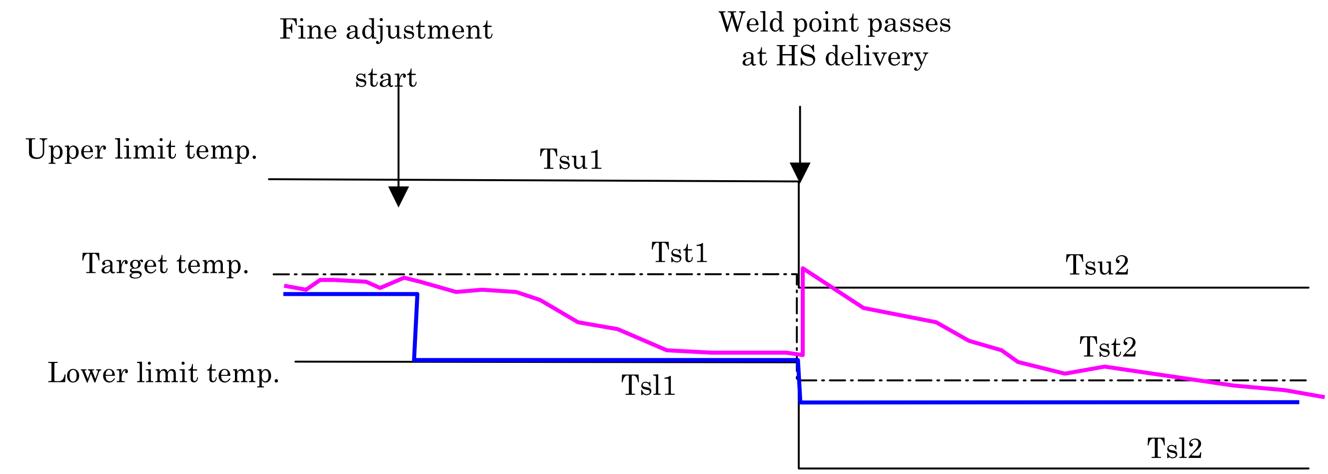


Fig.7-10 Heat cycle change control with Size change: HIGH→LOW, Thick→Thin

Strip temperature jump △Tj (next coil – previous coil) is,
Tsti=(Tsl1 +Tsu2)/2 -△Tj/2 (△Tj is plus value)

If previous coil lower temperature > next coil upper temperature,
Tsti= Tsl1-△Tj/2

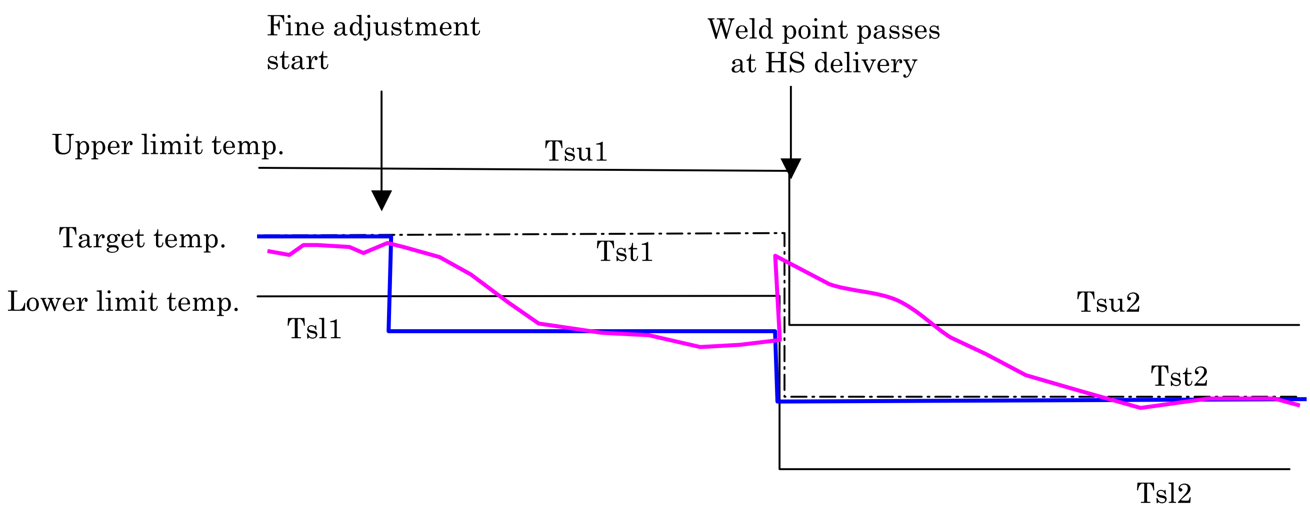


Fig.7-11 Bigger Heat cycle change control with Size change: HIGH→LOW, Thick→Thin

7.3 Heat cycle change control for HS

Heat cycle change control is same as CASE-3 of Size change control, and target temperature of Strip temperature fine adjustment is only changed.

1) Procedure

i) To obtain Strip temperature jump

Refer to the calculation $\triangle Tj/2$ "Strip temperature jump "

(If no Size change, $\triangle Tj/2=0$)

ii) To obtain Strip temperature fine adjustment

(a) Heat cycle:Low temperature→High temperature

The target of Strip temperature fine adjustment(Tsti)=(previous coil upper temperature+next coil lower temperature)/2-$\triangle Tj/2$

$=(Tsu1 + Tsl2) / 2 - \triangle Tj/2$

(b) Heat cycle:High temperature→Low temperature

The target of Strip temperature fine adjustment(Tsti)=(previous coil lower temperature + next coil upper temperature)/2-$\triangle Tj/2$

$=(Tsl1 + Tsu2) / 2 - \triangle Tj/2$

iii) Start timing of Strip temperature fine adjustment (Heat cycle change controlSchedule)

Strip temperature change value is defined as $\triangle Tam=Tsti-Tst1$. Start timing of Strip temperature fine adjustment is $\triangle tm$(necessary period to rise temperarure $\triangle Tam$) before Size change point comes to HS Delivery. $\triangle tm$ is obtained by furnace response table (rising temperature) Here, time is converted to the length using furnace response ,$Ly= \triangle tm* Va$

So, Start timing of Strip temperature fine adjustment is when X-WPD passing length of heat cycle change point = -(Ly-Lhs)

* It is necessary for Ly to satisfy "Ly <= Previous coil".

iv) Heat cycle change point comes to HS Delivery

If mode is Furnace temperature, Furnace temperature for next coil using Heat cycle table, Size and actual speed is calculated and set to DCS. Strip temperature fine adjustment is finisfed.

2) Status of HS Heat cycle change control

ON :Start timing of Strip temperature fine adjustment, That is, X-WPD passing length of heat cycle change point = -(Ly-Lhs)

OFF : When the second sampling timing comes after Heat cycle change point passes the HS Delivery, Tsac is defined as Strip temperature Actual and $\triangle Tahc$ is as $\triangle Tahc = Tsac - Tst2$. When the weld point (= Heat cycle change point) comes to HS Delivery, Strip temperature is chaged and the change value of strip temperature is $\triangle Tahc$. If $\triangle Tahc$ is plus value, Strip temperature is corrected to the dropping temperature direction, and if it is mainus value, the temperaure is to rising temperature dorection. The time until the strip temperature is chaged to the target, is estimated same as Heat cycle change control start time, in this during, Actual strip temperature monitoring is executed and furnace temperature is corrected.

$\triangle Tahc /CS*Va =Lz$

CS :Furnace response speed(Rising temperature ,Dropping temperature in Table)

Va :Actual speed

Lz :necessary transport distance for $\triangle Tahc$ change

Therefre, when the X-WPD passing length of next coil becomes Lhs+Lz, HS Heat cycle change control Status turns to OFF.

* It is necessary for Lz to satisfy "Lz <= Next coil".

3) Monitoring of actual strip temperature and Furnace temperature Correction

See the Appendix (Periodical processing)

7.4 Heat cycle change control for SS

The Strip temperature fine adjustment shall be done for SS Heat cycle change. The target strip temperature of Strip temperature fine adjustment is the same as HS.

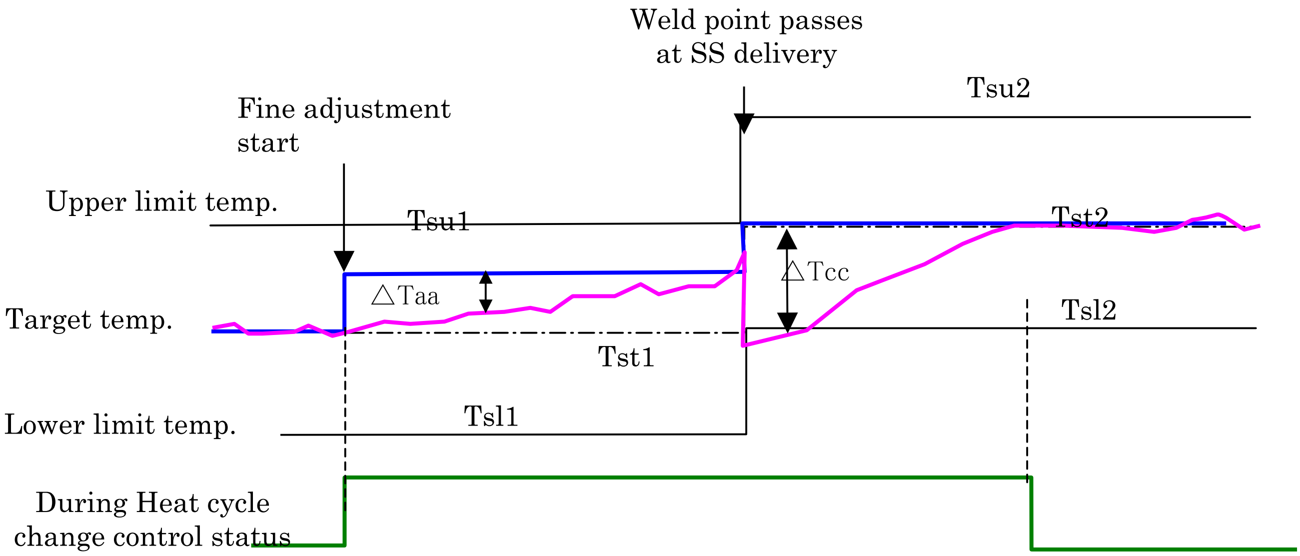


Fig.7-12 SS Heat cycle change control: LOW→HIGH, Thin→Thick

1) Procedure

i) The target of Strip temperature fine adjustment

(a) Heat cycle:Low temperature→High temperature

The target of Strip temperature fine adjustment(Tsti)=(previous coil upper temperature+next coil lower temperature)/2-Strip temperature jump /2

=(Tsu1 +Tsl2) / 2 -△Tj/2

(b) Heat cycle:High temperature→Low temperature

The target of Strip temperature fine adjustment= (previous coil lower temperature + next coil upper temperature)/2-Strip temperature jump /2

=(Tsl1 +Tsu2) / 2 -△Tj/2

ii) Start timing of Strip temperature fine adjustment (Heat cycle change control Schedule)

The strip length is necessary for chaging the strip temperature to the fine adjustment in SS. It is defined as Ly.(it is from Furnace response Table)

So, Start timing of Strip temperature fine adjustment is time when the next coil passed is -(Ly-Lhs-Lss)

* It is necessary for Ly to satisfy “Ly <= Previous coil”.

iii) End timimg of Strip temperature fine adjustment

Heat cycle change point passes at SS Delivery

If Furnace temperature Mode is selected for the strip temperature control, Furnace temperature is used for setting value for next coil.

2) Status of SS Heat cycle change control

This status is basically obtaoed by the same argorithm as HS.

ON:Start timing of Strip temperature fine adjustment.

That is, the next coil passing length = -(Ly-Lhs)+Lss

OFF:the next coil passing length= Lhs+Lz +Lss

* It is necessary for Lz to satisfy “Lz <= Next coil”.

3) Monitoring of actual strip temperature and Furnace temperature Correction

See the Appendix (Periodical processing)

7.5 Heat cycle change control for SCS, RCS, OAS

The Strip temperature fine adjustment shall be done for SS Heat cycle change. the start timing of Strip temperature fine adjustment is depend on the furnace response.

1) Procedure

i) Strip temperature fine adjustment target strip temperature

(a) Heat cycle :Low temperature→High temperature

The target of Strip temperature fine adjustment (Tsti) = (previous coil upper temperature next coil lower temperature)/2-Strip temperature jump /2

=(Tsu1 +Tsl2) / 2 -△Tj/2

(b) Heat cycle :High temperature→Low temperature

The target of Strip temperature fine adjustment (Tsti) = (previous coil lower temperature + next coil upper temperature)/2-Strip temperature jump /2

=(Tsl1 +Tsu2) / 2 -△Tj/2

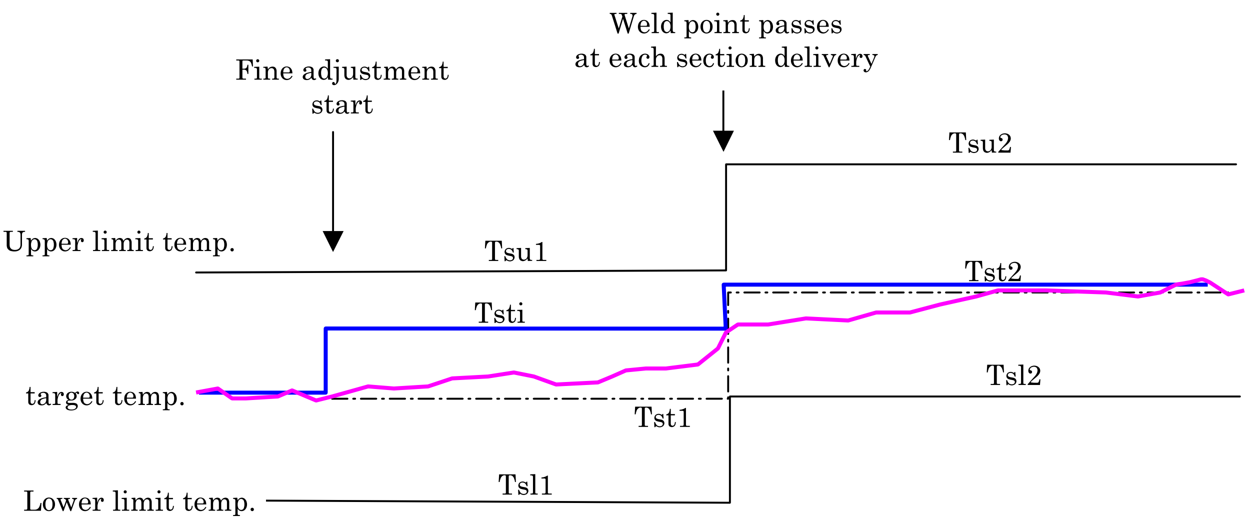


Fig.7-13 Cooling section Heat cycle change control: LOW→HIGH

ii) Start timing of Strip temperature fine adjustment

The period, which is necessary time to get Strip temperature change value △Taa=Tsti-Tst1, is obtained by furnace response Table. It is converted to the distance which the head end WP of next coil passes at X-WPD.

Lys: Necessary transport distance for SCS Strip temperature fine adjustment
Lzs: Necessary transport distance for △Tahc temperature change in SCS
Lyr: Necessary transport distance for RCS Strip temperature fine adjustment
Lzr: Necessary transport distance for △Tahc temperature change in RCS
Lyo: Necessary transport distance for OAS Strip temperature fine adjustment
Lzo: Necessary transport distance for △Tahc temperature change in OAS

<Table7-1>

Section	Necessary transport distance		Section Pass length	Heat cycle change status ON (X-WPD pass length)	Heat cycle change status OFF (X-WPD pass length)
SCS	Lys	Lzs	Lsc	Lys+Lhs+Lss+Lsc	Lzs+Lhs+Lss+Lsc
RSC	Lyr	Lzr	Lrc	Lyr+Lhs+Lss+Lsc+Lrc	Lzr+Lhs+Lss+Lsc+Lrc
OAS	Lyo	Lzo	Loa	Lyo+Lhs+Lss+Lsc+Lrc+Loa	Lzo+Lhs+Lss+Lsc+Lrc+Loa

* For each section, it is necessary for Ly to satisfy “Ly <= Previous coil”.

iii) End timing of Strip temperature fine adjustment

When Heat cycle change point comes to each Section Delivery, the target strip temperature is changed to the next coil target, which is on the heat cycle table or operator input.

* For each section, it is necessary for Lz to satisfy “Lz <= Next coil”.

7.6 Heat cycle change control using Dummy coil

1) Overview

When Heat cycle change is big, the dummy coils are charged between previous coil and next coil.
Then, the furnace condition is controlled for the next product coils during the Dummy coil passes the each section.
In the case of HS, SS, The Furnace temperature is calculated using the next product coil size and heat cycle target temperature and actual line speed, and is sent to DCS.
In the case of cooling section(SCS,RCS), Furnace temperature ,gas pressure for the next product coil are calculated , and using their parameters and dummy coils size, the strip temperature is calculated and it applied to the dummy coil target temperate, and sent to DCS.
If the next coil of Dummy coil is a Dummy coil, the product coil is found in next coils in PDI sequence.
Furnace temperature calculation (HS,SS) and Strip temperature calculation (SCS,RCS,OA) are executed when the Dummy coil comes to each section Delivery and sent to DCS.
When Dummy coil passes in the line, Actual strip temperature monitoring and Furnace temperature Correction are not done. But Furnace temperature (HS, SS), Strip temperature (SCS, RCS, OA) for Dummy coil are calculated and sent to DCS every 20 seconds due to the speed change.

When Size change of product coils is big, dummy coils are used same as heat cycle change.
The Dummy coil strip temperature is controlled same as "Heat cycle change control" in the case of Heat cycle change = 0.

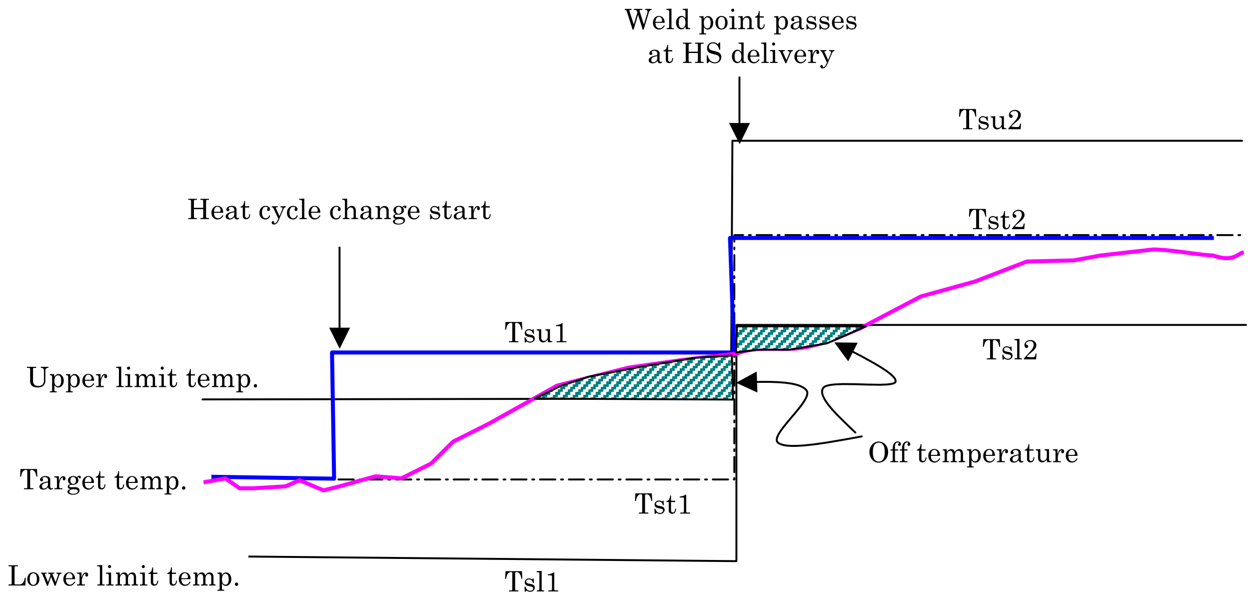


Fig.7-14 Heat cycle change control without dummy coil: LOW→HIGH (at HS)

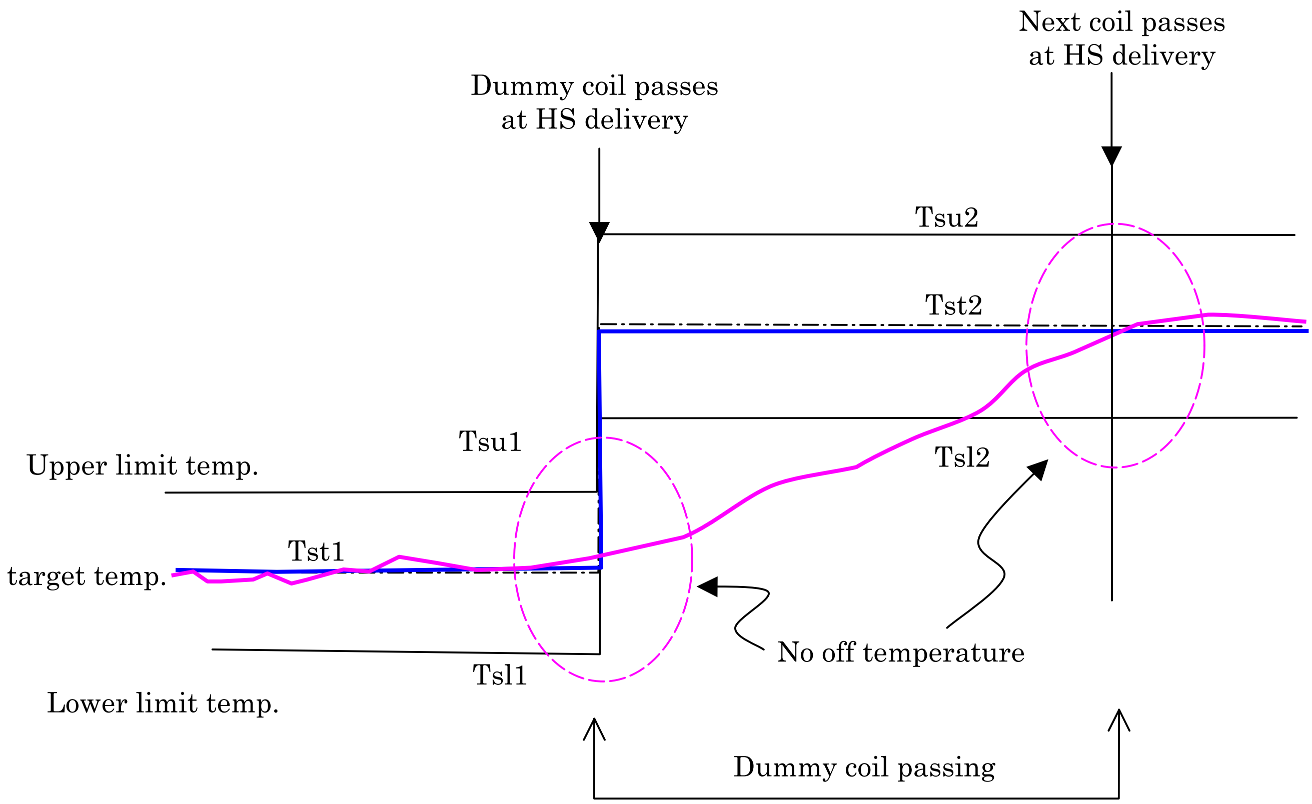


Fig.7-15 Heat cycle change control with dummy coil: LOW→HIGH (at HS)

7.7 Strip temperature calculation and Furnace temperature calculation for Dummy coil (HS, SS, OAS)

1) Furnace condition calculation

The furnace condition is calculated with following procedure.

i) When the Dummy coil comes to HS, SS, OAS Delivery, the furnace temperature for the next product coil is calculated.

Where,

Line speed: Actual line speed

Delivery Strip temperature: target temperature in Heat cycle Table of the product coil ore operator input value.

(Operator setting value is prior to the table value)

parameters: for the next product coil

If calculated Furnace temperature is out of upper or lower limit, Furnace temperature is replace to the upper or lower limit temperature.

ii) The strip temperature for the dummy coil is calculated using above calculated furnace temperature.

line speed :Actual line speed

Coil size :Dummy coil

If the strip temperature of dummy coil is out of strip temperature limit, Strip temperature of dummy coil is replaced to the Strip temperature Upper or lower limit temperature.

The above calculated Strip temperature is sent to DCS, when the Dummy coil comes to HS,SS,OAS Delivery.

* At Dummy control calculation, the strip temperature of the entry side of a section is the strip temperature of the delivery side of previous section.

For example, the strip temperature of the entry side of SS section is the strip temperature of the delivery side of HS section.

2) Strip temperature calculation and gas pressure calculation for Dummy coil (SCS, RCS)

The furnace condition is calculated with following procedure.

i) When the Dummy coil comes to SCS, RCS Delivery, the gas pressure for the next product coil is calculated.

Where,

line speed: Actual line speed

Furnace temperature: Actual Furnace temperature

Delivery Strip temperature: Heat cycle Table for the next product coil or operator input value (operator input value is have a priority to the table value)

If calculated Furnace temperature is out of the limit of temperature tolerance, the Furnace temperature is replace to the limit value.

ii) Target temperature for Dummy coil is calculation using the above mentioned calculated gas pressure.

line speed :Actual line speed

coil size: Dummy coil size

If Strip temperature for Dummy coil is out of Strip temperature limit, Strip temperature for Dummy coil is Strip temperature Upper limit.

This target strip temperature for Dummy coil is sent to DCS when the dummy coil comes to each section delivery.

* At Dummy control calculation, the strip temperature of the entry side of a section is the strip temperature of the delivery side of previous section.

For example, the strip temperature of the entry side of SS section is the strip temperature of the delivery side of HS section.

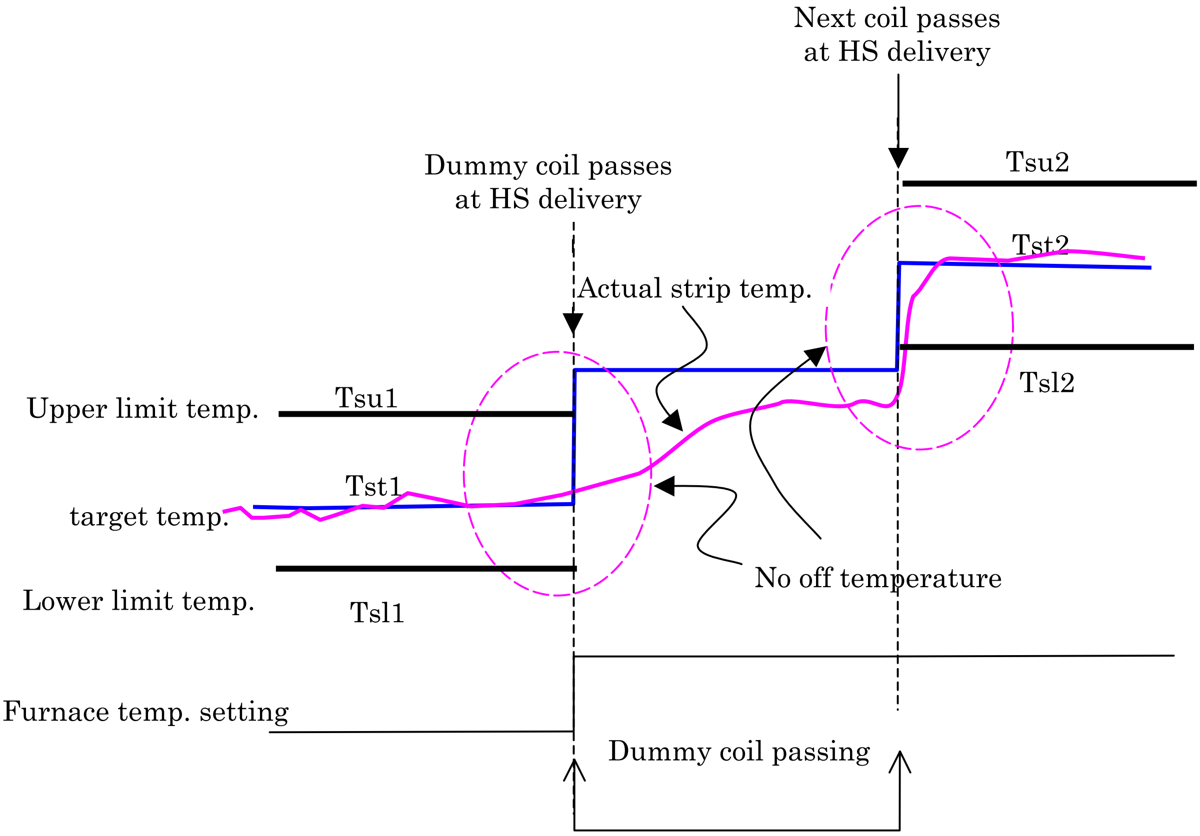


Fig.7-16 Heat cycle change control with dummy coil: LOW→HIGH, Thick→Thin (at HS)

7.8 Heat cycle change control Schedule

It is basically same as Size change control.

1) Target Heat cycle change point

Target coils of the plan for Heat cycle change control are 1~10 coils including the coils which pass Line, and if there is the heat cycle change point in these 10 coils, the calculation for heat cycle control is executed.

2) Calculation items

i) Start position of Strip temperature fine adjustment for each section (X-WPD passing length of WP)

ii) Strip temperature fine adjustment value (Tsti)

iii) Furnace temperature of HS, SS for Strip temperature fine adjustment value

8. Control in steady state

8.1 Overview

1) The stable annealing is defined as the condition, which is not in Size change control nor Heat cycle change control nor dummy coil passing the section. In this condition, the control mode of all section is same, that is, Level-2 Strip Temperature control mode. And the target temperature in the heat cycle table or operator input is used and set to DCS.
2) The periodical processing runs in the stable annealing condition, and the adaptive calculation of U value is executed at the stable condition. (Refer to 9. Periodical processing)

Section	During Size change control	During Heat cycle change control	During Dummy coil passing	During Stable annealing
HS, SS	- Furnace temp. control - Strip jump deviation control	- Furnace temp. control - Strip jump deviation control + Intermediate temperature set between different heat cycle	- Furnace temp. control - Furnace condition changes for next product coil	- Strip temp. control - Strip temp. on the heat cycle table or operator set value is set to DCS
SCS, RCS, OAS	- Strip temp. control - Strip jump deviation control	- Strip temp. control - Strip jump deviation control + intermediate temperature set between different heat cycle	- Strip temp. control - Furnace condition changes for next product coil	

"During Size change control" means the condition Size change control status is ON at each section.
"During Heat cycle change control" means the condition Heat cycle change control status is ON at each section.
"During Dummy coil passing" means the condition Dummy coil is passing through the exit of each furnace section.

9. Periodical processing

9.1 Overview

Periodical processing works every 20 seconds and has the following functions.

1) Furnace actual data collection
2) Judgement of Stable Annealing Condition
3) Monitoring of tracking
4) Monitoring of actual strip temperature, Correcting of furnace temperature
5) Learning Calculation

9.2 Furnace actual data collection

Furnace actual data, such as strip temperature, are used to judge Stable Annealing Condition etc. And actual strip temperature is monitored. When off temperature occurs, Alarm is issued. Correcting of furnace temperature is done if necessary. So it is necessary to gather Furnace actual data.

1) Cycle

Strip temperature control system receives Periodical actual data every 20 seconds from DCS.

2) Actual data collection item

The following item of Actual data from DCS are store.

< Table9-1 > Actual data collection item (zone number, sensor number)

No.	Judgement item	Section					Remarks
		HS	SS	SCS	RCS	OA	
1	Furnace temp.	8	2	4	×	4	
2	Strip temp.	2	1	1	1	1	
3	GAS pressure	×	×	4	8	×	
4	GAS temperature	×	×	4	6	×	

3) Actual Data Table for Judgement of Stable Annealing Condition

i) Actual Data for Judgement of Stable Annealing Condition (HS, SS, SCS, RCS, OA) are stored in the data table.
A maximum of fifteen Actual Data are gathered in a cycle. A cycle is every 20 seconds.
(When actual data exceeds fifteen, the oldest data is deleted and the latest data is added.)

ii) The average of each actual data is calculated and stored in Actual Data Table.

9.3 Judgement of Stable Annealing Condition

The purpose of this process ("Judgement of Stable Annealing Condition") is judging whether Annealing condition is stable or not by using Actual process data. Actual process data is gathered by actual data collection. Then each section is decided on stable condition or not.

1) Actual data item to judge
  i) Furnace speed
  ii) Furnace temperature
  iii) Strip temperature

2) Judgement of stable condition

  Stable condition is satisfied the following.
  i) Each section is NOT "During Size change control".
  ii) Each section is NOT "During Heat cycle change control".
  iii) Each section is NOT "During Dummy coil passing".
  iv) Being satisfied the following condition

① Furnace speed judgement (each section common)

- Average Furnace speed; MLS calculation

  Averaging latest 15 Furnace speed data on actual data collection, MLS is calculated.

- Judgement of stable condition

  About all the latest 15 Furnace speed data; LS, Stable condition is satisfied the following.

  $|LS - MLS| <= \Delta LS$

② Strip temperature judgement (each section common)

- Average Strip temperature; MTS calculation

  Averaging latest 15 Strip temperature data on actual data collection, MTS is calculated.

- Judgement of stable condition

  About all the latest 15 strip temperature data; TS, Stable condition is satisfied the following.

  $|TS - MTS| <= \Delta TS$

③ Furnace temperature judgement (HS, SS, SCS, OAS)

- Average Furnace temperature; MTFi calculation (i :Zone No.)

  Averaging latest 15 Furnace temperature data on actual data collection, MTFi is calculated.

- Judgement of stable condition

  About all the latest 15 Furnace temperature data; TFi, Stable condition is satisfied the following.

  $|TFi - MTFi| <= \Delta TFi$

④ GAS pressure judgement (SCS,RCS)

- Average GAS pressure; MPi calculation (i :Zone No.)

  Averaging latest 15 GAS pressure data on actual data collection, MPi is calculated.

- Judgement of stable condition

  About all the latest 15 GAS pressure data; Pi, Stable condition is satisfied the following.

  $|Pi - MPi| <= \Delta Pi$

⑤ GAS temperature judgement (SCS,RCS)

- Average GAS temperature; MTGi calculation (i :Zone No.)

  Averaging latest 15 GAS temperature data on actual data collection, MTGi is calculated.

- Judgement of stable condition

  About all the latest 15 GAS temperature data; TGi, Stable condition is satisfied the following.

  $|TGi - MTGi| <= \Delta TGi$

3) Management Table of stable condition

i) Management Table: Storing the result of Judgement of Stable Annealing Condition

ii) Table image:

stable condition (*3)
Learning ON/OFF (*4)
Judgement of Stable Annealing Condition (*5)

*3 stable condition

	HS	SS	SCS	RCS	OAS
state					

0; stable, 1; unstable

*4 Learning ON/OFF

	HS	SS	SCS	RCS	OAS
state					

0; OFF, 1; ON

*5 Judgement of Stable Annealing Condition

	HS	SS	SCS	RCS	OAS
No.					

No.; number of times of stable at Judgement

-Being unstable, “No.” is reset to “0”.

-“No.” can count until “three”.

When stable time continues 4 times, “No.” shows “three”.

< Table9-2 > Management Table of stable condition

4) Actual Data Table for Judgement of Stable Annealing Condition

i) Table Overview:

Actual Data Table is stored Furnace actual data and the result of Stable Annealing Condition to judge Stable Annealing Condition.

ii) Table image:

Furnace speed data for Judgement of Stable Condition

	1	2	3	・	・	・	15
Actual data							
Average data							
Stable condition							

Each section data for Judgement of Stable Condition
(HS, SS, SCS, RCS, OAS)

	1	2	3	・	・	・	15
Strip temp. actual							
Furnace temp. actual							
GAS pressure actual							
GAS temp. actual							
Strip temp. average							
Furnace temp. average							
GAS pressure average							
GAS temp. average							
Strip temp. stable condition							
Furnace temp. stable condition							
GAS pressure stable condition							
GAS temp. stable condition							

A maximum of fifteen Actual Data are gathered in a cycle.
The average of each 15 actual data is calculated.

Stable Condition: Stable; 0 Unstable; 1

< Table9-3 > Actual Data Table for Judgement of Stable Annealing Condition

9.4 Learning Calculation

When LS condition is changed from unstable to stable, the judgement of Learning Calculation about Model updating parameter is done against each section.
Learning Calculation is done just once against one coil.
When Learning Calculation is complete, U value updating is not done at that time. Periodical processing works every 20 seconds. So, U value updating is done by the periodical processing.

1) Learning Calculation Overview

Each U value is updated by using Actual furnace data. Learning ON/OFF is decided by Judgement of Stable Condition (ON/OFF) and L2 monitor setting (ON/OFF).
(Refer to < Table9-4 > Learning ON/OFF.) “Learning ON” is updating U value about each section.

< Table9-4 > Learning ON/OFF (at each section)

		Judgement of Stable Condition	
		ON	OFF
Monitor	ON	○	×
	OFF	×	×

○:U value (Model updating parameter) is modified. (Learning ON)
×:U value (Model updating parameter) is not modified. (Learning OFF)

2) HS Learning Calculation

About whole HS section, U value (Model updating parameter) is learned.

i) HS Learning Calculation flow

Using the following flow, HS Learning Calculation is done.

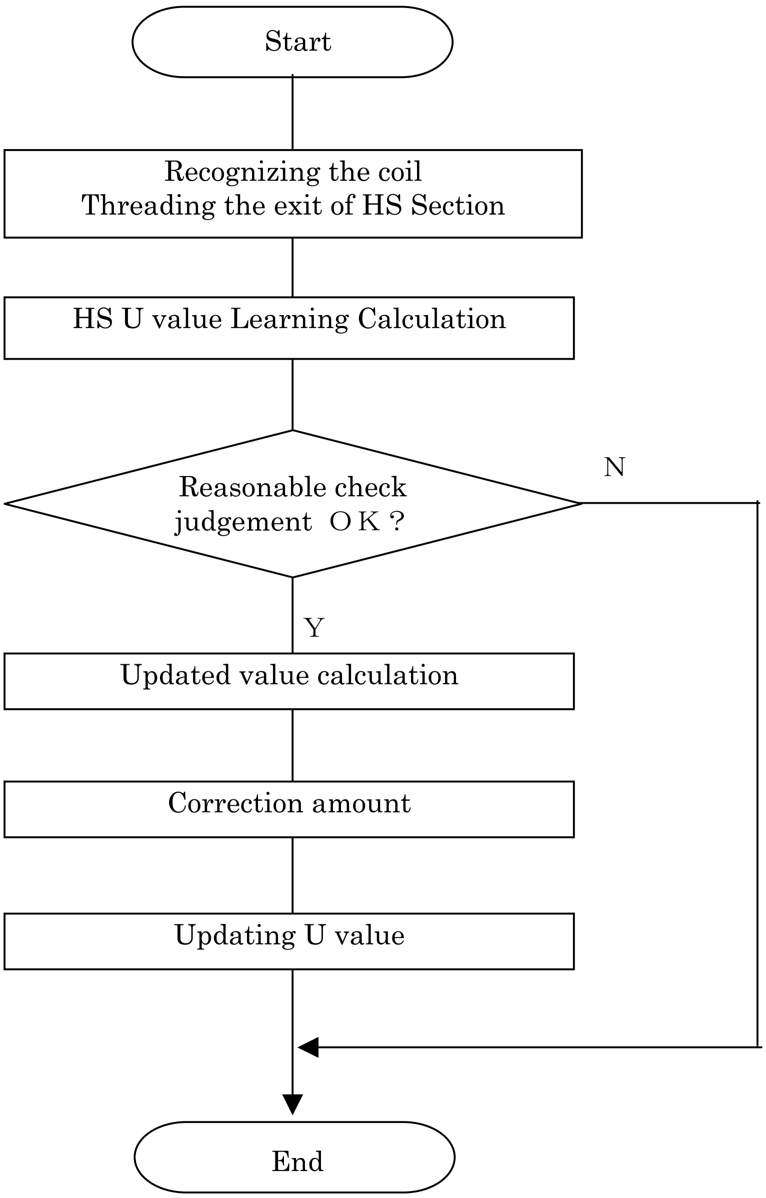


Fig.9-1 HS Learning Calculation flow

ii) HS U value Learning Calculation

HS U value is calculated by using the actual furnace data.

iii) Reasonable check judgement

Being obtained new U value satisfied the below condition, U value shall be updated.

$$\left| \frac{New\ \text{U value} - \text{Current Uvalue}}{\text{Current Uvalue}} \right| <= \varepsilon$$

ε : Reasonable criterion value (0.5)

iv) Updated value calculation

U value is smoothed below equation and updated U value is calculated as bellow.

$$\text{U value} = (1-\mu)\cdot New\ \text{U value} + \mu \cdot \text{Current U value}$$

μ : parameter updating rate (0.9)

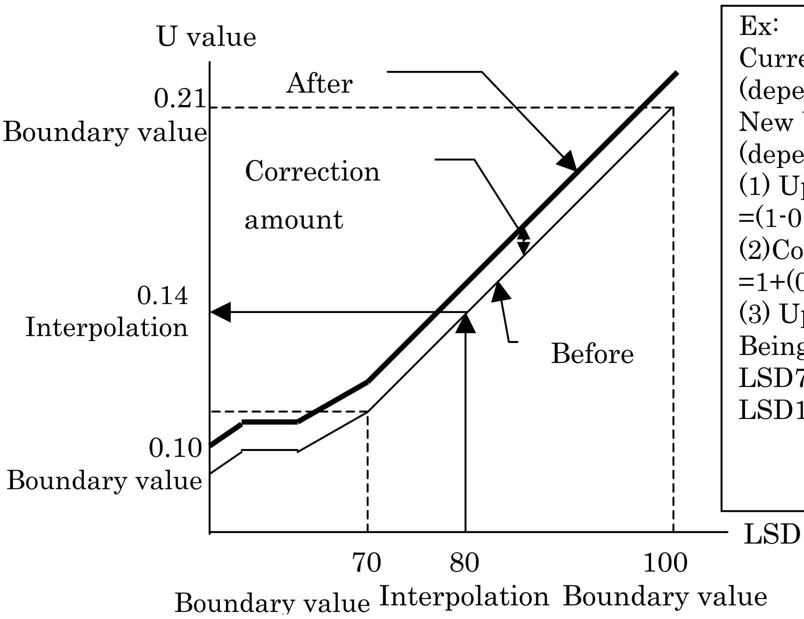
v) Correction amount

Correction amount of U value is calculated by the below equation.

$$\text{correction amount of U value} = 1 + \frac{\text{U value} - \text{Current U value}}{\text{Current U value}}$$

vi) Updating U value

About each Heat cycle, the boundary values of calculated U value in U value Learning Table are updated. Correction amount is used to the boundary values. The example is below.



Ex: LSD is 80 at Learning Calculation
Current U value = 0.14
(depending on interpolation)
New U value = 0.17
(depending on mathematical model)
(1) Updated U value
=(1-0.9)*0.17+0.9*0.14=0.143
(2)Correction amount
=1+(0.143-0.14)/0.14=1.02 (Correction amount +2%)
(3) Updating U value
Being based on LSD, U value is updated.
LSD70 :U value (70) =0.10 * 1.02 = 0.102
LSD100:U value (100)=0.21 * 1.02 = 0.2142

Fig.9-2 Updating Learning Calculation

Following the above example, U value Learning Table is updated.

*Refer to 12.2 Two-dimensional interpolation

3) SS Learning Calculation

About SS section, U value (Model updating parameter) is learned.

i) SS Learning Calculation flow

Using the following flow, SS Learning Calculation is done.

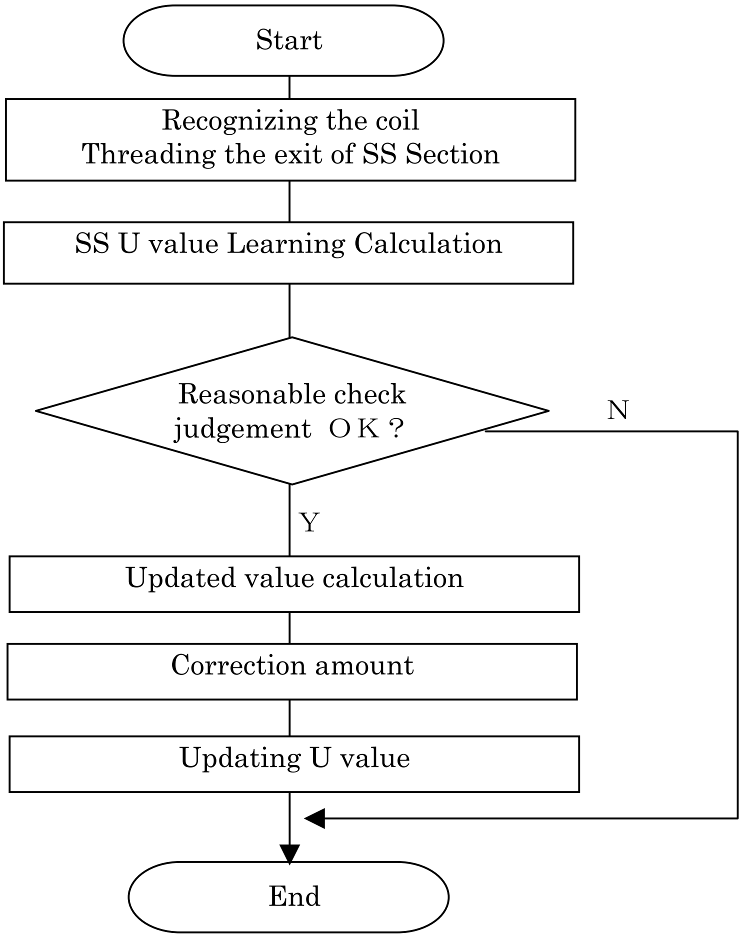


Fig.9-3 SS Learning Calculation flow

ii) SS U value Learning Calculation

SS U value is calculated by using the actual furnace data.

iii) Reasonable check judgement

Being obtained new U value satisfied the below condition, U value shall be updated.

$$\left| \frac{New \text{ U value} - \text{Current Uvalue}}{\text{Current Uvalue}} \right| <= \varepsilon \qquad \varepsilon : \text{Reasonable criterion value (0.1)}$$

iv) Updated value calculation

U value is smoothed below equation and updated U value is calculated as bellow.

$$\text{U value} = (1 - \mu) \cdot New \text{ U value} + \mu \cdot \text{Current U value}$$

μ : Parameter updating rate (0.3)

v) Correction amount

Correction amount of U value is calculated by the below equation.

$$\text{correction amount of U value} = 1 + \frac{\text{U value} - \text{Current U value}}{\text{Current U value}}$$

vi) Updating U value

The boundary values of U value are updated (same as HS).

*Refer to < Table9-6 > U value Learning Table.

4) RCS, SCS, OAS: U value Learning Calculation

Same as HS and SS.

Learning parameters at each section are below table.

< Table9-5 > Learning parameter

	HS	SS	SCS	RCS	OAS
reasonable criterion value: ε					
parameter updating rate: μ					

U value Learning Table

U value Learning Table is held at each Heat cycle and each section.

< Table9-6 > U value Learning Table

LSD / Width (mm)	50 mpm*mm	150 mpm*mm	250 mpm*mm	350 mpm*mm
800				
1200				
1600				
1900				

Using this table, U value is calculated by Two-dimensional interpolation.

*Refer to 12.2 Two-dimensional interpolation.

9.5 Furnace Tracking processing

1) Definition of Furnace Tracking

Weld point position of coils at Entry side is monitored by using L1 (Line PLC) tracking data. Weld point passing length at each zone and coil condition at exit of each section are recognized by L1 tracking data.

2) Purpose of Furnace Tracking

The purpose is recognizing control timing at the target area of Strip temperature control.

3) Tracking event

Furnace Tracking is carried out using the length from X-WPD.

* X-WPD; an imaginary WPD at HS Entry

4) Each section length

X-WPD　　　Start　　　　　　　　　　　　　　OAS Delivery

Section	HS1	HS2	SS	SCS	RCS	OAS
Section length	325.4	270.9	193.7	146.7	44.2	667.4
Length from X-WPD	325.4	596.3	790.0	936.7	980.9	1648.3

5) Tracking target coil

The target of Tracking coils is the coils which have concern about Strip temperature control.

Entry side: Five coils before welding are included.

(In other words, six coils before the welding completed coil are included.)

Delivery side: The coil whose tail end passed at OAS delivery is out of tracking.

6) Calculation for the tracking target point (LL)

About all the tracking target points, the length from X-WPD is calculated.

i) Case1: The head of target coil is in Furnace Tracking area.

LL: coil length from head of coil to X-WPD

In case of Fig.9-4, Coil B passing length (LLb) is satisfied the following.

LLb = Laa - La

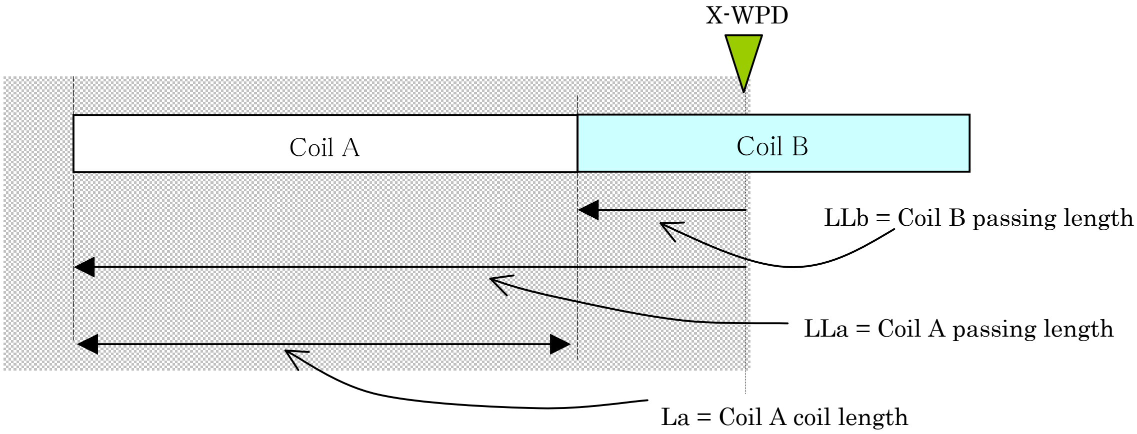


Fig.9-4 length from X-WPD-1

ii) Case2: The head of target coil is NOT in Furnace Tracking area.
(The tracking target point is front of X-WPD.)
LL: coil length from head of coil to X-WPD

In case of Fig.9-5, Coil B passing length (LLb) is satisfied the following (same as Fig.9-4).

LLb = Laa – La (* Sign of LLb is minus.)

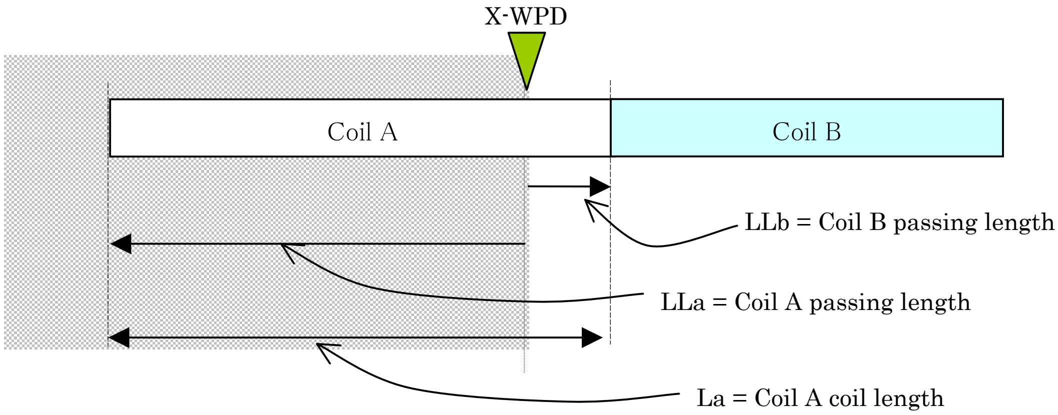


Fig.9-5 Length from X-WPD -2

9.6 Monitoring of actual strip temperature

1) Overview

Strip temperature control system receives Periodical actual data every 20 seconds from DCS. Then this system gathers the actual data, and monitors actual strip temperature. Correcting of furnace temperature is done if necessary.

Strip temperature control has three statuses. The statuses are the following.

i) Stable annealing

ii) Size change control

iii) Heat cycle change control

2) Monitoring of actual strip temperature and Alarm

Actual strip temperature is always monitored. When off temperature (out of Heat cycle limit) occurs, alarm is issued. If alarm is issued at one section, alarm can't be issued again until condition changes. That is, if strip temperature comes back in the limit of Heat cycle and then off temperature occurs again, alarm is issued once again.

Correcting of furnace temperature is done during Size change control and Heat cycle change control. (Refer to 10. Monitoring of actual strip temperature)

Monitoring of actual strip temperature and Correcting of furnace temperature are not done during Dummy coil passing.

(Refer to 7.6 Heat cycle change control using Dummy coil)

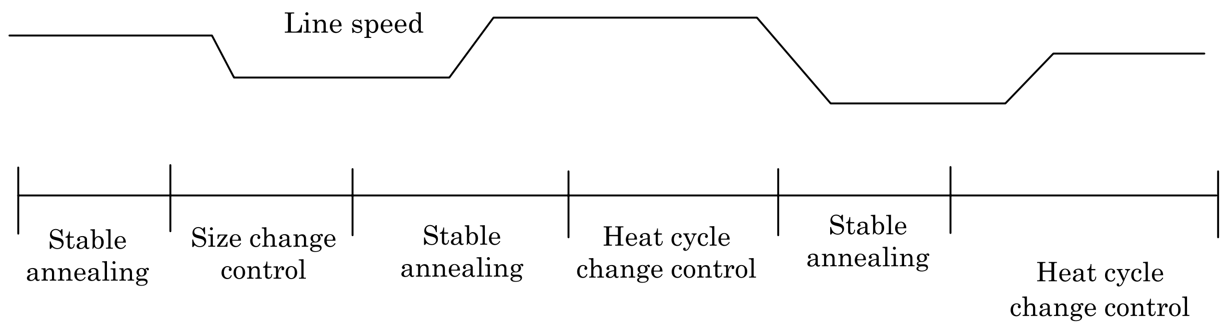


Fig.9-6 Transition of the operation condition

10. Monitoring of actual strip temperature

10.1 Overview

Strip temperature is always monitored watchig the Strip temperature of each section delivery any time using the traking signals. If the strip temperatyre is abnormal, the alarm is issued. Lower and upper limit is shown at each Heat cycletable. In this chaper, Strip temperature monitoring and Furnace temperature Correction in Size change control and Heat cycle change control are described.

1) Actual strip temperature monitoring and Furnace temperature Correction in HS Size change control

i) 【CASE-1】Actuator is furnace speed only

strip temperarure is monitored, but furnace temperature is not corrected. If off-temperature occurs, the alarm message is issued.

ii) 【CASE-2】Furnace speed+Strip temperature fine adjustment

Actual strip temperature is monitored during Size change control status is ON. Furnace temperature is also corrected.

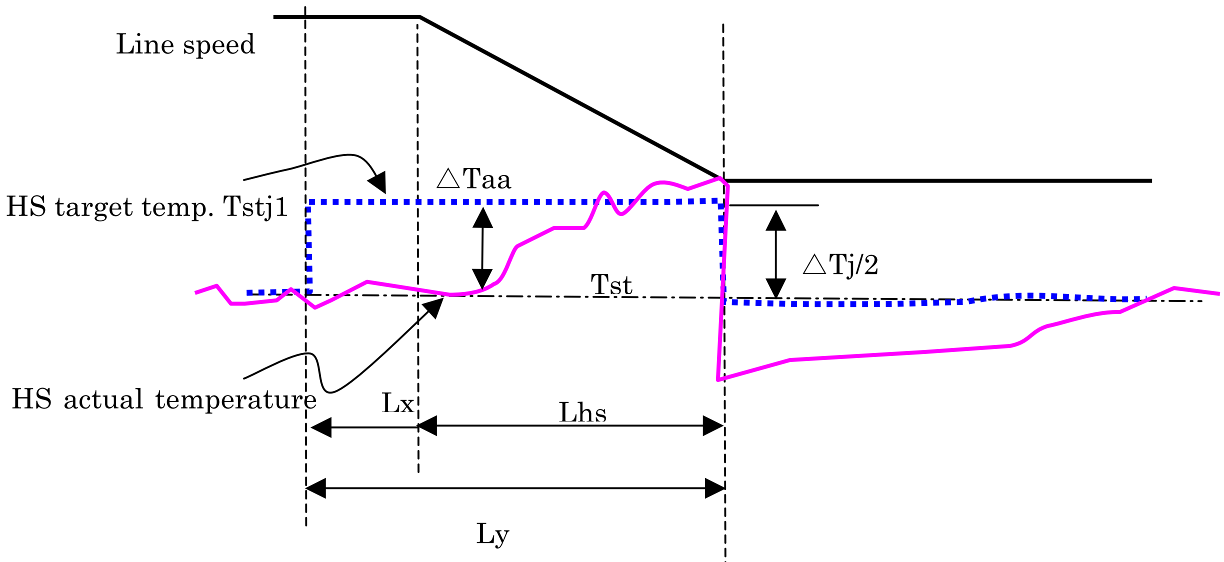


Fig.10-1Target strip temperature calculation for temperature monitoring in case of Line speed+Strip temperature fine adjustment (previous coil)

(a) Target strip temperature before WP passing HS Delivery (transient condition)

target temperature of Strip temperature fine adjustment,Tstj1 is Tstj1=Tst-△Tj/2. (△Tj is Strip temperature jump between next coil and previous coil. In the above case, thikckness chage from thin to thiccker, △Tj is Minus value)

Tst	:target strip temperature (Heat cycle)
Ly	:necessary length for Strip temperature fine adjustment
Lhs	: Pass length of HS Section
Lx	:next coil X-WDP passing length
Tstj1	:Target strip temperature of Strip temperature fine adjustment of Size change control (transient condition)
△Tj	:Strip temperature jump (next coil - previous coil)

(b) Furnace temperature Correction before WP passing HS Delivery (transient condition)

strip temperature deviation △Taa = Strip temperature Actual – target of Strip temperature fine adjustment=Tsa- Tstj1

Actual temperature is monitored every 20 seconds from Strip temperature fine adjustment start.

Furnace temperature Correction is as follows.

Each furnace temperature is corrected as $\triangle Tfi=-Gc\times\triangle Taa$ (i: Zone number)
So, Correction Furnace temperature Tf' is as $Tf'=Tfs+\triangle Tf$

Tf' :Correction Furnace temperature
Tfs :setting Furnace temperature
Gc :Furnace temperature Correction gain
$\triangle$Taa :strip temperature deviation

Correction Furnace temperature is included to the setting furnace temperature.

< Table 10-1> Gc: Furnace temperature Correction gain

Heat cycle	Size change control Correction gain		Heat cycle change control Correction gain	
	Rising temperature	Dropping temperature	Rising temperature	Dropping temperature
LC-CQ				
LC-DQ				
IF-ULC-DDQ				
IF-ULC-EDDQ				
IF-ULC-SEDDQ				
IF-ULC-HS440				
BH-HS-340				
LC-HSS440				
LC-HSS590				
DP-HSS590				

(c) Target strip temperature after passing the HS Delivery

Target strip temperature after WP passing HS delivery is same as the target before WP passing HS delivery.

(d) Furnace temperature Correction agter WP passing HS Delivery

In principle, strip temperature deviation ocurs at WP passing HS delivery. HS Delivery $\triangle$Tasz is defined as strip temperature deviation between actual Strip temperature and target 20 seconds after WP passing HS delivery.

After WP passing HS Delivery, transport distance necessary for Strip temperature settling to the target temperature is defined as Lz and Furnace temperature is corected as follows.

$\triangle Tf=-Gc\times\triangle Tcc$

$\triangle$Tcc :strip temperature deviation
Lz :Necessary strip length for Strip temperature change
Lhs : Pass length of HS Section
Lx :next coil X-WDP passing length
$\triangle$Tasz: strip temperature deviation between actual Strip temperature and target after WP passing HS delivery = Tas- Tst

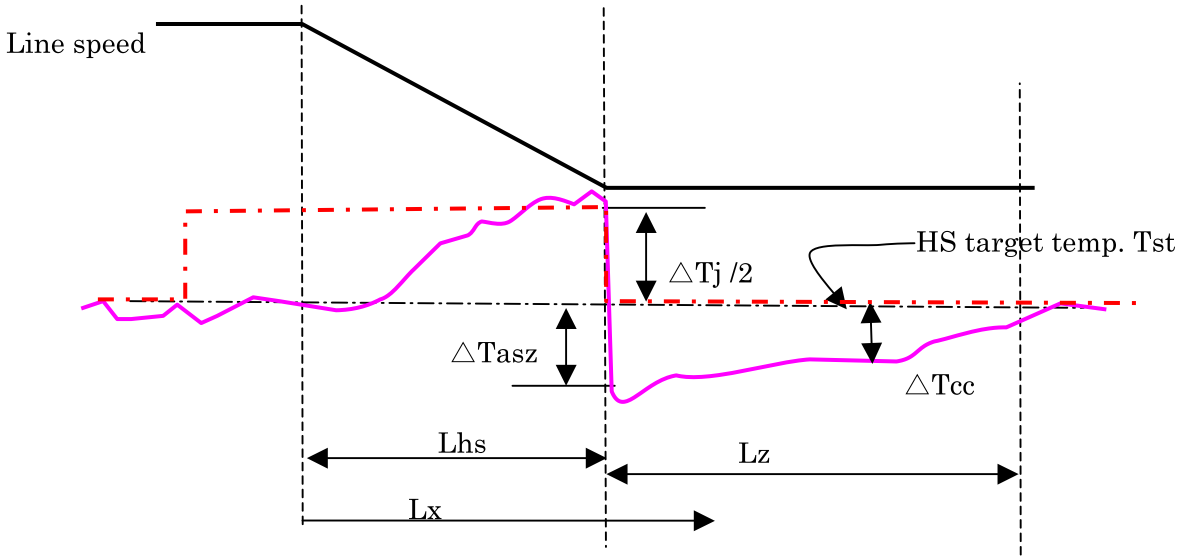


Fig. 10-2 Target strip temperature calculation for temperature monitoring in case of Line speed+Strip temperature fine adjustment (next coil)

iii)【CASE-3】Speed is not used for size change control

(a) Target strip temperature before WP passing HS Delivery and Furnace temperature Correction

It is same as CASE-2.

(b) Target strip temperature after WP passing HS Delivery and Furnace temperature Correction

It is same as CASE-2.

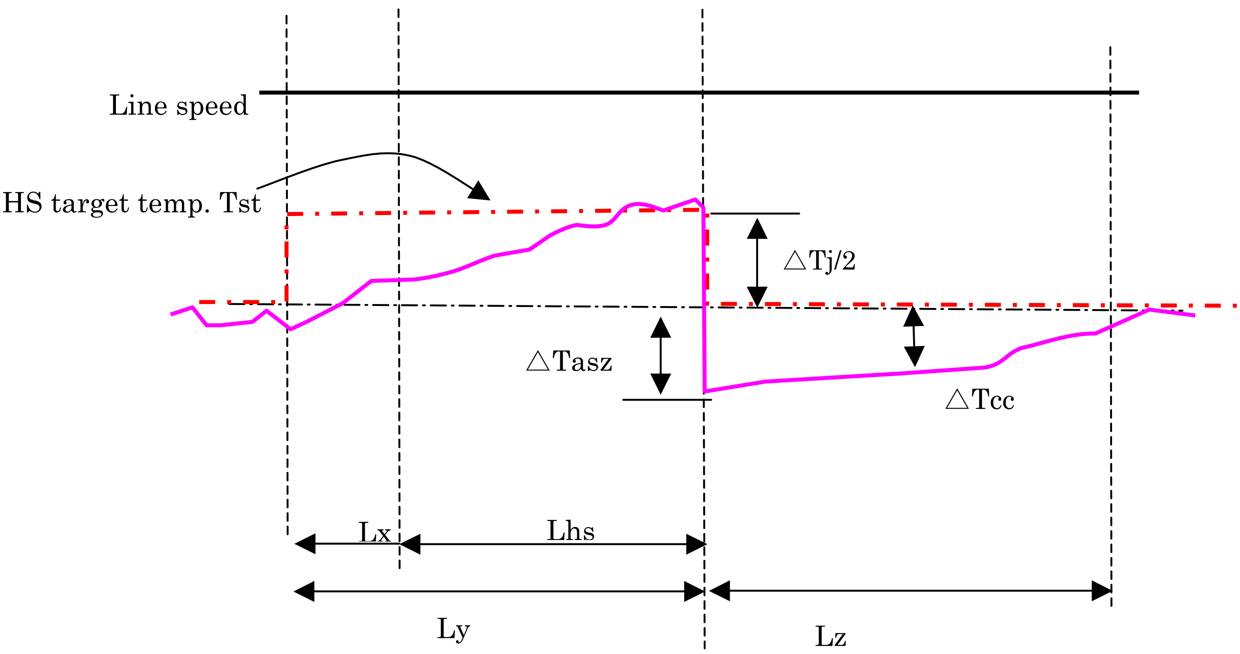


Fig. 10-3 Target strip temperature calculation for temperature monitoring in case of Strip temperature fine adjustment without speed manipulation

2) Actual strip temperature monitoring for Heat cycle change control

It is same as CASE-2, CASE-3 in Size change control.

Target strip temperature before Heat cycle change point passes HS Delivery is The target of Strip temperature fine adjustment(Tsti) as mensioed at 7.3. And it chages to the next cil target temp(Heat cycle or operator input value) after pssing HS Delivery.

i) Furnace temperature Correction for Heat cycle change control

Actual temperature is monitored every 20 seconds from Strip temperature fine adjustment start same as above mentioned in Size change control

(a) Before passing HS Delivery

Strip temperature deviation △ Taa = Strip temperature Actual - target strip temperature =Tsa - Tsti

Furnace temperature Correction is as follows.

△Tf is defined as △Tf=-Gc×△Taa, and each Furnace temperature is changed. So, Correction Furnace temperature Tf' is Tf'=Tfs+△Tf

(Correction Furnace temperature is added to Furnace temperature Tfs calculated by the temperature model)

Gc :Furnace correct gain (Refer to Table)

(b) After passing HS Delivery HS

strip temperature deviation △Taa=Strip temperature Actual -target strip temperature =Tsa - Tsti

Furnace temperature Correction is as follows.

△Tf is defined as △Tf=-Gc×△Tcc and each Furnace temperature is changed. So, Correction Furnace temperature Tf' is Tf'=Tfs+△Tf

(Correction Furnace temperature is added to Furnace temperature Tfs calculated by the temperature model) Tf'=Tfs+△Tf

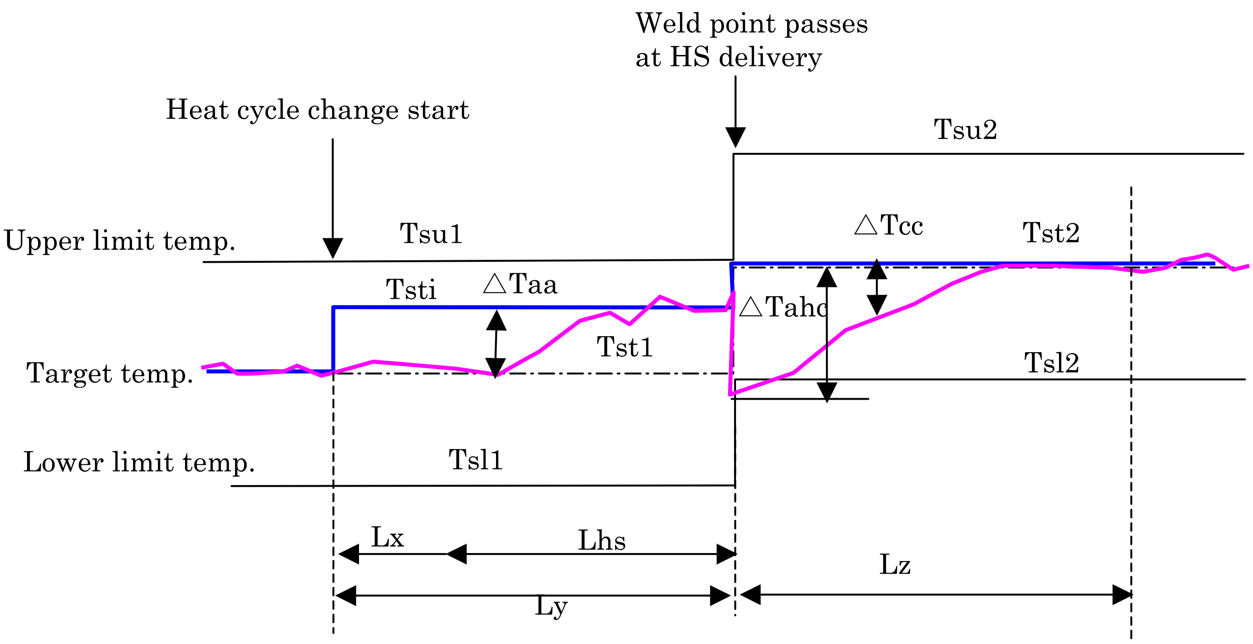


Fig. 10-4 Monitoring strip temp. and Correcting furnace temp. at Heat cycle change

11. Setting for passing Section

11.1 Overview

The function of setting for passing Section is executed when the weld point of coil head passes Section Delivery. The setting items are edited and transferred to Instrumentation DCS.

11.2 Setting at passing Section Delivery

The setting items for passing Section are edited using PDI information and Constant data, and are sent to Instrumentation DCS. The Setting for passing Section do not depend on the status of strip temperature control. When the setting value is abnormal, it is not sent to DCS. Setting at passing Section Delivery is executed at Dummy coil passing same as the normal product coil.

11.3 Sending Result of edited information to Instrumentation

Setting value at passing Section is edited successfully, the value for each section shall be sent o DCS.

11.4 Setting timing

Setting timing is decided by following table.

< Table 11-1 > Setting timing

Setting timing	Level-2→Instrumentation DCS Transaction name
CAL Weld point HS Delivery passing	HS target temp. setting
CAL Weld point SS Delivery passing	SS target temp. setting
CAL Weld point SCS Delivery passing	SCS target temp. setting
CAL Weld point RCS Delivery passing	RCS target temp. Setting
CAL Weld point OAS Delivery passing	OAS target temp. setting

11.5 HS target temperature Setting items and way to edit

< Table 11-2 > setting items

No.	Setting items	Remarks
1	HS Delivery target strip temperature	Heat cycle Table
2	HS Delivery Strip temperature Upper limit	Heat cycle Table
3	HS Delivery Strip temperature Lower limit	Heat cycle Table
4	HS Delivery Strip temperature Emissivity	Heat cycle Table
5	Thickness	PDI
6	Strip Width	PDI
7	Specific gravity	Constant data Table
8	Specific heat	Constant data Table

Hereinafter, SS, SCS, RCS, OAS is same as above table.

12. Others

12.1 Furnace response Table

H : Thickness

V : Actual line speed

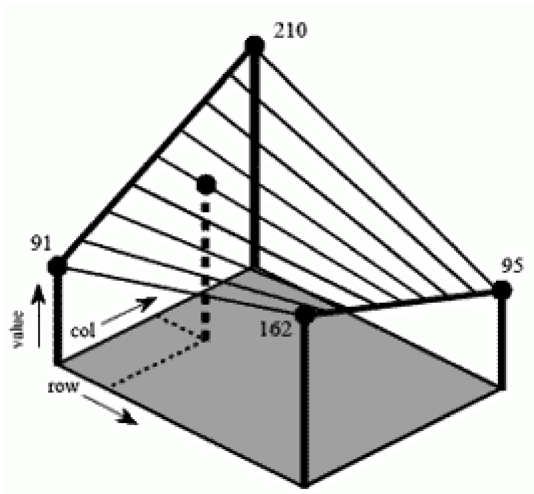
Furnace response (rising temperature)--- Unit: ℃/min TDUP

< Table 12-1 > Furnace response Table

VH / Heat cycle	～100 mpm*mm	100～200 mpm*mm	200～300 mpm*mm	300～ mpm*mm
LC-CQ				
LC-DQ				
IF-ULC-DDQ				
IF-ULC-EDDQ				
IF-ULC-SEDDQ				
IF-ULC-HS440				
BH-HS-340				
LC-HSS440				
LC-HSS590				
DP-HSS590				

Furnace response (dropping temperature) --- Unit: ℃/min TDDW

Furnace response table of Other Section is same form as above table. But the furnace response of HS, SS means strip temperature response for furnace temperature set value change, and SCS, RCS,OAS means strip temperature response for strip temperature set value change.



12.2 Two-dimensional interpolation

1) Object

Normally, look-up tables in Level-2 have many of stratified data. And the stratified segments are independent each other. But essentially, physical data at tables such U values stratified by thickness -width segment shall be continuous. So, the segments tend to small mesh and the tuning data is too much. As a result, the data cannot be tuned. In this project, we employ the Two-dimensional interpolation method for U value tables. The number segment data becomes small in number.

< Standard Lookup Table format >

Thickness / Width		T1	T2	T3	T4
W1		C0	C1		
W2		C2	C3	A0	A1
W3				A2	A3

2) Interpolation formula

If the next condition is given under the above table, the target value is obtained as follows.

$W2 < W < W1$
$T1 < T < T2$
The Interpolation formula is obtained by the below.

$$D = \frac{W - W2}{W1 - W2}\left(\frac{T2 - T}{T2 - T1} \times C0 + \frac{T - T1}{T2 - T1} \times C1\right) + \frac{W1 - W}{W1 - W2}\left(\frac{T2 - T}{T2 - T1} \times C2 + \frac{T - T1}{T2 - T1} \times C3\right)$$

* At the condition out of Lookup Table, nearest value is applied.
For example, when the condition is “W < W3” and “T > T4”, “A0~A3” is applied.

3) Example

Thickness / Width	0.8	1.2
1400	100	200
1000	80	150

When W=1200,T=1.0,D=132.5

4) Reflection to adaptive value

In the case the intermediate value of boundary value is corrected at the at adaptive calculation, boundary value is reflected by variable ratio of adaptive value.
For example, adaptive value is changed 132.5 to 150,
variable ratio, R=150/132.5=1.132
So, boundary value of the table is as follows.
(a) C0 = 100*R=113.2
(b) C1 = 200*R=226.4
(c) C2 = 80*R=90.6
(d) C3 = 150*R=169.8