(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 145 485**
A2

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: 84308613.3

(51) Int. Cl.⁴: **C 21 D 9/573**, C 21 D 11/00

(22) Date of filing: 11.12.84

(30) Priority: 15.12.83 JP 234986/83

(43) Date of publication of application: 19.06.85
Bulletin 85/25

(84) Designated Contracting States: DE FR GB

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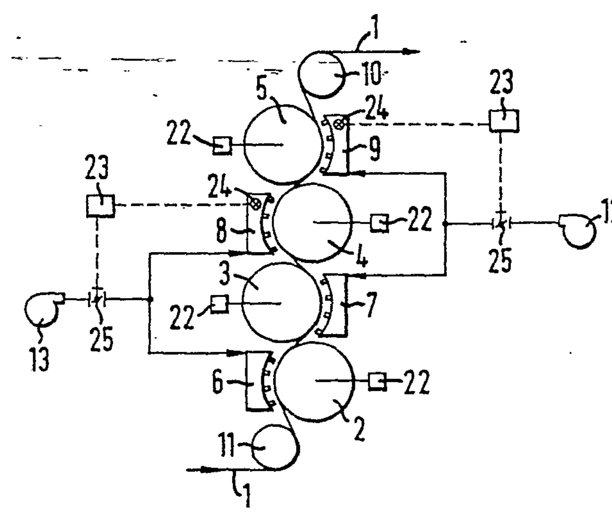
(54) **Method of controlling the temperature of steel strip in the cooling zone of a continuous annealing furnace.**

(57) The invention relates to a method of controlling the temperature of a steel strip (1) in the cooling zone of a continuous annealing furnace which is provided with a plurality of cooling rolls (2 to 5) in which a coolant is circulated via a circuit (14 to 18) for cooling the strip as it is brought into contact with the outer peripheral surfaces of the rolls, the coolant temperature being controlled via temperature control means (19 to 21), and a plurality of gas jet coolers (6 to 9) for blowing cooling gas against the strip.

In accordance with the invention, the flow rate of the cooling gas, the angle at which the strip is brought into contact with the surfaces of the rolls and the coolant temperature are controlled selectively in the order of, first, at least one of either the flow rate of coolant, or the angle, and then the coolant temperature, so that the strip may be cooled quickly and efficiently to a predetermined temperature irrespective of any change in strip gauge during the continuous annealing of a plurality of strips which are different gauge.



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METHOD OF CONTROLLING THE TEMPERATURE OF STEEL STRIP IN THE COOLING ZONE OF A CONTINUOUS ANNEALING FURNACE

BACKGROUND OF THE INVENTION

1. Field of the Invention:

This invention relates to a method of controlling the temperature of steel strip in the cooling zone of a continuous annealing furnace.

2. Description of the Prior Art:

A continuous annealing furnace is an apparatus which performs the heat treatment of a cold rolled steel strip in accordance with a heat cycle as shown by way of example in FIGURE 1 in order to improve its workability. The heat treatment according to the heat cycle of FIGURE 1 is effected by a furnace having a fast cooling zone and a final cooling zone.

There is known a system for cooling a steel strip in the cooling zone of a continuous annealing furnace by a combination of roll cooling and gas jet cooling. FIGURE 2 shows the cooling system disclosed in Japanese Patent Publication No. 10973/1981. A steel strip 1 travels in contact with four cooling rolls 2 to 5 in which a coolant flows, and its heat is transferred to the cooling rolls. Four plenum chambers 6 to 9 are provided in front of the cooling rolls 2 to 5, respectively, for blowing jets of cooling gas against the strip 1. Each plenum chamber has a plurality of nozzles through which the cooling gas is jetted out of the plenum chamber. The cooling gas having an elevated pressure is supplied through blowers 12 and 13 and blown against the strip 1 through the plenum chambers 6 to 9 not only for cooling the strip 1, but also for bringing it into intimate contact with the cooling rolls 2 to 5, as the failure of the strip to contact the cooling rolls intimately due to the distortion of its edge or central portion results in the lack of cooling uniformity. FIGURE 2 also shows a pair of deflector rolls 10 and 11, devices 22 for moving the cooling rolls to control the angle at which the strip is brought into contact with the cooling rolls, pressure controllers 23 for controlling the pressure of the cooling gas in the plenum chambers, sensors 24 for detecting the pressure of the cooling gas in the plenum chambers and dampers 25.

The coolant is circulated through the cooling rolls 2 to 5 by a circuit which is shown by way of example in FIGURE 3 as disclosed in Japanese Patent Application No. 129069/1982. FIGURE 3 shows only one of the cooling rolls at 2 for the sake of simplicity. The coolant is returned from the cooling roll 2 to a coolant tank 15 through a discharge line 14. It is delivered by a pump 16 from the tank 15 to a heat exchanger 17 in which it is cooled, and supplied to the cooling roll 2 by a supply line 18. The temperature of the coolant entering the cooling roll is controlled by a coolant temperature controller 19. More specifically, the coolant temperature is detected by a sensor 20 and the flow of cooling water entering the heat exchanger 17 is controlled by a control valve 21 to obtain an appropriate coolant temperature set by the temperature controller 19.

The cooling system employing the combination of roll cooling and gas jet cooling as hereinabove described effects the control of the temperature of the strip 1 by controlling three variable factors, i.e., the length of a strip portion contacting each cooling roll or in other words the angle at which the strip is brought into contact with each cooling roll, the coolant temperature and the flow rate of the cooling gas blown against the strip. The control of the coolant temperature has already been described. The angle at which the strip contacts the cooling rolls is controlled by the roll moving devices 22. The flow rate of the cooling gas is controlled by adjusting the position of each damper 25 so that the pressure of the cooling gas detected by the pressure sensors 24 may reach a predetermined level.

In order to cool the strip to a predetermined final temperature, it is necessary to control the three factors, i.e., (1) the flow rate of the cooling gas, (2) the angle at which the strip is brought into contact with the cooling rolls and (3) the coolant temperature, by taking into account not only the target strip temperature, but also other conditions of the annealing operation such as the dimensions of the strip and the speed of its travel. Insofar as there exist a plurality of factors to be controlled, however, it is impossible to determine each individual factor in a definite fashion. It is necessary to develop some procedure which enables an appropriate control of those factors.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a method of controlling the temperature of a steel strip in the cooling zone of a continuous annealing furnace so that a high yield of production may be achieved.

According to one aspect of this invention, a predetermined strip temperature is obtained in the cooling zone by controlling the flow rate of the cooling gas, the angle at which the strip is brought into contact with the cooling rolls and the coolant temperature in the order mentioned.

According to another aspect of this invention, its object is attained by controlling first the flow rate of the cooling gas and the angle of the strip simultaneously and the coolant temperature thereafter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a graph showing by way of example a heat cycle which is employed in a continuous steel strip annealing furnace;

FIGURE 2 is a schematic diagram of a system for cooling strip by a combination of roll cooling and gas jet cooling;

FIGURE 3 is a schematic diagram of a circuit for the circulation of a coolant through cooling rolls;

FIGURE 4 is a graphical representation of the control of three factors during the cooling of strips having a gradually increasing gauge;

FIGURE 5 is a graphical representation of the control of the three factors during the cooling of strips having a gradually decreasing gauge;

FIGURE 6 is a graphical representation of the control of the three factors during the cooling of strips having a gradually increasing gauge and a gradually decreasing gauge;

FIGURE 7 is a flow chart showing by way of example the sequence of calculations for setting the three factors to control the temperature of each strip to be cooled; and

FIGURE 8 is a schematic diagram showing another example of the cooling system employing the combination of roll cooling and gas jet cooling.

DETAILED DESCRIPTION OF THE INVENTION

According to an essential feature of this invention, the control of the strip temperature is effected by varying the three control factors or parameters in a specific order of preference. This order of preference is determined by the quickness in the response of control. Insofar as the strip takes only several seconds to pass through the cooling zone, the quickness in the response of control has the most important bearing on an improved yield of production in the event there is any change in the conditions of the annealing operation, for example, during the passage of a welded joint between two strips which are different in gauge. The three control factors or parameters differ from one another in response time, as follows:

(1) Flow rate of cooling gas - About 10 seconds;

(2) Angle of strip relative to the cooling rolls - About two minutes; and

(3) Coolant temperature - About 10 minutes.

The inventors of this invention have, therefore, thought of establishing a specific order of preference or priority when varying the three factors in order to obtain an appropriate heat cycle suited for the annealing conditions and thereby an appropriate final cooling temperature for the strip. According to a first aspect of this invention, priority is in the order of (1) flow rate of cooling gas, (2) angle of the strip relative to the cooling rolls and (3) coolant temperature. This is exactly the order of quickness in response and enables a high yield of production irrespective of any change in the annealing conditions.

According to a second aspect of the invention, the flow rate of cooling gas and the angle of the strip relative to the cooling rolls are first controlled simultaneously, and the control of the coolant temperature having a longer response time is delayed. This delay ensures an improved yield of production. The simultaneous control of the flow rate of the cooling gas and the angle of the strip has the advantage of achieving a large change in the cooling conditions at a time within a relatively short length of time.

The invention will now be described by way of example with reference to FIGURES 4 to 7 of the drawings. FIGURE 4 is a graphical illustration of the control of the three factors for the continuous cooling of a plurality of strips which gradually increase in gauge, while the other annealing conditions remain the same for all the strips. The points marked o in FIGURE 4 are the starting points. As long as there is any room for an increase in the flow rate of cooling gas, it is increased with an increase in strip gauge as shown at A in FIGURE 4, since its control has a faster response than the control of the other two factors. If the flow rate of cooling gas has reached its maximum level, the angle of the strip relative to the cooling rolls is, then, increased with an increase in strip gauge as shown at B in FIGURE 4, as long as there is any room for such increase in the angle. If it has, then, become impossible to increase the angle to any further extent, the coolant temperature is lowered, as shown at C in FIGURE 4, in order to increase the cooling capacity of the cooling system, though it shows a slower response to control than the other two factors.

FIGURE 5 is a graphical illustration of the control of the three factors for the continuous cooling of a plurality of strips which gradually decrease in gauge. With a gradual reduction in strip gauge, the flow rate of cooling gas is first decreased as shown at A' in FIGURE 5, then the angle of the strip relative to the cooling rolls is decreased as shown at B', and finally the coolant temperature is raised as shown at C'.

FIGURE 6 is a graphical illustration of the control of the three factors for the continuous cooling of a plurality of strips having first a gradually increasing gauge and then a gradually decreasing gauge. The control under this situation may be effected by a combination of the procedures shown in FIGURES 4 and 5. It will, however, be noted that FIGURE 6 shows an example of operation in which the coolant temperature is not varied irrespective of the change in strip gauge.

In order to ensure stabilized or reliable control of strip temperature, it is important to leave some allowance for each of the maximum and minimum values to be set for each of the three factors. Referring, for example, to the flow rate of cooling gas, its maximum value may be 90% of the blower capacity and its minimum value may be the minimum required for avoiding nonuniform cooling plus, say, 10% of the blower capacity. The minimum flow rate required for avoiding nonuniform cooling can be obtained experimentally.

FIGURE 7 is a flow chart showing by way of example the calculations which are performed for setting the three factors at optimum levels for the cooling of each strip. In FIGURE 7, the following symbols have the following meanings:

$T_{S\emptyset}$: Final strip temperature as measured;

$T_{S\emptyset}^{*}$: Target value of final strip temperature;

$T_{S\emptyset U}$: Upper limit of final strip temperature (e.g., $T_{S\emptyset U} = T_{S\emptyset}^{*} + 20$);

$T_{S\emptyset L}$: Lower limit of final strip temperature (e.g., $T_{S\emptyset L} = T_{S\emptyset}^{*} - 20$);

P : Pressure of cooling gas in the plenum chambers;

θ : Angle of strip relative to the cooling rolls.

The cooling curve, flow rate of cooling gas, angle of strip relative to the cooling rolls and coolant temperature may be calculated as will hereinafter be described.

(i) Calculation for the Cooling Curve:

The characteristics of strip cooling by the system shown in FIGURE 2 may be expressed by the following equation:

$$c \cdot \gamma \cdot d \cdot v \cdot \frac{dT_s}{dx} = \alpha(T_g - T_s) + K(T_w - T_s) \qquad (1)$$

where T_s: strip temperature (°C);

T_g: temperature of cooling gas at the nozzles (°C);

T_w: average temperature of the coolant in the cooling rolls (°C);

α : coefficient of heat transfer between strip and cooling gas ($Kcal/m^2h°C$);

K : coefficient of heat transfer between strip and coolant in the cooling rolls ($Kcal/m^2h°C$);

c : specific heat of strip (Kcal/kg°C);

γ : specific gravity of strip (kg/m^2);

v : velocity of travel of strip (m/h);

d : strip gauge (m);

x : strip length (m).

The cooling curve for strip can be obtained by the integration of equation (1) by the length of the strip portion cooled by the cooling rolls and the cooling gas. The relationship between the coefficient α of heat transfer to the cooling gas and the flow rate of the cooling gas (in the case of cooling by the system of FIGURE 2, the pressure P of the cooling gas in the plenum chambers) may be determined experimentally as expressed, for example, by the following equation:

$$P = a_1 \cdot \alpha^{a_2} + a_3 \qquad (2)$$

where P: pressure of the cooling gas in the plenum chambers;

a_1, a_2 and a_3: constants.

(ii) Calculation of the Flow Rate of Cooling Gas:

The pressure P of the cooling gas in the plenum chambers which makes it possible to obtain the target value of the final strip temperature may be determined in accordance with equations (1) and (2) by taking into account the specific values of the angle of the strip relative to the cooling rolls and the coolant temperature T_W which are known.

(iii) Calculation of the Angle of Strip Relative to the Cooling Rolls:

The angle which makes it possible to obtain the target value of the final strip temperature may be determined in accordance with equations (1) and (2) by taking into account the specific values of the flow rate of the cooling gas or the pressure P of the cooling gas in the plenum chambers and the coolant temperature T_W which are known. The angle may be expressed by the following equation:

$$\text{Strip length cooled by the cooling rolls (m)} = \text{Angle of strip relative to the rolls (deg.)} \times \frac{\Pi}{360} \times \text{Outside dia. of the rolls (m)}$$

(iv) Calculation of the Coolant Temperature:

The coolant temperature T_W which makes it possible to obtain the target value of the final strip temperature may be determined in accordance with equations (1) and (2) by taking into account the flow rate of the cooling gas or the pressure P of the cooling gas in the plenum chambers and the angle of the strip relative to the cooling rolls which are known.

The calculations set forth at (i) to (iv) above are easy to perform by an electronic computer based on the information on the annealing of each particular strip, such as the strip dimensions, line speed and target heat cycle.

The foregoing description has been based on the use of the cooling system shown in FIGURE 2. This invention is also applicable to the cooling of strip by other cooling apparatus. Another cooling system is shown by way of example in FIGURE 8. It includes gas jet coolers 26 and 27 by which the strip is cooled before it is cooled by the cooling rolls 2 to 5. The gas jet coolers can alternatively be disposed downstream of the cooling rolls. It is also possible to combine the cooling systems of FIGURES 2 and 8 by, for example, disposing the gas jet coolers of FIGURE 8 upstream of the cooling system of FIGURE 2. In the event the combined cooling system of FIGURES 2 and 8 is utilized, it will be appropriate to employ four control factors, namely:

(1) Flow rate of the cooling gas blown by the gas jet coolers of FIGURE 8;

(2) Flow rate of the cooling gas blown by the gas jet coolers facing the cooling rolls as shown in FIGURE 2;

(3) Angle of the strip relative to the cooling rolls; and

(4) Coolant temperature.

The foregoing description of FIGURES 4 to 8 has been based on the control of one of the factors at a time in accordance with the order of priority. According to this invention, it is also possible to control the flow rate of cooling gas and the angle of the strip relative to the cooling rolls simultaneously as hereinbefore set forth. In this case, it is necessary to find experimentally the proportions of the contributions which those two factors make to the cooling of the strip, and it is, then, possible to determine the values in accordance with equations (1) and (2).

As is obvious from the foregoing description, this invention is most saliently characterized by effecting the preferential control of one or two factors or parameters having a better response to control than the other factor or factors, while keeping the other factor or factors intact as far as practically feasible. Thus, the method of this invention makes it possible to achieve the best possible yield of production irrespective of any change in the annealing conditions.

CLAIMS

1. A method of controlling the temperature of a steel strip (1) in the cooling zone of a continuous annealing furnace, said cooling zone being provided with a plurality of cooling rolls (2 to 5) in which a coolant is circulated via a cooling circuit (14 to 18) for cooling said strip as it is brought into contact with the outer peripheral surfaces of said rolls, said circuit having means (19 to 21) for controlling the temperature of said coolant, and a plurality of gas jet coolers (6 to 9) for blowing cooling gas against said strip, characterised by controlling the flow rate of said cooling gas, the angle at which said strip is brought into contact with said surfaces of said rolls, and the temperature of said coolant, in the order of first, at least one of said flow rate and said angle, and then said coolant temperature, whereby the response time for cooling said strip to a predetermined temperature is enhanced.

2. A method as claimed in Claim 1, characterised in that said flow rate is first controlled.

3. A method as claimed in Claim 1, characterised in that said flow rate and said angle are controlled simultaneously.

4. A method as claimed in Claim 2 or 3, characterised in that each of said gas jet coolers (6 to 9) faces said outer peripheral surface of one of said cooling rolls (2 to5).

5. A method as claimed in Claim 2 or 3, characterised in that said gas jet coolers (6 to 9) are located upstream of respective said cooling rolls (2 to 5) in the direction of strip travel.

6. A method as claimed in Claim 2 or 3, characterised in that said gas jet coolers (6 to 9) are located downstream of respective said cooling rolls (2 to 5) in the direction of strip travel.

7. A method as claimed in Claim 2 or 3, characterised in that each of said of said gas jet coolers (6 to 9) faces the outer peripheral surface of a respective one of said cooling rolls (2 to 5), while the other gas jet coolers are located upstream of respective said cooling rolls in the direction of strip travel.

8. A method as claimed in Claim 7, characterised in that said flow rate of said cooling gas through said other gas jet coolers is controlled before said flow rate of said cooling gas through said some gas jet coolers is controlled.

FIG.1

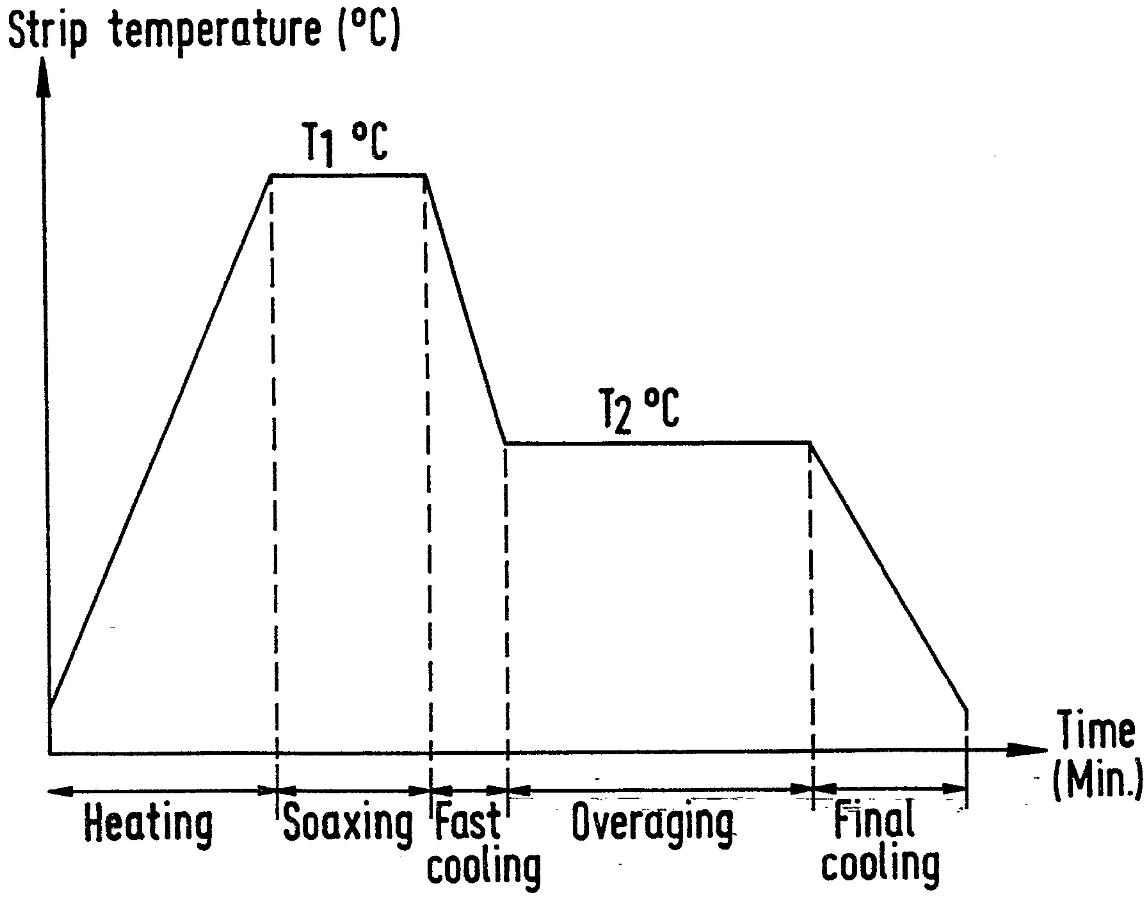
Strip temperature (°C)
T1 °C
T2 °C
Time (Min.)
Heating
Soaxing
Fast cooling
Overaging
Final cooling

FIG. 2

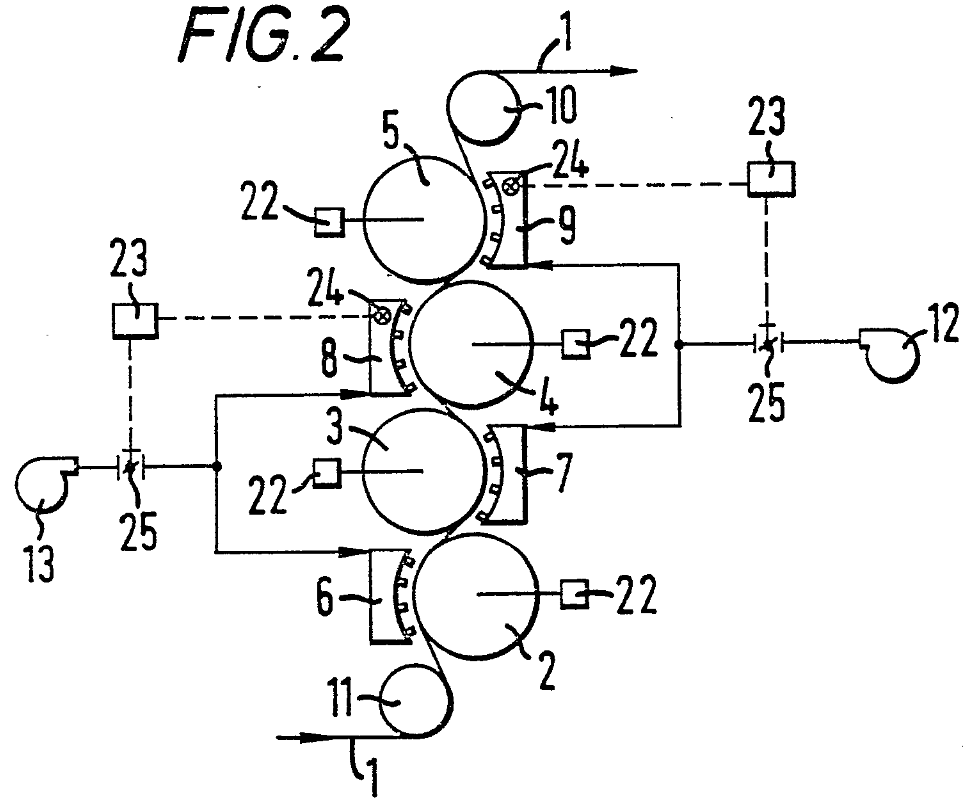
1
10
5
23
24
22
9
23
24
22
12
8
4
25
3
7
22
13
25
6
22
2
11
1

FIG. 3

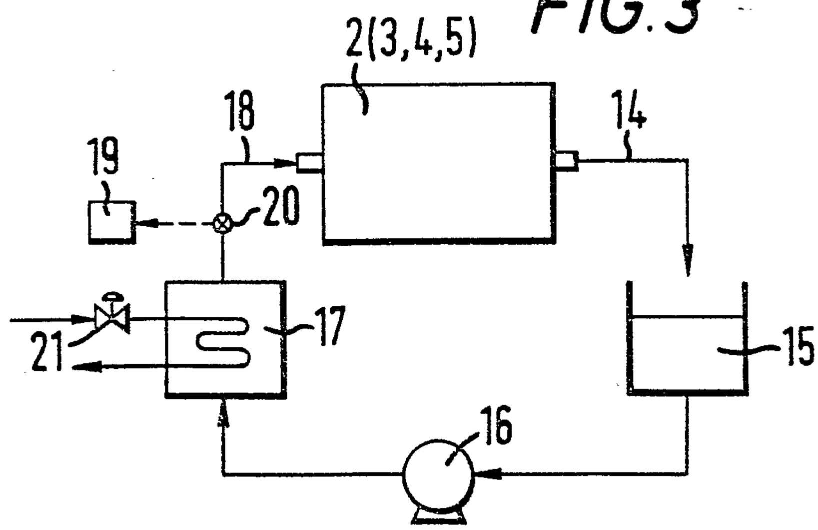
2(3,4,5)
18
14
19
20
17
21
15
16

FIG.4

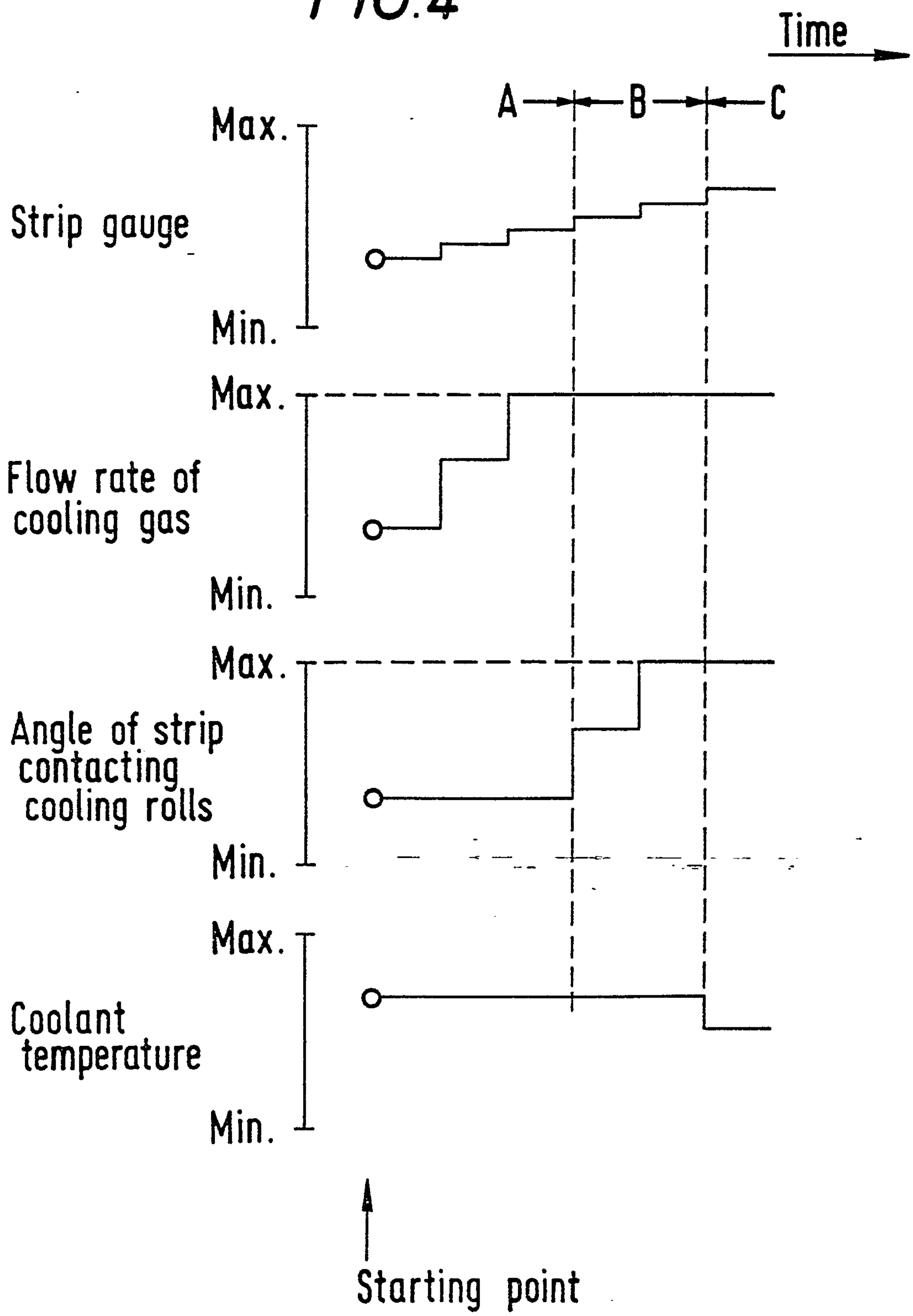
Time
A
B
C
Max.
Strip gauge
Min.
Max.
Flow rate of cooling gas
Min.
Max.
Angle of strip contacting cooling rolls
Min.
Max.
Coolant temperature
Min.
Starting point

FIG.5

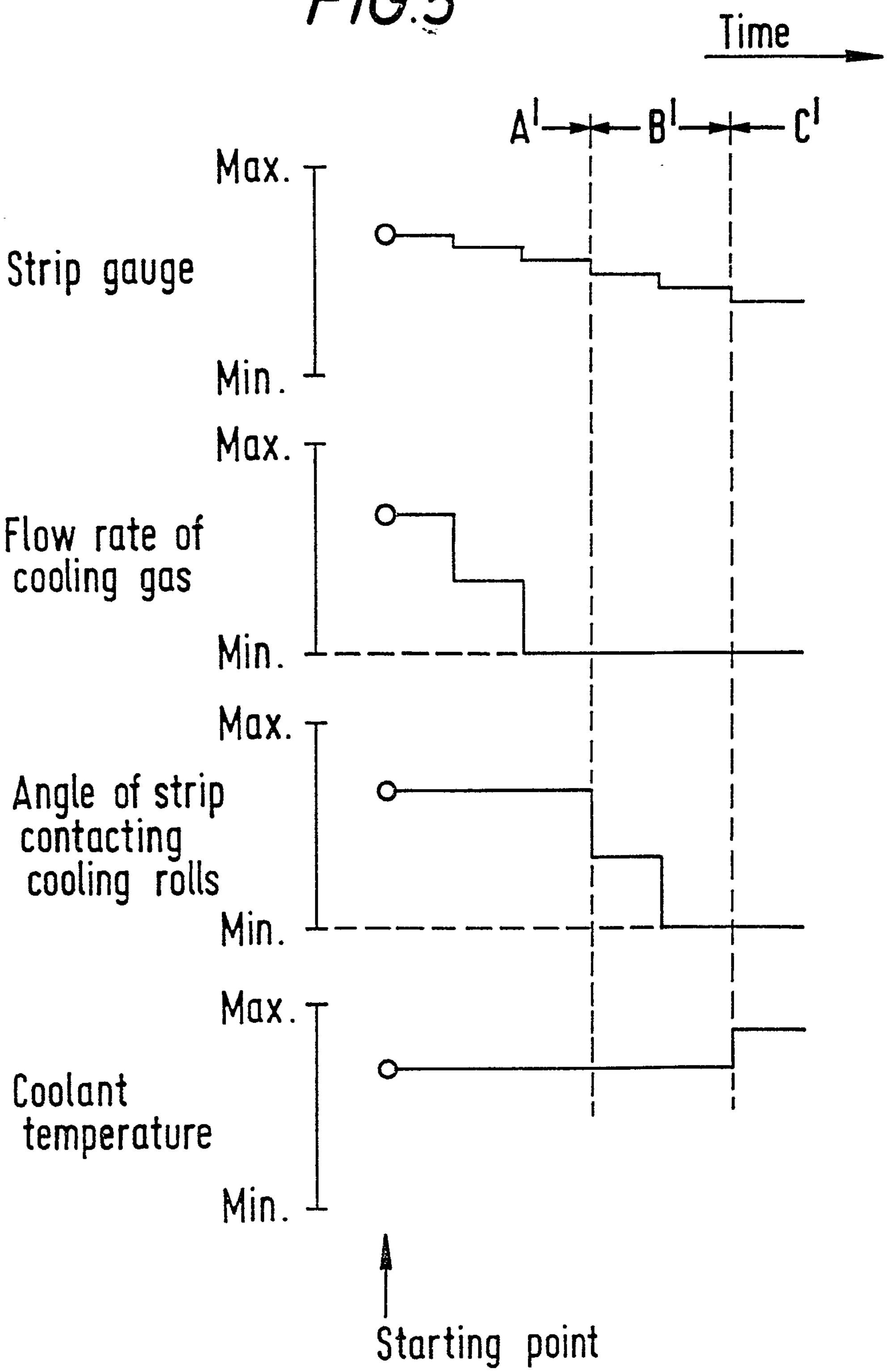
Time
A'
B'
C'
Max.
Strip gauge
Min.
Max.
Flow rate of cooling gas
Min.
Max.
Angle of strip contacting cooling rolls
Min.
Max.
Coolant temperature
Min.
Starting point

FIG.6

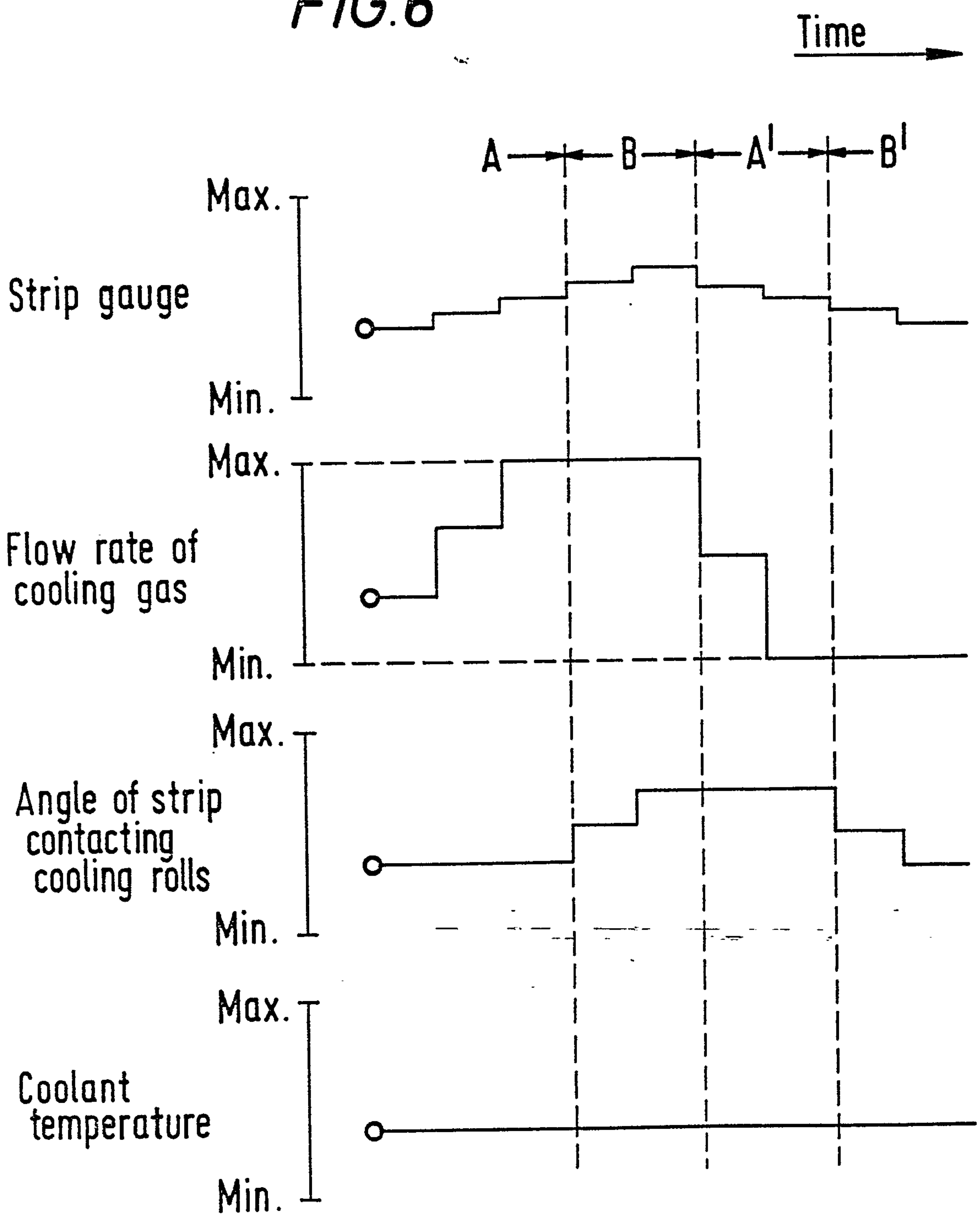
Time
A
B
A'
B'
Max.
Min.
Strip gauge
Max.
Min.
Flow rate of cooling gas
Max.
Min.
Angle of strip contacting cooling rolls
Max.
Min.
Coolant temperature

FIG.7

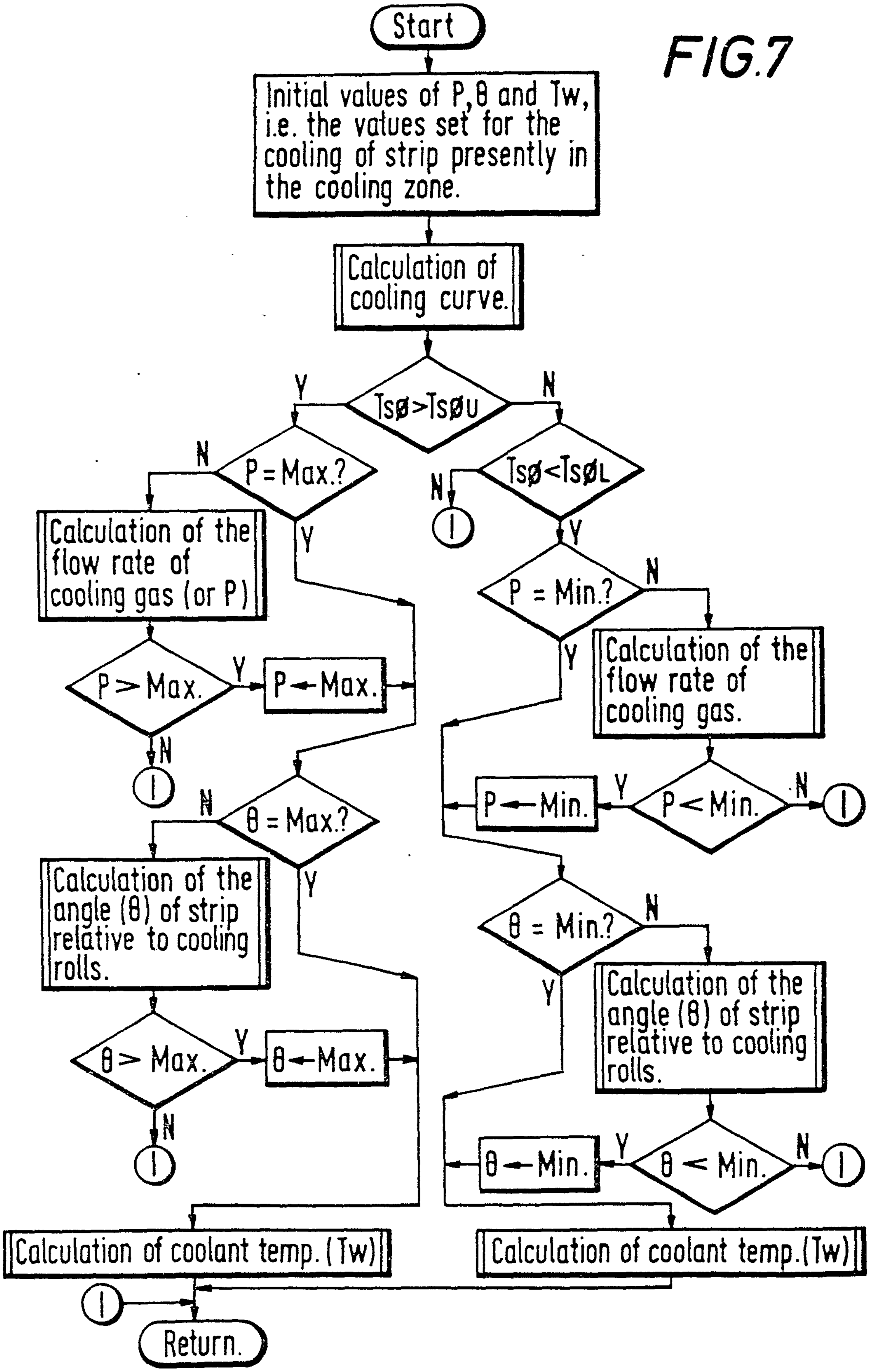
Start
Initial values of P, θ and Tw, i.e. the values set for the cooling of strip presently in the cooling zone.
Calculation of cooling curve.
Tsø>TsøU
Y
N
P = Max.?
Tsø<TsøL
Calculation of the flow rate of cooling gas (or P)
P > Max.
P ← Max.
P = Min.?
Calculation of the flow rate of cooling gas.
P ← Min.
P < Min.
θ = Max.?
Calculation of the angle (θ) of strip relative to cooling rolls.
θ > Max.
θ ← Max.
θ = Min.?
θ ← Min.
θ < Min.
Calculation of coolant temp. (Tw)
Calculation of coolant temp. (Tw)
Return.

FIG.8