

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
29.10.1997 Bulletin 1997/44

(51) Int. Cl.⁶: **C21D 9/573**

(21) Application number: **97105044.8**

(22) Date of filing: **25.03.1997**

(84) Designated Contracting States:
AT DE GB

(30) Priority: **26.04.1996 JP 130851/96**

(71) Applicant: **NIPPON STEEL CORPORATION**
Tokyo 100-71 (JP)

(72) Inventors:
• **Mine, Tatsunori,**
c/o Nippon Steel Corporation
Tobata-ku, Kitakyushu City, Fukuoka 804 (JP)

• **Sakurai, Koichi,**
c/o Nippon Steel Corporation
Tobata-ku, Kitakyushu City, Fukuoka 804 (JP)
• **Waki, Kouichi,**
c/o Nippon Steel Corporation
Tobata-ku, Kitakyushu City, Fukuoka 804 (JP)

(74) Representative: **VOSSIUS & PARTNER**
Siebertstrasse 4
81675 München (DE)

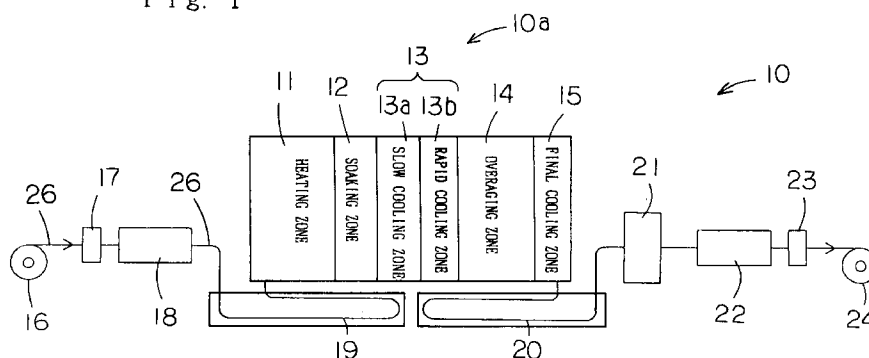
(54) **Primary cooling method in continuously annealing steel strips**

(57) In a primary cooling method in continuously annealing steel strips which comprises a heating step (A), a soaking step (B), a primary cooling step (C) including at least a rapid cooling step in a second half thereof, an overaging step (D), and a final cooling step (E), inert atmosphere gas containing H₂ gas is employed as cooling gas for use in the rapid cooling step and concentration of the H₂ gas is switched between two ranges of low and high concentrations of

H₂ gas, depending on the required cooling rate of the rapid cooling step corresponding to the product grades of steel strips (26).

Accordingly, the consumption of expensive H₂ gas is reduced thus enhancing the economy of the cooling operation while assuring the safety and efficiency of the primary cooling operation.

Fig. 1



Description

The present invention relates to a primary cooling method in continuously annealing steel strips which includes a rapid cooling step before an overaging step, wherein inert atmosphere gas containing H₂ gas is used as a cooling gas for rapid cooling.

Because of being too hard and thereby exhibiting almost no workability, a steel strip after cold rolling cannot be subjected to press forming and hence cannot be put into practical use so long as no further treatment is effected. To improve the workability of the steel strip, it is necessary to increase the grain size of the steel strip sufficiently, and to reduce the amount of solid-solution state carbon contained in the steel strip as small as possible.

To this end, continuous annealing treatment including heating, soaking, primary cooling, overaging and final cooling is performed. More specifically, a steel strip after cold rolling is heated above the recrystallization temperature and is kept at the soaking temperature of 700 - 850 °C for a certain period of time for growth of crystal grains. During the soaking step, the dissolved carbon is generated in solid-solution state, and it must be settled to be harmless in the succeeding steps. Therefore, in the first half of the primary cooling, the steel strip is slowly cooled down to a certain temperature (600 - 700 °C) so as to increase the amount of solid-solution state carbon in the ferrite matrix, and to prevent deterioration of flatness of the steel strip such as cooling buckle for achieving satisfactory operation. In the second half of the primary cooling, the steel strip is rapidly cooled down to the overaging temperature (about 400 °C). Then the steel strip is kept at the overaging temperature for a certain period of time so that the solid-solution state carbon is precipitated as cementite for reducing the amount thereof. Lastly the steel strip is subjected to the final cooling.

Where cooling by water-gas mixture is performed in the second half of the primary cooling to rapidly cool the steel strip, an oxide film is formed on the surface of the steel strip so that a post-treatment such as acid pickling is required immediately after the continuous annealing.

In view of the above, a method of cooling a steel strip by blowing inert atmosphere gas on N₂ basis on the strip wherein the cooling gas contains a large amount of H₂ gas that has a great cooling ability, has been proposed in Japanese Patent Publication No. Sho 55-1969 and Japanese Laid-Open Patent Publication No. Hei 6-346156, for example.

Japanese Patent Publication No. Sho 55-1969 suggests the concentration of H₂ gas being adjusted within the range equal to or more than 50 %, while Japanese Laid-Open Patent Publication No. Hei 6-346156 suggests the concentration of H₂ gas being adjusted within the range from 70 to 90 %. However, following problems have not yet been resolved satisfactorily by the methods disclosed in these publications.

(1) While an increase in the concentration of H₂ gas surely increases the cooling ability, such an increase of the H₂ gas concentration pushes up the operation cost. The use of inert atmosphere gas including H₂ gas exceeding 6 %, which is a critical limit of explosion, increases the possibility of an explosion and causes a problem in terms of safety.

(2) There is a case that different product grades of steel (steel grades) such as commercial quality CQ (low carbon steel), drawing quality DQ (low carbon steel), deep drawing quality DDQ (low carbon steel), extra deep drawing quality EDDQ (ultra low carbon steel) and high strength steel of dual phase type (high Mn steel) are to be annealed by the same facility for continuously annealing sheet steel strip, wherein CQ DQ, DDQ and EDDQ belong to mild steel. In such an annealing, CQ and EDDQ require less rapid cooling compared to other product grades such as DQ and DDQ which require rapid cooling. In view of the above, it is considered ineconomical to carry out the rapid cooling on CQ and EDDQ with the same H₂ gas concentration as that of DQ and DDQ. Especially, nowadays, demand for continuously annealing various product grades of steel strip using the same facility for continuously annealing sheet steel strip is increasing. Accordingly, the use of cooling gas, in which the H₂ gas concentration is changed corresponding to the product grades of strip, is strongly requested.

(3) If the concentration of H₂ gas is lowered and the blowoff speed of the gas from nozzles is raised, a higher cooling ability can be achieved. However, if the blowoff speed exceeds a certain value, the running steel strip tends to flutter and suffer from scratches on the surface thereof.

Here, the term " blowoff speed " means the speed at which the cooling gas is ejected from nozzles to be blown upon the steel strip.

The present invention has been made in view of these drawbacks of the conventional method, and its object is to provide a primary cooling method in continuously annealing steel strips which can reduce the consumption of expensive H₂ gas thus enhancing the economy of the cooling operation while assuring the safety and efficiency of the cooling operation at low cost.

To achieve the above object, according to the present invention, there is provided a primary cooling method in continuously annealing steel strips comprising a heating step, a soaking step, a primary cooling step including at least a rapid cooling step in a second half thereof, an overaging step, and a final cooling step, which is characterized in that inert atmosphere gas containing H₂ gas is employed as cooling gas for use in the rapid cooling step and concentration of said H₂ gas is switched between two ranges of 1 to 5 % and 30 to 60 %, depending on the required cooling rate of

said rapid cooling step corresponding to product grades of steel strip.

In the above-mentioned primary cooling method according to the present invention, the blowoff temperature of the cooling gas should preferably be 30 - 150 °C, and the blowoff speed of the cooling gas should preferably be 80 - 150 m/sec.

5 To be more specific, in the above-mentioned primary cooling method according to the present invention, inert atmosphere gas containing H₂ gas is employed as cooling gas for use in the rapid cooling and means for changing the concentration of H₂ gas is capable of changing the concentration of H₂ gas in two ranges corresponding to the product grades of steel. Namely, with respect to product grades of steel which require a less rapid cooling such as CQ and EDDQ, the concentration of H₂ gas should preferably be 1 to 5 %, while with respect to product grades of steel which
10 require a rapid cooling such as DQ, DDQ and high strength steel of dual phase type, the concentration of H₂ gas should preferably be 30 to 60 %.

In the above-mentioned primary cooling method according to the present invention, with the concentration of H₂ gas being 1 to 5 %, the blowoff temperature of the cooling gas should preferably be 80 - 150 °C and the blowoff speed of the cooling gas should preferably be 80 - 100 m/sec, while with the concentration of H₂ gas being 30 to 60 %, the
15 blowoff temperature of the cooling gas should preferably be 30 - 150 °C and the blowoff speed of the cooling gas should preferably be 100 - 150 m/sec. Throughout this specification, the percentage expression of the concentration of H₂ gas is by volume.

The present invention will be described in more detail in conjunction with the accompanying drawings.

Fig. 1 is an explanatory view of a continuous annealing line for sheet to which is applied a primary cooling method
20 in continuously annealing steel strips according to one embodiment of the present invention.

Fig. 2 is a graph showing the relationship between the passing time and the temperature of a steel strip in the furnace section of continuous annealing line.

Fig. 3 is a perspective view of an apparatus for carrying out rapid cooling step.

Fig. 4 is a front view of a blow gas box and nozzles thereon for ejecting cooling gas.

25 Fig. 5 is a cross sectional view of the blow gas box and nozzles taken along the line I-I of Fig. 4.

Fig. 6 is a block diagram showing the control unit for controlling the rapid cooling operation.

Fig. 7 is a flow chart showing steps for controlling the concentration of H₂ gas by the control unit.

Fig. 8 is a graph showing the relationship between the nozzle opening area ratio and the blower power index.

Fig. 9 is a graph showing the relationship between the quotient of inner diameter of nozzle aperture to blowoff distance and the blower power index.
30

Fig. 10 is a graph showing the relationship between the upper limit of the cooling gas blowoff speed which can prevent the steel strip fluttering and the H₂ gas concentration in the cooling gas.

Fig. 11 is a graph showing the relationship between the H₂ gas concentration and the operation cost index for the rapid cooling zone.

35 Fig. 12 is another graph showing the relationship between the H₂ gas concentration and the operation cost index for the rapid cooling zone.

Fig. 13 is a graph showing the relationship between the passing time and the temperature of the steel strip in a rapid cooling zone.

Fig. 14 is a graph showing the relationship between the H₂ gas concentration and the heat transfer coefficient.

40 A furnace section (hereinafter referred to as a continuous annealing furnace) 10a of a continuous annealing line 10 to which a primary cooling method in continuously annealing steel strips according to one embodiment of the present invention is applied is shown in Fig. 1. As shown in the drawing, the continuous annealing furnace 10a comprises a heating zone 11, a soaking zone 12, a primary cooling zone 13, an overaging zone 14, and a final cooling zone 15 as a secondary cooling zone. The primary cooling zone 13 consists of a slow cooling zone 13a in the first half and a rapid
45 cooling zone 13b in the second half.

On the entry side of the continuous annealing furnace 10a, there are a uncoiler 16 for unreeling a material coil, a welder 17 for joining preceding and succeeding steel strips 26 together, a pretreatment apparatus 18 for performing electrolytic cleaning and the like, and an entry looper 19. On the delivery side of the continuous annealing furnace 10a, there are a delivery looper 20, a temper rolling mill 21, a finishing apparatus 22 for performing treatment such as side
50 trimming, inspection and oiling of steel strip, a dividing shear 23 for cutting the steel strip in units of product coils, and a coiler 24 for reeling a product coil around the same.

Fig. 3 shows a rapid cooling apparatus 13c which constitutes the rapid cooling zone 13b in the second half of the primary cooling zone 13. Blow gas boxes 27 and 28 are provided so as to sandwich a vertically running steel strip 26 supported by a plural pairs of stabilizing rolls 25 arranged vertically. A unified blow duct 30 for supplying cooling gas has a plurality of upper outlets thereof connected to one side of the blow gas boxes 27 and 28 which are located at both
55 sides of the steel strip 26 by way of bifurcated blow ducts 29 having a Y-shaped cross section and a plurality of dampers 27a and 28a which are disposed parallelly on both sides of the steel strip 26. The unified blow duct 30 has a lower inlet thereof connected with an outlet of a blower 34 which is driven by a drive motor 35. A plurality of suction ducts 31 for collecting the cooling gas blown upon the steel strip 26 by blow gas boxes 27 and 28 are provided at the other side of

the blow gas boxes 27 and 28. The inlets of the suction ducts 31 for collecting the cooling gas face the other side of the blow gas boxes 27 and 28 while the outlets of these ducts 31 are connected to the upper portion of a unified suction duct 31a. The unified suction duct 31a is provided with a heat exchanger 32 at the lower portion thereof which uses water or the like as a coolant. The heated cooling gas is cooled by the heat exchanger 32 and is introduced to a blower 34 through a lower duct 33. It should be noted that in association with the heat exchanger 32, a refrigerator using fluorocarbon, ammonia or the like as a coolant may also be provided to further cool the cooling gas.

As shown in Fig. 3, an H_2 gas sensor 36 is disposed in the blow gas box 28 so as to measure the concentration of H_2 gas contained in the cooling gas blown off from the blow gas box 28. The concentration values measured by the H_2 gas sensor 36 are transmitted to a control unit 37. An H_2 gas storage tank 38 and an N_2 gas storage tank 39 are disposed in the vicinity of the continuous annealing furnace 10a. These tanks 38, 39 are connected with a mixer 43a by way of an H_2 gas supply line 42 and an N_2 gas supply line 43 respectively so that H_2 gas and N_2 gas are mixed together in the mixer 43a. The mixer 43a is connected with the unified blow duct 30. The H_2 gas supply line 42 and the N_2 gas supply line 43 are provided with an H_2 gas flow valve 40 and an N_2 gas flow valve 41 in the midst thereof respectively which are, in turn, controlled by operation signals transmitted from the control unit 37. In Fig. 3, an arrow shows a flow direction of the cooling gas.

Although in Fig. 3, the H_2 gas sensor 36 is disposed in the upper blow gas box 28, a plurality of H_2 gas sensors 36 may be disposed in the upper and lower blow gas boxes 28 respectively. In this case, the concentration of H_2 gas in all blow gas boxes 28 may be controlled based on the mean value calculated from the respective detected values or the concentration of H_2 gas in the respective blow gas boxes 28 may be independently controlled based on the respective detected values.

The construction of the blow gas box 27 (or 28) is shown in Figs. 4 and 5. A multiplicity of nozzles 44 each being formed of a short tube are provided on the front surface of the blow gas box 27. Each nozzle 44 is made of a cylindrical tube having a circular hollow cross section and projects toward the steel strip 26. The inner diameter D of the blowoff opening of the nozzle 44 is, for example, 9.2 mm. These nozzles 44 are arrayed on the front surface of the blow gas box 27 in a zigzag or staggered pattern.

Also, the nozzles 44 are so arranged that a total opening area of the nozzles 44 occupies 2 to 4 % of the front surface area of the blow gas box 27 and the cooling gas is blown through all the nozzles 44 at a uniform flow rate. Fig. 8 shows the relationship between the nozzle opening area ratio (percentage of opening areas of the nozzles 44 to the front surface area of the blow gas box 27) and the blower power index (the motor power ratio of the blower 34). As shown in Fig. 8, the maximum efficiency results at the nozzle opening area ratio of about 2 to 4 %. This result is construed from the reason that so long as the amount of cooling gas blown from the nozzles 44 is the same, if the opening area percentage of the nozzles 44 exceeds 4 %, the flow speed of the cooling gas is excessively lowered, while if the opening area percentage of the nozzles 44 does not exceed 2 %, the flow speed is excessively increased, thus producing a large pressure loss at the nozzles 44.

Further, as shown in Fig. 5, the distance from the tip ends of the nozzles 44 to the surface of the steel strip 26, namely, the blowoff distance d is determined to be equal to or less than 70 mm, and the projecting length L of each nozzle 44 is determined to be equal to or greater than (100 mm - d).

The reason is that if the distance d from the nozzles 44 to the steel strip 26 is increased, the flow speed of the cooling gas blown upon the surface of the steel strip 26 is much attenuated. The reason of setting the projecting length L of each nozzle 44 to be equal to or more than (100 mm - d) is to define an escape space of the cooling gas among the projecting nozzles 44 thereby not only to improve cooling efficiency by preventing the cooling gas having been blown upon and heated by the steel strip 26 from residing on the surface of the steel strip 26 and disturbing the cooling performance, but also to improve cooling uniformity in the direction of width of the steel strip 26.

The inner diameter D of the blowoff opening of each nozzle 44 will now be considered. Fig. 9 shows the relationship between (the inner diameter D of the blowoff opening of nozzle 44 / blowoff distance d) and the power index of the blower 34. As seen in the graph, the power of the blower 34 is reduced as the quotient of inner diameter D of blowoff opening to blowoff distance d decreases.

Also, in order to realize a high cooling ability to be obtained by blowing the cooling gas through the nozzles 44, it is required to arrange the nozzles 44 at such a high density that those portions of individual jet streams of the cooling gas which are located near the nozzle axes and have a maximum cooling ability are densely and uniformly distributed over the steel strip 26. Accordingly, the inner diameter D of the blowoff opening should be as small as possible. However, an excessive reducing of the inner diameter D of the blowoff opening would lead to a disadvantage that the number of nozzles 44 is to be increased and the cost of the facility and maintenance is pushed up. Taking account of these contradictory aspects, the inner diameter D of the blowoff opening is preferably set to be not larger than one fifth of the distance d, but not less than 3 mm at which the blowoff opening can be machined practically.

A description will now be made of the outline of the operation of the continuous annealing line 10 referring to Figs. 1 and 2, focusing on the primary cooling method in continuously annealing steel strips according to one embodiment of the present invention.

The steel strip 26 unreeled from the uncoiler 16 is joined to another preceding steel strip 26 by the welder 17, and

then sent to the pretreatment apparatus 18 including an electrolytic cleaner and the like. After that, the steel strip 26 is supplied through the entry loop 19 to the heating zone 11 of the continuous annealing furnace 10a where it is heated above the recrystallization temperature (heating step A). Subsequently, the steel strip 26 is supplied to the soaking zone 12 where it is kept at the temperature of 700 - 850 °C for a certain period of time (soaking step B). During these steps A and B, the steel strip 26 is recrystallized and the grain growth proceeds, whereby it is softened and exhibits high workability. However, because carbides in the steel strip 26 are dissolved in the matrix when the steel strip 26 is subjected to thermal treatment at a high temperature, a large amount of carbon in solid-solution state would exist in the steel strip 26 if the steel strip 26 is cooled directly after the soaking step B. The presence of carbon in solid-solution state is not desirable for the reason that such carbon is precipitated with time to make the steel strip 26 harder and cause a large yield point elongation.

To reduce the amount of solid-solution state carbon in the steel strip 26 as far as possible, therefore, the steel strip 26 is subjected to overaging treatment in the overaging zone 14 after the soaking treatment. In the overaging zone 14, the steel strip 26 is left to stand for a certain period of time in a certain temperature range (approximately 400 °C) in which the solubility limit of carbon is smaller and the solid-solution state carbon is still capable of diffusing. As a result, the solid-solution state carbon is precipitated as cementite (Fe_3C) and the amount of solid-solution state carbon in the steel strip 26 is reduced greatly (overaging step D).

To promote the overaging treatment, after the soaking step B, the steel strip 26 is first slowly cooled in the slow cooling zone 13a down to a certain temperature T_S not higher than the A_1 transformation temperature (723 °C), and is then rapidly cooled down to the overaging temperature in the rapid cooling zone 13b. This rapid cooling brings about a supersaturated condition in which, at the end point of the rapid cooling (temperature T_E in Fig. 2), the solid-solution state carbon exists in the ferrite matrix in an amount exceeding the solubility limit of carbon allowable at the same temperature in the Fe - C equilibrium diagram. This supersaturated condition promotes precipitation of solid-solution state carbon into cementite during the overaging treatment. After the soaking step B, as mentioned above, the steel strip 26 is slowly cooled in the first half of the primary cooling down to a certain temperature T_S not higher than the A_1 transformation temperature. The purpose of this slow cooling is to increase the amount of solid-solution state carbon in the ferrite matrix and to prevent deterioration of flatness of the steel strip such as cooling buckle for achieving satisfactory operation. For those reasons from operational point of view, the upper limit of T_S is 700 °C.

Also, as seen in Fig. 2, since T_S is the temperature to start the rapid cooling and would be of no significance if it is too close to the overaging temperature at which the rapid cooling is ended, the lower limit of T_S is 600 °C.

Further, the upper limit of the rapid cooling end temperature T_E is equal to the upper limit of the overaging start temperature and hence should be 450 °C. A cooling rate of the rapid cooling step carried out in the second half of the primary cooling, namely, in the rapid cooling zone 13b, is required to be not lower than 60 °C/sec, preferably not lower than about 80 °C/sec from a metallurgical point of view for achieving the aforesaid supersaturated condition. In other words, if the cooling rate is lower than 60 °C/sec, the amount of solid-solution state carbon in the steel sheet as a product would be too large and the product would be excessively hardened, thus deteriorating the workability during press forming (primary cooling step C).

Then, the steel strip 26 after the overaging treatment is slowly cooled down to the room temperature in the final cooling zone 15 (final cooling step E).

When producing a high strength steel strip, particularly a high strength steel strip of dual phase type that martensite is mixed in the ferrite matrix, an annealing cycle is modified to be such that the steel strip 26 is heated (heating step A') to a temperature not lower than the A_1 transformation temperature and the heated steel strip 26 is kept at the same temperature in the soaking zone 12 (soaking step B') to create a two-phase state of ferrite and austenite, and is then slowly cooled in the slow cooling zone 13a before it is rapidly cooled down from the rapid cooling start temperature T_S in the rapid cooling zone 13b. Also, the rapid cooling end temperature T_E' is a temperature lower than the martensitic transformation temperature M_S (about 250 °C though depending on chemical composition) so that the austenite is efficiently transformed into martensite.

Accordingly, a lower limit temperature of T_E' is 200 °C.

If the cooling rate in the rapid cooling step is not sufficient, a part of austenite would be caught by the nose in the continuous cooling transformation curve at which transformation into ferrite, pearlite, etc. begins and would be transformed into such phases, resulting in poor efficiency of the martensitic transformation. From the above reason, the cooling rate of 60 °C/sec is required in the rapid cooling step from a metallurgical point of view. In the case of attempting to further save the alloying element components, it is desired that the cooling rate be not less than 100 °C/sec. This case is represented by one-dot-chain lines in Fig. 2. Specifically, the steel strip is rapidly cooled down to about 200 °C in a primary cooling step C', then is subjected to a low-temperature holding step D' in the overaging zone 14, and thereafter transferred to a final cooling step E'.

In an actual annealing operation, it is sometimes necessary to anneal various product grades of steel using the same continuous annealing line 10. As product grades of steel which are annealed in this manner, CQ (low carbon steel), DQ (low carbon steel), DDQ (low carbon steel), EDDQ (ultra low carbon steel) and high strength steel of dual phase type (high Mn steel) are considered, wherein CQ, DQ, DDQ and EDDQ belong to mild steel. In annealing these

steels, the cooling conditions in the rapid cooling must be changed corresponding to the product grades of steel. Those desirable cooling conditions for respective product grades of steel are shown in Table 1.

Table 1

Product grade of steel (steel grade)		Required cooling rate (CR)	Concentration of H ₂ gas in cooling gas (%)
Mild steel	CQ (low carbon steel)	low	1 to 5
	DQ (low carbon steel)	high	30 to 60
	DDQ (low carbon steel)	high	30 to 60
	EDDQ (ultra low carbon steel)	low	1 to 5
High strength steel of dual phase type (high Mn steel)		high	30 to 60
(Note) CQ : Commercial quality DQ : Drawing quality DDQ : Deep drawing quality EDDQ : Extra deep drawing quality			

As shown in Table 1, with respect to DQ, DDQ and high strength steel of dual phase type, it is desirable to set a high cooling rate and determine the concentration of H₂ gas within the range from 30 to 60 %. The reason is explained later.

With respect to CQ and EDDQ, the cooling rate can be lowered, compared to the above-mentioned DQ, DDQ and high strength steel of dual phase type, and the concentration of H₂ gas can also be lowered to 1 to 5 %. As the concentration of H₂ gas exceeds 5 %, the cooling rate tends to increase and exceed the level which is necessary for CQ and EDDQ. This brings about the loss of expensive H₂ gas. Furthermore, the concentration of H₂ gas exceeds 6 %, which is the gas explosion limit. Accordingly, it is desirable to restrict the concentration of H₂ gas in the range of 1 to 5 %.

However, to compensate the slowness of the cooling rate, the travelling path of the steel strip 26 in the rapid cooling step must be elongated or the travelling speed of the steel strip 26 is slowed down to assure the aimed final temperature of rapid cooling step. The reasons for not requiring the high cooling rate with respect to CQ and EDDQ are as follows. For CQ, the hardening of steel strip 26 and the increase of yield point elongation thereof which are caused by the gradual precipitation of solid-solution state carbon with the time passing after production do not constitute any material problems in view of the practical usage thereof. For EDDQ, an amount of carbon contained in the steel is extremely small and a special treatment is provided so that almost no solid-solution state carbon is present in the steel, whereby the overaging step can be unnecessitated.

To change the product grade of steel, a succeeding steel strip which is different from a preceding steel strip 26 in grade is welded to the preceding steel strip 26 by means of the welder 17 and then is subjected to the continuous annealing. In the rapid cooling of the primary cooling step C, the concentration of H₂ gas in the cooling gas is changed and the cooling rate is regulated. Since changing of the composition of the blowoff gas needs some time, to enhance the productivity, it is desirable to arrange the product grades of steel which require the low cooling rate and the product grades of steel which require the high cooling rate as shown in Table 1 in two lots or groups and change the concentration of H₂ gas along with the changing of the lot.

Means F for changing the concentration of H₂ gas, as explained previously, substantially comprises the H₂ gas sensor 36, the control unit 37, the H₂ gas storage tank 38, the N₂ gas storage tank 39, the H₂ gas flow valve 40, the N₂ gas flow valve 41, the H₂ gas supply line 42, the N₂ gas supply line 43 and the mixer 43a.

The manner of changing the concentration of H₂ gas in the cooling gas using the means F for changing the concentration of H₂ gas is described hereinafter in view of Fig. 3, Fig. 6 and Fig. 7.

The targeted or predetermined concentration C_{set} of H₂ gas in the cooling gas for a product grade of steel is input to the control unit 37 from a key board 49 and is stored in a RAM 47 in the control unit 37 (Step S1). It is desirable to change the concentration of H₂ gas within the range exceeding 0 % and equal to or below 60 %. The concentration of H₂ gas exceeding 60 % should be avoided since such a gas concentration merely increases the amount of expensive H₂ gas while the cooling effect is no more improved even if the concentration of H₂ gas is increased exceeding 60 % as explained in detail later.

When a new product grade of steel is to be annealed, the concentration of H₂ gas for this new product grade of steel is input to the control unit 37 from the key board 49 and is stored in the RAM 47 (Step S2). The H₂ gas sensor 36 con-

stantly measures the concentration of H₂ gas in the cooling gas in the blow gas box 28 and the measured concentration C_{mes} of H₂ gas is transmitted to the control unit 37 and fed to a computer CPU 46 by way of an input/output interface 45 (Step S3).

In the CPU 46, the predetermined concentration C_{set} of H₂ gas is subtracted from the measured concentration C_{mes} of H₂ gas and the subtracted value is compared with an allowance value δ which is an allowable range and the CPU 46 judges whether the subtracted value is greater than the allowance value δ or not (Step S4).

If the judgement at Step S4 is YES, it means that the concentration of H₂ gas must be lowered. Accordingly, the N₂ gas flow valve 41 is opened so as to increase the amount of N₂ gas supplied to the mixer 43a and increase the mixing ratio of the N₂ gas in the blowoff gas. In the above valve operation, the H₂ gas flow valve 40 may be temporarily closed so as to sharply decrease the concentration of H₂ gas. After opening the N₂ gas flow valve 41, the measuring operation in Step S3 is again carried out so as to measure the concentration of H₂ gas in the cooling gas (Step S5).

If the judgement at Step S4 is NO, the subtracted value obtained by subtracting the measured concentration C_{mes} of H₂ gas from the predetermined concentration C_{set} of H₂ gas is compared with the allowance value δ so as to judge whether the concentration of H₂ gas is lower than the predetermined concentration C_{set} of H₂ gas or not (Step S6).

If the judgement at Step S6 is YES, namely, if the subtracted value obtained by subtracting the measured concentration C_{mes} of H₂ gas from the predetermined concentration C_{set} of H₂ gas is greater than the allowance value δ and the predetermined concentration C_{set} of H₂ gas is greater than the measured concentration C_{mes} of H₂ gas, the operation is advanced to Step S7.

At Step S7, the H₂ gas flow valve 40 is opened so as to supply H₂ gas to the unified blow duct 30 from the H₂ gas storage tank 38 by way of the H₂ gas supply line 42 and the mixer 43a. The measuring operation at Step S3 is again carried out to monitor the concentration of H₂ gas.

If the judgement in Step S6 is NO, namely, if the subtracted value obtained by subtracting the measured concentration C_{mes} of H₂ gas from the predetermined concentration C_{set} of H₂ gas falls within the allowance value δ, without actuating the H₂ gas flow valve 40 and the N₂ gas flow valve 41, the measuring operation of Step S3 is carried out so as to measure the concentration of H₂ gas in the cooling gas again. The above-mentioned control sequence is programmed and stored in a ROM 48 and is sequentially fed to the CPU 46 corresponding to the operational commands.

The rapid cooling conditions of DQ, DDQ and high strength steel of dual phase type are discussed hereinafter. Given the cooling rate being CR (°C/sec) and the thickness of the steel strip 26 being t (mm) while considering that the steel strip 26 annealed in the continuous annealing furnace 10a usually has a thickness of approx. 1 mm, the cooling ability of the rapid cooling zone 13b in the continuous annealing furnace 10a is required to meet the following formula (1).

$$CR \cdot t \geq 60 \text{ } ^\circ\text{C} \cdot \text{mm/sec} \quad (1)$$

On the other hand, it is known on the basis of heat transfer theory that the heat transfer coefficient α (kcal/m²h°C) is expressed by the following formula (2).

$$CR = k \cdot \alpha / t \quad (2)$$

, where k is a constant.

This formula (2) can be modified into the following formula (3).

$$CR \cdot t = k \cdot \alpha \quad (3)$$

Putting the formula (3) in the above formula (1) leads to the following formula (4).

$$k \cdot \alpha \geq 60 \text{ } ^\circ\text{C} \cdot \text{mm/sec} \quad (4)$$

Here, when the rapid cooling zone 13b is specified as the rapid cooling apparatus 13c as shown in Fig. 3, a value of the constant k is determined. By putting this value in the formula (4), a value of the heat transfer coefficient α, which meets the condition of the formula (1), is given by the following formula (5).

$$\alpha \geq 410 \text{ kcal/m}^2\text{h}^\circ\text{C} \quad (5)$$

If cooling by water-gas mixture is employed in the rapid cooling step as mentioned previously, the cooling which meets the formula (5) can be performed. However, since a thin oxide film is formed on the surface of the steel strip 26, steps such as light pickling, rinsing after the pickling, special treatment for improving phosphatability, and final rinsing are required in the post-treatment after the annealing. This leads to a disadvantage of pushing up the facility cost. In view of the above, an attention was focused on a method of rapidly cooling the steel strip 26 by blowing jet streams of

inert atmosphere gas upon the steel strip 26. Since H₂ gas has a high cooling ability, a mixture gas made of H₂ gas and N₂ gas is chosen as the cooling gas.

Meanwhile, in accordance with the experimental formula found by the inventors based on pilot line test, the heat transfer coefficient α indicating a degree of cooling ability in the rapid cooling zone 13b is a function of the blowoff speed V of the cooling gas from the nozzles 44 and the kind of the cooling gas, and is expressed by the following formula (6).

$$\alpha = K \cdot \lambda^a \cdot V^b \quad (a > 0 \text{ and } b > 0) \quad (6)$$

,where

λ : variable depending on the kind of gas,
V: blowoff speed,
K, a and b : constant.

As can be understood from the formula (6), because the heat transfer coefficient α is increased at the higher blow-off speed V of the cooling gas, the cooling ability can be enhanced by increasing the blowoff speed of the cooling gas without using expensive 100 % H₂ gas. But if the blowoff speed of the cooling gas is increased above a certain value, the cost of electric power necessary for the blower operation is greatly raised and, at the same time, the steel strip 26 is apt to flutter. This tendency becomes more remarkable if the proportion of N₂ gas having a larger specific gravity increases. This is because the force causing the steel strip 26 to flutter is most affected by or in proportion to kinetic energy of the blow gas, wherein the kinetic energy E of the blow gas is expressed by the following formula (7).

$$E = \gamma / 2g \cdot v^2 \quad (7)$$

,where γ is the specific gravity of the gas, g is the acceleration of gravity, and v is the gas flow speed.

If the steel strip 26 flutters, there arises a problem that the steel strip 26 may hit against, for example, the tip ends of the nozzles 44 and may suffer from scratches. To avoid such a problem, experiments for measuring the gas blowoff speed limit beyond which the steel strip 26 begins to flutter were carried out by using the rapid cooling apparatus 13c as shown in Fig. 3, keeping the temperature of the cooling gas constant (100 °C), and blowing the cooling gas containing various concentrations of H₂ gas upon the steel strip 26. The measured results are shown in Fig. 10. The upper limit of gas blowoff speed preventing the steel strip fluttering is somewhat varied depending on the thickness t and tension of the steel strip 26. Also, by narrowing the spacing between the stabilizing rolls 25 shown in Fig. 3, the tendency of the steel strip fluttering is mitigated and, therefore, the blowoff speed of the cooling gas can be increased correspondingly.

Furthermore, the temperature of the cooling gas is counted as one of the factors which affects the condition of the above formula (6). In the rapid cooling apparatus 13c shown in Fig. 3, the cooling gas used for cooling the steel strip 26 is sucked through the suction duct 31 and then subjected to heat exchange in the heat exchanger 32. Since the water which is inexpensive is employed as a coolant for the heat exchanger 32, the temperature of the cooling gas having passed the heat exchanger 32 is in the range of 80 - 150 °C. From an economical point of view in the field of rapid cooling, however, the temperature of the cooling gas is preferably kept in the range of about 80 - 100 °C through more efficient heat exchange. It is further possible to additionally install a refrigerator using fluorocarbon, ammonia or the like as a coolant in association with the heat exchanger 32 so that the temperature of the cooling gas can be kept in the range of 30 - 80 °C. This enables the steel strip 26 to be cooled more efficiently.

In processing CQ and EDDQ in the rapid cooling, it is preferable that the cooling rate is set to be not so high and the concentration of H₂ gas is determined to fall in the range of 1 to 5 %. In these conditions, the temperature of the cooling gas should preferably be in the range of 80 to 150 °C. If the temperature of the cooling gas is lowered below 80 °C, as mentioned previously, the refrigerator must be provided. Such a provision of the refrigerator makes the construction of the rapid cooling apparatus 13c more complicated and the maintenance thereof cumbersome and increases the operation cost thereof as the electric power consumption is increased. On the other hand, since no strict condition is given to the cooling rate, it is considered that even when the temperature of the cooling gas is raised above 80 °C, the steel strip 26 will suffer from the least adverse effect. Meanwhile, if the temperature of the cooling gas is raised above 150 °C, the cooling ability becomes insufficient so that the steel strip 26 cannot be cooled down to the predetermined temperature provided that the steel strip 26 is travel led at a normal running speed.

In processing DQ, DDQ and high strength steel of dual phase type, which require a high cooling rate, in the rapid cooling, it is desirable that the the concentration of H₂ gas is determined to fall in the range of 30 to 60 % and the temperature of the cooling gas is in the range of 30 to 150 °C. If the temperature of the cooling gas is lowered below 30 °C, as mentioned previously, under the recirculation, the rapid cooling apparatus 13c must be provided newly with the heat exchanger 32 extended and a refrigerator which enable the cooling gas to be equal to or less than 30 °C but such provision is not practical. If the blowoff temperature of the cooling gas is raised above 150 °C, as in the case of CQ and EDDQ, the cooling ability becomes insufficient so that the steel strip 26 cannot be cooled down to the predetermined

temperature provided that the steel strip 26 is travelled at a normal running speed.

Next, if the concentration of H₂ gas in the cooling gas is lowered, the concentration of N₂ gas is raised and the cost of the cooling gas used is reduced correspondingly because N₂ gas is inexpensive. On the other hand, if the concentration of H₂ gas in the cooling gas is lowered, the concentration of N₂ gas is raised and the specific gravity of the cooling gas is increased to push up the cost of electric power consumed by the operation of the blower 34 and the like. Also, if the concentration of H₂ gas in the cooling gas is raised, the heat transfer coefficient α is increased. Figs. 11 and 12 show respectively results of Experiment 1 and Experiment 2 carried out for studying the operation cost of the cooling gas varying the concentration of H₂ gas in the cooling gas under the conditions meeting the above formula (1). Although the heat transfer coefficient α is reduced as the amount of H₂ gas in the cooling gas diminishes, such a reduction is compensated for by increasing the blowoff speed of the cooling gas from the nozzles 44.

Fig. 11 shows the operation cost index of the cooling gas per ton of steel strip 26 resulting on condition that a steel strip being 0.798 mm thick and 1300 mm wide is processed at 270 m/min and the temperature of the steel strip is rapidly cooled down from 675 °C to 410 °C.

Fig. 12 shows the operation cost index of the cooling gas per ton of steel strip resulting on condition that a steel strip being 0.633 mm thick and 1300 mm wide is processed at 260 m/min and the temperature of the steel strip is rapidly cooled down from 670 °C to 270 °C. In Figs. 11 and 12, a broken line represents the cost of the cooling gas, a one-dot-chain line represents the cost of electric power, and a solid line represents the total cost.

The operation cost is minimized at the concentration of H₂ gas in the cooling gas being about 45 % in the case of Fig. 11, and at about 55 % in the case of Fig. 12.

Next, the heat transfer coefficient α , resulting when cooling conditions such as the shape and array of the nozzles and the blowoff speed of the cooling gas are fixed, is calculated on the basis of the formulae (8) and (9) below by using actual data obtained from the operational experiment for rapid cooling performed as shown in Fig. 13.

$$\alpha = A \cdot t \cdot (i_1 - i_2) / (\Delta T \cdot \theta) \quad (8)$$

$$\Delta T = (T_1 - T_2) / \ln(T_1 - T_g) / (T_2 - T_g) \quad (9)$$

,where T₁: temperature of steel strip on the entry side, T₂: temperature of steel strip on the delivery side, i₁: enthalpy of steel strip on the entry side, i₂: enthalpy of steel strip on the delivery side, θ : passing time of steel strip from the entry side to the delivery side of rapid cooling zone, A: constant, t: thickness of steel strip, and T_g: temperature of cooling gas.

Fig. 14 shows the heat transfer coefficient α calculated from the data obtained by variously changing the concentration of H₂ gas with the blowoff speed of the cooling gas 130 m/sec and 100 m/sec. As can be seen from Fig. 14, when the concentration of H₂ gas exceeds 60 %, the heat transfer coefficient α is saturated. Accordingly, a significant improvement in the cooling effect is not achieved even with the use of cooling gas having a concentration of H₂ gas in excess of 60 %.

Further, by applying the condition of the above formula (5), which was derived from the metallurgical requirements, to Fig. 14, it is found that the blowoff speed V of the cooling gas should be not less than 100 m/sec and the concentration of H₂ gas in the cooling gas should be not lower than 30 % to satisfy the above formula (5).

From the results shown in Figs. 10 to 14, it is understood that in processing DQ, DDQ and high strength steel of dual phase type in the rapid cooling, the cooling ability capable of satisfying the condition of the above formula (1) is economically attained by using the cooling gas containing H₂ gas in the concentration of 30 - 60 %. In this range of H₂ gas concentration, the maximum blowoff speed of the cooling gas under which the steel strip does not flutter is 115 - 150 m/sec, as shown in Fig. 10. However, a lower limit of the blowoff speed of the cooling gas meeting the above other cooling conditions as well as the above formula (5) is 100 m/sec. If the blowoff speed of the cooling gas is less than 100 m/sec, the cooling ability capable of meeting the above formula (5) could not be achieved.

According to experimental results, when the blowoff speed of the cooling gas is less than 100 m/sec, an immobile layer (sometimes called a boundary layer) adhering to the surface of the steel strip 26 in an immobile state tends to be formed and the heat transfer coefficient is reduced correspondingly. With respect to CQ (low carbon steel) and EDDQ (ultra low carbon steel), since the blowoff speed of the cooling gas is 80 to 100 m/sec, a certain amount of immobile layer is formed thereby lowering the cooling speed. However, as mentioned previously, such product grades of steel do not necessarily require the high cooling rate so that the steel strip can be processed without problems. It is not desirable to lower the blowoff speed below 80 m/sec since such a blowoff speed brings about an insufficient cooling ability and cannot cool down the steel strip 26 to a desired temperature with a normal running speed. It is also not desirable to raise the blowoff speed of the cooling gas above 100 m/sec since the resultant cooling rate is excessive and the electric power consumption of the blower 34 exceeds the reasonable electric power consumption.

While the foregoing embodiment has been described in conjunction with specific numerical values for easier understanding of the present invention, the invention can be of course modified within the range not departing from the scope of the invention and any those modifications are also involved in the invention.

With the primary cooling method in continuously annealing steel strips according to the present invention compris-

ing a heating step, a soaking step, a primary cooling step including at least a rapid cooling step in a second half thereof, an overaging step, and a final cooling step, inert atmosphere gas containing H₂ gas is employed as cooling gas for use in the rapid cooling step and concentration of the H₂ gas is switched between two ranges of 1 to 5 % and 30 to 60 %, depending on the required cooling rate of the rapid cooling step corresponding to the product grades of steel strips. Accordingly, various steels having different required properties can be processed in the rapid cooling step with cooling conditions which meet the respective steels. The consumption of expensive H₂ gas is greatly saved. Since a proper amount of H₂ gas is always mixed in the the cooling gas regardless of the product grades of steel, the excessive use of H₂ gas can be avoided thus lowering the risk of gas explosion enhancing the safety and operability of cooling operation. In addition, since various product grades of steel can be annealed using the same apparatus for continuously annealing the sheet steel, the range of operation is expanded or the continuous annealing operation becomes versatile thus enhancing the flexibility of the continuous annealing operation.

Furthermore, in the above-mentioned primary cooling method according to the present invention, if the concentration of H₂ gas is in the range of more than 0 % and equal to or less than 60 %, the consumption of H₂ gas in the cooling gas can be greatly saved and the cooling rates which correspond to respective product grades of steel can be obtained.

Still furthermore, in the above-mentioned primary cooling method according to the present invention, if the blowoff temperature of the cooling gas is 30 - 150 °C and the blowoff speed of the cooling gas is 80 - 150 m/sec, the optimum cooling condition, which satisfies both cooling capacity and economy, can be obtained by properly setting the temperature and the blowoff speed of the cooling gas in addition to the proper setting of the concentration of H₂ gas in the cooling gas, corresponding to the cooling rate required by the product grades of steel.

Claims

1. A primary cooling method in continuously annealing steel strips comprising a heating step, a soaking step, a primary cooling step including at least a rapid cooling step in a second half thereof, an overaging step, and a final cooling step, being characterized in that
inert atmosphere gas containing H₂ gas is employed as a cooling gas for use in said rapid cooling step and concentration of said H₂ gas is switched between two ranges of 1 to 5 % and 30 to 60 %, depending on the required cooling rate of said rapid cooling step corresponding to product grades of said steel strips.
2. A primary cooling method in continuously annealing steel strips according to claim 1, a blowoff temperature of said cooling gas is 30 - 150 °C and a blowoff speed of said cooling gas is 80 - 150 m/sec.
3. An apparatus for carrying out the method of claim 1 or 2.

Fig. 1

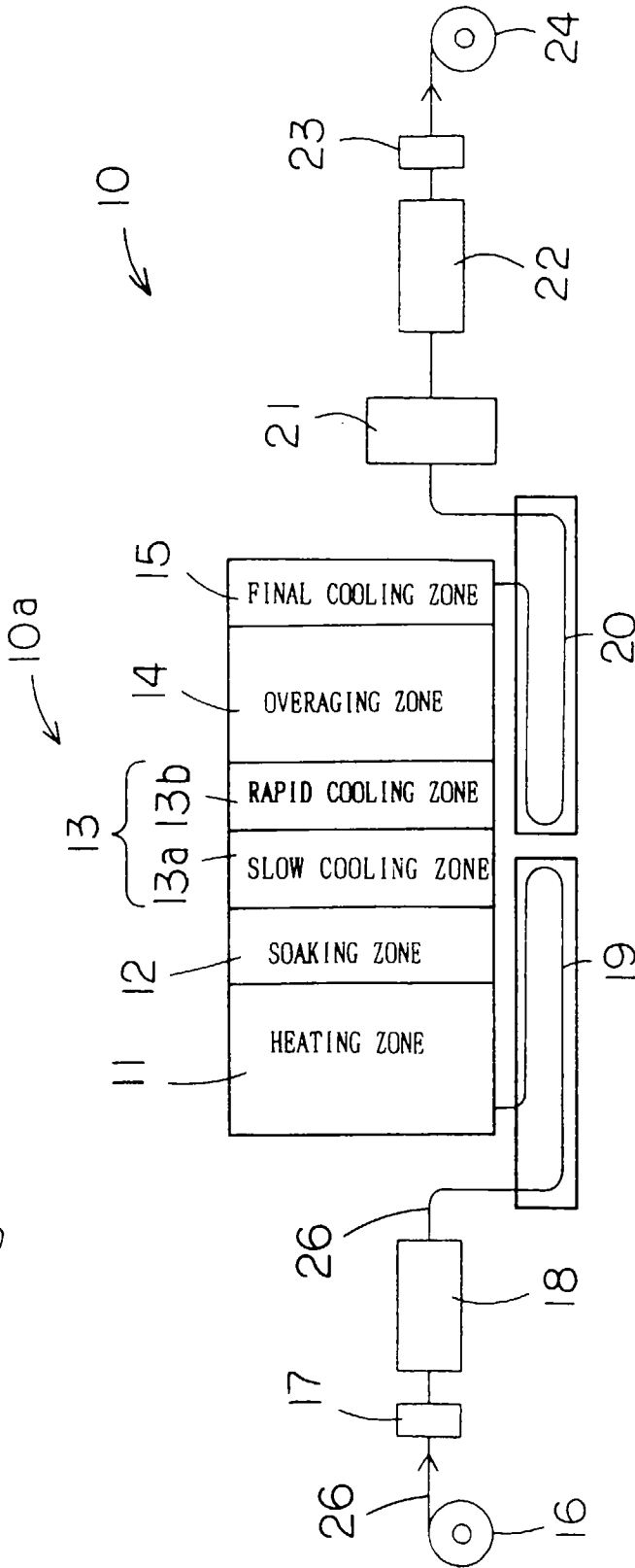


Fig. 2

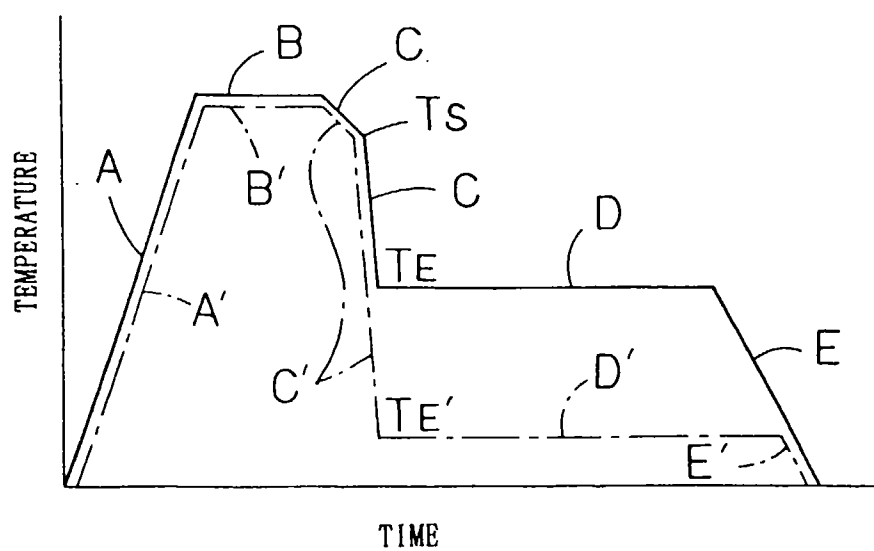


Fig. 3

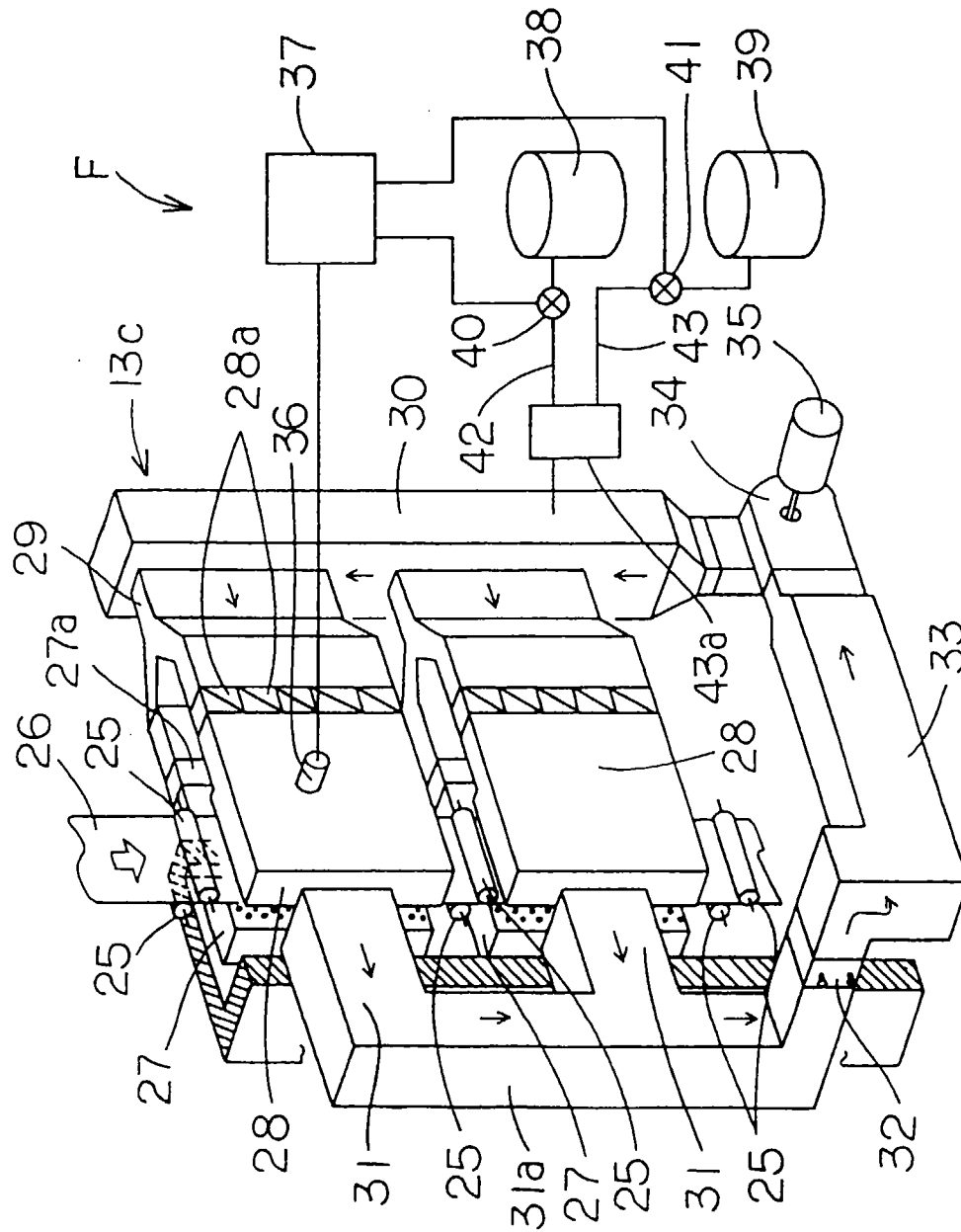


Fig. 4

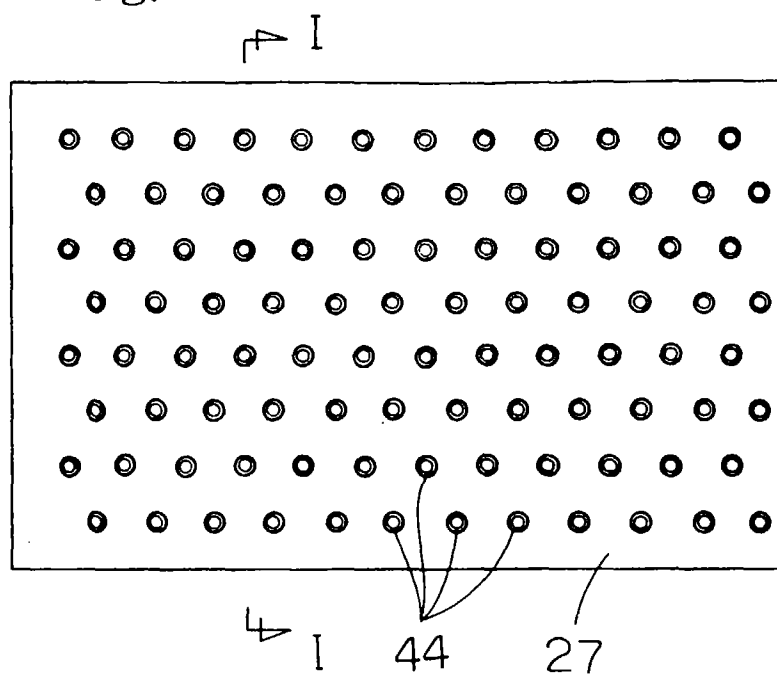


Fig. 5

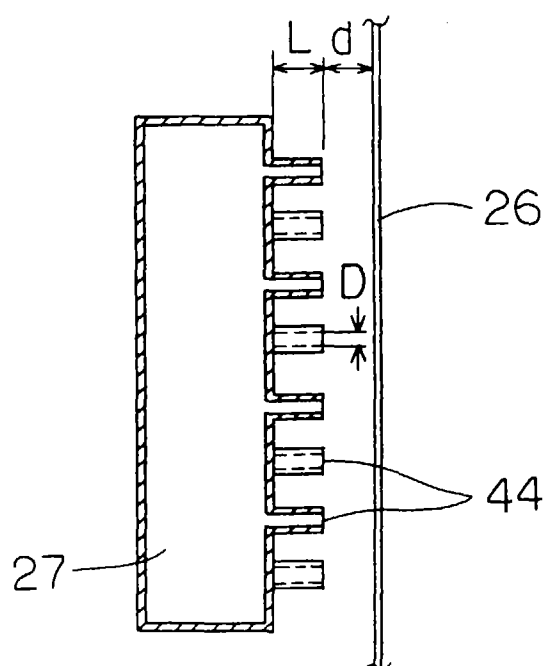


Fig. 6

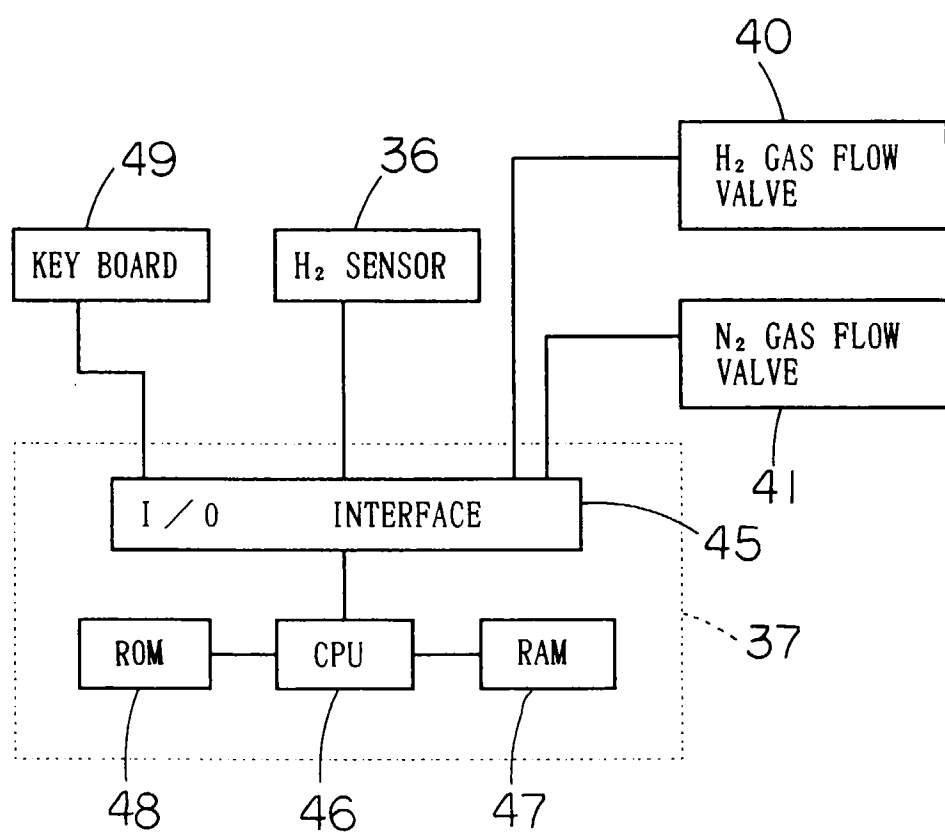


Fig. 7

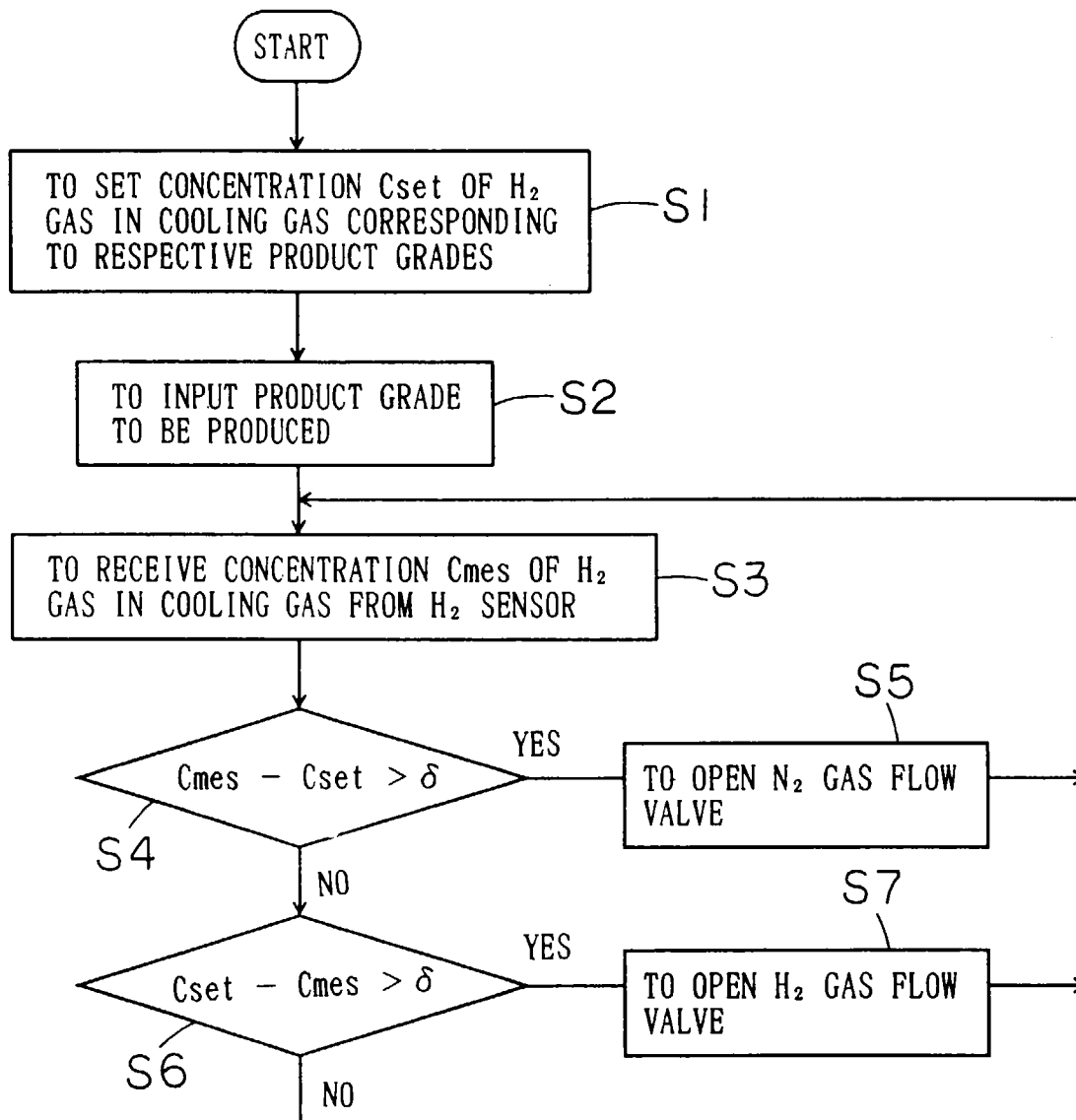


Fig. 8

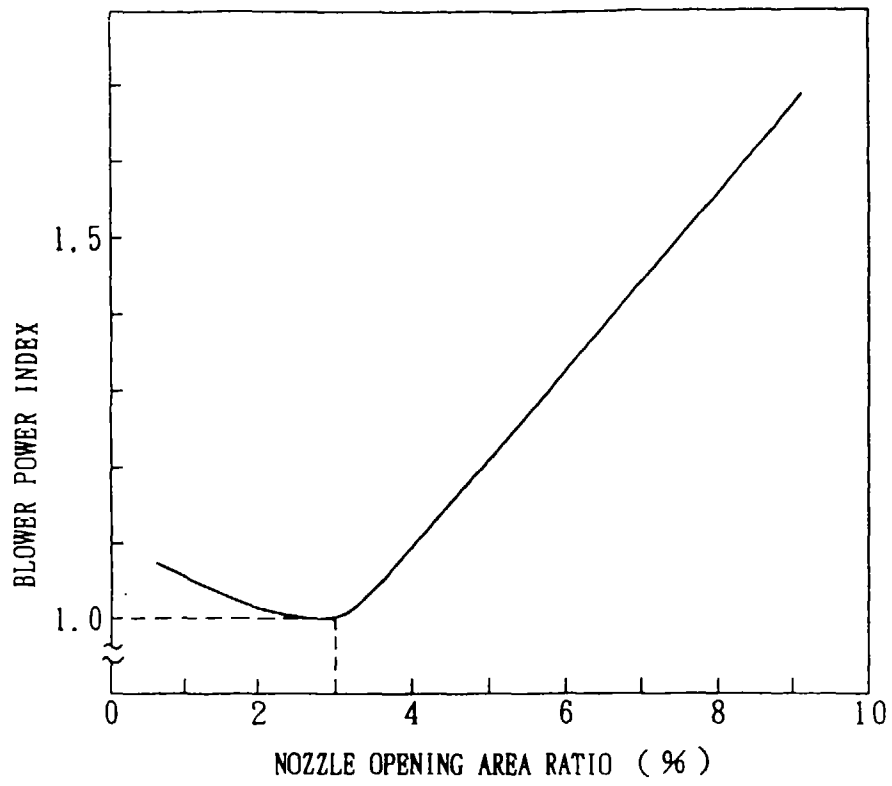


Fig. 9

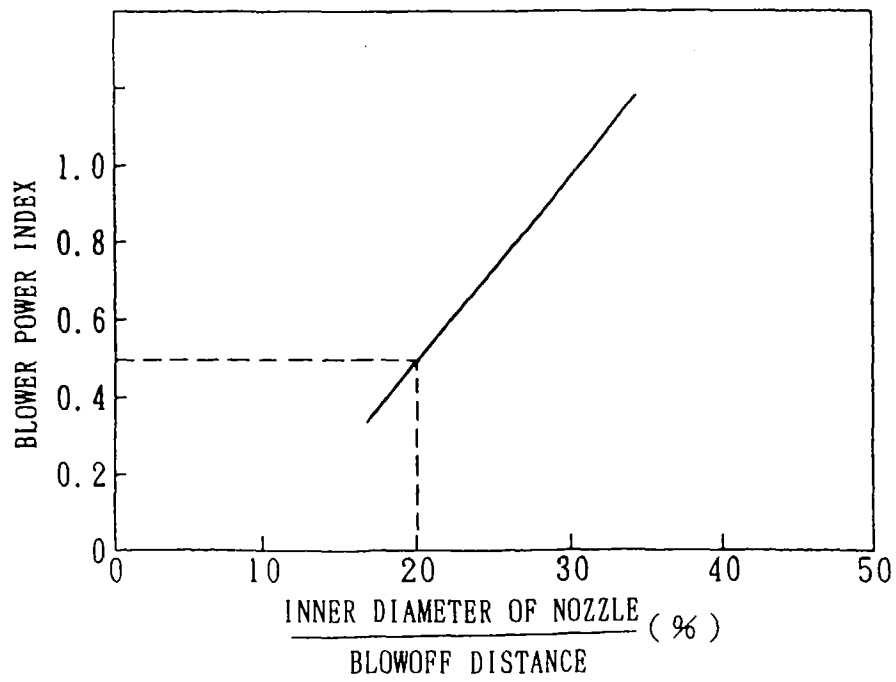


Fig. 10

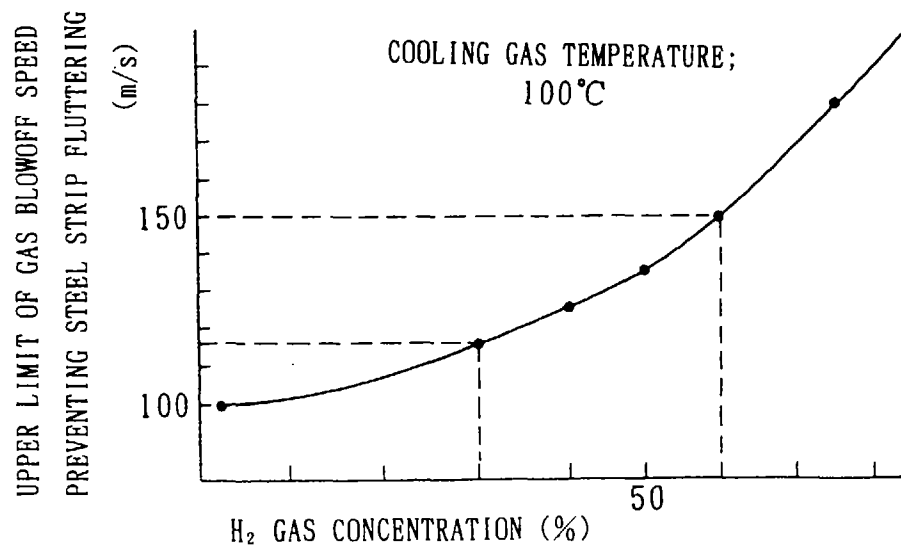


Fig. 11

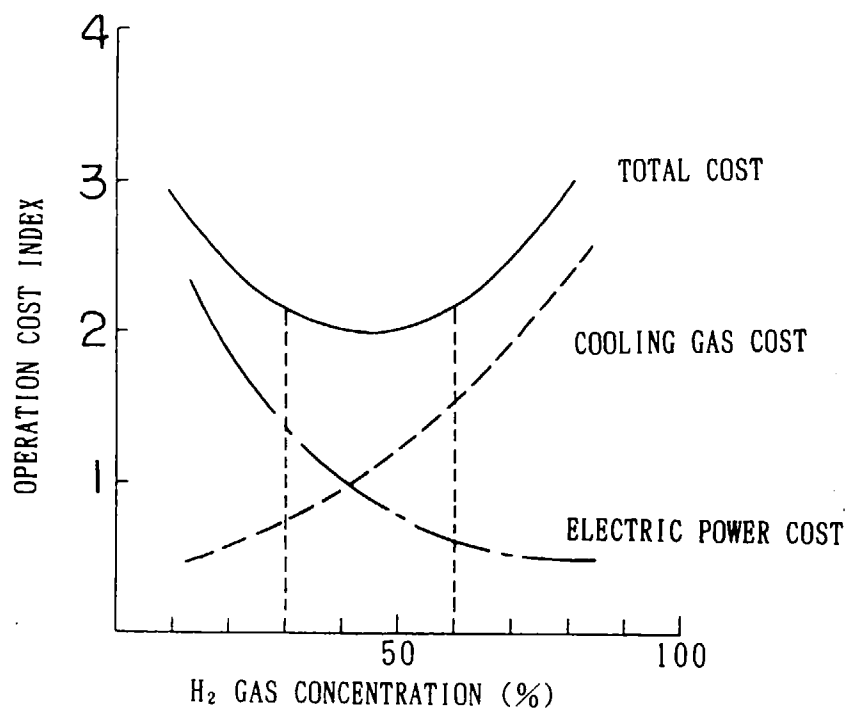


Fig. 12

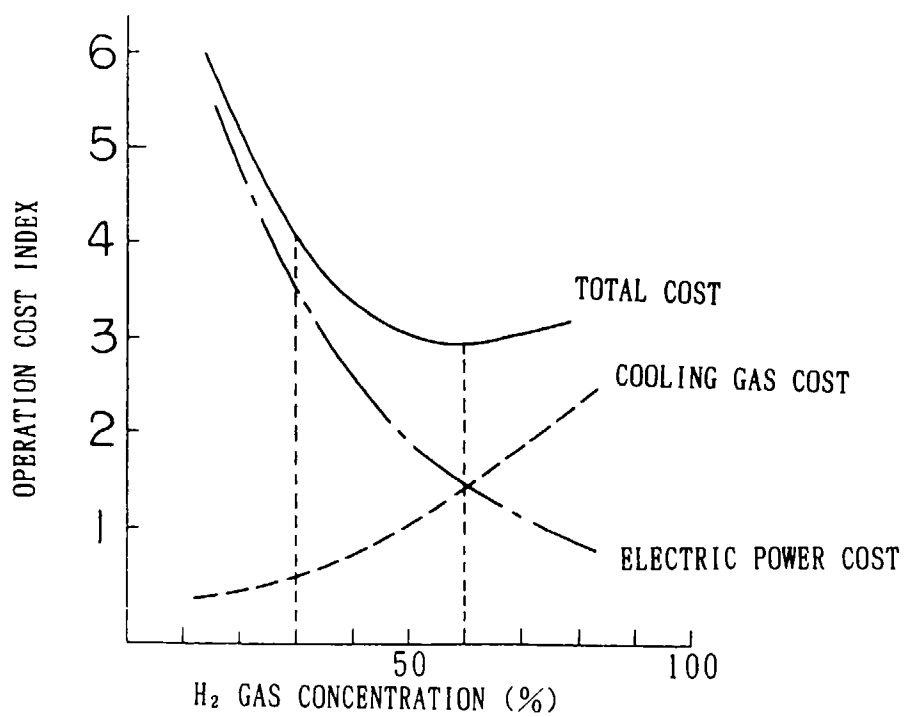


Fig. 13

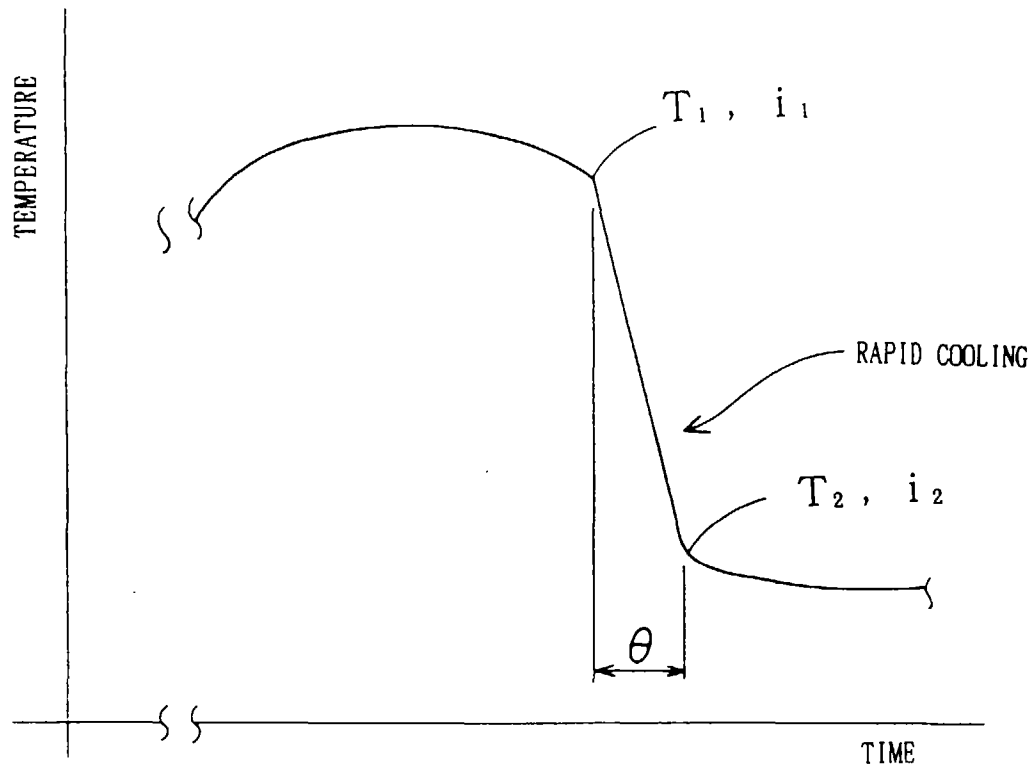


Fig. 14

