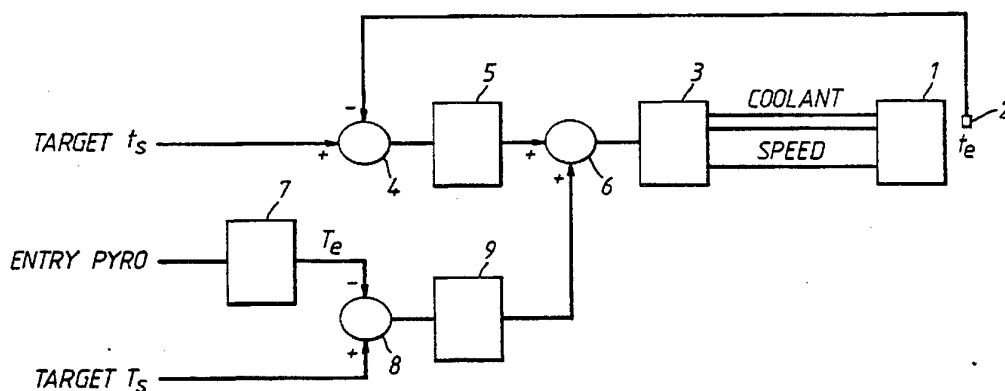




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B21B 37/74	A1	(11) International Publication Number: WO 95/05904 (43) International Publication Date: 2 March 1995 (02.03.95)
(21) International Application Number: PCT/GB94/01851 (22) International Filing Date: 24 August 1994 (24.08.94) (30) Priority Data: 9317928.1 26 August 1993 (26.08.93) GB (71) Applicant (for all designated States except US): DAVY MCKEE (POOLE) LIMITED [GB/GB]; Wallisdown Road, Poole, Dorset BH12 5AG (GB). (72) Inventors; and (75) Inventors/Applicants (for US only): BEATTIE, Robert, John [GB/GB]; 33 Highway, Broadstone, Dorset BH18 9NB (GB). ROUND, Philip, Francis [GB/GB]; 15 Glendale Avenue, Ferndown, Dorset BH22 9LF (GB). STOREY, Andrew [GB/GB]; 51 Inglesham Way, Hamworthy, Poole, Dorset BH15 4PA (GB). (74) Agent: KIRK, Geoffrey, Thomas; Batchellor, Kirk & Co., 2 Pear Tree Court, Farringdon Road, London EC1R 0DS (GB).		(81) Designated States: JP, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>With international search report.</i>

(54) Title: ROLLING OF METAL STRIP**(57) Abstract**

A rolling mill (1) for rolling metal strip has provision for applying discrete levels of liquid coolant to the strip and the temperature (t_e) of the strip leaving the mill is compared with a target temperature (t_s) and the temperature (T_e) of the incoming workpiece is compared with a target temperature (T_s). The difference signals are employed to control the levels of liquid coolant and the rolling speed so that the exit temperature remains substantially equal to the target exit temperature.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	GB	United Kingdom	MR	Mauritania
AU	Australia	GE	Georgia	MW	Malawi
BB	Barbados	GN	Guinea	NE	Niger
BE	Belgium	GR	Greece	NL	Netherlands
BF	Burkina Faso	HU	Hungary	NO	Norway
BG	Bulgaria	IE	Ireland	NZ	New Zealand
BJ	Benin	IT	Italy	PL	Poland
BR	Brazil	JP	Japan	PT	Portugal
BY	Belarus	KE	Kenya	RO	Romania
CA	Canada	KG	Kyrgyzstan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo	KR	Republic of Korea	SE	Sweden
CH	Switzerland	KZ	Kazakhstan	SI	Slovenia
CI	Côte d'Ivoire	LI	Liechtenstein	SK	Slovakia
CM	Cameroon	LK	Sri Lanka	SN	Senegal
CN	China	LU	Luxembourg	TD	Chad
CS	Czechoslovakia	LV	Latvia	TG	Togo
CZ	Czech Republic	MC	Monaco	TJ	Tajikistan
DE	Germany	MD	Republic of Moldova	TT	Trinidad and Tobago
DK	Denmark	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	US	United States of America
FI	Finland	MN	Mongolia	UZ	Uzbekistan
FR	France			VN	Viet Nam
GA	Gabon				

ROLLING OF METAL STRIP

This invention relates to the rolling of metal strip, particularly, but not solely, to the warm rolling of aluminium and its alloys. It is well known that the temperature of strip exiting from a rolling mill is a factor in determining the metallurgical quality of the metal strip. For aluminium and its alloys it is important that the temperature of the strip exiting the rolling mill, or the last stand, of a multistand rolling mill, is at, or close to, a predetermined value so that the metallurgical properties of the metal are enhanced.

It is well known that the temperature of strip exiting from a rolling mill varies with the rolling speed of the mill, the faster the rolling speed, the higher the temperature. Consequently, the exit temperature of the strip can be controlled, to some degree, by adjusting the rolling speed.

It is also known to control the temperature of metal strip being rolled in a multistand rolling mill by applying liquid coolant, usually water, to the strip. The coolant may be applied to the strip when it is on a roller table downstream of the last stand of the mill or it may be applied to the strip at inter-stand locations.

In US-A-3267709 there is described a method and apparatus for controlling the temperature of a workpiece during rolling. The temperature of the workpiece exiting from the last stand is determined and compared with a desired temperature. the difference, if any, is used to adjust the speed of the mill so that the difference between the actual temperature and the desired temperature is reduced substantially to zero. Provision is made for cooling the workpiece downstream of the mill and the cooling effect of the cooling means is varied commensurate with the varying speed of the rolling mill.

GB-A-1258421 also discloses a method and apparatus for controlling the temperature of a workpiece during rolling. A finishing mill for metal strip comprises a multiplicity of rolling mill stands. Means for applying liquid coolant to the strip are located at inter-stand locations. Temperature detectors are located at selected regions including one immediately downstream of the last stand. The cooling means at each location are adjustable. The rate of flow of the cooling liquid is decreased to compensate for loss of heat from the workpiece as it is fed into the mill and the rate of flow of the cooling liquid is increased to maintain the delivery temperature substantially constant as a function of the acceleration rate of the workpiece.

US-A-3418834, discloses a hot strip rolling mill which is controllably accelerated to hold the desired strip delivery temperature at a substantially constant level. Closed loop control of mill acceleration is based on delivery temperature detection. Downstream of the last stand of the multi-stand rolling mill, provision is made for supplying liquid coolant to the strip.

According to the present invention in a method of rolling metal strip in a rolling mill which has provision for applying discrete levels of liquid coolant to the strip, the temperature of the strip leaving the mill is compared with a target temperature to provide an exit difference signal;

the temperature of the workpiece entering the mill is compared with a target temperature to provide an entry difference signal; and

said difference signals are used to control both the levels of liquid coolant applied to the strip and the rolling speed of the mill such as to reduce the exit difference signal substantially to zero.

In a preferred arrangement, the rolling mill comprises at least those stands arranged in tandem and the liquid coolant is applied to the strip at interstand locations. At each interstand location, the levels of liquid coolant conveniently include maximum coolant flow, minimum coolant flow and at least one intermediate level of coolant flow. Switching from one level to another is controlled by a non-linear deadband type switching device and switching from one level to another level is inhibited in less than predetermined time intervals.

When the mill is brought into use it is accelerated to an initial rolling speed and the initial rolling speed is determined using data obtained from the previously rolled strip and the difference in entry temperature between the current strip and the previously rolled strip. Hence the initial mill speed can be quickly and accurately determined and the speed is updated based on information obtained from previously rolled strips.

In order that the present invention may be more readily understood, it will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of a control system in accordance with the invention;

Figure 2 is a block diagram showing details of the feedback controller (5) shown in figure 1;

Figure 3 is a transfer function diagram of a control scheduler (3) forming part of the control system of Figure 1; and

Figure 4 shows graphs of certain parameters of the control system.

Referring to Figure 1, a multistand rolling mill for rolling aluminium and its alloys comprises, say, three stands arranged in tandem with liquid cooling provided

between the first and second stands and between the second and third stands. The mill is indicated by reference numeral 1. A pyrometer 2 preferably located immediately downstream of the last stand measures the temperature of the strip exiting from the last stand.

The speeds of rotation of the rolls of the three stands, and the control of the coolant applied to the strip between the stands, is controlled by a control scheduler 3.

The output signal t_e from the pyrometer 2 is fed back as a negative signal to a summer 4 to which a positive signal t_s representing the desired exit temperature is also applied and the temperature difference signal, i.e., the error signal, is applied to a feedback controller 5. The output of the controller 5 serves as one positive input to a summer 6, the output of which is connected to the control scheduler 3.

An entry pyrometer, not shown, measures the temperature of the strip entering the mill and the signal T_e from this pyrometer is delayed in delay circuit 7, for a time corresponding to the strip transit time from the pyrometer to the first stand, to produce a signal T_e which is compared with the target entry temperature T_s in a comparator 8. The difference signal, i.e., the error signal is supplied to a controller 9 and the output from the controller is fed forward as the second input into the summer 6.

The interstand coolant coverage comprises interstand coolant spraybars (sb) and air and coolant blow-offs (b-o). To minimise the coolant coverage between a pair of stands, the interstand coolant spraybar is switched off and the air/coolant blow-offs are switched on, thereby preventing additional coolant from flowing on to the strip from the mill stands. To maximise coolant coverage, the spraybar is switched on and the blow-offs off, this causes

the strip to be flooded with coolant.

The speed control part of the circuit is basically linear, although the mill transport delay does come into account. The coolant coverage part is discrete since there are only three different states:

<u>state</u>	<u>sb 1-2</u>	<u>b-o 1-2</u>	<u>sb 2-3</u>	<u>b-o 2-3</u>	<u>effect</u>
1	ON	OFF	ON	OFF	Maximum cooling
2	ON	OFF	OFF	ON	Intermediate cooling
3	OFF	ON	OFF	ON	Minimum cooling

This combination of linear and non-linear is handled by the control scheduler 3 which for cooling control is in the form of a deadband controller as shown in Figure 3. When the speed change required gets above or below a threshold, the control scheduler triggers a transition to the appropriate higher or lower coolant coverage state. It then inhibits further transitions for a certain period to avoid continuous switching.

The feedback controller 5 is a PI type with a Smith Predictor in the integral term as shown in figure 2. The aim of the Smith Predictor is to discount the effect of integral corrections already pending due to the transport delay of the mill. The exit temperature error is multiplied at block 10 by the integral gain K_I and inputted to the normal integrator 11 and to a fixed period integrator 12 whose integration period is chosen to be the same as the mill transport delay. The output of the fixed period integrator 12 is scaled by the mill gain K_M in block 13 to predict the likely change in exit strip temperature which will result from integral mill speed corrections already pending. This is subtracted in a summer 14 from the original temperature error to produce a difference which is the temperature error still to be corrected for. The

proportional part of the PI controller is fed through its proportional gain K_p in block 15 and summed at 16 with the output of the integral loop to generate the total feedback speed correction.

Components 7, 8 and 9 shown in figure 1 provide a feedforward signal. The outputs of the proportional feedforward controller 9 and the feedback controller 5 are summed at 6 to produce a single speed change signal for the control scheduler 3. As far as the speed control part of the system is concerned, the control scheduler has no effect. For coolant control, the control scheduler works as illustrated graphically in Figure 3. The horizontal axis represents the speed change required. When this goes above or below a threshold value, a coolant system transition is triggered. For example, say the system starts rolling a slab with the coolant system ON, i.e., producing a maximum cooling; if the strip is too cold, then a positive speed change error will be generated, causing the mill to speed up and raising the exit strip temperature. If the speed change required goes above a threshold value, then the control scheduler will trigger a transition in the coolant system to its INT (intermediate) state, causing one of the sprays to be switched off (and the associated blow-offs to be switched on). It also triggers a timer which temporarily inhibits further transitions. As a result of the decreased coolant, the exit strip temperature will increase and the required speed change may decrease slightly. Since the control scheduler incorporates some hysteresis, this will not generate a transition back on the ON state. If the strip continues to cool, the required speed change will again increase. When it goes back above the threshold, a second transition will be triggered to the OFF state, in which both sprays will be off and strip cooling will be at a minimum. This may again cause the speed change required to reduce

slightly, but not enough to generate a negative going transition. The width of the control scheduler deadband is chosen such that the change in the speed change signal resulting from a state transition is not large enough to cause a negative going transition. To prevent multiple transitions in the same direction, i.e., ON to INT to OFF, being triggered, as soon as the speed change goes above the threshold, a timer is fired as soon as a single transition is made preventing further transitions until the effect of the first transition has had time to propagate through the mill. The duration of the inhibit timer is calculated from physical separation of the mill stands and the known strip speed from each stand.

Also to improve head end response, a recommended target speed is calculated based on the speed when the previous coil got on target temperature and the entry temperature difference between the current coil and the previous one, i.e.

$$S_N = S_C - k \left\{ \frac{(T_N - T_C) \times \frac{\partial t}{\partial T}}{\frac{\partial t}{\partial S}} \right\}$$

where

S_N - recommended run speed target

S_C - speed at which the exit temperature was on target in the previous coil

k - multiplying factor (default 1.0)

T_N - entry temperature of the next coil

T_C - entry temperature of the previous coil

$\frac{\partial t}{\partial T}$ - rate of change of exit temperature with entry temperature

$\frac{\partial t}{\partial S}$ - rate of change of exit temperature with mill speed.

where $\frac{\partial t}{\partial \gamma}$ and $\frac{\partial t}{\partial S}$ are previously found either from special tests or by on-line identification during normal mill operation.

If there has been no rolling for a period of time, for example, if the mill has been shutdown for maintenance, then values of S_c and T_c may be retrieved from stored data.

The feedforward loop has two different modes of operation. In "offset" mode, it uses the difference between the measured entry temperature and a target entry temperature. In "lock-on" mode, operation of the feedforward loop is delayed until the exit temperature is on target, it then stores the entry temperature of the strip and uses any subsequent difference as the feedforward error signal. This improves performance near the strip tail.

It can be seen from Figure 4 that, at the beginning of rolling, the pyrometer 2 indicates that the exit temperature of the strip is above the target temperature of 300°C. The exit error signal, which is the output of the adder 4, is shown to be at its maximum level, and this error signal is applied to the controller 5. The controller 5 produces a speed trim signal and the corresponding rolling speed of the last stand S3 is shown. It can be seen from the exit temperature graph that the temperature falls until the target temperature is reached wherefrom the speed trim is kept at a suitable value to eliminate any errors and the exit temperature remains substantially constant at the target temperature.

Claims:

1. A method of rolling metal strip in a rolling mill having provision for applying discrete levels of liquid coolant to the strip in which the temperature of the strip leaving the mill is compared with a target temperature to provide an exit difference signal;

the temperature of the workpiece entering the mill is compared with a target temperature to provide an entry difference signal;

said difference signals are used to control both the levels of liquid coolant applied to the strip and the rolling speed of the mill such as to reduce the exit difference signal substantially to zero.

2. A method as claimed in claim 1 in which the rolling mill comprises at least three stands arranged in tandem and the liquid coolant is applied to the strip at interstand locations.

3. A method as claimed in claim 2 in which at each interstand location the levels of liquid coolant include maximum coolant flow, minimum coolant flow, and at least one intermediate level of coolant flow and switching from one level to another level is inhibited in less than predetermined time intervals.

4. A method as claimed in claim 3 in which the levels of liquid coolant are controlled by a non-linear deadband-type switching mechanism.

5. A method as claimed in claim 1, 2, 3 or 4 in which the exit difference signal is supplied to a feedback controller of the PI type.

6. A method as claimed in claim 5 in which the feedback controller includes a Smith Predictor which serves to discount the effect of integral corrections already pending due to the transport delay of the mill.

7. A method as claimed in claim 6 in which a signal is obtained in said controller which predicts the likely change in exit strip temperature which will result from mill speed corrections already pending and said signal is subtracted from the exit difference signal.

8. A method of rolling metal strip in a rolling mill having provision for applying liquid coolant to the strip, means for determining the temperature of the strip entering the mill and means for determining the temperature of the strip exiting from the mill; and

wherein a signal representing the difference between the temperature of the strip leaving the mill and a target temperature is used to control both the liquid coolant applied to the strip and the rolling speed of the mill such as to reduce said difference signal substantially to zero and the initial rolling speed of the mill is determined using data obtained from the previously rolled strip and the difference in entry temperature between the current strip and the previously rolled strip.

1/3

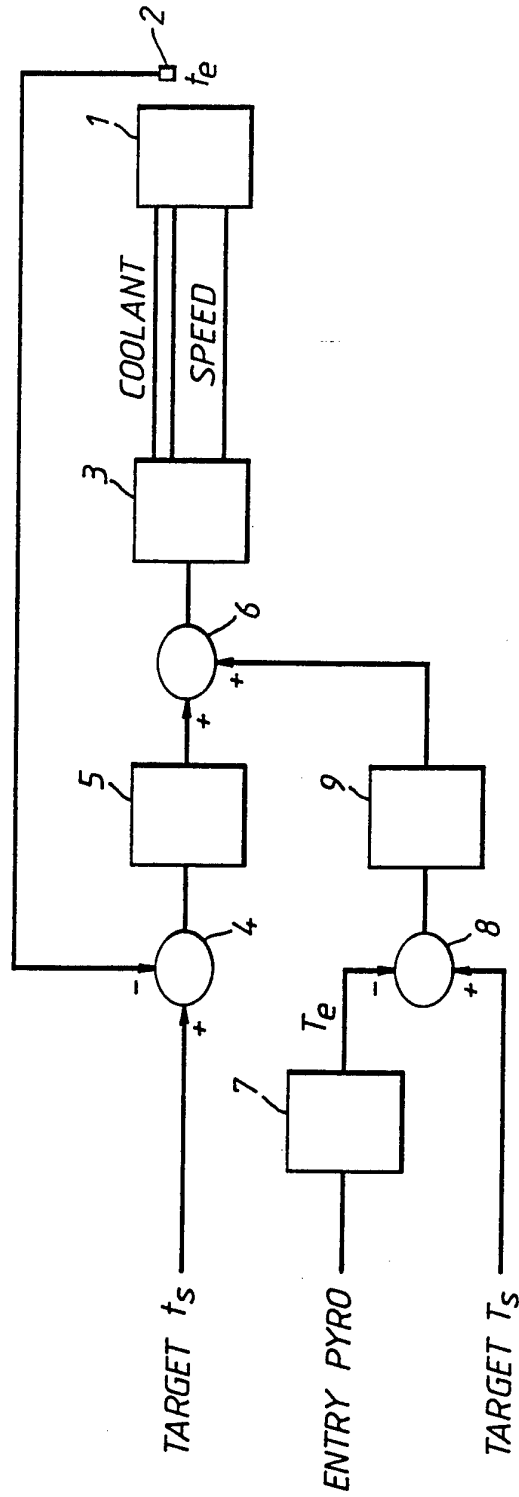


Fig.1

2/3

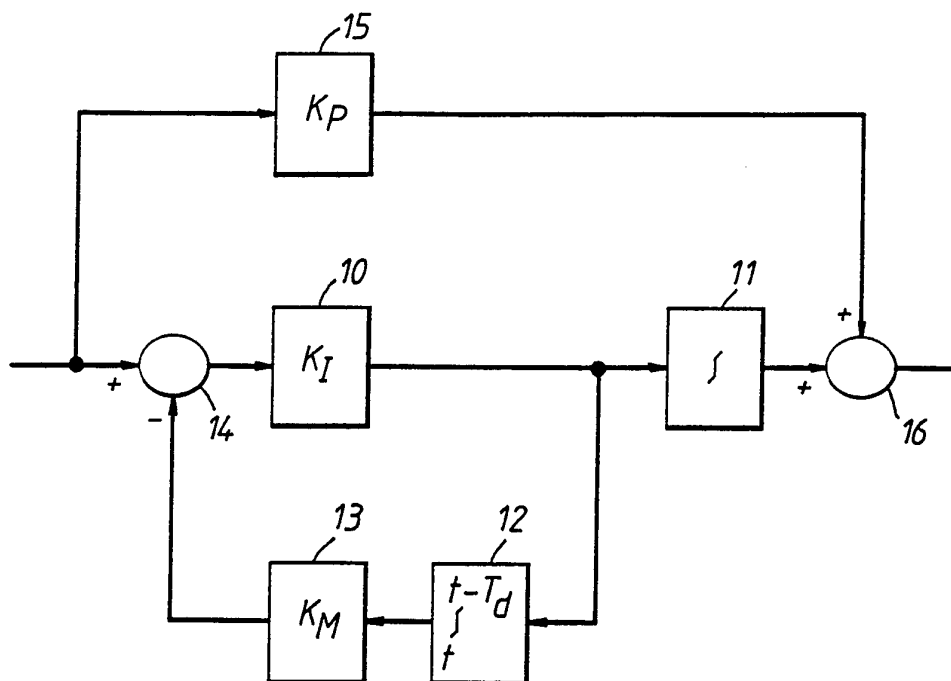


Fig. 2

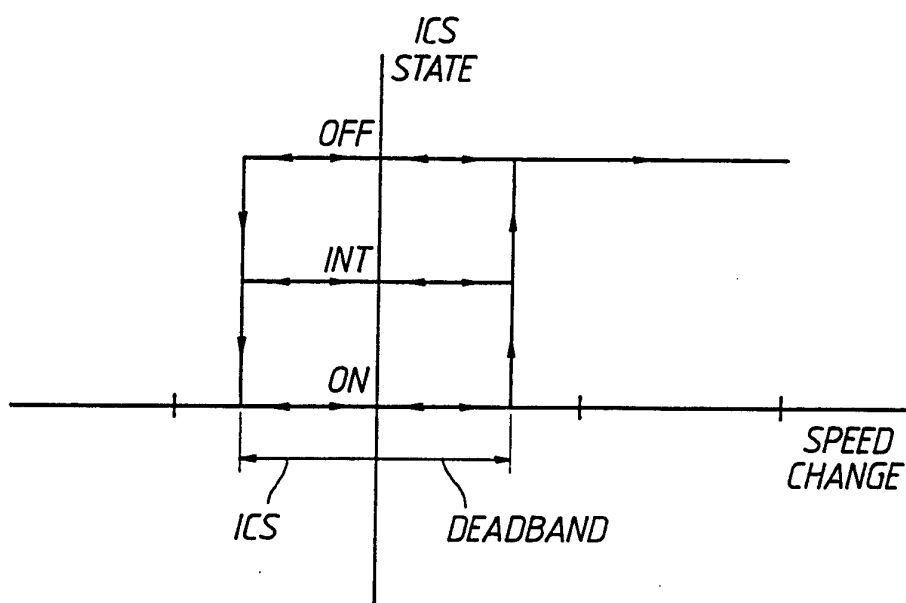


Fig. 3

3/3

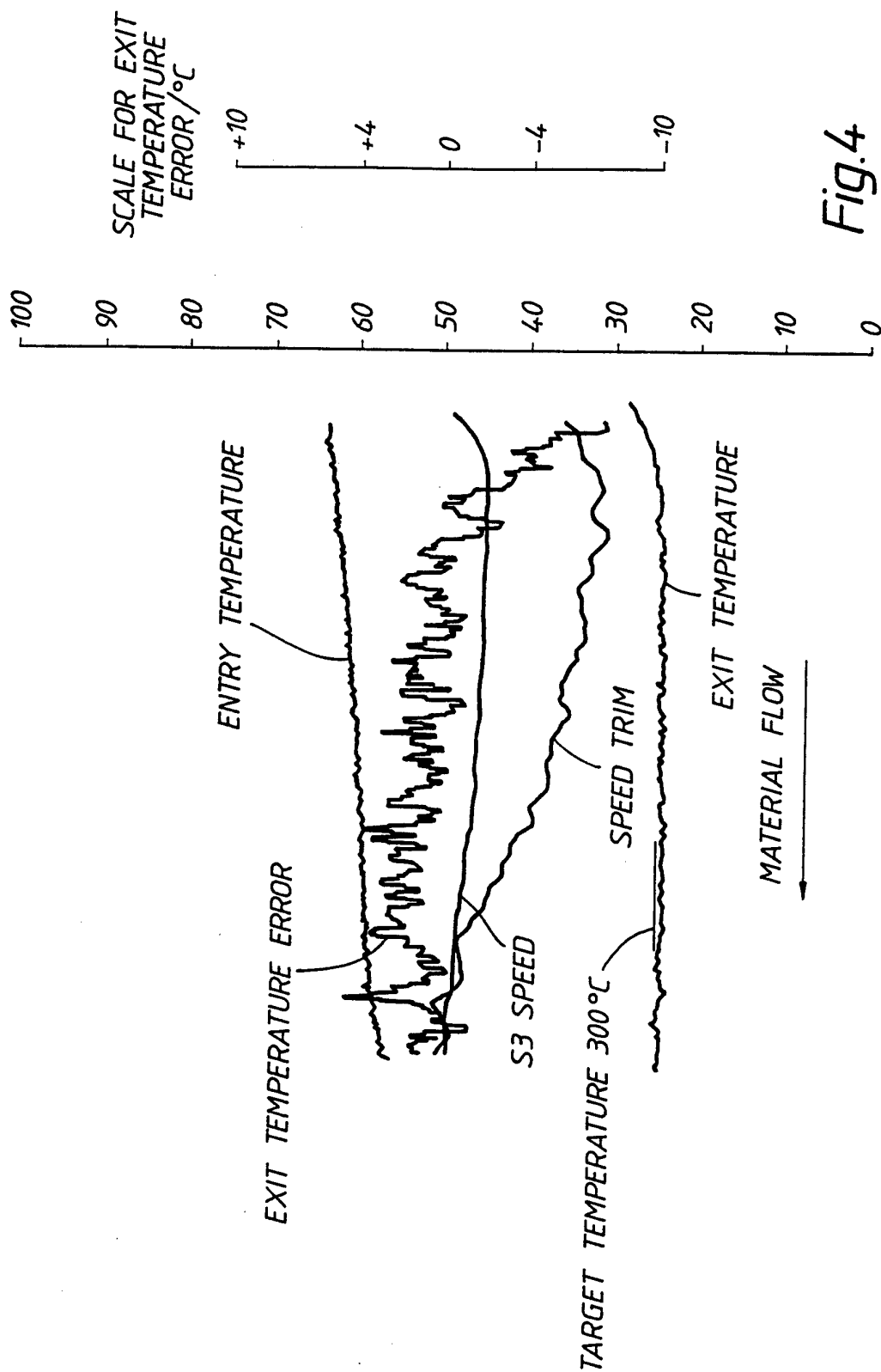


Fig.4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 94/01851

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B21B37/74

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B21B C21D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 12, no. 434 (M-764) 16 November 1988 & JP,A,63 168 211 (SUMITOMO) 12 July 1988 see abstract	1,2
Y		5
A		8
Y	--- PATENT ABSTRACTS OF JAPAN vol. 16, no. 118 (C-0922) 25 March 1992 & JP,A,03 287 720 (SUMITOMO) 18 December 1991 see abstract	5
X	--- PATENT ABSTRACTS OF JAPAN vol. 9, no. 282 (M-428) 9 November 1985 & JP,A,60 124 411 (HITACHI) 3 July 1985 see abstract	1
A	--- -/--	8

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
 "E" earlier document but published on or after the international filing date
 "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
 "O" document referring to an oral disclosure, use, exhibition or other means
 "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
 "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
 "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
 "&" document member of the same patent family

Date of the actual completion of the international search

23 November 1994

Date of mailing of the international search report

01.12.94

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+ 31-70) 340-3016

Authorized officer

Plastiras, D

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 94/01851

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 13, no. 163 (M-816) 19 April 1989 & JP,A,64 002 711 (HITACHI) 6 January 1989 see abstract ---	1,8
A	PATENT ABSTRACTS OF JAPAN vol. 10, no. 211 (M-501) 24 July 1986 & JP,A,61 052 924 (KAWASAKI) 15 March 1986 see abstract ---	1
A	US,A,3 418 834 (COOK) 31 December 1968 cited in the application see the whole document ---	1,2,8
A	PATENT ABSTRACTS OF JAPAN vol. 15, no. 298 (M-1141) 29 July 1991 & JP,A,03 110 010 (NIPPON STEEL CORP.) 10 May 1991 see abstract ---	1,8
A	PATENT ABSTRACTS OF JAPAN vol. 12, no. 15 (C-469) 16 January 1988 & JP,A,62 170 422 (KAWASAKI) 27 July 1987 see abstract ---	3
A	PATENT ABSTRACTS OF JAPAN vol. 15, no. 215 (M-1119) 31 May 1991 & JP,A,03 060 810 (KAWASAKI) 15 March 1991 see abstract ---	4
A	PATENT ABSTRACTS OF JAPAN vol. 14, no. 420 (M-1023) 11 September 1990 & JP,A,02 165 806 (KAWASAKI) 26 June 1990 see abstract ---	6
A	PATENT ABSTRACTS OF JAPAN vol. 16, no. 165 (M-1238) 21 April 1992 & JP,A,04 013 410 (NIPPON STEEL CORP.) 17 January 1992 see abstract ---	6
A	IRON & STEEL ENGINEER, vol.53, no.10, October 1976, PITTSBURG USA pages 29 - 34 E.HINRCHSEN 'Hot strip mill runout table cooling-A system view of control, operation and equipment' see the whole document -----	5-7

Information on patent family members

PCT/GB 94/01851

Form PCT/ISA/210 (patent family annex) (July 1992)