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JP 620166014 A
JP 620142017 A
JP 620130222 A
JP 560114521 A
JP 100249430 A

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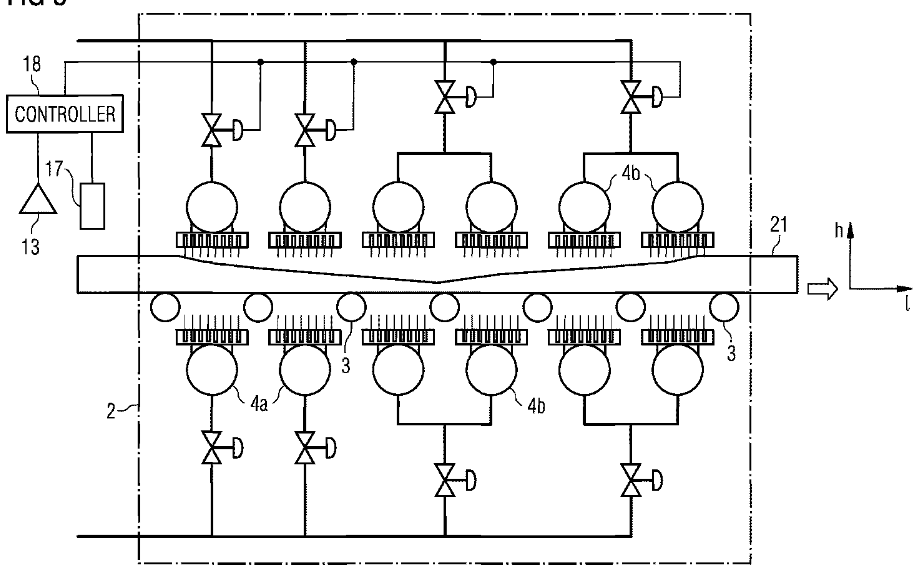
Other: **EPODOC, WPI**

(54) Title of the Invention: **Cooling method and system**
Abstract Title: **Method of cooling a longitudinally profiled plate**

(57) The method comprises calculating a target cooling flow 29b for a plurality of points along the length of a longitudinally profiled plate, monitoring the position of the plate relative to flows in a cooling machine and adjusting the flows 40 according to the target cooling flows at the plurality of points. The target cooling flows may be interpolated to produce a reference profile along at least part of the length of the plate. The method may comprise calculating an anticipated entry thickness 43 and temperature 44 of the plate at the plurality of points and comparing these with measured values 41,42 to calculate a required change in flow. The method ensures that the exit temperature of the plate from the cooling machine is accurately controlled even though the plate is of differing thickness along its length. A plate cooling system comprising a controller, a plurality of cooling headers and a conveyor is also claimed.

FIG 5



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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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FIG 1

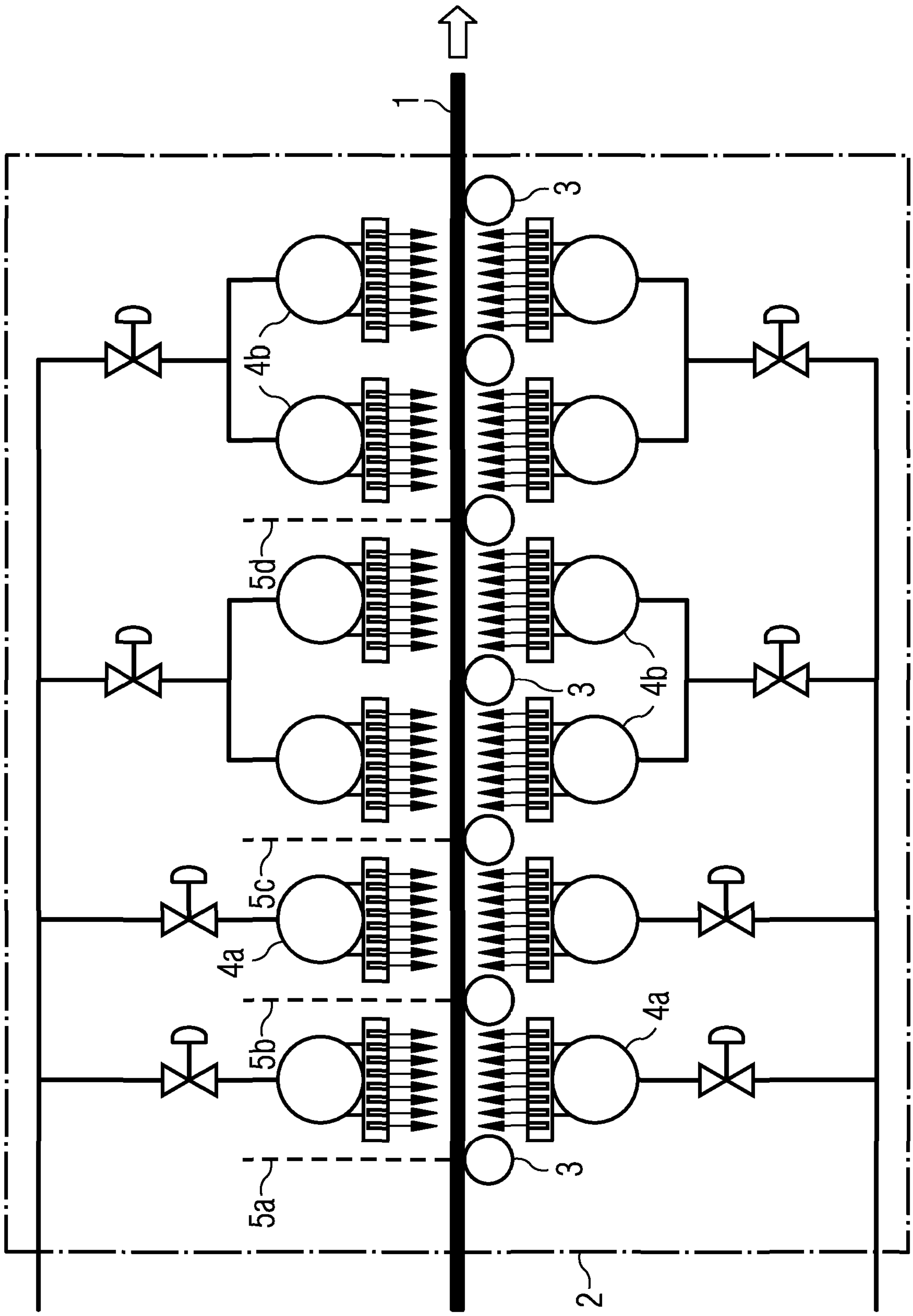


FIG 2

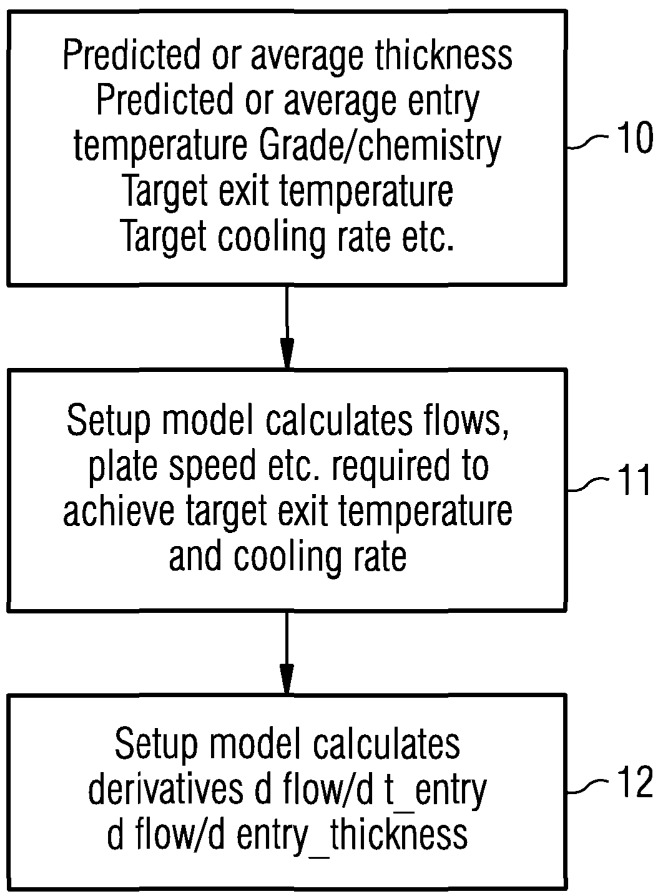
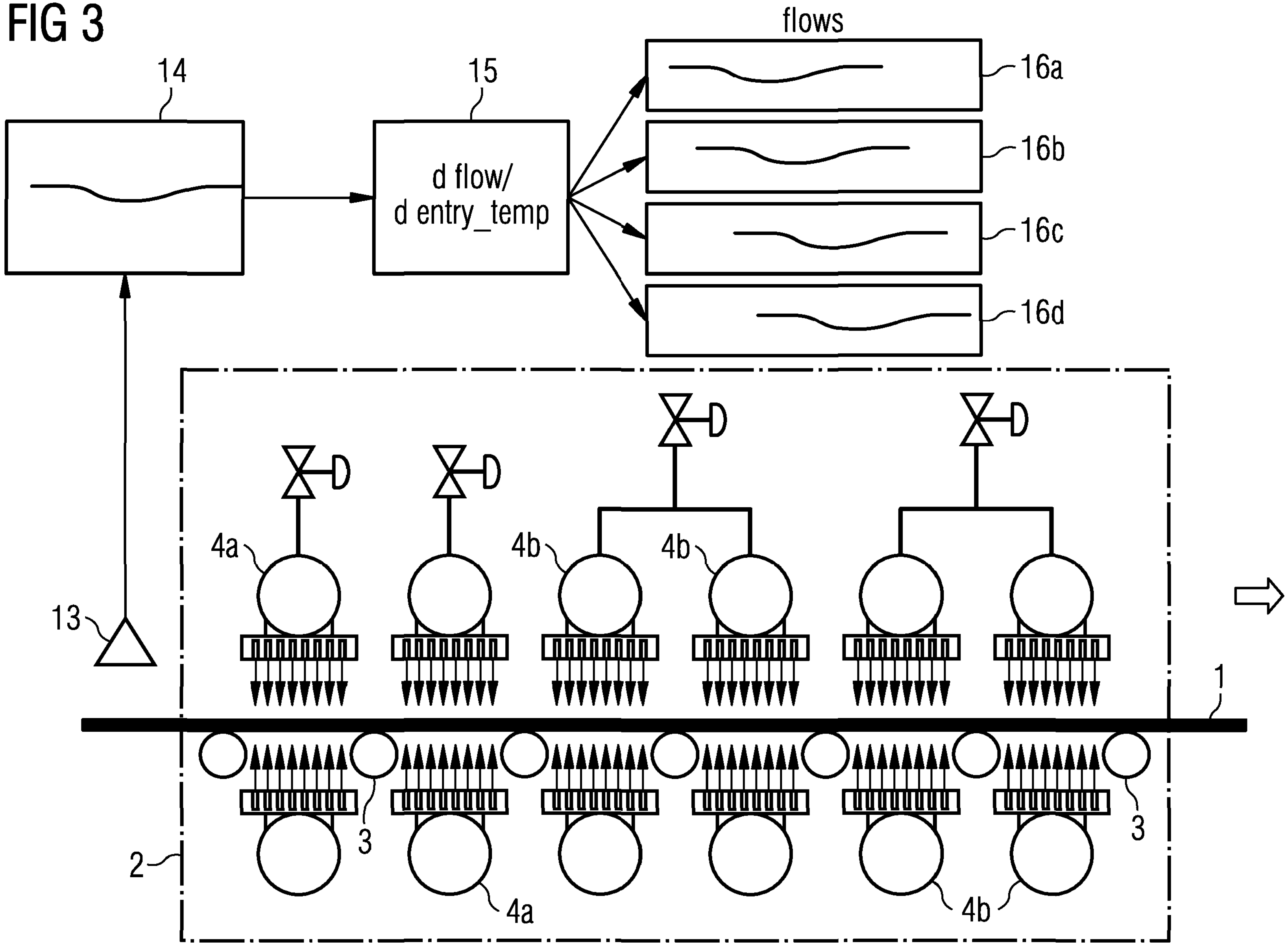

Predicted or average thickness
Predicted or average entry temperature Grade/chemistry
Target exit temperature
Target cooling rate etc.
10
Setup model calculates flows, plate speed etc. required to achieve target exit temperature and cooling rate
11
Setup model calculates derivatives d flow/d t_entry
d flow/d entry_thickness
12

FIG 3


flows
14
15
d flow/
d entry_temp
16a
16b
16c
16d
13
4a
4b
4b
1
2
3
3
4a
4b

02 02 11

FIG 4

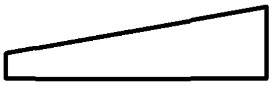
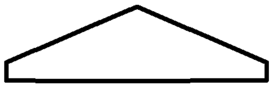
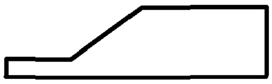
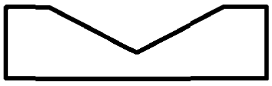
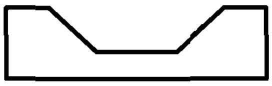
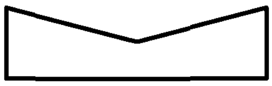
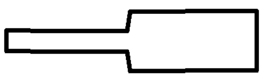
Type	Form	Maximum difference in thickness in mm	Maximum diffe-rence in thickness per meter in mm
1		45	10
2		45	10
3		45	10
4		45	10
5		45	10
6		35	10
7		30	10
8		30	10
9		30	10
10		45	–

FIG 5

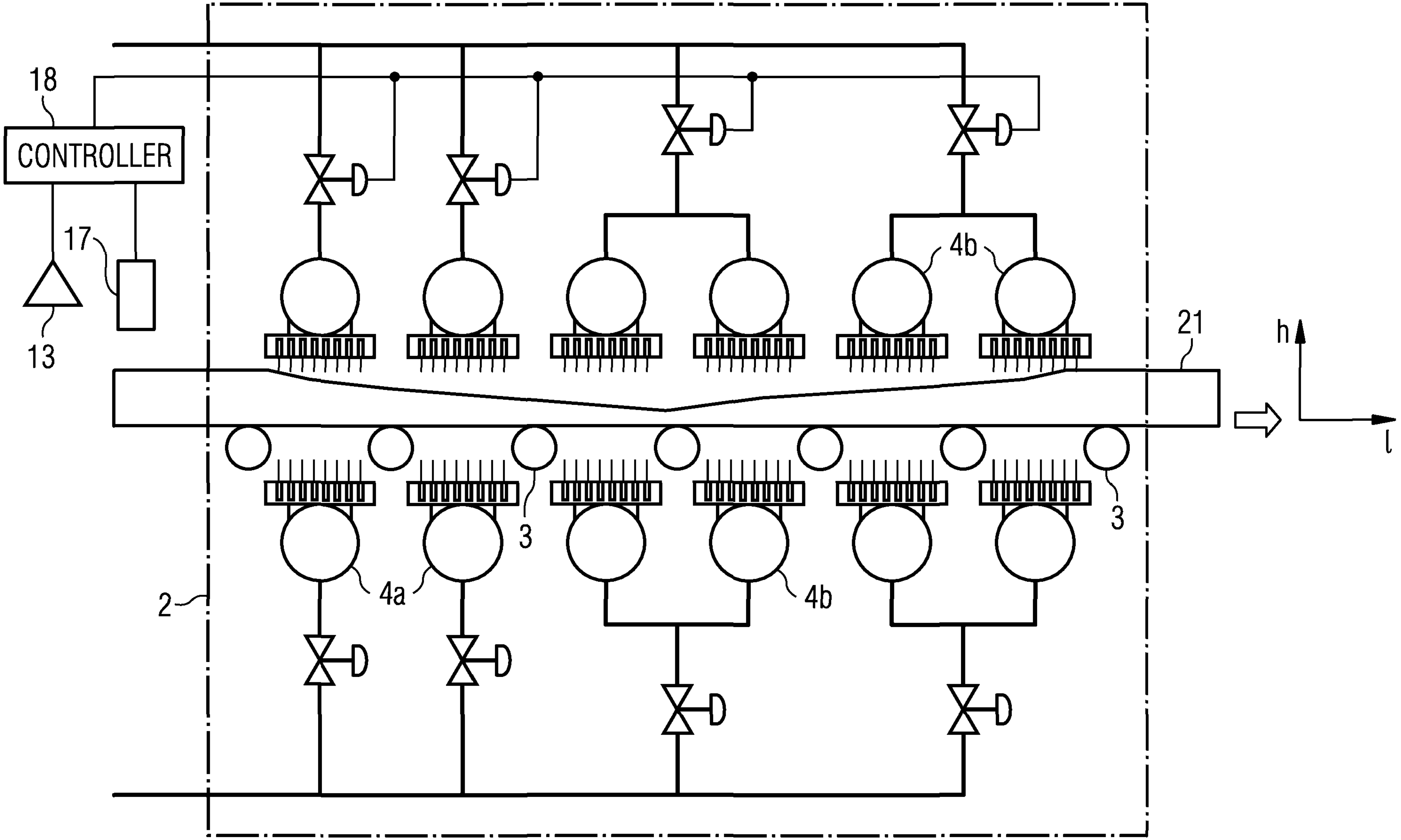


FIG 6A

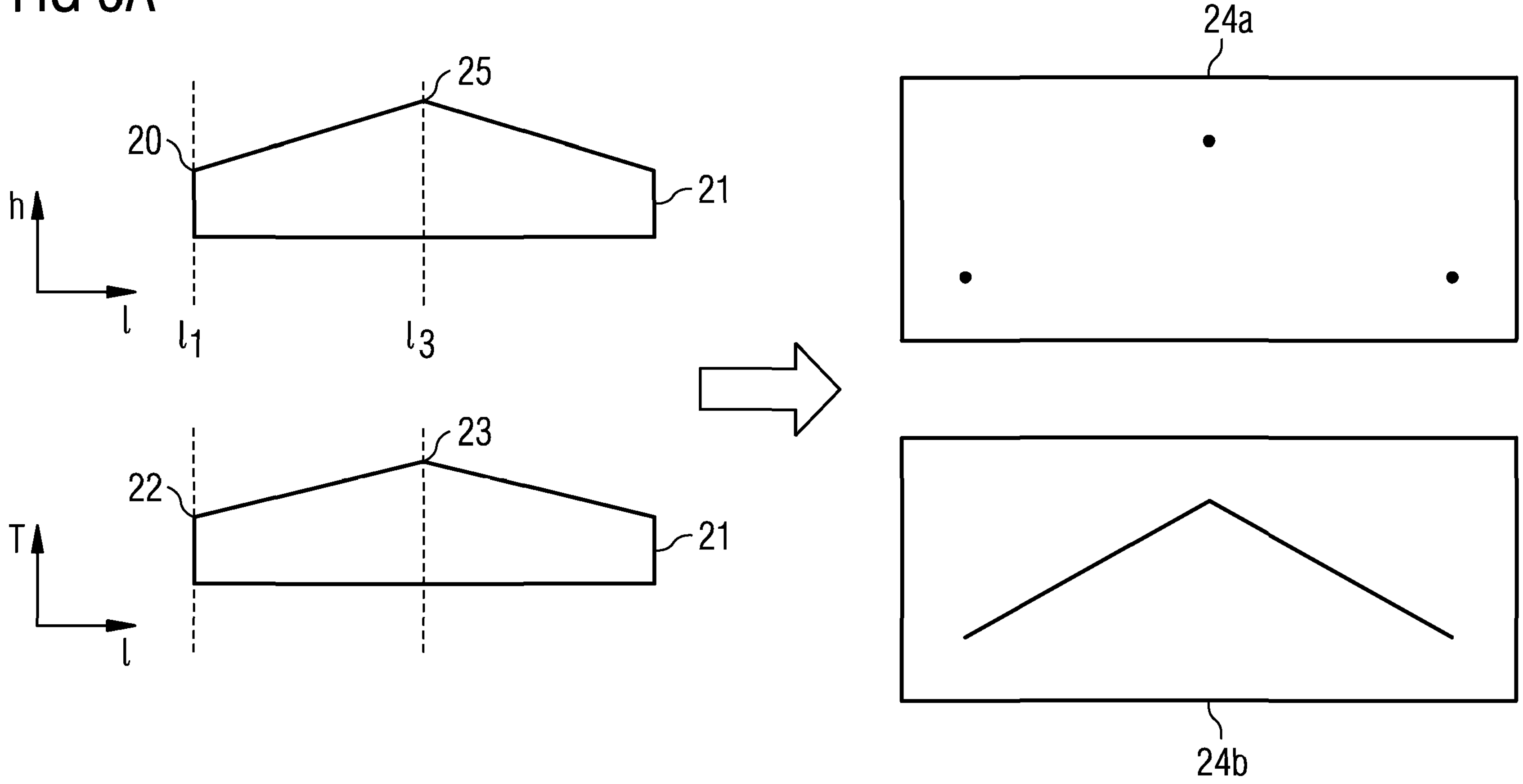


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FIG 6B

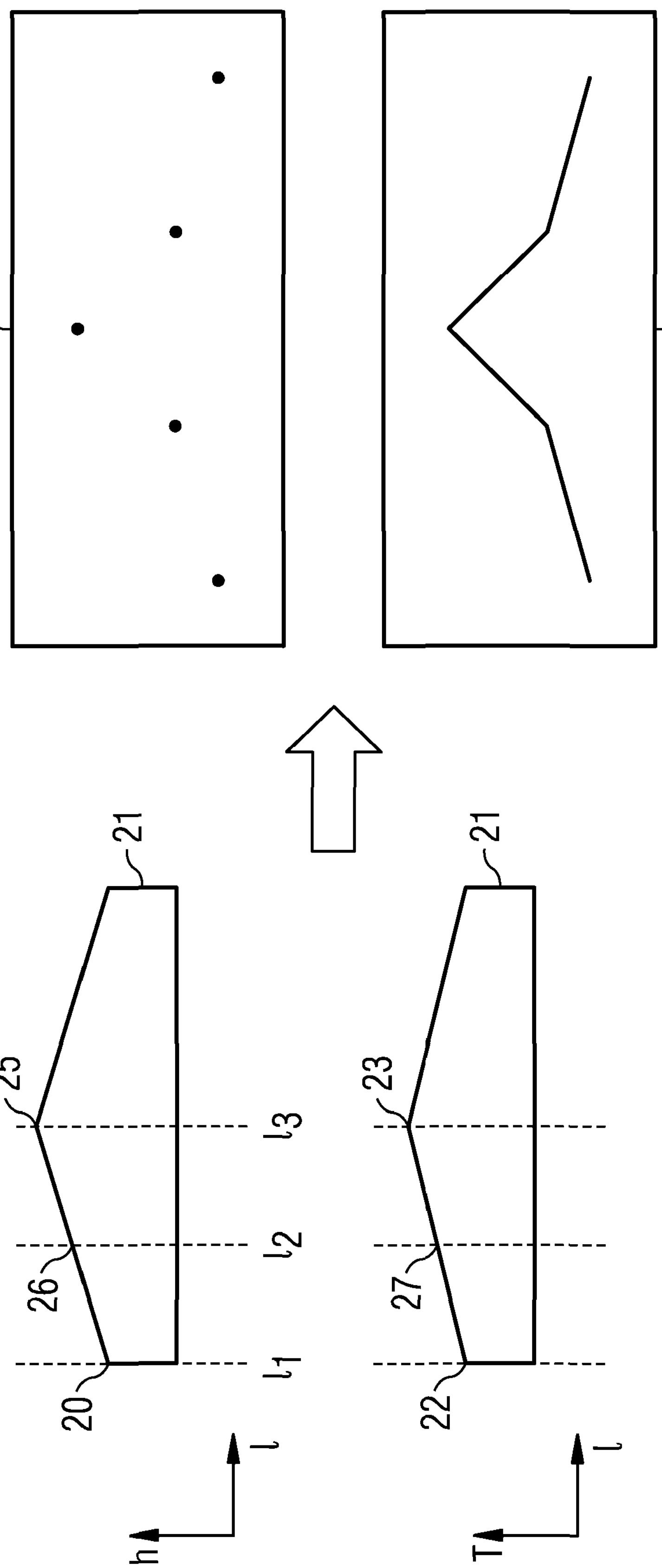

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FIG 6C

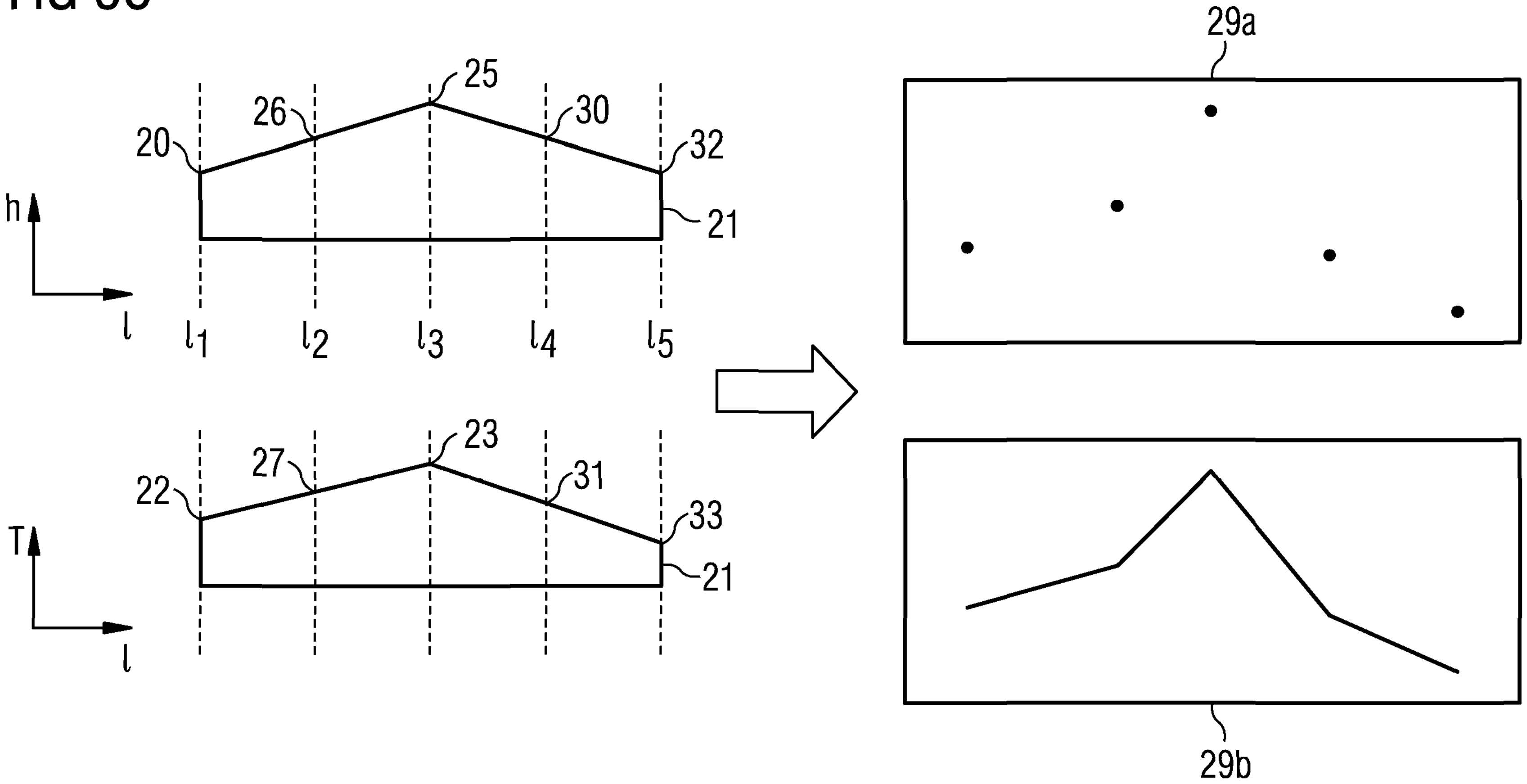


FIG 7A

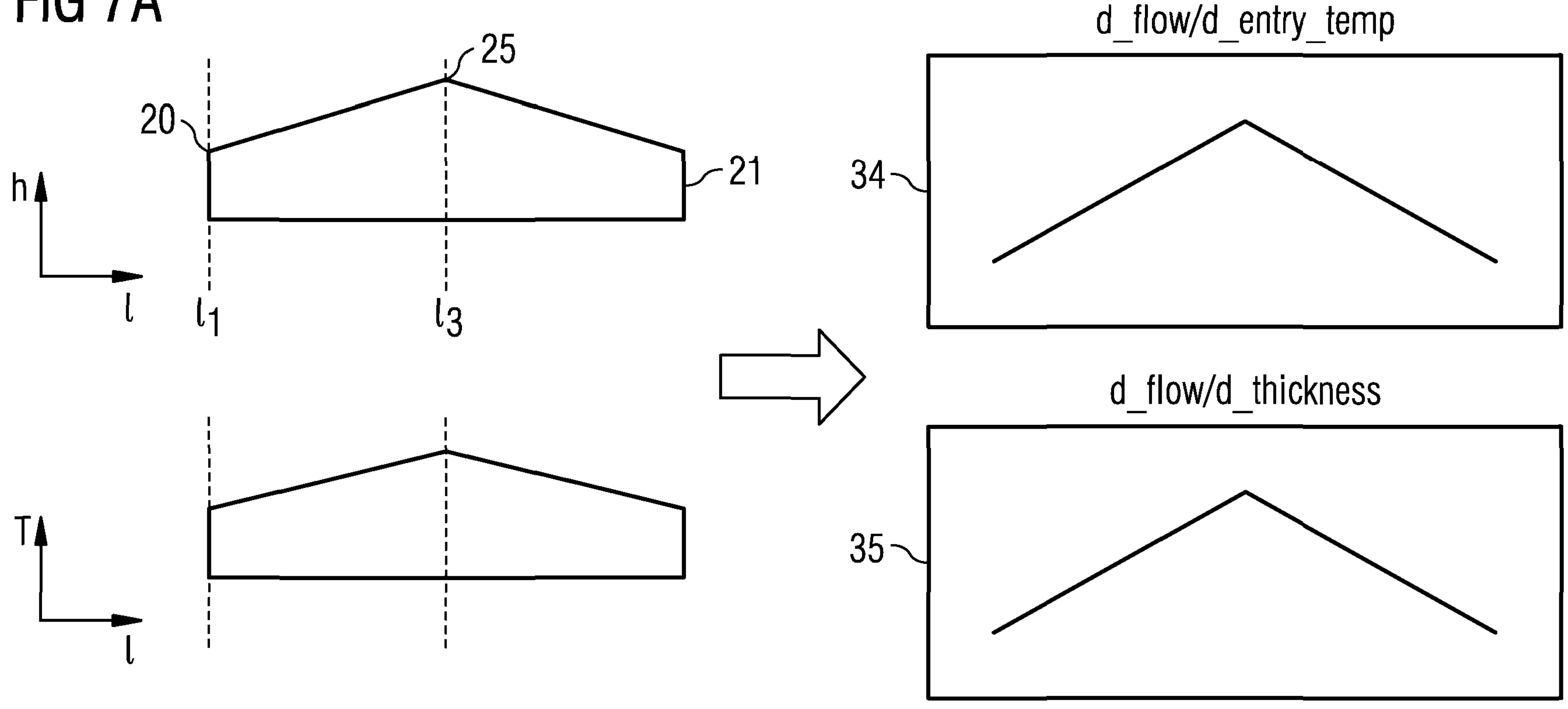


FIG 7B

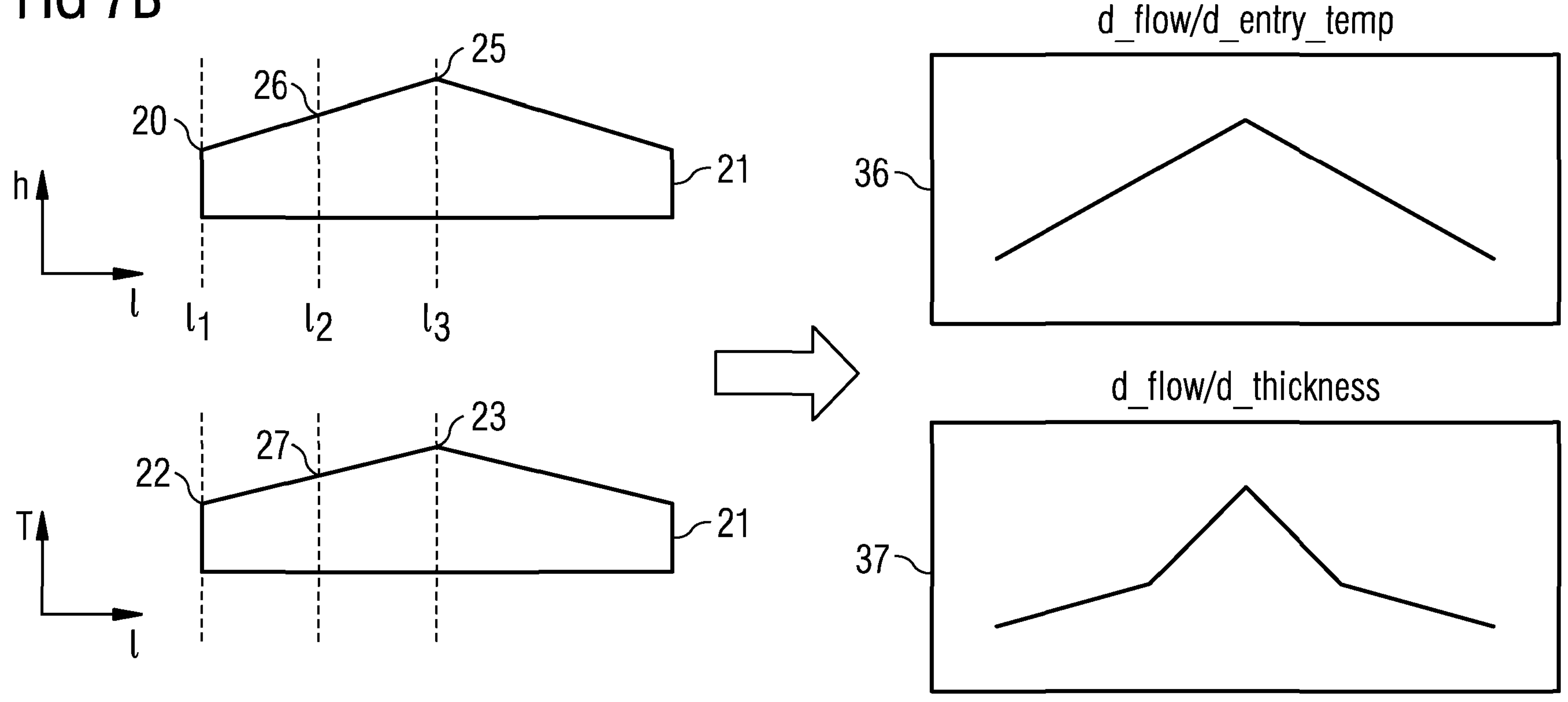
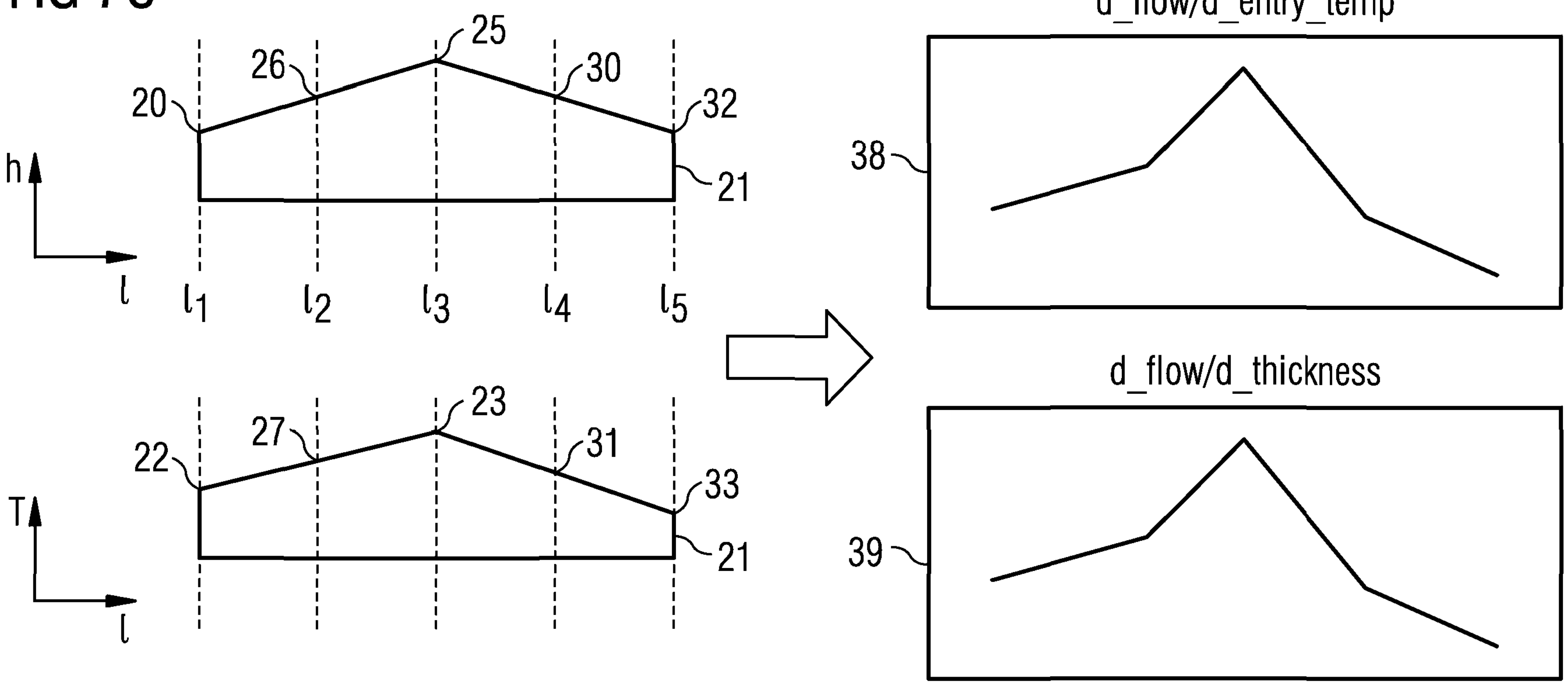
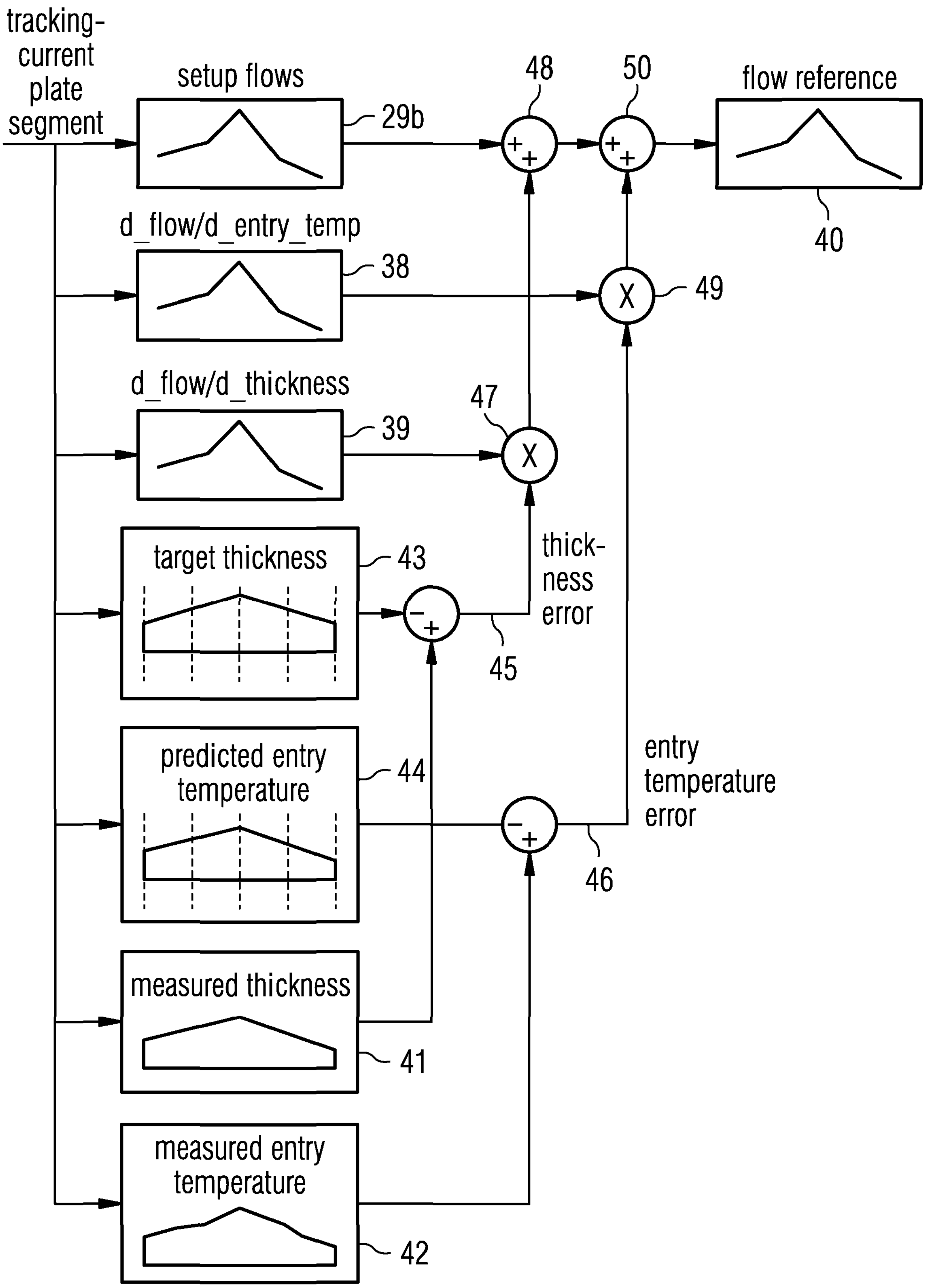

h
l
T
l
20
26
25
21
22
27
23
21
l_1
l_2
l_3
d_flow/d_entry_temp
d_flow/d_thickness
36
37

FIG 7C



h
T
l
l_1
l_2
l_3
l_4
l_5
20
21
22
23
25
26
27
30
31
32
33
d_flow/d_entry_temp
d_flow/d_thickness
38
39

FIG 8



tracking-current plate segment
setup flows
29b
48
50
flow reference
40
d_flow/d_entry_temp
38
49
X
d_flow/d_thickness
39
47
X
target thickness
43
thick-ness error
45
predicted entry temperature
44
entry temperature error
46
measured thickness
41
measured entry temperature
42

COOLING METHOD AND SYSTEM

This invention relates to a method and system for cooling a profiled plate, in particular for longitudinally profiled metal plates.

In order to improve material properties, such as strength, toughness and weldability, metal plates may undergo a cooling cycle during production. Conventionally, metal plates have been formed with a substantially uniform thickness along their length and control of cooling rates and stop temperatures has been based on this assumption. Cooling machines such as the Siemens MULPIC® are only designed to cool plates which nominally have a constant thickness along the length. The control system for the cooling machine calculates setup data, such as plate speed, cooling flows etc., based on the thickness, entry temperature, target exit temperature and target cooling rate. Small variations in thickness or temperature from the values on which the cooling cycle has been derived, can be coped with by measuring the entry temperature and thickness and comparing them with a setup temperature and thickness used to derive the cooling cycle.

In recent years it has become common for mills to produce some plates which are 'longitudinally profiled' i.e. they have deliberately varying thickness along the length. However, these longitudinally profiled plates could not be properly cooled to enhance their mechanical properties because either the thin parts would be overcooled, or the thick parts would be under-cooled, or both, which would result in undesirable changes in the mechanical properties along the length.

In accordance with a first aspect of the present invention a method of cooling a longitudinally profiled plate comprises calculating setup flow at a plurality of points along the length of the profiled plate; monitoring the position of the plate relative to flows in a cooling machine and adjusting the flows according to the calculated setup flows at the plurality of points.

The plate is longitudinally profiled, so that deliberate changes in thickness are incorporated along the length of the plate. By monitoring and adjusting the flows, suitable cooling is applied for the different thicknesses along the length of the plate.

Preferably, the calculated setup flows at the plurality of points are interpolated to generate a reference profile along at least part of the length of the plate.

Using data calculated at a number of discrete points along the length, a reference profile may be generated by interpolation to cover all, or part of, the length of the plate. The flows may then be adjusted as necessary to reflect the change in thickness and its associated temperature along the length of the plate.

Preferably, the method further comprises calculating setup entry temperature at each of the plurality of points.

Preferably, the method further comprises calculating setup entry thickness at each of the plurality of points.

Preferably, the points comprise at least the points of maximum thickness and minimum thickness of the plate.

Preferably, the method further comprises determining entry temperature for each of the points.

Typically, the temperature is determined by measuring the surface temperature of the plate at a point upstream of the cooling machine, using a pyrometer and a controller calculates expected entry temperature at the cooling machine therefrom.

In one embodiment, the calculated thickness at the plurality of points, or of the reference profile is assumed to be accurate, so only entry temperature is determined, but preferably, the method further comprises determining entry thickness for each of the points.

This allows the cooling flows to be adapted to compensate for any deviation of the thickness from the thickness assumed in calculating the setup flows, or may even be used to generate the setup values directly, if determined sufficiently far ahead of entry of the plate into the cooling machine.

Preferably, the method further comprises calculating a required change in flow for a difference in determined entry temperature with respect to setup entry temperature at a point on the plate.

Preferably, the method further comprises calculating a required change in flow for a difference in determined thickness with respect to setup thickness at a point on the plate.

Preferably, the calculated required change in flow is determined at the plurality of points and interpolated to generate a reference profile along at least part of the length of the plate.

Preferably, the method further comprises adjusting the flows according to reference profile of the calculated required change.

Preferably, the flows are controlled by adjusting flow headers in the cooling machine, either individually or in groups according to the position of the plate in the cooling machine.

In accordance with a second aspect of the present invention, a plate cooling system comprises a controller, a plurality of cooling headers; and a conveyor; wherein the cooling system is adapted to cool a profiled plate; wherein the controller calculates setup flow values at a plurality of points along the plate; and wherein the controller adjusts flow from the cooling headers according to the calculated setup flows at the plurality of points.

Preferably, the setup flows are calculated for at least the points of maximum and minimum thickness of the plate.

Preferably, the cooling headers are grouped and the controller modifies operation of each group according to the position of the plate in the cooling machine.

Preferably, the system further comprises an entry temperature sensor; wherein the temperature sensor determines entry temperature; and wherein the controller adjusts flow from the cooling headers according to the difference between calculated setup temperature and determined entry temperature

Preferably, the system further comprises a thickness sensor; wherein the thickness at the thickness sensor is measured and the controller determines entry thickness from the measured thickness; and wherein the controller adjusts flow from the cooling headers according to the determined entry thickness.

Preferably, the system further comprising a thickness sensor; wherein the thickness at the thickness sensor is measured and the controller determines entry thickness from the measured thickness; and wherein the controller adjusts flow from the cooling headers according to the difference between calculated thickness and determined thickness, at each point along the plate.

Preferably, the calculated setup flows at the plurality of points are interpolated to generate a reference profile along at least part of the length of the plate and the controller adjusts flow from the cooling headers according to the reference profile.

An example of a method of cooling a profiled plate and a system according to the present invention will now be described with reference to the accompanying drawings in which:

Figure 1 shows an example of a conventional plate cooling system;

Figure 2 illustrates how the conventional plate cooling system carries out setup calculation to produce a single nominal flow setting, plus derivatives;

Figure 3 illustrates use of feedforward of entry temperature variation into flows in the conventional plate cooling system;

Figure 4 is a table showing typical range of longitudinally profiled plates;

Figure 5 shows an example of a plate cooling system according to the present invention, with cooling headers flow controlled individually, or in groups;

Figure 6 illustrates calculation of set-up flows for a given target thickness and predicted entry temperature using the method of the present invention;

Figure 7 illustrates calculation of change in flow required for a given change in target thickness, or change in flow required for a given change in entry temperature, using the method of the present invention;

Figure 8 is a block diagram illustrating flow references based on multi-point calculation of nominal setup flows and multi-point calculation of derivative terms

Fig.1 illustrates a rolled plate 1 as it passes through a cooling machine 2. The plate has a substantially constant thickness and is moved through the cooling machine on conveyor rollers 3. Cooling headers 4a, 4b are mounted on either side of the conveyor, providing cooling from above and below the plate. The cooling headers may be individual 4a, or connected in groups 4b in different cooling zones 5a, 5b, 5c, 5d and controlled separately or in their groups. Before passing into the cooling machine, the surface temperature of the plate is measured at a pyrometer and a controller (not shown) modifies the cooling provided at one or more of the cooling zones in response.

Fig.2 is a flow diagram illustrating the steps involved in determining necessary information to control the cooling. In step 10, predicted or average thickness are determined, predicted or average entry temperature are determined, the grade of material or chemistry are determined, then a target exit temperature and target cooling rate are set. From this information, in step 11, a setup model calculates the flows and plate speed through the cooling machine, which are required in order to achieve the target exit temperature and target cooling rate. In step 12, the setup model then calculates what change in flow is required for a difference in entry temperature of the plate, or for a difference in entry thickness of the plate as compared with the temperature or thickness used to make the calculation of the setup values. Thus, the setup calculation produces a single nominal flow setting, plus two derivative values. The calculation is highly non-linear, so it typically uses finite difference through thickness model plus heat transfer model plus model of phase transformations etc.

It is also common for existing machines to use feed-forward control. This is illustrated in Fig.3. Based on the nominal setup the system calculates two derivatives as described above to determine how the flow needs to change in response to small differences between the setup entry temperature and the actual measured entry temperature. Using the measured entry temperature 14 obtained from a pyrometer 13, the system then makes small changes to the flow 16a, 16b, 16c, 16d, as the plate passes through the cooling machine 2 to compensate for the entry temperature variations and hence maintain a constant exit temperature. The same principle applies to small variations in entry thickness. The entry thickness can be measured before the plate enters the cooling machine and flow to each header or group is adjusted in sequence according to the tracked position of the plate. The system calculates a "dQ/dh" value i.e. how much the flow needs to change for a small change in thickness. Using the measured thickness the system can therefore compensate for small changes in thickness by adjusting the flow.

However, longitudinally profiled plates, such as the examples shown in Fig.4, where plate length typically may be from 10 metres up to 50 metres, are becoming more common and the method described above does not work properly for longitudinally profiled plates because the changes in incoming thickness and temperature are too large to be properly compensated by simple linear correction terms based on derivatives, d_flow / d_thickness and d_flow / d_entry_temp at a single nominal operating point.

The present invention addresses this problem as illustrated in the following figures. Fig.5 shows a cooling machine 2, cooling a profiled plate 21. The plate passes a pyrometer 13 to measure the surface temperature of the plate and a thickness sensor 17 to measure actual thickness of the plate. This data is fed into a controller 18 which uses the information to determine entry temperature and thickness. The thickness measurement gauge may be for example, an X-ray gauge or gamma-ray gauge, after the rolling mill (not shown), but upstream of the cooling machine 2. The measured thickness, h against length, l along the plate is stored and a tracking system may then determine the thickness of the plate at any given point when the plate 21 is in the cooling machine 2. This information is used by the controller 18 to adjust the cooling headers 4a, 4b as required, so that the appropriate cooling flows are applied to each part of the plate.

Cooling is applied to a sub-section of the plate, immediately after that section has entered the cooling zone, the thickness or temperature sensors keep providing measurements to the controller as the plate moves through the sensors and these measurements are compared by the controller with the calculated values for that point on the plate and the controller then adjusts the cooling flow accordingly, until the next comparison is triggered by the controller determining that the appropriate length of plate has passed through. The plate moves through the cooling machine in one continuous motion and the flow is already switched on before the plate enters. So at the very beginning only the head end is being cooled - the tail is still outside the machine. And at the end only the tail is being cooled - the head has already finished and exited from the machine. Depending on the length of the plate it might be that the whole plate is inside the cooling machine for part of the time - or if the plate is very long then there will always be some part of the plate outside the machine. Measurements from the thickness and temperature sensors at one location are stored as a function of the length along the plate by tracking the position of the plate as it passes the sensor, so values for each segment of the plate is stored.

With a combination of movement and cooling and measurement, requiring adjustment, the result of any calculation comparing measured entry temperature with calculated entry temperature, or comparing measured thickness, with calculated thickness, has to take account of the delay in providing a revised flow to get the cooling to be done at the correct flow for the part of the plate passing the cooling headers at that time, as the sensors are upstream of the cooling machine. So the tracking system has to delay the adjustments according to the actual position of each segment in the cooling machine. The flow control has a finite response time, typically of the order of 1 to 2 seconds, corrections are applied slightly earlier than needed to in order to give the flow control time to respond.

Fig.6a illustrates the simplest embodiment of the present invention, in which setup flows are calculated for two different points l_1, l_3 along the length of the profiled plate 21, in this case the points of minimum thickness 20 and maximum thickness 25. The predicted entry temperature 22, 23 at those points is obtained and then used to determine the setup flows 24a at those points. Optionally, interpolation may be applied to the setup calculations for each point to generate intermediate points for a setup flow graph 24b and the setup flows are assume to vary in accordance with the graph. The setup flows may be determined according to the target thickness, h or as a function of both thickness and predicted entry temperature, T. Fig.6b illustrates how the setup flows 28a and associated setup flow graph 28b can be improved by adding an intermediate point, l_2 for target thickness 26 and associated predicted entry temperature 27. Because the calculations are highly non-linear, more points give a more accurate result, so even better accuracy is obtained by calculating more points along the length, as shown in Fig.6c. In this case, it can be seen that points, l_4 and l_5 with the same thickness 30, 32 as points l_2 and l_1 , but further along the plate length can have slightly different setup flows 29a because the entry temperature 31, 33 is different and the effect on the interpolation shows this clearly in the setup flow graph 29b.

As explained above, in the present invention the setup system pre-calculates setup flows for a number of points l_1 to l_5 along the length of the plate. A further feature of the invention is that the system may also calculate derivatives of delta flow / delta entry temperature and delta flow / delta thickness for each of these points, l_1 to l_5.

In the examples shown in Figs.7a to 7c, during cooling, the position of the plate 21 in the cooling machine 2 is accurately tracked and the flows in each section of the cooling machine are adjusted according to an interpolation between the multiple setup values. The flows in different headers or groups of headers within the cooling machine can be adjusted separately according to which part of the plate is under each header, or group of headers. As shown in Fig.7a, at each setup point the model may also calculate the derivatives (d_flow / d_entry _temp) 38, (d_flow / d_entry_thickness) 39 and the derivative values may also be interpolated according to the thickness and position along the length. In operation, the controller can then adjust the flows according to the difference 34, 36, 38 between the setup entry temperature and actual entry temperature and the difference 35, 37, 39 between the setup entry thickness and the actual entry thickness at each point along the plate. In this way the cooling machine is able to accurately control the exit temperature of the plate 21 for longitudinally profiled plates. It can be seen from Fig.7c that points with the same thickness, but further along the plate length, can have slightly different derivatives because the entry temperature is different.

Fig.8 illustrates how all of the elements discussed above may be combined to generate a flow reference 40 based on multi-point calculation of nominal setup flows and multi-point calculation of derivative terms. The controller tracks a current plate segment. Measured thickness 41 for that segment and measured entry temperature 42 may be used to correct the target thickness 43 and predicted entry temperature 44, generating a thickness error 45 and entry temperature error 46. The thickness error 45 is combined 47 with the derivative 39 and adjusts 48 the setup flows 29b. The entry temperature error 46 is combined 49 with the derivative 38 and also adjusts 50 the setup flows and the flow reference 40 is generated. Flow references for other headers / groups of headers may be calculated similarly.

In summary, the present invention makes use of multiple setup calculations for different points along the length of the plate to accurately cool the plate as it passes through the cooling machine. This may be further improved by means of interpolation between the setup flows according to the actual position of the plate in the cooling machine, the use of multiple derivative calculations for different points along the length of the plate and interpolation between these derivative figures according to the actual position of the plate in the cooling machine and the use of the interpolated derivative values together with the differences between the measurements of the entry temperature and the predicted entry temperature and the differences between the measurements of the entry thickness and the target of setup entry thickness to adjust the reference flows according to the actual position of the plate in the cooling machine.

Various modifications of the invention described are possible. For example, in one embodiment of the invention, the thickness is not directly measured at all, but is assumed to match the target thickness profile 43, so only entry temperature 42 needs to be measured and used to modify 50 the setup flows. Setup calculations based on knowledge of either the target or the measured thickness profile and at least a calculated entry temperature for each point allow setup flows to be calculated for a plurality of points and the flow to be adjusted between these setup flows according to the position of the plate. Use of interpolation for the adjustment method is optional.

If the measured thickness is used to do the setup, which is feasible if the thickness is measured early enough to allow for processing before the plate reaches the cooling machine, then the derivative (delta flow / delta entry thickness) is not required. The controller knows the expected thickness profile of the plate, so it can calculate the anticipated thickness and entry temperature for each point along the length. Alternatively, where a thickness measurement gauge is provided after the rolling mill, around 50 metres upstream of the cooling machine, then assuming that the thickness does not change, except by a very small amount due to temperature changes, between the rolling mill and the cooling machine, this thickness measurement can be used directly. The measured thickness vs. length along the plate is stored and then the tracking system can determine the thickness of the plate at any given point in the cooling machine.

With a sufficiently fast processor, or with sufficient distance between the pyrometer and the cooling machine to allow time for the calculations to be carried out, then the measured temperature may be used to do the setup, rather than a predicted entry temperature and in this case the derivative (delta flow / delta entry temperature) is not required. An entry temperature may be measured by the pyrometer upstream of the cooling machine, but this measures the actual surface temperature. Since the plate is cooling down all the time - even outside of the cooling machine - the 'actual' entry temperature at the cooling machine has to be determined by calculation based on the measured surface temperature at the pyrometer and a model of the temperature distribution within the plate (the centre is hotter than the surface) and the cooling due to radiation, convection etc.

In practice, the calculations take some time and therefore it may be necessary to use the target entry thickness and / or a preliminary entry temperature calculation for the setup calculations. In this case the derivative terms can be calculated during the initial setup calculations and then used to correct for any errors between the setup values and the actual values of thickness and / or temperature.

CLAIMS

1. A method of cooling a longitudinally profiled plate, the method comprising calculating setup flow at a plurality of points along the length of the profiled plate; monitoring the position of the plate relative to flows in a cooling machine and adjusting the flows according to the calculated setup flows at the plurality of points.

2. A method according to claim 1, wherein the calculated setup flows at the plurality of points are interpolated to generate a reference profile along at least part of the length of the plate.

3. A method according to claim 1 or claim 2, wherein the method further comprises calculating setup entry temperature at each of the plurality of points.

4. A method according to any of claims 1 to 3, wherein the method further comprises calculating setup entry thickness at each of the plurality of points.

5. A method according to claim 4, wherein the points comprise at least the points of maximum thickness and minimum thickness of the plate.

6. A method according to any preceding claim, further comprising determining entry temperature for each of the points.

7. A method according to any preceding claim, further comprising determining entry thickness for each of the points.

8. A method according to claim 6, wherein the method further comprises calculating a required change in flow for a difference in determined entry temperature with respect to setup entry temperature at a point on the plate.

9. A method according to claim 7, wherein the method further comprises calculating a required change in flow for a difference in determined thickness with respect to setup thickness at a point on the plate.

10. A method according to claim 8 or claim 9, wherein the calculated required change in flow is determined at the plurality of points and interpolated to generate a reference profile along at least part of the length of the plate.

11. A method according to claim 10, wherein the method further comprises adjusting the flows according to reference profile of the calculated required change.

12. A method according to any preceding claim, wherein the flows are controlled by adjusting flow headers in the cooling machine, either individually or in groups according to the position of the plate in the cooling machine.

13. A plate cooling system, the system comprising a controller, a plurality of cooling headers; and a conveyor; wherein the cooling system is adapted to cool a profiled plate; wherein the controller calculates setup flow values at a plurality of points along the plate; and wherein the controller adjusts flow from the cooling headers according to the calculated setup flows at the plurality of points.

14. A system according to claim 8 wherein the setup flows are calculated for at least the points of maximum and minimum thickness of the plate.

15. A system according to claim 13 or claim 14, wherein the cooling headers are grouped and the controller modifies operation of each group according to the position of the plate in the cooling machine.

16. A system according to claim 8 or claim 9, the system further comprising an entry temperature sensor; wherein the temperature sensor determines entry temperature; and wherein the controller adjusts flow from the cooling headers according to the difference between calculated setup temperature and determined entry temperature

17. A system according to any of claims 13 to 16, further comprising a thickness sensor; wherein the thickness at the thickness sensor is measured and the controller

determines entry thickness from the measured thickness; and wherein the controller adjusts flow from the cooling headers according to the determined entry thickness.

18. A system according to any of claims 13 to 16, further comprising a thickness sensor; wherein the thickness at the thickness sensor is measured and the controller determines entry thickness from the measured thickness; and wherein the controller adjusts flow from the cooling headers according to the difference between calculated thickness and determined thickness, at each point along the plate.

19. A system according to any of claims 13 to 18, the calculated setup flows at the plurality of points are interpolated to generate a reference profile along at least part of the length of the plate and the controller adjusts flow from the cooling headers according to the reference profile.

Application No:	GB1017955.4	**Examiner:**	Colin Whitbread
Claims searched:	1-12, 14, 15 when dependent upon claim 14, 16 and 17-19 when dependent upon claims 14 or 16	**Date of search:**	21 February 2011

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-7 and 12	JP 62130222 A (NIPPON STEEL) See whole document.
X	1-7 and 12	JP 62142017 A (NIPPON STEEL) See whole document.
X	1, 3-6 and 12	JP 10249430 A (SUMITOMO METAL) See whole document.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

B21B; C21D; F28C

The following online and other databases have been used in the preparation of this search report

International Classification:

Subclass	Subgroup	Valid From
B21B	0045/02	01/01/2006
B21B	0037/74	01/01/2006

Application No: GB1017955.4 **Examiner:** Colin Whitbread

Claims searched: 13, 15 and 17-19 **Date of search:** 1 July 2011

Patents Act 1977
Further Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	13, 15, 17 and 19	JP 56114521 A (MITSUBISHI ELECTRIC CORP AND NIPPON STEEL CORP) 09.09.81 (See EPODOC abstract and figure 1 especially).
X	13, 15, 17 and 19	JP 62130222 A (NIPPON STEEL CORP) 12.06.87 (See EPODOC abstract and figure 1 especially).
X	13, 15, 17 and 19	JP 62142017 A (NIPPON STEEL CORP) 25.06.87 (See EPODOC abstract, WPI Abstract Accession No. 1987-216786 [31], and figure 1 especially).
X	13 and 15	JP 10249430 A (SUMITOMO METAL IND) 22.09.98 (See EPODOC abstract, WPI Abstract Accession No. 1998-561498 [48], and figure 3 especially).
A	-	JP 62166014 A (NIPPON STEEL CORP) 22.07.87 (See EPODOC abstract and figure 2 especially).

Categories:

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