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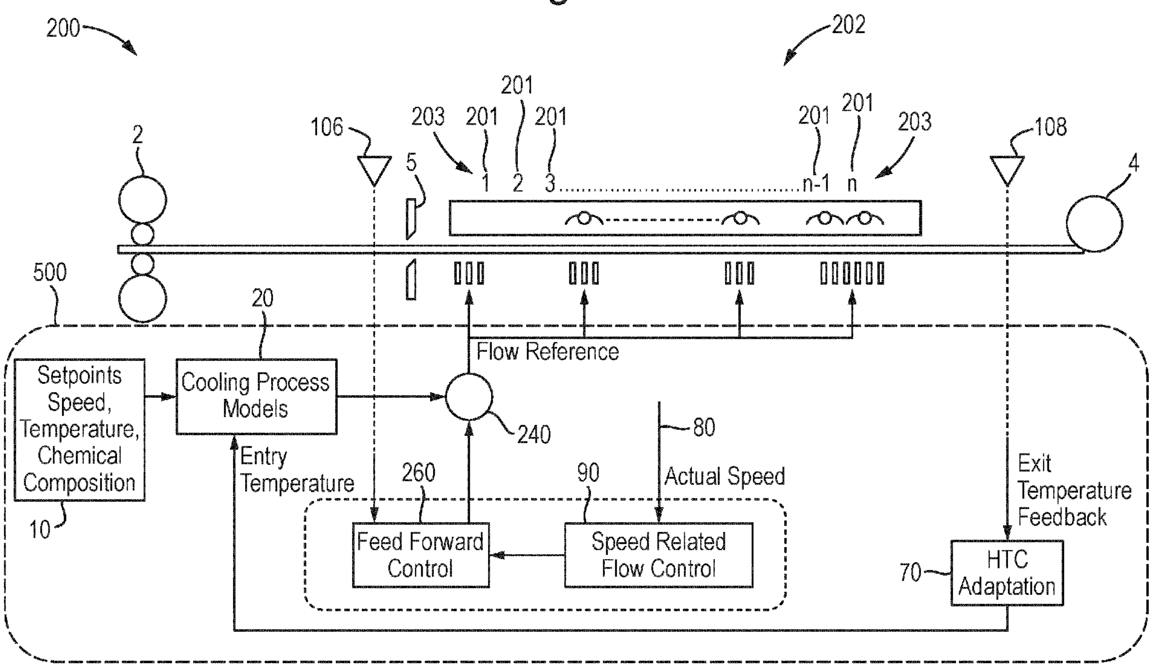
(54) **COOLING SYSTEM FOR A ROLLING MILL**

(57) A method of cooling a material in a cooling system of a rolling mill using a cooling fluid, the method comprising the steps of: conveying, by a transportation mechanism, a length of material into the cooling system of a rolling mill; measuring, by a sensor, a speed of the length of material; comparing, by a control system, the measured speed to a setpoint speed, wherein the setpoint speed has a corresponding first flow rate of the cooling fluid; calculating, by the control system, a second flow rate of the cooling fluid based on the comparison, wherein the second flow rate is different from the first flow rate; and applying, to the material in the cooling system, the cooling fluid at the second flow rate.

Fig. 2



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Description

Field of Invention

[0001] The present invention relates to a cooling system for a rolling mill, including hot and cold rolling mills.

Background

[0002] The production of a material coil or plate typically involves the use of a single stand or multi-stand rolling mill. The final rolled product (i.e. a coil or plate) often needs to be passed to a cooling section to reduce the product temperature down to the required target temperature. This is generally done by the application of water. The speed and accuracy at which the product temperature is reduced will influence the final mechanical properties of the product, namely the yield strength, tensile strength and elongation.

[0003] Due to the length of the material, the product may be present in the rolling mill and the cooling section at the same time. If the product is to be coiled there is also the possibility for the material to also be present in the coiler at the same time as being in the rolling mill and/or cooling section. The speed that the material travels through the cooling section is fixed by the rolling mill or by the coiler. During the cooling operation, the calculated water flow to be used by the cooling section will be dependent upon the operating speed of the rolling mill and coiler. For example, a greater speed typically requires a greater water flow, and vice versa. The operating speed is pre-defined and known as the setpoint speed. This is supplied or set prior to the material passing through the cooling section so as to calculate the required flow of water, known as the flow reference.

[0004] In practice the actual speed of the product may deviate from the setpoint speed for several reasons. Some of these reasons are as follows:

a) The product may solely be present in the rolling mill with a fixed speed which deviates from the initial setpoint speed.
b) The product may be present in both the rolling mill and the coiler with a fixed speed which deviates from the initial setpoint speed.
c) When the product leaves the rolling mill and is solely in the coiler, the loss of tension between the rolling mill and the coiler will result in a sudden speed change.
d) The product length may be such that it is neither in the rolling mill nor the coiler, and so the product speed is then dependent on the speed of the roller tables.
e) If the product is required to be divided into smaller sections, for example using a flying crop shear (FCS), the product may be divided again resulting in a speed deviation as the tension is lost between the rolling mill, the product, and the coiler.

[0005] Any deviation from the speed setpoint will result in a temperature error following cooling, ultimately resulting in the product being out of temperature tolerance and therefore with varying mechanical properties across the length. In particular, if the speed is higher than the original speed setpoint the product will be hotter due to the reduced contact time with the cooling water. Conversely, if the speed is slower than the original speed setpoint the product will be colder due to the increased contact time with the cooling water.

[0006] It would be desirable to provide a method of cooling a rolled product in which the impact of the temperature variation caused by changes to the operating speed is reduced.

Summary

[0007] According to a first aspect there is provided a method of cooling a material in a cooling system of a rolling mill using a cooling fluid, the method comprising the steps of: conveying, by a transportation mechanism, a length of material into the cooling system of a rolling mill; measuring, by a sensor, a speed of the length of material; comparing, by a control system, the measured speed to a setpoint speed, wherein the setpoint speed has a corresponding first flow rate of the cooling fluid; calculating, by the control system, a second flow rate of the cooling fluid based on the comparison, wherein the second flow rate is different from the first flow rate; and applying, to the material in the cooling system, the cooling fluid at the second flow rate.

[0008] The setpoint speed may be the speed at which the material is programmed to travel through the cooling system, in the absence of any factors which may interfere with this set speed. In this case, the cooling system may apply a first flow rate of the cooling fluid to the material.

[0009] The result of the comparison may be a speed difference, which can be thought of as a change in speed. The second flow rate, calculated based on the comparison, may be thought of as an adjustment to the first flow rate which takes into account the speed difference. Thus, the control system may be considered to adjust the first flow rate to the second flow rate.

[0010] The cooling method therefore calculates a difference in speed of the material, between a setpoint speed which is the programmed operating speed of the rolling mill and the actual speed at which the material moves through the rolling mill. This difference in speed results in a difference in temperature from the setpoint temperature after cooling, due to the material not being suitably cooled. For example, if the measured speed is higher than the setpoint speed, the material will be hotter due to the reduced contact time with the cooling system. Alternatively, if the measured speed is lower than the setpoint speed, the material will be colder due to the increased contact time with the cooling system. By accounting for the difference in speed, the amount of cooling liquid applied by the cooling system can be suitably adjusted so that the contact time of the material with the cooling system is sufficient for the speed at which the material is travelling in order to cool the material to the desired temperature.

[0011] Preferably the second flow rate is different to the first flow rate. In some cases the second flow rate may be greater than the first flow rate. In other cases the second flow rate may be smaller than the first flow rate. The first flow rate can therefore be adjusted such that the cooling system applies more or less cooling liquid depending on whether the measured speed is greater or less than the programmed operating speed.

[0012] The second flow rate may comprise an adjustment value. The adjustment value may be the result of the comparison between the measured speed and the setpoint speed. In some cases, calculating the second flow rate comprises adding the adjustment value to the first flow rate to give the second flow rate. Preferably, the adjustment value may be a value which minimises a difference between a final temperature of the length of material after the length of material has exited the cooling system and a setpoint temperature.

[0013] The method may further comprise measuring, by a first temperature sensor, an initial temperature of the length of material before the length of material has entered the cooling system; comparing the measured temperature to a setpoint temperature; calculating, by the control system, a third flow rate based on the comparison; and combining the third flow rate with the second flow rate.

[0014] The result of the comparison between the measured temperature and the setpoint temperature may be a first temperature difference. The third flow rate, calculated based on the comparison, may be thought of as a flow rate adjustment which takes into account the temperature difference. Combining the third flow rate with the second flow rate may give a resultant flow rate.

[0015] The setpoint temperature may be the target final temperature of the material after cooling. The control system may therefore calculate how much cooling liquid needs to be applied in order to cool the material from its initial temperature to reach the setpoint temperature. Based on this calculation, the control system may calculate a new flow rate corresponding to an amount by which the flow rate of the cooling liquid needs to be adjusted in order to reach the target level of cooling. The cooling system therefore applies more or less cooling liquid, in accordance with the new flow rate, depending on the difference between the measured initial temperature and the setpoint temperature.

[0016] Preferably, the above method step is carried out before applying the cooling fluid to the material in accordance with the second flow rate. This allows both the flow rate based on the speed difference and the flow rate based on the temperature difference to be taken into account before the cooling system applies the cooling liquid to the material.

[0017] Calculating the first flow rate may comprise receiving, by the control system, a set of initial conditions relating to the material; modelling, by the control system and using the set of initial conditions, a cooling process of the material; calculating, by the control system, the first flow rate based on the modelled cooling process.

[0018] The initial state of the material may affect the rate at which the material cools, and therefore may affect that amount of liquid that needs to be applied to the material by the cooling system. The initial state of the material may be defined by a set of initial conditions. The initial conditions may include, but are not limited to, the chemical composition of the material and the physical dimensions of the material. The modelling may be carried out by a computer program model configured to run on a computing device, as part of the control system. The model may use the initial conditions as inputs to the model in order to model the cooling process of a particular material having a particular initial state. This may be used to calculate a flow rate of cooling liquid that needs to be applied to the material in order to cool the material to the setpoint temperature. Thus, the cooling method can be tailored and adapted to be suitable for a large variety of materials having a large range of initial states.

[0019] Preferably, the set of initial conditions comprises the setpoint temperature. The setpoint temperature may be considered as an input to the model. This may help the modelling process more accurately calculate how much liquid needs to be applied to the material in order to reach the target temperature, and thus calculate a suitable flow rate.

[0020] Preferably the first flow rate is combined with the second flow rate. This allows the cooling method to take into account the difference in speed, the difference in temperature, and the initial state of the material when the cooling system applies the cooling liquid to the material. Combining flow rates, for example but not limited to combining the first and second flow rates, may comprise adding together the first and second flow rates.

[0021] The modelling may further comprise measuring, by a second temperature sensor, a final temperature of the length of material after the length of material has exited the cooling system; comparing, by the control system, the measured final temperature to a predicted final temperature; calculating, by the control system, a difference between the measured final temperature and the predicted final temperature, where the predicted final temperature is the final temperature predicted by the modelling process. The method may further comprise: modelling, by the control system, an enhanced cooling process of the material using the set of initial conditions and the difference; calculating, by the control system, a fourth flow adjustment based on the modelled enhanced cooling process; combining the fourth flow rate with the second flow rate.

[0022] Measuring the temperature after the material has exited the cooling system indicates whether the material has been suitably cooled by the cooling system such that the setpoint temperature has been substantially reached. The result of the comparison between the measured temperature and the predicted final temperature may be a second temperature difference. If the second temperature difference indicates that the final measured temperature is different to the setpoint temperature by more than an acceptable level of tolerance, the amount of cooling liquid being applied to the material can be adjusted.

[0023] In this case, the second temperature difference may be an additional input to the model. The modelling process can be considered to take into account the performance of the cooling system on a previous length of material and use this information as an input to the subsequent modelling process. That is, the model is informed about the actual level of cooling provided by the cooling system, and this information is used to more accurately model the cooling process of the material. In particular, the modelling process can calculate a more accurate flow rate of the cooling liquid that is needed to be applied by the cooling system to a subsequent length of material, based on the amount of cooling applied to a previous length of material. The modelling process may therefore more accurately calculate how much liquid needs to be applied to the material in order to cool the material to the setpoint temperature. Thus, the cooling method can be updated to take into account real-time performance of the cooling system.

[0024] Preferably the fourth flow rate is combined with the third flow rate. More preferably, the fourth flow rate is combined with the third flow rate and the second flow rate. This allows the cooling method to take into account the speed difference, the initial temperature difference, the initial state of the material, and the final temperature difference when the cooling system applies the cooling liquid to the material.

[0025] In some examples, the measuring, by a sensor, a speed of the length of material comprises measuring the speed of the length of material within the cooling system. In other examples, the measuring, by a sensor, a speed of the length of material comprises measuring the speed of the length of material before and or after the cooling system. Generally, as the speed of the material will be the same any point along the cooling section, including before, during, and after cooling, the speed can be measured at any suitable first location as this will also correspond to the material speed at another suitable location for example a second and/or subsequent location.

[0026] The second flow rate may comprise a plurality of flow references. The cooling system may comprise a plurality of spray headers. The step of applying the cooling liquid at the second flow rate may comprise: applying, to the material by each of the plurality of spray headers, the cooling liquid according to eh corresponding flow reference of said spray header.

[0027] Thus, each spray header may be associated with a different flow reference, and so each spray header may be configured to apply a different amount of cooling liquid to the material. This may allow the cooling system to fine-tune the cooling of the material by controlling the amount of liquid applied to the material along the length of the material.

[0028] According to another aspect there may be provided a system configured to cool a material in a rolling mill comprising: a transportation mechanism configured to convey a length of material into a cooling apparatus of a rolling mill; a sensor configured to measure a speed of the length of material; a control system configured to: compare the measured speed to a setpoint speed, wherein the setpoint speed has a corresponding first flow rate of the cooling fluid; calculate a second flow rate of the cooling fluid based on the comparison, wherein the second flow rate is different from the first flow rate; and applying, to the material in the cooling system, the cooling fluid at the second flow rate.

[0029] Preferably, the apparatus comprises a first temperature sensor configured to measure an initial temperature of a length of material before the length of material has been fed into a cooling system. The control system may be further configured to: compare the initial temperature to a setpoint temperature; calculate a third flow rate based on the comparison; and combine the third flow rate with the second flow rate.

[0030] In some examples, the control system is further configured to: receive a set of initial conditions relating to the material; model, using the set of initial conditions, a cooling process of the material; and calculate the first flow rate based on the modelled cooling process.

[0031] The apparatus may further comprise a second temperature sensor configured to measure a final temperature of a length of material after the length of material has exited a cooling system. The control system may be further configured to: compare the final temperature to a predicted final temperature; calculate a difference between the measured final temperature and the predicted final temperature; model an enhanced cooling process of the material using the set of initial conditions and the difference; calculate a fourth flow rate based on the modelled enhanced cooling process; and combine the fourth flow rate with the second flow rate.

[0032] In some examples, the sensor may be located within the cooling system.

[0033] Preferably, the cooling system comprises a plurality of spray headers. Each spray header may be configured to apply a flow rate of cooling liquid to the length of material. Each flow header may be configured to apply a flow of liquid to the length of material at the second flow rate.

Brief Description of Drawings

[0034]

Figure 1 is a schematic diagram of a cooling process;

Figure 2 is a schematic diagram of another cooling process; and

Figure 3 illustrates steps of a cooling method.

Specific Description

[0035] The present disclosure relates to a method of cooling a material by a cooling system of a rolling mill using a cooling fluid, and a corresponding system configured to carry out the cooling.

[0036] An example cooling system 100 is shown generally in Figure 1. The cooling system 100 cools a sheet of material 6 that has been rolled in a rolling mill 2 before the material is turned into a final product. In some cases, in order to produce the final product, the sheet of material 6 is rolled up into a coil using a coiler 4, for example an up-coiler. In other cases, the sheet of material 6 is divided, for example using a flying crop shear 5, into a number of smaller sections which may be referred to as plates. The sheet of material 6 is passed from the rolling mill 2, through the cooling system 100, and optionally to a coiler 4 using a transportation mechanism (not illustrated). Typically the transportation mechanism takes the form of a series of rollers, on which the sheet of material 6 is placed, so that rotational movement of the rollers causes advancement of the material 6 through the various components of the rolling mill and cooling system 100 (from left to right in Figure 1). The material 6 is typically a metallic product such as elemental metal or, more commonly, an alloy. In particular the metallic product may be a ferrous alloy such as steel, or an aluminium alloy.

[0037] The cooling system 100 comprises a cooling apparatus 102 configured to cool the material using a cooling fluid and a control system 300, in communication with the cooling apparatus 102, configured to control the cooling apparatus 102. In particular, the sheet of material 6 is cooled by the cooling apparatus 102 which is arranged to spray a cooling liquid onto the material 6 as it passes through the cooling system 100 via the transportation mechanism. The particular form of cooling liquid may vary depending on the type of material being cooled. For example, if the material 6 is steel or steel-based the cooling liquid is water. As another example, if the material 6 is aluminium or aluminium based- the cooling liquid is an oil-water mixture. In the example shown in Figure 1 the cooling apparatus 102 comprises a plurality of nozzles 101. The nozzles 101 spray cooling liquid through the nozzles onto the external surface of the material 6, in order to cool the material 6 using the cooling liquid. The plurality of nozzles can be split into two groups. A first groups of nozzles are located at the beginning of the cooling apparatus 102 and may be referred to as spray headers 103. A second group of nozzles are located at the end of the cooling apparatus 102 and may be referred to as trim headers 104.

[0038] The final temperature of the sheet of material 6 is controlled through control of the amount of cooling liquid applied to the material 6 by the cooling apparatus 102 through the various nozzles 101.

[0039] More particularly, the final temperature of the material 6 is controlled using a combination of the initial temperature of the sheet of material 6 as it enters the cooling system 100 and the final temperature of the sheet of material 6 as it exits the cooling system 100. This may be referred to as feedforward control (using the initial temperature) and feedback control (using the final temperature). The trim headers 104 are configured to apply a fixed flow of cooling liquid to the material 6 controlled as part of a feedback control loop. By fixed flow, each trim header 104 can either be in the on or off state, and when in the on state the flow of that trim header 104 is set at a fixed level. In other words, each trim header can apply either no cooling liquid or cooling liquid at a fixed flow rate. The spray headers 103 are configured to apply a variable flow of cooling liquid to the material 6, controlled as part of a feedforward control loop. By variable flow each spray header 103 is generally in the on state and the flow of that spray header 103 can be at any flow rate from zero up to a maximum flow rate. In other words, each spray header 103 can apply no cooling liquid or cooling liquid at any flow rate up to a maximum flow rate. The feedforward and feedback control processes will be described in further detail later.

[0040] In the absence of any form of control loop (either feedforward or feedback control), the cooling system will apply cooling fluid to the material at a first flow rate. The effect of including a control loop is to adjust the first flow rate to a new flow rate, which is generally different from the first flow rate, to be applied by the nozzles 101 to the material 6. The new flow rate comprises the first flow rate and an adjustment to be made to the first flow rate, the adjustment being referred to as a flow trim. The resultant new flow rate is referred to as the flow reference.

[0041] There are a number of factors which affect the amount of cooling liquid that needs to be applied to the material 6 in order to reach the final desired temperature of the material (known as the setpoint temperature) including various properties of the material 6 (for example, but not limited to, the chemical composition and the physical dimensions of the material 6) and the speed at which the material 6 enters and passes through the cooling system 100. The first flow rate is calculated taking into account these factors.

[0042] These factors form part of a set of initial conditions 10 which are input into a cooling model 20 within the control system 300 to calculate the amount of cooling liquid to be applied by the cooling apparatus 102 to the material 6, defined by the first flow rate. In particular, the cooling model 20 receives the set of initial conditions relating to the material and then the cooling model 20 models, based on the initial conditions, the physical cooling processes in order to calculate the flow rate of cooling liquid needed to be applied by the cooling apparatus 102 from the nozzles 101. This calculated flow rate, which has been calculated in the absence of any control loops, is the first flow rate. The first flow rate is passed from the cooling model 20 to a flow reference controller 40 within the control system 300.

[0043] In order to verify whether the amount of cooling liquid applied to the material 6 is suitable such that the final temperature of the material after it exits the cooling system 100 is substantially the same as the setpoint temperature, within industry accepted tolerance levels of +/- 20 degrees Celsius, the temperature of the material 6 after it has exited the cooling system 100 is measured by a temperature sensor 108, in the form of a pyrometer and located between the cooling system 100 and the coiler 4. This temperature measurement may be referred to as the exit temperature.

[0044] The exit temperature is fed into a feedback controller 50, forming part of the control system 300, which compares the exit temperature to the setpoint temperature. If the exit temperature is different to the setpoint temperature, by more than an acceptable level of tolerance, the cooling apparatus 102 is applying an unsuitable amount of cooling liquid to the material and so the flow rate of cooling liquid from the nozzles 101 needs to be adjusted in some way. Any resulting temperature difference is used to adjust control of the trim headers 104, as part of the feedback control loop. For example, if the exit temperature is too cold compared to the setpoint temperature, less cooling liquid needs to be applied to the material 6, and vice versa. The temperature difference is used to calculate an adjustment which needs to be made to the first flow rate. This adjustment may be referred to as a first temperature-based adjustment and is an example of a type of flow trim. Other types of flow trim are also possible, as will be discussed later.

[0045] The first temperature-based adjustment is sent to the flow reference controller 40 where it is combined with the first flow rate from the physical model 20 to give a resulting flow reference for the trim headers 104. The flow reference controller 40 controls the flow of cooling liquid from the trim headers 104 in accordance with the flow reference, where each trim header 104 is able to apply the same flow reference (i.e. the same amount) of cooling liquid to the material 6. That is, the flow rate of all the trim headers 104 in the plurality of trim headers 104 is the same across the plurality of trim headers 104. In order to adjust the flow rate of cooling liquid applied by the trim headers 104, the trim headers 104 can be switched on and off. In this case, each trim header 104 can be switched on and off independently of the other trim headers 104 in the plurality of trim headers so that any number of trim headers 104 can be on. Thus, less cooling liquid can be applied by turning some of the trim headers 104 off and more cooling liquid can be applied by turning some of the trim headers 104 on. All trim headers 104 that are on apply cooling liquid at the same flow rate and so the amount of cooling is dependent on the number of trim headers 104 that are switched on at any given time.

[0046] The accuracy with which the physical model 20 calculates the flow reference is improved and maintained by a Heat Transfer Coefficient (HTC) Adaption 70 process. This process 70 uses feedback in the form of the exit temperature when the material leaves the cooling system 100. The HTC Adaption process 70 calculates the difference between the measured exit temperature and the exit temperature predicted by the physical model 20, based on the inputs 10. This difference is fed back into the physical cooling model 10 so that the difference can be accounted for during subsequent modelling and calculations. Generally, this process can be thought of as modelling an enhanced cooling process of the material using both the set of initial conditions 10 and the calculated difference between the measured exit temperature and the predicted exit temperature. The calculated amount of cooling liquid to be applied by cooling apparatus 102 based on the enhanced physical model can be referred to as a fourth flow rate. This fourth flow rate is passed from the cooling model 20 to the flow reference controller 40.

[0047] The amount by which the material 6 needs to be cooled will also depend on the measured temperature of the material just before it enters the cooling system 100 compared to the setpoint temperature. A greater difference between the two temperatures will require more cooling and vice versa.

[0048] Another temperature sensor 106, in the form of a pyrometer and positioned between the cooling system 100 and the rolling mill 2, measures the temperature of the material just before it enters the cooling system 100. This temperature sensor 106 may be considered a first temperature sensor and the previously described temperature sensor 108 may be considered a second temperature sensor.

[0049] The temperature measurement from the first temperature sensor 106, which may be referred to as the initial temperature or entry temperature, is input into a feedforward control 60 which is part of the control system 300. The feedforward control 60 compares the measured initial temperature to the setpoint temperature. Any resulting temperature difference is used to adjust control of the spray headers 103, as part of the feedforward control loop. The temperature difference is used to calculate an adjustment which needs to be made to the first flow rate. This adjustment may be referred to as a second temperature-based adjustment and is another example of a type of flow trim.

[0050] The second temperature-based adjustment is sent to the flow reference controller 40 where it is combined with the flow rate from the physical model 20 to give a resulting flow reference for the spray headers 103. As such, generally the control system can be considered as calculating a third flow rate of the cooling liquid based on the result of the temperature comparison. Thus the second temperature based adjustment can be thought of as the third flow rate. The flow reference controller 40 controls the flow of cooling liquid from the spray headers 103 in accordance with this flow reference, where each spray header 103 can apply a different amount of cooling liquid to the material 6. That is, the flow rate of the spray headers 103 in the plurality of spray headers 103 can be different across the plurality of spray headers 103.

[0051] In general, the flow reference sent from the flow reference controller 40 and applied by the spray headers 103 varies because the second temperature-based adjustment is not always the same, over a period of time. For example, at a first time period there may be a large difference between the setpoint temperature and the initial measured temperature, resulting in a large second temperature-based adjustment. However, at another time period such as a second time period there may be a small difference between the setpoint temperature and the initial measured temperature, resulting in a small second temperature-based adjustment. By configuring the spray headers 103 to be able to apply a variable flow rate to the material 6, the different flow references due to different temperature differences can be taken into account.

[0052] In more detail, all the spray headers 103 are generally on (rather than off). The amount of cooling is therefore dependent on the flow rate of each spray header 103. The entry temperature is measured and averaged for a segment of material having a predefined length, for example a segment of 1 m in length. The amount of liquid needed to cool the segment of material is calculated to give the flow reference for the spray headers 103 associated with that particular segment, as described previously. This calculation is repeated for each subsequent segment. The position of each segment through the cooling system 100 is tracked by the control system 300 so that the position of each segment of material relative to each spray header 103 is known at any given time. As each segment of material passes under a spray header 103, the flow reference that was calculated for that segment of material is applied by that particular spray header 103. As the segment of material progresses through the cooling system 100, and passes under subsequent spray headers 103, the flow rate applied by the subsequent spray headers 103 will be the flow reference calculated for that segment. As different segments of material pass through the cooling system 100, different flow references will be applied by the spray headers 103 that have been calculated for these different segments. Thus, because the entry temperature measured for each segment is generally different, the calculated flow reference for each segment is different and so the flow rate applied by the spray headers 103 changes as the material 6 passes through the cooling system 100.

[0053] As a result of the distance between the end of the cooling system 100 and the position where the second temperature sensor 108 is located, and thus where the exit temperature is measured, there is an inherent delay in the temperature difference being compensated for by the control system 300. As a result, there will be a length of material which has a temperature that is out of acceptable tolerance levels, the length corresponding to the distance from the cooling system exit and the exit temperature measurement position.

[0054] As can be seen in Figure 1 two control loops are used to calculate the flow rate of cooling liquid. A first control loop comprises the second temperature sensor 108, the feedback controller 50, and the flow reference controller 40 of the control system 300, which measures the temperature after the material 6 exits the cooling system 100 and uses this to perform multiple calculations to adjust the flow rate for all the trim headers 104. This control loop may be considered a feedback temperature control loop. A second control loop comprises the first temperature sensor 106, the feedforward control 60, and the flow reference controller 40 of the control system 300, which measures the temperature before the material 6 enters the cooling system 100 and uses this to perform multiple calculations to adjust the flow rate for each spray header 103. This control loop may be considered a feedforward temperature control loop. Together, the feedback temperature control loop and the feedforward temperature control loop help ensure that the exit temperature of the material 6 is maintained at substantially the required setpoint temperature, within acceptable tolerance levels.

[0055] During these calculations the speed at which the material 6 travels through the cooling system 100 is assumed to match the setpoint speed supplied to the cooling model 20 as part of the initial conditions 10. However, as mentioned earlier, it is often the case that the actual speed at which the material 6 moves through the cooling system 100 is different to this setpoint speed. This difference in speed may be referred to as a speed error. As a result of the material 6 moving through the cooling system 100 at a different speed, the flow rate of cooling water being applied to the material 6 is not suitable for the actual speed at which the material 6 is moving, because the flow rate was calculated based on the setpoint speed, which affects the exit temperature of the material 6.

[0056] In order to improve the cooling of the material 6 to ensure the exit temperature is substantially the same as the setpoint temperature, the difference in the speed of the material 6 needs to be taken into account when calculating the flow rate. This process will be explained with reference to Figure 2.

[0057] Figure 2 shows another example cooling system 200 which is similar to Figure 1 and like reference numeral represent like features and processes which will not be explained again. A general method of using the apparatus of Figure 2 is illustrated in Figure 3. The cooling apparatus 202 of the cooling system 200 comprises a plurality of nozzles

201. However, in this case, the nozzles 201 are all spray headers 203; there are no trim headers 104. This is because this cooling system 200 does not include the feedback temperature control loop of Figure 1, which feeds back the exit temperature into the flow reference controller 40.

[0058] As before, and with reference to Figure 3, in order to cool a material using a cooling fluid, a transportation mechanism firstly conveys a length of material into the cooling system of a rolling mill S300. During the cooling process, when the material 6 passes through the cooling system 200, a sensor measures the speed of the length of material S302. In particular, the actual speed at which the material 6 moves through the cooling system 200 is repeatedly measured using at least one speed sensor 80. In some examples the speed sensor 80 may take the form of one or more speed encoders on the transportation mechanism over which the material 6 passes. In other examples, the speed sensor 80 may take the form of a laser speed device.

[0059] The speed measured by the speed sensor 80 is input into a speed related flow controller 90 which is part of the control system 500. The speed related flow controller compares the measured speed to the setpoint speed. In other words, the control system then compares the measured speed to a setpoint speed S304, where the setpoint speed has a corresponding first flow rate of the cooling fluid associated with it. As discussed previously, if the speed of the material 6 through the cooling system 200 deviates from the setpoint speed then the exit temperature will vary from the desired setpoint temperature. Any resulting difference between the measured material speed and the setpoint speed can be thought of as a speed error. In some cases the speed error will indicate the material 6 is moving faster than expected and in other cases the speed error will indicate the material 6 is moving slower than expected. The resulting speed difference is used to adjust control of the spray headers 203, as part of another feedforward control loop. The speed difference is used to calculate an adjustment which needs to be made to the first flow rate. This adjustment may be referred to as a speed-based adjustment and is another example of a type of flow trim. The speed-based adjustment is the amount which minimises the resulting temperature difference. As the speed error varies over time the speedadjusted flow rate also varies over time.

[0060] Generally, the speed-based adjustment is input into the feedforward control 260, and subsequently sent to the flow reference controller 240 where it is combined with the flow rate from the physical model 20 to give a resulting flow reference for the spray headers. Thus, generally, this process can be thought of as the control system calculating a second flow rate (the speed-based adjustment) of the cooling fluid based on the result of the comparison S306 and then applying the cooling fluid to the material according to the second flow rate S308.

[0061] In most cases, the adjustments calculated as a result of both the temperature comparison and the speed comparison are taken into account together, rather than considered separately. In this case, the speed-based adjustment is input into the feedforward control 260, where it is combined with the temperature-based adjustment calculated based on the initial temperature, to give a resultant feedforward adjustment. The resultant feedforward adjustment is another type of flow trim.

[0062] The resultant feedforward adjustment is subsequently sent to the flow reference controller 240 where it is combined with the flow rate from the physical model 20, to give a resultant flow reference for the spray headers 203. The flow reference controller 240 controls the flow of cooling liquid from the spray headers 203 in accordance with this flow reference, where each spray header is able to apply a different amount of cooling liquid to the material 6 in a similar manner as described with reference to Figure 1. This means that the resulting flow reference compensates for both the errors in temperature and speed. Thus, the feedforward control 260 can be considered responsible for compensating for both the temperature and speed errors.

[0063] As can be seen in Figure 2 two control loops are present within the control system 500. The first control loop comprising the first temperature sensor 106, the feedforward control 260, and the flow reference controller 240 of the control system 300 is substantially the same as the feedforward temperature control loop of Figure 1. As such, this control loop is also a feedforward temperature control loop. This feedforward temperature control loop adjusts the flow rate for each spray header 204. The second control loop comprises the speed sensor 80, the speed related flow control 90, the feedforward control 260, and the flow reference controller 240 of the control system 500. This second control loop measures the speed at which the material moves through the cooling system 200 and uses this to perform multiple calculations to adjust the flow rate for all spray headers 204 so that the exit temperature of the material 6 is maintained at substantially the required setpoint temperature, within acceptable tolerance levels. This second control loop may be considered a feedforward speed control loop.

[0064] Using the combination of the two feedforward control loops, namely the feedforward temperature control loop and the feedforward speed control loop, differences in both temperature and speed are greatly reduced.

[0065] Further details about how the change in material speed is accounted for will now be described.

[0066] The cooling model 20 is a physical-based model which models the cooling process within a material. The model 20 comprises a finite difference temperature model which includes details of the cooling liquid-to-material heat transfer coefficients (for example water-to-steel heat transfer coefficients) as well as a microstructural model. The model 20 is able to predict the change in the material temperature as it is cooled, and predict the final exit temperature, at the second temperature sensor 108 after the material 6 exits the cooling system 200, based on inputs into the cooling model 20 including the first flow rate, the setpoint speed, and material properties (such as the thickness, temperature, and chemistry).

[0067] The distance over which the material passes through the cooling section 200 is fixed by the length of the cooling section 200, and is known as the cooling distance. This is the distance travelled by the material 6 while it is cooled. The length of time the material 6 is in the cooling section 6, and so the length time over which the material is being cooled, is known as the cooling time.

[0068] As the cooling distance is fixed, any speed errors result in a change in the cooling time because the material will be present in the cooling system 200 for a greater or lesser amount of time. For example, if the speed of the material increases from the setpoint the cooling time decreases, and vice versa. Therefore, since a change in speed is equivalent to a change in the cooling time, the cooling time can be varied in order to calculate the effect of a change in speed. The physical model 20 uses the cooling time (based on the setpoint speed) to calculate how much heat will be removed from the material 6, and as a result the exit temperature can be predicted by the model 20. By applying a small deviation to the cooling time about a nominal set of conditions, to take into account variations in speed, then the rate of change of material exit temperature with respect to the speed can be calculated by the physical model 20.

[0069] Variations in the flow rate of the cooling liquid also result in a change in the heat removal rate from the surface of the material 6. For example a high flow rate, corresponding to a large flow reference, leads to a high heat removal rate from the material and so the material cools down quickly. Conversely, a low flow rate, corresponding to a small flow reference, leads to a low heat removal rate from the material and so that material cools down slowly. Changes in flow rate, which cause changes in the heat removal rate, therefore cause changes in the exit temperature of the material. The relationship between the change in flow rate and the change in exit temperature can be determined and taken into account by the physical model 20. By applying a small deviation to the flow rate about the nominal set of conditions, to take into account variations in the flow rate of the cooling liquid, the rate of change of material exit temperature with respect to the flow rate can be calculated by the physical model.

[0070] By combining the relationship between the speed and exit temperature with the relationship between the flow rate and the exit temperature, a relationship between flow rate and speed can be calculated, as follows.

[0071] The physical model 20 generates two relationships, using nominal conditions. The first relationship is the rate of change of temperature at the second temperature sensor 108 (that is, the exit temperature) with respect to the change in material speed, which is given by dT/dv, where T is temperature in degrees Celsius and v is speed in metres per second. The second relationship is the rate of change of temperature at the second temperature sensor 108 (i.e. the exit temperature) with respect to the flow rate of cooling liquid from the nozzles, which is given by dT/dF, where T is temperature in degrees Celsius and F is the flow rate in litres per second.

[0072] These two relationships are combined to give the rate of change of flow rate with respect to a change in speed, as follows:

$$\frac{dF}{dv} = \frac{dT}{dv} \times \frac{dT}{dF}$$

where the change in flow rate dF (in litres per second) is given by:

$$dF = \frac{dF}{dv} \times (measured\ speed - setpoint\ speed)$$

[0073] Thus, the model 20 can predict what change in exit temperature will occur when the material speed is changed by a certain percentage. The flow rate can then be adjusted to compensate for the over- or under-cooling which will result from the speed change. The change in flow rate is applied to all spray headers 203. This means that the proportional change in flow rate at each spray header 203 is the same because the instantaneous change in speed of the material is the same for each spray header 203.

[0074] The use of two feedforward control loops compensates for speed variations and temperature variations occurring within the process. The main steps of the control process are as follows:

a) measuring a speed error by comparing the setpoint speed of the material to the actual measured speed.

b) calculating the variation in exit temperature with speed and the variation in exit temperature with flow rate.

c) combining the calculated variations to give a variation in the flow rate with speed, which is the change in flow rate required to compensate for a variation in the speed.

d) calculating the flow trim as a result of the change in speed and applying the flow trim to the flow trim calculated as a result of the feedforward temperature control loop.

e) adjusting and maintaining the flow rate at the updated flow reference supplied from the feedforward controller based on the flow trims received from the feedforward temperature control loop and the feedforward speed control loop.

[0075] In summary the cooling systems and processes described herein provides an improvement in the temperature performance of the cooled material which results in a reduction in out-of-tolerance product and hence a reduction in operating costs.

Claims

1. A method of cooling a material in a cooling system of a rolling mill using a cooling fluid, the method comprising the steps of:

    conveying, by a transportation mechanism, a length of material into the cooling system of a rolling mill;
    measuring, by a sensor, a speed of the length of material;
    comparing, by a control system, the measured speed to a setpoint speed, wherein the setpoint speed has a corresponding first flow rate of the cooling fluid;
    calculating, by the control system, a second flow rate of the cooling fluid based on the comparison, wherein the second flow rate is different from the first flow rate; and
    applying, to the material in the cooling system, the cooling fluid at the second flow rate.

2. The method of claim 1 wherein the second flow rate comprises an adjustment value, wherein the adjustment value is the result of the comparison between the measured speed and the setpoint speed, and further wherein calculating the second flow rate comprises adding the adjustment value to the first flow rate to give the second flow rate.

3. The method of claim 2 wherein the adjustment value is a value which minimises a difference between a final temperature of the length of material after the length of material has exited the cooling system and a setpoint temperature.

4. The method according to any preceding claim wherein the method further comprises:

    measuring, by a first temperature sensor, an initial temperature of the length of material before the length of material has entered the cooling system;
    comparing the measured temperature to a setpoint temperature;
    calculating, by the control system, a third flow rate based on the comparison;
    combining the third flow rate with the second flow rate.

5. The method according to any preceding claim wherein calculating the first flow rate comprises:

    receiving, by the control system, a set of initial conditions relating to the material;
    modelling, by the control system and using the set of initial conditions, a cooling process of the material;
    calculating, by the control system, the first flow rate based on the modelled cooling process.

6. The method according to claim 5 wherein the modelling further comprises:

    measuring, by a second temperature sensor, a final temperature of the length of material after the length of material has exited the cooling system;
    comparing, by the control system, the measured final temperature to a predicted final temperature;
    calculating, by the control system, a difference between the measured final temperature and the predicted final temperature;
    modelling an enhanced cooling process of the material using the set of initial conditions and the difference;
    calculating, by the control system, a fourth flow rate based on the modelled enhanced cooling process;
    combining the fourth flow rate with the second flow rate.

7. The method according to any preceding claim wherein the measuring, by a sensor, a speed of the length of material comprises measuring the speed of the length of material within the cooling system.

8. The method according to any preceding claim wherein the second flow rate comprises a plurality of flow references and the cooling system comprises a plurality of spray headers, and wherein the step of applying the cooling liquid at the second flow rate comprises:

applying, to the material by each of the plurality of spray headers, the cooling fluid according to the corresponding flow reference of said spray header.

9. A system configured to cool a material in a rolling mill comprising:

a transportation mechanism configured to convey a length of material into a cooling apparatus of a rolling mill;
a sensor configured to measure a speed of the length of material;
a control system configured to:

compare the measured speed to a setpoint speed, wherein the setpoint speed has a corresponding first flow rate of the cooling fluid;
calculate a second flow rate of the cooling fluid based on the comparison, wherein the second flow rate is different from the first flow rate; and
applying, to the material in the cooling system, the cooling fluid at the second flow rate.

10. The apparatus according to claim 9 further comprising a first temperature sensor configured to measure an initial temperature of a length of material before the length of material has been fed into a cooling system; and wherein the control system is further configured to:

compare the initial temperature to a setpoint temperature;
calculate a third flow rate based on the comparison;
combine the third flow rate with the second flow rate.

11. The apparatus according to claim 9 or claim 10 wherein the control system is configured to:

receive a set of initial conditions relating to the material;
model, using the set of initial conditions, a cooling process of the material;
calculate the first flow rate based on the modelled cooling process.

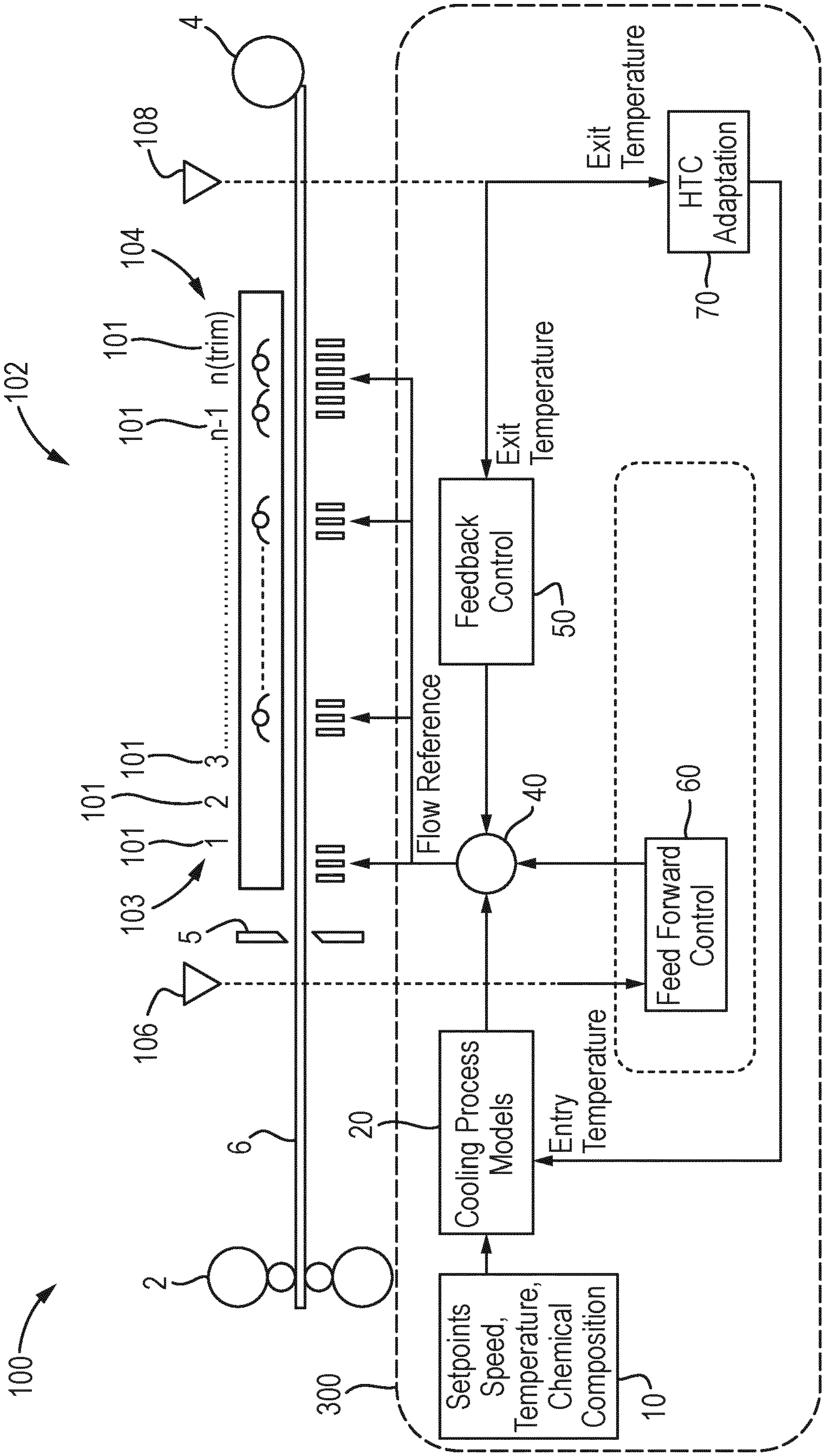
12. The apparatus according to any of claims 9 to 11 further comprising a second temperature sensor configured to measure a final temperature of a length of material after the length of material has exited a cooling system; and wherein the control system is further configured to:

compare the final temperature to a predicted final temperature;
calculate a difference between the measured final temperature and the predicted final temperature;
model an enhanced cooling process of the material using the set of initial conditions and the difference;
calculate a fourth flow rate based on the modelled enhanced cooling process; and
combine the fourth flow rate with the second flow rate.

13. The apparatus according to any of claims 9 to 12 wherein the sensor is located within the cooling system.

14. The apparatus according to any of claims 9 to 13 wherein the cooling system comprises a plurality of spray headers.

Fig. 1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Setpoints
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Temperature,
Chemical
Composition
10
Cooling Process
Models
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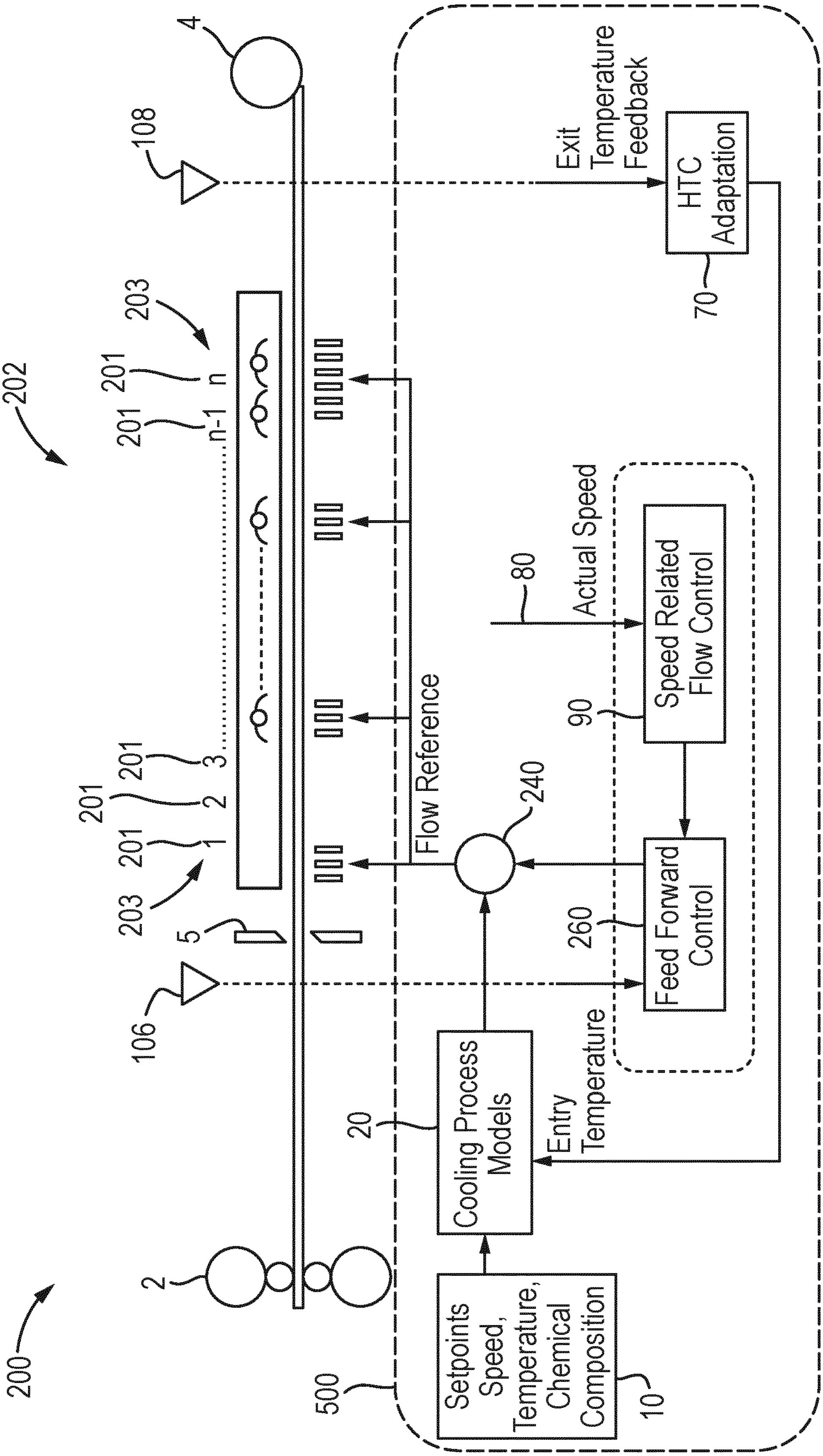
Temperature
Feed Forward
Control
60
40
Flow Reference
Feedback
Control
50
Exit
Temperature
HTC
Adaptation
70

Fig. 2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Chemical
Composition
10
500
Cooling Process
Models
20
Entry
Temperature
Feed Forward
Control
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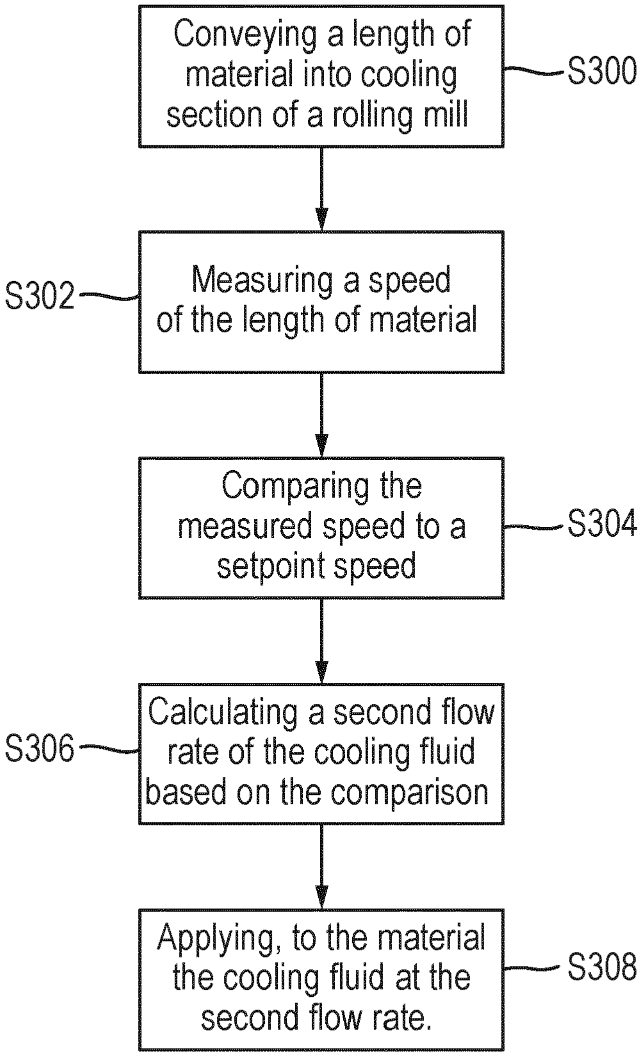
Speed Related
Flow Control
90
80
Actual Speed
Exit
Temperature
Feedback
HTC
Adaptation
70

Fig. 3


Conveying a length of material into cooling section of a rolling mill
S300
Measuring a speed of the length of material
S302
Comparing the measured speed to a setpoint speed
S304
Calculating a second flow rate of the cooling fluid based on the comparison
S306
Applying, to the material the cooling fluid at the second flow rate.
S308

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EUROPEAN SEARCH REPORT

Application Number
EP 21 19 5167

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	SU 1 357 100 A1 (KRIVOROZH KI I AVTOMATIKI [SU]) 7 December 1987 (1987-12-07) * the whole document * -----	1-14	INV. B21B45/02 B21B37/74 B21B38/00
X	CN 106 583 453 B (WISDRI ENG & RES INC CO LTD) 17 April 2018 (2018-04-17) * the whole document * -----	1-14	

TECHNICAL FIELDS SEARCHED (IPC)
B21B

1 The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	16 February 2022	Frisch, Ulrich

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16-02-2022

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SU 1357100	A1	07-12-1987	NONE	
CN 106583453	B	17-04-2018	NONE	

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