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(54) **RAPID QUENCH LINE**

SCHNELLE QUENCH-LEITUNG

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Description

REFERENCE TO RELATED APPLICATION

TECHNICAL FIELD

[0001] The present disclosure relates to metalworking generally and more specifically to controlling temperature of metal articles during production of the metal articles.

BACKGROUND

[0002] The metallurgical structure of a metal article can have substantial impact on various properties of the metal article, such as the metal article's strength and/or formability. During production processes, care must be taken to ensure the metal article being produced has the desired metallurgical properties. Precise control of a metal article's temperature during production of the metal article can enable the metal article to be produced with the desired metallurigal properties and desired metallurgical structure.

[0003] Direct chill (DC) and continuous casting are two methods of casting solid metal from liquid metal. In DC casting, liquid metal is poured into a mold having a retractable false bottom capable of withdrawing at the rate of solidification of the liquid metal in the mold, often resulting in a large and relatively thick ingot (e.g., 1500 mm x 500 mm x 5 m). The ingot can be processed, homogenized, hot rolled, cold rolled, annealed and/or heat treated, and otherwise finished before being coiled into a metal strip product distributable to a consumer of the metal article (e.g., an automotive manufacturing facility).

[0004] Continuous casting can include continuously injecting molten metal into a casting cavity defined between a pair of moving opposed casting surfaces and withdrawing a cast metal article (e.g., a metal strip) from the exit of the casting cavity. Continuous casting can produce metal articles of any suitable length, which can be especially suitable for producing coilable metal strip.

[0005] Often, a metal article must be thermally processed to achieve desired metallurgical structure and/or metallurgical properties. Examples of such thermal treatments include high-temperature annealing or homogenization, which both involve heating the metal article to relatively high temperatures. Annealing is a high-temperature process performed on a worked (e.g., work hardened) metal article, often at temperatures at or near the metal's recrystallization temperature (e.g., around 300-400 °C for some types of Aluminum alloy). Homogenization is a high-temperature process performed on metal articles to reduce the grain-level heterogeneity of an as-cast microstructure. Homogenization is often performed at temperatures above the metal's recrystallization temperature, such as temperatures of around 450-600 °C in some types of Aluminum alloy, dependent on the alloy's system. When heated to these ranges of temperatures (e.g., at or above the recrystallization temperature), the metallurgical microstructure of the metal article can become more homogenous, improving the formability of the metal article and/or other metallurgical properties. However, at these high temperatures, the metal article is especially susceptible to damage if mistreated. Often, annealing or homogenization is performed on DC cast ingots.

[0006] Annealing or homogenization for metal strip, such as coiled metal strip, often requires the use of a continuous annealing and solution heat treatment (CASH) line such as in WO 2018132604. These CASH lines occupy a very large footprint and require many specialized pieces of equipment designed to uncoil the metal strip, levitate the metal strip through furnaces and cooling zones, and re-coil the metal strip. Without levitating the metal strip, physical contact with rollers or the like may harm the delicate metal strip when the metal strip is at elevated temperature. The path taken by the metal strip through the CASH line is often long and circuitous, requiring long lengths of metal strip to be scrapped due to the need to thread the metal strip through the CASH line to begin processing it. Additionally, to avoid having to scrap these large amounts of metal strip for each coil, CASH lines often require the use of accumulators and cutters to combine separate coils together into a continuous metal strip and then cut the continuous metal strip into separate, processed coils.

SUMMARY

[0007] The invention is given in the claims. The term embodiment and like terms are intended to refer broadly to all of the subject matter of this disclosure and the claims below. Statements containing these terms should be understood not to limit the subject matter described herein or to limit the meaning or scope of the claims below. Embodiments of the present disclosure covered herein are defined by the claims below, not this summary. This summary is a high-level overview of various aspects of the disclosure and introduces some of the concepts that are further described in the Detailed Description section below. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used in isolation to determine the scope of the claimed subject matter. The subject matter should be understood by reference to appropriate portions of the entire specification of this disclosure, any or all drawings and each claim.

[0008] Embodiments of the present disclosure include a system, comprising: a low-tension unwinding unit for receiving and unwinding a metal coil of metal strip; a non-contacting hold-down device positioned adjacent the low-tension unwinding unit to provide force on the metal strip towards the center of the metal coil during unwinding of the metal coil; a set of quenching zones for cooling the metal strip, wherein the set of quenching zones provides sufficient coolant to reduce a temperature of the metal strip by a rate of at least 100 °C per second; a coolant removal unit positioned downstream of the set of quenching zones; and a bridle unit positioned downstream of the coolant removal unit for increasing tension in the metal strip.

[0009] In some cases, the low-tension unwinding unit comprises insulation disposed to retain heat within coiled portions of the metal coil. In some cases, the low-tension unwinding unit comprises a heat source for providing heat to coiled portions of the metal coil, wherein the heat source is coupled to a controller for maintaining the metal coil at or above a threshold temperature. In some cases, the non-contacting hold-down device comprises one or more magnets for generating a changing magnetic field through the metal strip. In some cases, the changing magnetic field is configured distribute the force over time across a width of the metal strip. In some cases, the non-contacting hold-down device comprises a nozzle for blowing heated air against the metal strip. In some cases, the system further comprises: a flatness measurement unit positioned to measure a flatness of the metal strip; and a controller coupled to the flatness measurement unit and the set of quenching zones to adjust delivery of the coolant based on measured flatness of the metal strip. In some cases, the system further comprises a stabilization system positioned upstream of the set of quenching zones to introduce a wave into the metal strip. In some cases, the metal strip remains supported without mechanical contact between the metal coil and the coolant removal unit. In some cases, the set of quenching zones comprises a steam reclamation module for redirecting humid air from at least one of the set of quenching zones to the metal strip at a location downstream of the at least one of the set of quenching zones. In some cases, the location downstream of the at least one of the set of quenching zones is a location where the temperature of the metal strip is at or below a Leidenfrost point. In some cases, the system further comprises: a pre-quench heating unit positioned downstream of the low-tension unwinding unit; and a controller coupled to the pre-quench heating unit to heat the metal strip to a target temperature prior to the metal strip entering the set of quenching zones. In some cases, the non-contacting hold-down device is positioned to provide the force on the metal strip at a location at or adjacent to where the metal strip falls away from the metal coil due to gravity.

[0010] Embodiments of the present disclosure include a method, comprising: unwinding a hot metal coil using a low-tension unwinder, wherein unwinding the hot metal coil comprises applying a non-contacting hold-down force to the hot metal coil and permitting metal strip of the hot metal coil to fall away from the metal coil; rapidly quenching the metal strip in a set of quenching zones, wherein rapidly quenching the metal strip comprises applying coolant to the metal strip to reduce a temperature of the metal strip at a rate of at least 100 °C per second; removing the coolant from the metal strip; and applying downstream tension to the metal strip.

[0011] In some cases, the method further comprises maintaining an initial temperature of the hot metal coil at the low-tension unwinder. In some cases, the method further comprises preheating the metal strip immediately prior to rapidly quenching the metal strip. In some cases, applying the non-contacting hold-down force comprises generating a changing magnetic field through the metal strip. In some cases, applying the non-contacting hold-down force comprises blowing heated air against the metal strip. In some cases, the method further comprises: measuring flatness of the metal strip; and adjusting delivery of the coolant based on the measured flatness. In some cases, the method further comprises inducing a wave in the metal strip without contacting the metal strip. In some cases, the method further comprises: capturing steam from at least one of the quenching zones; and redirecting the captured steam towards the metal strip. In some cases, redirecting the captured steam comprises redirecting the capture steam towards the metal strip at a location where a temperature of the metal strip is at or below the Leidenfrost point.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The specification makes reference to the following appended figures, in which use of like reference numerals in different figures is intended to illustrate like or analogous components.

FIG. 1 is a schematic side view of a system for rapidly quenching and recoiling a hot metal coil according to certain aspects of the present disclosure.

FIG. 2 is a schematic side view of a system for rapidly quenching a hot metal coil for further rolling according to certain aspects of the present disclosure.

FIG. 3 is a schematic block diagram of a rapid quench line according to certain aspects of the present disclosure.

FIG. 4 is a combination schematic block diagram and temperature graph depicting relative temperatures of a metal strip passing through a rapid quench line according to certain aspects of the present disclosure.

FIG. 5 is a schematic side view of a steam reclamation module on a rapid quench line according to certain aspects of the present disclosure.

FIG. 6 is a schematic top view of a magnetic rotor non-contacting hold-down roll according to certain aspects of the present disclosure.

FIG. 7 is a flowchart depicting a process for rapidly quenching a hot metal coil according to certain aspects of the present disclosure.

DETAILED DESCRIPTION

[0013] Certain aspects and features of the present disclosure relate to a rapid quenching line suitable for use with hot coil, or coiled metal strip at temperatures near, at, or above the metal strip's recrystallization point. The recrystallization point can be at or approximately between 40%-50% of the melting temperature of the metal strip. The rapid quenching line can include a low tension uncoiler making use of a non-contacting hold-down device. The metal strip coming off the low tension uncoiler is rapidly quenched (e.g., at rates of at or above 30 °C/s, 50 °C/s, 100 °C/s or 200 °C/s) through multiple quenching zones. Coolant can be removed, such as through the use of an air knife and/or an ultra-compliant wiper. In some cases, steam collected from earlier quenching zones can be repurposed to provide humid air to the metal strip at regions where the temperature of the metal strip is at or below the Leidenfrost point. The cooled metal strip can pass through a bridle to increase the tension in the metal strip before the metal strip is optionally lubricated and then recoiled or otherwise further processed.

[0014] In metal production, continuous casting processes or rolling processes (e.g., hot rolling) can result in a coiled product, such as a coiled metal strip. As disclosed herein, the term metal strip is inclusive of metal articles of any suitable thickness capable of being coiled, such as a metal sheet or metal shate. A metal strip can have any suitable length or width. In some cases, certain aspects of the present disclosure may be suitable for use with metal strip products that are not necessarily coiled, although in some cases certain aspects of the present disclosure may be especially suitable for use with metal coils. A metal coil can comprise a metal strip coiled.

[0015] As used herein, a sheet generally refers to an aluminum product having a thickness of less than about 4 mm. For example, a sheet may have a thickness of less than about 4 mm, less than about 3 mm, less than about 2 mm, less than about 1 mm, less than about 0.5 mm, or less than about 0.3 mm (e.g., about 0.2 mm).

[0016] As used herein, terms such as "cast metal product," "cast product," "cast aluminum alloy product," and the like are interchangeable and refer to a product produced by direct chill casting (including direct chill co-casting) or semi-continuous casting, continuous casting (including, for example, by use of a twin belt caster, a twin roll caster, a block caster, or any other continuous caster), electromagnetic casting, hot top casting, or any other casting method.

[0017] As used herein, the meaning of "room temperature" can include a temperature of from about 15 °C to about 30 °C, for example about 15 °C, about 16 °C, about 17 °C, about 18 °C, about 19 °C, about 20 °C, about 21 °C, about 22 °C, about 23 °C, about 24 °C, about 25 °C, about 26 °C, about 27 °C, about 28 °C, about 29 °C, or about 30 °C. As used herein, the meaning of "ambient conditions" can include temperatures of about room temperature, relative humidity of from about 20 % to about 100 %, and barometric pressure of from about 975 millibar (mbar) to about 1050 mbar. For example, relative humidity can be about 20 %, about 21 %, about 22 %, about 23 %, about 24 %, about 25 %, about 26 %, about 27 %, about 28 %, about 29 %, about 30 %, about 31 %, about 32 %, about 33 %, about 34 %, about 35 %, about 36 %, about 37 %, about 38 %, about 39 %, about 40 %, about 41 %, about 42 %, about 43 %, about 44 %, about 45 %, about 46 %, about 47 %, about 48 %, about 49 %, about 50 %, about 51 %, about 52 %, about 53 %, about 54 %, about 55 %, about 56 %, about 57 %, about 58 %, about 59 %, about 60 %, about 61 %, about 62 %, about 63 %, about 64 %, about 65 %, about 66 %, about 67 %, about 68 %, about 69 %, about 70 %, about 71 %, about 72 %, about 73 %, about 74 %, about 75 %, about 76 %, about 77 %, about 78 %, about 79 %, about 80 %, about 81 %, about 82%, about 83 %, about 84 %, about 85 %, about 86 %, about 87 %, about 88 %, about 89 %, about 90 %, about 91 %, about 92 %, about 93 %, about 94 %, about 95 %, about 96 %, about 97 %, about 98 %, about 99 %, about 100 %, or anywhere in between. For example, barometric pressure can be about 975 mbar, about 980 mbar, about 985 mbar, about 990 mbar, about 995 mbar, about 1000 mbar, about 1005 mbar, about 1010 mbar, about 1015 mbar, about 1020 mbar, about 1025 mbar, about 1030 mbar, about 1035 mbar, about 1040 mbar, about 1045 mbar, about 1050 mbar, or anywhere in between.

[0018] While certain aspects of the present disclosure may be suitable for use with any type of metal, certain aspects of the present disclosure may be especially suitable for use with aluminum. In this description, reference is made to alloys identified by AA numbers and other related designations, such as "series" or "7xxx." For an understanding of the number designation system most commonly used in naming and identifying aluminum and its alloys, see "International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys" or "Registration Record of Aluminum Association Alloy Designations and Chemical Compositions Limits for Aluminum Alloys in the Form of Castings and Ingot," both published by The Aluminum Association.

[0019] Certain aspects of the present disclosure are especially suitable for use with aluminum alloys from the 2xxx, 6xxx, 7xxx, or 8xxx series, although other alloys can be used. When certain aluminum alloys are produced, alloying elements can form precipitates. In the case of some alloys, such as 2xxx, 6xxx, 7xxx, or 8xxx series alloys, especially massive precipitates can form when the aluminum alloy is being cooled from high temperatures, such as down to room temperature. These massive precipitates do not dissolve well in the aluminum product, can be difficult or impossible to correct, and can result in undesirable mechanical properties. For example, in 6xxx series aluminum alloys, cooling from high temperatures to room temperature at traditional rates can result in the formation of large Mg2Si precipitates, which can be detrimental to the desired metallurgical structure of the aluminum product. These problems are especially prevalent when cooling from temperatures above a metal's recrystallization temperature, such as during an annealing or homogenization process, down to room temperature. However, if a metal article can be cooled sufficiently quickly, such as disclosed herein, dissolved elements that would otherwise form precipitates can remain in a supersaturated solid solution all the way down to room temperature.

[0020] In a homogenization step, the metal product described herein can be heated to a temperature ranging from about 400 °C to about 600 °C. For example, the product can be heated to a temperature of about 400 °C, about 410 °C, about 420 °C, about 430 °C, about 440 °C, about 450 °C, about 460 °C, about 470 °C, about 480 °C, about 490 °C, or about 500 °C. The product is then allowed to soak (i.e., held at the indicated temperature) for a period of time. In some examples, the total time for the homogenization step, including the heating and soaking phases, can be up to 24 hours. For example, the product can be heated up to 500 °C and soaked, for a total time of up to 18 hours for the homogenization step. Optionally, the product can be heated to below 490 °C and soaked, for a total time of greater than 18 hours for the homogenization step. In some cases, the homogenization step comprises multiple processes. In some non-limiting examples, the homogenization step includes heating the product to a first temperature for a first period of time followed by heating to a second temperature for a second period of time. For example, the product can be heated to about 465 °C for about 3.5 hours and then heated to about 480 °C for about 6 hours.

[0021] Following the homogenization step, a hot rolling step can be performed. Prior to the start of hot rolling, the homogenized product can be allowed to cool to a temperature between 300 °C to 520 °C. For example, the homogenized product can be allowed to cool to a temperature of between 325 °C to 425 °C or from 350 °C to 400 °C. The product can then be hot rolled at a temperature between 300 °C to 450 °C to form a hot rolled plate, a hot rolled shate or a hot rolled sheet having a gauge between 3 mm and 200 mm (e.g., 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, 60 mm, 65 mm, 70 mm, 75 mm, 80 mm, 85 mm, 90 mm, 95 mm, 100 mm, 110 mm, 120 mm, 130 mm, 140 mm, 150 mm, 160 mm, 170 mm, 180 mm, 190 mm, 200 mm, or anywhere in between).

[0022] Optionally, the cast product can be a continuously cast product that can be allowed to cool to a temperature between 300 °C to 520 °C. For example, the continuously cast product can be allowed to cool to a temperature of between 325 °C to 425 °C or from 350 °C to 400 °C. The continuously cast products can then be hot rolled at a temperature between 300 °C to 450 °C to form a hot rolled plate, a hot rolled shate or a hot rolled sheet having a gauge between 3 mm and 200 mm (e.g., 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, 60 mm, 65 mm, 70 mm, 75 mm, 80 mm, 85 mm, 90 mm, 95 mm, 100 mm, 110 mm, 120 mm, 130 mm, 140 mm, 150 mm, 160 mm, 170 mm, 180 mm, 190 mm, 200 mm, or anywhere in between). During hot rolling, temperatures and other operating parameters can be controlled so that the temperature of the hot rolled intermediate product upon exit from the hot rolling mill is no more than 470 °C, no more than 450 °C, no more than 440 °C, or no more than 430 °C.

[0023] The plate, shate or sheet can then be cold rolled using conventional cold rolling mills and technology into a sheet. The cold rolled sheet can have a gauge between about 0.5 to 10 mm, e.g., between about 0.7 to 6.5 mm. Optionally, the cold rolled sheet can have a gauge of 0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm, 2.5 mm, 3.0 mm, 3.5 mm, 4.0 mm, 4.5 mm, 5.0 mm, 5.5 mm, 6.0 mm, 6.5 mm, 7.0 mm, 7.5 mm, 8.0 mm, 8.5 mm, 9.0 mm, 9.5 mm, or 10.0 mm. The cold rolling can be performed to result in a final gauge thickness that represents a gauge reduction of up to 85 % (e.g., up to 10 %, up to 20 %, up to 30 %, up to 40 %, up to 50 %, up to 60 %, up to 70 %, up to 80 %, or up to 85 % reduction). Optionally, an interannealing step can be performed during the cold rolling step. The interannealing step can be performed at a temperature of from about 300 °C to about 450 °C (e.g., about 310 °C, about 320 °C, about 330 °C, about 340 °C, about 350 °C, about 360 °C, about 370 °C, about 380 °C, about 390 °C, about 400 °C, about 410 °C, about 420 °C, about 430 °C, about 440 °C, or about 450 °C). In some cases, the interannealing step comprises multiple processes. In some non-limiting examples, the interannealing step includes heating the plate, shate or sheet to a first temperature for a first period of time followed by heating to a second temperature for a second period of time. For example, the plate, shate or sheet can be heated to about 410 °C for about 1 hour and then heated to about 330 °C for about 2 hours.

[0024] Subsequently, the plate, shate or sheet can undergo a solution heat treatment step. The solution heat treatment step can be any conventional treatment for the sheet which results in solutionizing of the soluble particles. The plate, shate or sheet can be heated to a peak metal temperature (PMT) of up to 590 °C (e.g., from 400 °C to 590 °C) and soaked for a period of time at the temperature. For example, the plate, shate or sheet can be soaked at 480 °C for a soak time of up to 30 minutes (e.g., 0 seconds, 60 seconds, 75 seconds, 90 seconds, 5 minutes, 10 minutes, 20 minutes, 25 minutes, or 30 minutes). After heating and soaking, the plate, shate or sheet is rapidly cooled at rates greater than 200 °C/s to a temperature between 500 and 200 °C. In one example, the plate, shate or sheet has a quench rate of above 200 °C/second at temperatures between 450 °C and 200 °C. Optionally, the cooling rates can be faster in other cases. In some cases, quenching can occur using a rapid quench line as disclosed herein.

[0025] After quenching, the plate, shate or sheet can optionally undergo a pre-aging treatment by reheating the plate, shate or sheet before coiling. The pre-aging treatment can be performed at a temperature of from about 70 °C to about 125 °C for a period of time of up to

6 hours. For example, the pre-aging treatment can be performed at a temperature of about 70 °C, about 75 °C, about 80 °C, about 85 °C, about 90 °C, about 95 °C, about 100 °C, about 105 °C, about 110 °C, about 115 °C, about 120 °C, or about 125 °C. Optionally, the pre-aging treatment can be performed for about 30 minutes, about 1 hour, about 2 hours, about 3 hours, about 4 hours, about 5 hours, or about 6 hours. The pre-aging treatment can be carried out by passing the plate, shate or sheet through a heating device, such as a device that emits radiant heat, convective heat, induction heat, infrared heat, or the like.

[0026] The cast products described herein can also be used to make products in the form of plates or other suitable products. For example, plates including the products as described herein can be prepared by processing an ingot in a homogenization step or casting a product in a continuous caster followed by a hot rolling step. In the hot rolling step, the cast product can be hot rolled to a 200 mm thick gauge or less (e.g., from about 10 mm to about 200 mm). For example, the cast product can be hot rolled to a plate having a final gauge thickness of about 10 mm to about 175 mm, about 15 mm to about 150 mm, about 20 mm to about 125 mm, about 25 mm to about 100 mm, about 30 mm to about 75 mm, or about 35 mm to about 50 mm.

[0027] In some cases, it can be desirable to store hot metal strip (e.g., at temperatures at or above the metal's recrystallization temperature) in the form of a metal coil. This hot metal coil can be a result of a continuous casting process or a rolling process (e.g., from a continuous cast or DC cast product). The metal coil format can be useful for storing long lengths of metal strip in an efficient manner. Rather than passing a long length of metal strip through a CASH line or other similar processing line with long lengths of furnaces and cooling zones, a single metal coil can be placed in a furnace and held at a desired temperature for a desired duration to achieve desired thermal processing effects. For example, an aluminum metal coil can be kept in a furnace at around 350 °C - 400 °C for a duration to anneal the metal strip.

[0028] While hot metal coils are useful for storing long lengths of metal strip in a relatively small footprint, hot metal coils must be carefully handled. Whenever the metal strip is above its recrystallization temperature, there exists risks that undue pressure, tension, mechanical contact, or other forces may harm the metal strip, requiring the scrapping of some or all of the metal strip. For example, too-high tension when uncoiling a hot metal coil can result in the metal strip sustaining rips, deformation, and/or surface damage. Therefore, the handling of hot metal coils is especially difficult. While it may be desirable to store the metal strip as a hot coil at certain times (e.g., during thermal processing, such as annealing or homogenization), it can be desirable to store the metal strip as a warm or cold coil at other times (e.g., to facilitate handling of the metal strip, such as using a forklift or other common factory equipment). In some cases, certain equipment (e.g., hot rolling mills) require sufficient back-tension to operate, which may be higher tension than a hot metal strip is capable of withstanding. In such cases, it can be necessary to cool the hot metal coil to a low enough temperature such that it can be fed into the desired equipment. As disclosed herein, the terms warm and cold refer to temperatures below the metal's recrystallization point.

[0029] Traditionally, hot metal coils may be cooled by leaving the hot metal coil in ambient temperature at or near room temperature or by forcing air over the metal coil, permitting the hot coil to cool down over many hours. In some cases, spraying the hot metal coils with fluids, such as rolling oil, has been attempted, but still requires hours to obtain the desired, cooled temperature, is environmentally unfriendly, is very expensive, and leaves the coil soaked in rolling oil, which limits the next operation to only a cold rolling mill. According to certain aspects of the present disclosure, a rapid quench system can cool a hot metal coil down to a warm or cold metal coil in a fraction of the time, such as in a manner of minutes, in a more environmentally friendly manner, with less expense, and with little or no residual coolant remaining on the metal strip.

[0030] According to certain aspects of the present disclosure, a low-tension uncoiler is disclosed that can safely unwrap a hot coil. While traditional coilers use tension to ensure proper pay-off of the metal strip from a metal coil, the low-tension uncoiler makes use of the natural pull of gravity to facilitate separating the metal strip from the remainder of the metal coil.

[0031] Additionally, a non-contacting hold-down device is used to apply sufficient force through the metal strip and towards the metal coil to help control proper pay-off of the metal strip. As used herein, the term non-contacting refers to non-mechanical-contact or a lack of physical contact between the metal strip and another structure. For example, a non-contacting hold-down roll can take the form of a magnetic rotor or a set of electromagnets that generates a changing magnetic field through the metal strip, inducing forces on the metal strip through Lenz's law, without contacting the metal strip. In another example, a non-contacting hold-down device can take the form of one or more nozzles designed to blow hot air (e.g., sufficiently hot to avoid quenching the metal strip) against the metal strip to control pay-off of the metal strip from the remainder of the metal coil. The one or more nozzles do not make contact with the metal strip, and instead directed fluid towards the metal strip.

[0032] In some cases, the non-contacting hold-down roll can be a magnetic rotor having alternating poles oriented in a chevron pattern, such that the total magnetic flux passing through the metal strip at any point in time is constant or near constant. Such a chevron pattern can generate a uniform force acting on the metal strip and can avoid oscillations in tension.

[0033] In some cases, the non-contacting hold-down roll can be positioned at the pay-off point (e.g., the point where the metal strip separates from the remainder of the metal coil), or can be positioned within 5°, 10°, 15°, or 20° of the pay-off point.

[0034] As the metal strip is payed-off from the remainder of the metal coil, the curvature of the metal strip being payed-off can be measured (e.g., through distance measurement devices or machine vision) and used to control the pay-off rate of the metal coil.

[0035] In some cases, the uncoiler can be maintained at a particular temperature, such as through the use of insulation or additional heading elements. By avoiding temperature drop in the hot coil itself, subsequent quenching steps can be more accurately performed, since the temperature of the metal strip entering the quenching zones will be relatively stable. In some cases, a stable starting temperature for the quenching process can be optionally achieved through the use of additional heating elements disposed downstream of the uncoiler, which can heat the metal strip to a target temperature despite fluctuation in the initial temperature of the metal strip. Such additional heating elements can take any suitable form, such as radiant, convection, infrared, flame, or magnetic heating elements. In some cases, such additional heating elements can take the form of rotating magnets disposed adjacent the metal strip and rotating at sufficient speeds to increase the temperature in the metal strip without contacting the metal strip. In some cases, the non-contacting hold-down device can work in concert with one or more additional heating elements bring the temperature of the metal strip to a target temperature. In some cases, when an additional heating element that is a magnetic rotor or set of electromagnets is used, cold spots near the edges of the metal strip can be avoided by introducing additional heat at those cold spots before or after passing by the additional heating element. In such cases, a non-contacting hold-down device in the form of a pair of magnetic rotors positioned adjacent the metal strip at locations just before the edges of the metal strip can be used to introduce this additional heat to avoid cold spot formation when the metal strip passes by the magnetic rotor additional heating element.

[0036] In some cases, magnetic rotors, electromagnets, and/or air nozzles can be used to induce a wave (e.g., a sine wave) to stabilize the sheet.

[0037] The uncoiled metal strip can pass through a set of quenching zones (e.g., one or more quenching zones or two or more quenching zones). Each quenching zone can comprise a set of spray headers (e.g., an upper spray header and a lower spray header) configured to deliver coolant to the metal strip. As used herein, a spray header can include a single nozzle, multiple nozzles, or any other suitable configuration. Coolant can include any suitable coolant, such as water, oil, air, or Leidenfrost-free fluid. The spray headers can be sized to deliver coolant to the metal strip to lower the temperature of the metal strip at rates of at or at least 100 °C/s or 200 °C/s. The set of quenching zones start adjacent the pay-off point, as the metal strip is falling flat, or can start spaced apart from the pay-off point, after the metal strip has fallen flat. In some cases, the spray headers of one or more quenching zones can be coupled to actuators to control their relative positions with respect to the metal strip, such as to maintain a desired spacing between the metal strip and the spray header.

[0038] In some cases, the parameters of the set of quenching zones can be adjusted to achieve a desired quench rate that is optimized for a particular alloy. In some cases, identification of an incoming alloy, whether automatic or manual, can be used to pre-adjust the parameters of the set of quenching zones.

[0039] In some cases, a steam reclamation module can collect steam from one or more of the set of quenching zones (e.g., first one or more quenching zones) and direct the steam to the metal strip at a point further downstream. It can be especially advantageous to direct the steam towards the metal strip at a location where the metal strip has sufficiently cooled to reach a temperature at or below the Leidenfrost point, although this need not always be the case. The steam reclamation module can optionally include a blower (e.g., fan) or other equipment necessary to facilitate redirection of the collected steam. The presence of this humid air around the metal strip after the Leidenfrost point avoids condensation on the metal strip and has more heat capacity to extract heat from the metal strip than dry air. Thus, the use of recaptured steam can provide a consistent environment for heat extraction through and/or after the Leidenfrost point. It has been found that this consistent, humid environment can protect the flatness of the cooling metal strip. In some cases, however, the steam reclamation module can collect and/or redirect steam away from the metal coil to help prevent staining of the metal strip still on the metal coil, with or without redirecting the steam to the metal strip at a point further downstream.

[0040] Above the Leidenfrost point, it can be trivial to keep the surface of the metal strip dry, due to the speed at which the coolant boils. However, below the Leidenfrost point, it can be non-trivial to remove residual coolant from the metal strip. Therefore, air knives can be used to wipe coolant off the top of the metal strip (e.g., away from the centerline and over the edges of the metal strip). In some cases, a squeegee can be used to remove excess coolant. Below the metal strip, a wiper can be used, such as an ultra-compliant. An ultra-compliant wiper can include numerous actuators designed to alter the shape of the ultra-compliant wiper to match the wave of the metal strip. In some cases, a lubricating spray (e.g., oil spray) can be applied to the metal strip before reaching the wiper.

[0041] After the metal strip has been rapidly quenched and excess coolant removed, the metal strip can pass through a device to add tension back into the metal strip, such as a bridle. The bridle can comprise a set of rollers around which the metal strip is wrapped to maintain tension in a downstream direction. Since the rapid quench system is especially suitable for processing individual hot metal rolls, it can be beneficial to use a bridle that is easy to thread, such as a bridle having lower and/or inner rolls that can be moved away from upper and/or outer rolls to a threading position for threading, then moved back into an operating position for introducing tension into the metal strip.

[0042] After the bridle roll, the metal strip can optionally pass through a lubricator and then pass around a deflector roll before proceeding to a desired piece of downstream equipment, such as a coiler. In some cases, the deflector roll can measure flatness of the metal strip (e.g., a flatness measuring roll). In some cases, this measured flatness can be used to provide feedback to the set of quenching zones to facilitate controlling flatness of the metal strip.

[0043] In some cases, the rapid quench system disclosed herein can facilitate the production of fully solutionized metal products without the use of a CASH line, thus saving time, expense, and capital expenditure.

[0044] The aluminum alloy products described herein can be used in automotive applications and other transportation applications, including aircraft and railway applications. For example, the disclosed aluminum alloy products can be used to prepare automotive structural parts, such as bumpers, side beams, roof beams, cross beams, pillar reinforcements (e.g., A-pillars, B-pillars, and C-pillars), inner panels, outer panels, side panels, inner hoods, outer hoods, or trunk lid panels. The aluminum alloy products and methods described herein can also be used in aircraft or railway vehicle applications, to prepare, for example, external and internal panels.

[0045] The aluminum alloy products and methods described herein can also be used in electronics applications. For example, the aluminum alloy products and methods described herein can be used to prepare housings for electronic devices, including mobile phones and tablet computers. In some examples, the aluminum alloy products can be used to prepare housings for the outer casing of mobile phones (e.g., smart phones), tablet bottom chassis, and other portable electronics.

[0046] All ranges disclosed herein are to be understood to encompass any and all subranges subsumed therein. For example, a stated range of "1 to 10" should be considered to include any and all subranges between (and inclusive of) the minimum value of 1 and the maximum value of 10; that is, all subranges beginning with a minimum value of 1 or more, e.g. 1 to 6.1, and ending with a maximum value of 10 or less, e.g., 5.5 to 10. Unless stated otherwise, the expression "up to" when referring to the compositional amount of an element means that element is optional and includes a zero percent composition of that particular element. Unless stated otherwise, all compositional percentages are in weight percent (wt. %).

[0047] As used herein, the meaning of "a," "an," and "the" includes singular and plural references unless the context clearly dictates otherwise.

[0048] These illustrative examples are given to introduce the reader to the general subject matter discussed here and are not intended to limit the scope of the disclosed concepts. The following sections describe various additional features and examples with reference to the drawings in which like numerals indicate like elements, and directional descriptions are used to describe the illustrative embodiments but, like the illustrative embodiments, should not be used to limit the present disclosure. The elements included in the illustrations herein may not be drawn to scale.

[0049] FIG. 1 is a schematic side view of a system 100 for rapidly quenching and recoiling a hot metal coil 104 according to certain aspects of the present disclosure. The hot metal coil 104 comprises metal strip 124 at high temperatures (e.g., temperature at or above the recrystallization temperature of the metal strip 124).

[0050] The metal coil 104 can be unwound by an unwinder 102. The unwinder 102 can unwind the hot metal coil 104 in unwinding direction 106. A non-contacting hold-down device 108 can apply slight force to facilitate controlled pay-off of the metal strip 124 from the remainder of the metal coil 104. As depicted in FIG. 1, the non-contacting hold-down device 108 is a non-contacting hold-down roll that rotates in direction 110 to apply a slight downstream tension in the metal strip 124.

[0051] The metal strip 124 can fall away from the remainder of the metal coil 104 naturally due to gravity, taking a curvature. The curvature can be monitored by a sensor 194, such as a distance sensor and/or a camera (e.g., the curvature being sensed via machine vision). The sensor 194 can be coupled to a controller 192. Controller 192 can use the curvature measurements to make adjustments to system 100, such as by adjusting the pay-off rate of the uncoiler 102. In some cases, adjustments can include manipulating the position of spray headers 114, 116 of one or more of the set of quenching zones 112.

[0052] In some cases, the uncoiler 102 can include insulation surrounding at least a portion of the metal coil 104 to retain heat within the metal coil 104. In some cases, the uncoiler 102 can include a heater, such as a heated arbor, sufficient to maintain the temperature of the metal strip 124 while the metal strip 124 is in the metal coil 104.

[0053] The uncoiled metal strip 124 can pass through a set of quenching zones 112. Each of the set of quenching zones can comprise an upper spray header 114 and a lower spray header 116. Each spray header 114, 116 can itself comprise one or more ports through which coolant is directed towards the metal strip. The rate of coolant flow can be controlled, such as via controller 192. The rate of coolant flow can be sufficient to reduce the temperature of the metal strip 124 by at least 100 °C/s or 200 °C/s.

[0054] After passing through the set of quenching zones 112, the metal strip can pass by air knives 118 that blow excess coolant off the top of the metal strip 124. In some cases, an optional squeegee 122 can be used to further remove excess coolant. In some cases, a wiper 120 can be used to remove excess coolant from the bottom of the metal strip 124. In some cases, the wiper 120 is an ultra-compliant wiper.

[0055] After coolant has been removed from the metal strip 124, the metal strip 124 can pass through a bridle zone 126. In the bridle zone 126, the metal strip 124 can wrap around upper bridle rolls 130 and lower bridle rolls 132 to impart a desired amount of tension on the metal strip 124 downstream of the bridle zone 126, without imparting additional tension on the metal strip 124 upstream of the bridle zone 126. In some cases, devices other than or in addition to bridle rolls 130, 132 can be used to impart the necessary tension onto the metal strip 124. In some cases, the bridle zone 126 can comprise an easy-thread bridle. As depicted in FIG. 1, the bridle zone 126 comprises two bridle arms 128 each coupling an upper bridle roll 130 to a lower bridle roll 132. The bridle arms 128 are in an operating position in FIG. 1. To thread the metal strip 124 through the bridle zone 126, bridle arms 128 can be pivoted around the upper bridle rolls 130 such that the lower bridle rolls 132 are positioned above the upper bridle rolls 130. Then, the metal strip 124 can be easily passed between the upper bridle rolls 130 and lower bridle rolls 132 (e.g., the metal strip 124 can pass above the upper bridle rolls 130 and below the lower bridle rolls 132). Then, to move the bridle arms 128 back to an operating position, the bridle arms 128 can be pivoted again around the upper bridle rolls 130 until the lower bridle rolls 132 fully engage the metal strip 124, as depicted in FIG. 1.

[0056] In some cases, the metal strip 124 can optionally pass through a lubricator 134 to apply lubricant to the metal strip 124, such as to lubricate the metal strip 124 in advance of coiling the metal strip 124.

[0057] In some cases, the metal strip 124 can pass around a deflection roll 136. The deflection roll 136 can redirect the metal strip 124 to be appropriately coiled by coiler 134. In some cases, the deflection roll 136 can measure the flatness of the metal strip. In such cases, the deflection roll 136 can be coupled to the controller 192 to facilitate feedback control of the set of quenching zones 112 based on measured flatness at the deflection roll 136. The deflection roll 136 can be a flatness measuring roll.

[0058] As depicted in FIG. 1, the metal strip 124, after being cooled and after tension is applied, is coiled into a metal coil 140 by coiler 138. The metal coil 140 is a warm or cold coil, at a temperature below the recrystallization temperature of the metal strip 124. In some case, the metal coil 140 is at room temperature. In some cases, the metal coil 140 (e.g., the metal strip 124 after quenching) is at a temperature suitable for warm or cold rolling.

[0059] FIG. 2 is a schematic side view of a system 200 for rapidly quenching a hot metal coil 204 for further rolling according to certain aspects of the present disclosure. System 200 can be similar to system 100, although with some different elements and configuration. Certain aspects and features of system 200 can be used with system 100 where appropriate, and certain aspects and features of system 100 can be used with system 200 where appropriate. The hot metal coil 204 comprises metal strip 224 at high temperatures (e.g., temperature at or above the recrystallization temperature of the metal strip 224).

[0060] The metal coil 204 can be unwound by an unwinder 202. The unwinder 202 can unwind the hot metal coil 204 in unwinding direction 206. A non-contacting hold-down device 208 can apply slight force to facilitate controlled pay-off of the metal strip 224 from the remainder of the metal coil 204. As depicted in FIG. 2, the non-contacting hold-down device 208 is a non-contacting hold-down roll that rotates in direction 210 to apply a slight downstream tension in the metal strip 224.

[0061] The metal strip 224 can fall away from the remainder of the metal coil 204 naturally due to gravity, taking a curvature. The curvature can be monitored by a sensor, as disclosed with reference to system 100 of FIG. 1. A controller can be used to make adjustments to system 200, such as disclosed with reference to system 100 of FIG. 1.

[0062] In some cases, the uncoiler 202 can include insulation surrounding at least a portion of the metal coil 204 to retain heat within the metal coil 204. In some cases, the uncoiler 202 can include a heater, such as a heated arbor, sufficient to maintain the temperature of the metal strip 224 while the metal strip 224 is in the metal coil 204.

[0063] The uncoiled metal strip 224 can pass through a set of preheaters 246 before passing through a set of quenching zones 212. As depicted in FIG. 2, the preheaters 246 are magnetic rotors that rotate and generate a changing magnetic field through the metal strip 224 sufficient to increase a temperature of the metal strip 224 to a target temperature. In some cases, however, other types of preheaters 246 can be used, such as direct flame heaters, infrared heaters, hot air blowers, or other heaters.

[0064] After being heated to a consistent target temperature, the metal strip 224 can be passed through the set of quenching zones 212. Each of the set of quenching zones can comprise an upper spray header 214 and a lower spray header 216. Each spray header 214, 216 can itself comprise one or more ports through which coolant is directed towards the metal strip. The rate of coolant flow can be controlled. The rate of coolant flow can be sufficient to reduce the temperature of the metal strip 224 by at least 100 °C/s or 200 °C/s.

[0065] In some cases, a steam reclamation module 242 can be positioned adjacent the set of quenching zones 212 to capture steam from areas near one or more of the set of quenching zones and redirect the steam towards the metal strip 224 at a location further downstream. As depicted in FIG. 2, the steam reclamation module 242 comprises ductwork configured to capture and redirect steam towards the metal strip 224, however this need not always be the case. For example, in some cases, a steam reclamation module 242 can carry steam away from the metal strip 224, through a blower, and back towards the metal strip 224. In some cases, however, the steam reclamation module 242 can collect and/or redirect steam away from the metal coil 204 to help prevent staining of the metal strip 224 still on the metal coil 204.

[0066] After passing through the set of quenching zones 212, the metal strip 224 can pass by air knives 218 that blow excess coolant off the top of the metal strip 224. In some cases, an optional squeegee 222 can be used to further remove excess coolant. In some cases, a wiper 220 can be used to remove excess coolant from the bottom of the metal strip 224. In some cases, the wiper 220 can be an ultra-compliant wiper.

[0067] After coolant has been removed from the metal strip 224, the metal strip 224 can pass through a bridle zone 226. In the bridle zone 226, the metal strip 224 can wrap around outer bridle rolls 230 and an inner bridle roll 232 to impart a desired amount of tension on the metal strip 224 downstream of the bridle zone 226, without imparting additional tension on the metal strip 224 upstream of the bridle zone 226. In some cases, devices other than or in addition to bridle rolls 230, 232 can be used to impart the necessary tension onto the metal strip 224. As depicted in FIG. 2, the bridle rolls 230, 232 are in an operating position. To easily thread the bridle zone 226, the inner bridle roll 232 can be raised and the metal strip 224 can be passed above the outer bridle rolls 230 and below the inner bridle roll 232. Then, the inner bridle roll 232 can be moved back down to the position seen in FIG. 2 to engage the metal strip 224 and enter the operating position.

[0068] In some cases, the metal strip 224 can optionally pass through a lubricator 234 to apply lubricant to the metal strip 224, such as to lubricate the metal strip 224 in advance of rolling the metal strip 224.

[0069] In some cases, the metal strip 224 can be directed to downstream equipment, such as a roll stack 224 of a rolling mill. The downstream equipment can be any suitable downstream equipment, such as downstream equipment that requires an amount of back-tension that is greater than the yield strength of the metal strip 224 at the temperatures of the hot coil 204, or downstream equipment that requires the metal strip 224 be at a temperature below that of the hot coil 204. Thus, the system 200 can enable a hot coil 204 to be fed into downstream equipment previously unusable with hot coils 204.

[0070] As depicted in FIG. 2, the metal strip 224 entering the downstream equipment is at a warm or cold temperature, such as a temperature below the recrystallization temperature of the metal strip 224. In some case, the metal coil 240 is at room temperature. In some cases, the metal strip 224 entering the downstream equipment is at a temperature suitable for warm or cold rolling.

[0071] FIG. 3 is a schematic block diagram of a rapid quench line 300 according to certain aspects of the present disclosure. Rapid quench line 300 can be systems 100, 200 of FIGs. 1, 2. The metal strip 324 moves downstream through the rapid quench line 300, from left-to-right as depicted in FIG. 3.

[0072] An uncoiler 302 can accept a hot metal coil (e.g., a metal coil at or above recrystallization temperature) and uncoil the metal strip 324 from the hot coil with low tension. The uncoiler 302 can rely on gravity to pay-off the metal strip 324. In some cases, the uncoiler 302 can include a non-contacting hold-down device 308 suitable to apply force to the metal coil to facilitate pay-off of the metal strip 324.

[0073] An optional non-contacting heater 346 can be positioned downstream of the uncoiler 302. The non-contacting heater 346 (e.g., preheater, such as preheater 246 of FIG. 2) can be any suitable device for heating the metal strip 324 prior to quenching, such as a magnetic rotor heater. A magnetic rotor heater can comprise a set of permanent magnets disposed on a rotor, which, when spun, can impart a temperature increase on an adjacent metal strip.

[0074] A set of quenching zones 312 can be positioned downstream of the uncoiler 302 and optional non-contacting heater 346. Each quenching zone can comprise one or more spray headers positioned to dispense coolant on the metal strip 324. In some cases, an optional steam reclamation module 342 can be positioned to collect steam from one or more of the set of quenching zones and redirect the steam towards the metal strip 324 to facilitate cooling the metal strip 324, especially when the temperature of the metal strip 324 is at or below the Leidenfrost point.

[0075] A coolant removal zone 318 can be positioned downstream of the set of quenching zones. The coolant removal zone 318 can comprise any equipment suitable for removing coolant from the metal strip 324. In some cases, the coolant removal zone 318 can comprise one or more air knives. In some cases, the coolant removal zone 318 can comprise one or more squeegees. In some cases, the coolant removal zone 318 can comprise one or more wipers (e.g., ultra-compliant wipers).

[0076] A bridle zone 326 can be positioned downstream of the coolant removal zone 318. The bridle zone 326 can comprise a set of bridle rolls about which the metal strip 324 can be partially wrapped to achieve a downstream tension in the metal strip 324 (e.g., a tension downstream of the bridle zone 326). In some cases, the bridle zone 326 can comprise easy-threading bridle rolls.

[0077] In some cases, an optional lubricator 334 can be positioned downstream of the bridle zone 326 to impart lubrication on the metal strip prior to reaching the downstream equipment 338.

[0078] The metal strip 324 can reach downstream equipment 338 for further processing or storage. In some cases, the downstream equipment 338 can comprise a coiler. In some cases, the downstream equipment 338 can comprise other equipment, such as warm or cold rolling mills. By the time the metal strip 324 reaches the downstream equipment 338, the metal strip will have cooled to a temperature below the recrystallization point and will have tension imparted thereon (e.g., more tension than suitable for the hot coil at the uncoiler 302).

[0079] FIG. 4 is a combination schematic block diagram 400 and temperature graph 401 depicting relative temperatures of a metal strip 424 passing through a rapid quench line according to certain aspects of the present disclosure. The metal strip 424 moves downstream through the rapid quench line, from left-to-right as depicted in FIG. 4. Block diagram 400 can be a diagram of the rapid quench line 300 of FIG. 3. The temperature graph 401 is a relative graph for illustrative purposes only and is not intended to be to scale. The block diagram 400 and temperature graph 401 are vertically aligned to depict the approximate relative temperatures of the metal strip 424 as it passes through the various components of the rapid quench line depicted in the block diagram 400.

[0080] At the uncoiler 402, the metal strip 424 can have a temperature that is considered hot, such as a temperature at or above the recrystallization temperature 457 of the metal strip 424. In some cases, the uncoiler 402 can receive a hot coil at various initial temperatures 450. In some cases, integrated heating and/or insulation in the uncoiler 402 can help maintain the initial temperature 450 of the metal strip 424.

[0081] In some cases, an optional non-contacting heater 446 can impart additional heating designed to raise the temperature of the metal strip 424 to a target temperature 456, despite the initial temperature 450 of the hot coil. In some cases, the non-contacting hold-down device 408 can impart some amount of heat into the metal strip 424, although that need not be the case.

[0082] Within the set of quenching zones 412, and number of quenching zones can be used to rapidly quench the metal strip 424. As depicted in FIG. 4, four quenching zones 458, 460, 462, 464 are shown, although any number of zones can be used. In some cases, when an optional steam reclamation module 442 is used, the steam reclamation module 442 can collect steam from upstream quenching zone(s), such as first quenching zone 458 and second quenching zone 460, and redirect the steam and/or humid air towards the metal strip 424 at a location downstream of where the steam was collected. In some cases, the steam reclamation module 442 can redirect the steam towards the metal strip 424 before, during, or after subsequent quenching zones (e.g., third quenching zone 462 and fourth quenching zone 464). In some cases, the steam reclamation module 442 can redirect the steam towards the metal strip 424 at a location 468 where the metal strip 424 is about to, is currently, or has already dropped below the Leidenfrost point 470.

[0083] After the set of quenching zones 412, the temperature of the metal strip 424 can be at a warm or cold temperature. The temperature of the metal strip 424 may not change significantly after the set of quenching zones 412, such as when passing through the coolant removal zone 418, bridle zone 426, optional lubricator 434, or downstream equipment 438; although in some cases the temperature of the metal strip 424 may slowly approach room temperature or ambient temperature. In some cases, the temperature of the metal strip 424 after the set of quenching zones 412 can be known as a cooled temperature 472.

[0084] FIG. 5 is a schematic side view of a steam reclamation module 542 on a rapid quench line 500 according to certain aspects of the present disclosure. FIG. 5 depicts a portion of a rapid quench line 500 located between an uncoiler and a bridle zone. The rapid quench line 500 can be rapid quench line 300 of FIG. 3.

[0085] As the metal strip 524 passes from left to right in a downstream direction, the metal strip can pass through several quenching zones 558, 560, 562, 564, 566. Each quenching zone can comprise spray headers 514 that dispense coolant 574 onto the metal strip 524. Coolant extract heat from the metal strip 524, especially near the first one, two, or several quenching zones (e.g., quenching zones 558, 560, 562) will generate a substantial amount of steam 576.

[0086] A steam reclamation module 542 can be positioned to capture steam 576 and redirect the steam 576 back onto the metal strip 524. In some cases, the steam reclamation module 542 can comprise a hood 578 for collecting the steam and ductwork 580 for redirecting the steam towards the metal strip 524. In some cases, the steam reclamation module 542 can comprise an optional blower 582 that facilitates moving the steam 576 towards the metal strip 524 (e.g., towards the end of the ductwork 580 opposite the hood 578.

[0087] As depicted in FIG. 5, the steam reclamation module 542 redirects the steam 576 back to the metal strip 524 at a location downstream of the first three quenching zones 558, 560, 562 and upstream of the last two quenching zones 564, 566, although this need not always be the case. The steam reclamation module 542 can instead redirect steam 576 to the metal strip 524 at any suitable location, including upstream or downstream of the location where the steam 576 is collected. However, it has been determined that redirecting steam 576 to the metal strip 524 adjacent to, at, and/or immediately after a location 568 where the temperature of the metal strip 524 is at or below the Leidenfrost point can be especially useful.

[0088] Also depicted in FIG. 5 is a set of air knives 518 positioned above the metal strip 524 to direct air 584 onto the surface of the metal strip 524 to remove coolant from the metal strip 524.

[0089] FIG. 6 is a schematic top view of a non-contacting hold-down roll 608 comprising a magnetic rotor 690 according to certain aspects of the present disclosure. In some cases, the non-contacting hold-down roll 608 can be a magnetic rotor 690. While any suitable magnetic rotor can be used, it has been determined that a magnetic rotor 690 with a chevron pattern of magnetic poles can be especially suitable for imparting consistent (e.g., non-fluctuating) tension on the metal strip, thus minimizing the risk of damaging the fragile hot coil.

[0090] The chevron pattern depicted in FIG. 6 shows alternating north poles 686 and south poles 688 distributed across the width and circumference of the magnetic rotor 690. In some cases, the chevron pattern is configured such that for all points along the rotation of the magnetic rotor 690, the magnetic rotor 690 will always be presenting at or approximately the same amount of magnetic flux to the metal strip. The chevron pattern can vary in overlap, gap, angle of attack, and other characteristics. In some cases, the magnetic rotor 690 is configured to rotate in the direction of the chevron patter (e.g., from the top of the page to the bottom of the page as depicted in FIG. 6), although that need not always be the case. In some cases, other types of patterns are used to achieve a consistent tension on the metal strip.

[0091] FIG. 7 is a flowchart depicting a process 700 for rapidly quenching a hot metal coil according to certain aspects of the present disclosure. In some cases, process 700 can use the systems 100, 200 of FIGs. 1, 2 or the rapid quench line 300 of FIG. 3.

[0092] At block 702, hot metal coil is unwound. Unwinding of the hot metal coil is performed by a low-tension unwinder. In some cases, unwinding the hot metal coil further comprises applying non-contacting hold-down force to the metal coil through a non-contacting hold-down device. In some cases, unwinding the hot metal coil comprises permitting the metal strip to pay-off from the metal coil through the use of gravity.

[0093] At optional block 706, the metal strip can be heated (e.g., preheated) to a target temperature. In some cases, if the hot metal coil is already at the target temperature, not preheating is necessary.

[0094] At block 708, the metal strip can be rapidly quenched. Rapid quenching can comprise lowering the temperature of the metal strip at a rate of at or at least 100 °C/s or 200 °C/s. Rapid quenching can involve dispensing coolant to the metal strip using one or more spray headers. In some cases, rapidly quenching the metal strip at block 708 can further include one or more of optional blocks 710, 712, 714. At block 710, steam from one or more quenching zones can be collected. At block 712, the metal strip can be quenched to a temperature below the Leidenfrost point. At block 714, steam collected from block 710 can be redirected to the metal strip. In some cases, block 714 can occur without block 712 first occurring. However, in some cases, block 714 occurs only after the metal strip has reached a temperature below the Leidenfrost point at block 712.

[0095] In some cases, quenching the metal strip at block 708 can comprise receiving flatness information (e.g., from a downstream flatness measurement device, such as a deflection roll) and adjusting the dispensing of coolant from the spray headers to achieve a desired flatness.

[0096] At block 716, coolant is removed from the metal strip. In some cases, removing coolant from the metal strip can comprise using any combination of air knives, squeegees, wipers (e.g., ultra-compliant wipers), or other coolant-removing devices.

[0097] At block 718, tension is applied to the metal strip. Tension applied to the metal strip at block 718 can be downstream tension, such that the tension does not carry up through the hot roll at the uncoiler, but rather carries through to the downstream equipment. Applying tension at block 718 can comprise passing the metal strip through bridle rolls of a bridle zone to impart tension into the metal strip.

[0098] At optional block 720, lubrication can be optionally applied to the metal strip.

[0099] The metal strip can proceed downstream to any suitable downstream equipment. In some cases, the downstream equipment can be a coiler, in which case the metal strip can be coiled at block 722. The resultant metal coil will be a warm metal coil or a cold metal coil. In some cases, other downstream equipment may be used, in which case the metal strip may undergo other downstream processing, such as warm rolling or cold rolling.

[0100] The foregoing description of the embodiments, including illustrated embodiments, has been presented only for the purpose of illustration and description and is not intended to be exhaustive or limiting to the precise forms disclosed. Numerous modifications, adaptations, and uses thereof will be apparent to those skilled in the art.

[0101] A collection of exemplary embodiments are provided below, including at least some explicitly enumerated as "Illustrations" providing additional description of a variety of example embodiments in accordance with the concepts described herein. These illustrations are not meant to be mutually exclusive, exhaustive, or restrictive; and the disclosure not limited to these example illustrations but rather encompasses all possible modifications and variations within the scope of the issued claims.

[0102] Illustration 1 is a system, comprising: a low-tension unwinding unit for receiving and unwinding a metal coil of metal strip; a non-contacting hold-down device positioned adjacent the low-tension unwinding unit to provide force on the metal strip towards the center of the metal coil during unwinding of the metal coil; a set of quenching zones for cooling the metal strip, wherein the set of quenching zones provides sufficient coolant to reduce a temperature of the metal strip by a rate of at least 100 °C per second; a coolant removal unit positioned downstream of the set of quenching zones; and a bridle unit positioned downstream of the coolant removal unit for increasing tension in the metal strip.

[0103] Illustration 2 is the system of any preceding or subsequent illustration or combination of illustrations, wherein the low-tension unwinding unit comprises insulation disposed to retain heat within coiled portions of the metal coil.

[0104] Illustration 3 is the system of any preceding or subsequent illustration or combination of illustrations, wherein the low-tension unwinding unit comprises a heat source for providing heat to coiled portions of the metal coil, wherein the heat source is coupled to a controller for maintaining the metal coil at or above a threshold temperature.

[0105] Illustration 4 is the system of any preceding or subsequent illustration or combination of illustrations, wherein the non-contacting hold-down device comprises one or more magnets for generating a changing magnetic field through the metal strip.

[0106] Illustration 5 is the system of any preceding or subsequent illustration or combination of illustrations, wherein the changing magnetic field is configured distribute the force over time across a width of the metal strip.

[0107] Illustration 6 is the system of any preceding or subsequent illustration or combination of illustrations, wherein the non-contacting hold-down device comprises a nozzle for blowing heated air against the metal strip.

[0108] Illustration 7 is the system of any preceding or subsequent illustration or combination of illustrations, further comprising: a flatness measurement unit positioned to measure a flatness of the metal strip; and a controller coupled to the flatness measurement unit and the set of quenching zones to adjust delivery of the coolant based on measured flatness of the metal strip.

[0109] Illustration 8 is the system of any preceding or subsequent illustration or combination of illustrations, further comprising a stabilization system positioned upstream of the set of quenching zones to introduce a wave into the metal strip.

[0110] Illustration 9 is the system of any preceding or subsequent illustration or combination of illustrations, wherein the metal strip remains supported without mechanical contact between the metal coil and the coolant removal unit.

[0111] Illustration 10 is the system of any preceding or subsequent illustration or combination of illustrations, wherein the set of quenching zones comprises a steam reclamation module for redirecting humid air from at least one of the set of quenching zones to the metal strip at a location downstream of the at least one of the set of quenching zones.

[0112] Illustration 11 is the system of any preceding or subsequent illustration or combination of illustrations, wherein the location downstream of the at least one of the set of quenching zones is a location where the temperature of the metal strip is at or below a Leidenfrost point.

[0113] Illustration 12 is the system of any preceding or subsequent illustration or combination of illustrations, further comprising: a pre-quench heating unit positioned downstream of the low-tension unwinding unit; and a controller coupled to the pre-quench heating unit to heat the metal strip to a target temperature prior to the metal strip entering the set of quenching zones.

[0114] Illustration 13 is the system of any preceding or subsequent illustration or combination of illustrations, wherein the non-contacting hold-down device is positioned to provide the force on the metal strip at a location at or adjacent to where the metal strip falls away from the metal coil due to gravity.

[0115] Illustration 14 is a method, comprising: unwinding a hot metal coil using a low-tension unwinder, wherein unwinding the hot metal coil comprises applying a non-contacting hold-down force to the hot metal coil and permitting metal strip of the hot metal coil to fall away from the metal coil; rapidly quenching the metal strip in a set of quenching zones, wherein rapidly quenching the metal strip comprises applying coolant to the metal strip to reduce a temperature of the metal strip at a rate of at least 100 °C per second; removing the coolant from the metal strip; and applying downstream tension to the metal strip.

[0116] Illustration 15 is the method of any preceding or subsequent illustration or combination of illustrations, further comprising maintaining an initial temperature of the hot metal coil at the low-tension unwinder.

[0117] Illustration 16 is the method of any preceding or subsequent illustration or combination of illustrations, further comprising preheating the metal strip immediately prior to rapidly quenching the metal strip.

[0118] Illustration 17 is the method of any preceding or subsequent illustration or combination of illustrations, wherein applying the non-contacting hold-down force comprises generating a changing magnetic field through the metal strip.

[0119] Illustration 18 is the method of any preceding or subsequent illustration or combination of illustrations, wherein applying the non-contacting hold-down force comprises blowing heated air against the metal strip.

[0120] Illustration 19 is the method of any preceding or subsequent illustration or combination of illustrations, further comprising: measuring flatness of the metal strip; and adjusting delivery of the coolant based on the measured flatness.

[0121] Illustration 20 is the method of any preceding or subsequent illustration or combination of illustrations, further comprising inducing a wave in the metal strip without contacting the metal strip.

[0122] Illustration 21 is the method of any preceding or subsequent illustration or combination of illustrations, further comprising: capturing steam from at least one of the quenching zones; and redirecting the captured steam towards the metal strip.

[0123] Illustration 22 is the method of any preceding or subsequent illustration or combination of illustrations, wherein redirecting the captured steam comprises redirecting the capture steam towards the metal strip at a location where a temperature of the metal strip is at or below the Leidenfrost point.

Claims

1. A system, comprising:

a low-tension unwinding unit for receiving and

unwinding a metal coil of metal strip;
a non-contacting hold-down device positioned adjacent the low-tension unwinding unit to provide force on the metal strip towards the center of the metal coil during unwinding of the metal coil;
a set of quenching zones for cooling the metal strip, wherein the set of quenching zones provides sufficient coolant to reduce a temperature of the metal strip by a rate of at least 30 °C per second;
a coolant removal unit positioned downstream of the set of quenching zones; and
a bridle unit positioned downstream of the coolant removal unit for increasing tension in the metal strip.

2. The system of claim 1, wherein the low-tension unwinding unit comprises insulation disposed to retain heat within coiled portions of the metal coil and/or a heat source for providing heat to coiled portions of the metal coil, wherein the heat source is coupled to a controller for maintaining the metal coil at or above a threshold temperature.

3. The system of claim 1 or 2, wherein the non-contacting hold-down device comprises one or more magnets for generating a changing magnetic field through the metal strip, wherein the changing magnetic field is preferably configured to distribute the force over time across a width of the metal strip.

4. The system of any one of claims 1 to 3, wherein the non-contacting hold-down device comprises a nozzle for blowing heated air against the metal strip.

5. The system of any one of claims 1 to 4, further comprising:

a flatness measurement unit positioned to measure a flatness of the metal strip; and
a controller coupled to the flatness measurement unit and the set of quenching zones to adjust delivery of the coolant based on measured flatness of the metal strip.

6. The system of any one of claims 1 to 5, further comprising a stabilization system positioned upstream of the set of quenching zones to introduce a wave into the metal strip, and/or wherein the metal strip remains supported without mechanical contact between the metal coil and the coolant removal unit.

7. The system of any one of claims 1 to 6, wherein the set of quenching zones comprises a steam reclamation module for redirecting humid air from at least one of the set of quenching zones to the metal strip at a location downstream of the at least one of the set of quenching zones, and/or wherein the location downstream of the at least one of the set of quenching zones is a location where the temperature of the metal strip is at or below a Leidenfrost point.

8. The system of any one of claims 1 to 7, further comprising:

a pre-quench heating unit positioned downstream of the low-tension unwinding unit; and
a controller coupled to the pre-quench heating unit to heat the metal strip to a target temperature prior to the metal strip entering the set of quenching zones.

9. The system of any one of claims 1 to 8, wherein the non-contacting hold-down device is positioned to provide the force on the metal strip at a location at or adjacent to where the metal strip falls away from the metal coil due to gravity.

10. A method, comprising:

unwinding a hot metal coil using a low-tension unwinder, wherein unwinding the hot metal coil comprises applying a non-contacting hold-down force to the hot metal coil and permitting metal strip of the hot metal coil to fall away from the metal coil;
rapidly quenching the metal strip in a set of quenching zones, wherein rapidly quenching the metal strip comprises applying coolant to the metal strip to reduce a temperature of the metal strip at a rate of at least 100 °C per second;
removing the coolant from the metal strip; and
applying downstream tension to the metal strip.

11. The method of claim 10, further comprising maintaining an initial temperature of the hot metal coil at the low-tension unwinder and/or preheating the metal strip immediately prior to rapidly quenching the metal strip.

12. The method of claim 10 or 11, wherein applying the non-contacting hold-down force comprises generating a changing magnetic field through the metal strip and/or blowing heated air against the metal strip.

13. The method of any one of claims 10 to 12, further comprising:

measuring flatness of the metal strip; and
adjusting delivery of the coolant based on the measured flatness.

14. The method of any one of claims 10 to 13, further comprising inducing a wave in the metal strip without contacting the metal strip.

15. The method of any one of claims 10 to 14, further comprising:

capturing steam from at least one of the quenching zones; and
redirecting the captured steam towards the metal strip,
wherein redirecting the captured steam preferably comprises redirecting the capture steam towards the metal strip at a location where a temperature of the metal strip is at or below a Leidenfrost point.

Patentansprüche

1. System, umfassend:

eine Abwickeleinheit mit niedriger Spannung zum Aufnehmen und Abwickeln einer Metallspule aus Metallband;
eine berührungslose Niederhaltevorrichtung, die neben der Abwickeleinheit mit niedriger Spannung so angeordnet ist, dass sie während des Abwickelns der Metallspule Kraft auf das Metallband in Richtung der Mitte der Metallspule ausübt;
einen Satz an Abschreckzonen zum Kühlen des Metallbandes, wobei der Satz an Abschreckzonen ausreichend Kühlmittel bereitstellt, um eine Temperatur des Metallbandes um eine Rate von mindestens 30 °C pro Sekunde zu reduzieren;
eine Einheit zum Entfernen von Kühlmittel, die stromabwärts des Satzes an Abschreckzonen angeordnet ist; und
eine Brückeneinheit, die stromabwärts der Einheit zum Entfernen von Kühlmittel angeordnet ist, um Spannung in dem Metallband zu erhöhen.

2. System nach Anspruch 1, wobei die Abwickeleinheit mit niedriger Spannung eine Isolierung umfasst, die so angeordnet ist, dass sie Wärme innerhalb aufgewickelter Abschnitte der Metallspule zurückhält und/oder eine Wärmequelle, um aufgewickelte Abschnitte der Metallspule mit Wärme zu versorgen, wobei die Wärmequelle mit einem Regler verbunden ist, um die Metallspule bei oder über einer Schwellentemperatur zu halten.

3. System nach Anspruch 1 oder 2, wobei die berührungslose Niederhaltevorrichtung einen oder mehrere Magnete zum Erzeugen eines sich ändernden Magnetfeldes durch das Metallband umfasst, wobei das sich ändernde Magnetfeld vorzugsweise dazu konfiguriert ist, die Kraft im Laufe der Zeit über eine Breite des Metallbandes zu verteilen.

4. System nach einem der Ansprüche 1 bis 3, wobei die berührungslose Niederhaltevorrichtung eine Düse zum Blasen von erwärmter Luft gegen das Metallband umfasst.

5. System nach einem der Ansprüche 1 bis 4, ferner umfassend:

eine Einheit zum Messen der Flachheit, die so angeordnet ist, dass sie eine Flachheit des Metallbandes misst; und
einen Regler, der mit der Einheit zum Messen der Flachheit und dem Satz an Abschreckzonen gekoppelt ist, um eine Zufuhr des Kühlmittels auf der Grundlage gemessener Flachheit des Metallbandes einzustellen.

6. System nach einem der Ansprüche 1 bis 5, ferner umfassend ein Stabilisierungssystem, das stromaufwärts von dem Satz an Abschreckzonen angeordnet ist, um eine Welle in das Metallband einzubringen, und/oder wobei das Metallband ohne mechanischen Kontakt zwischen der Metallspule und der Einheit zum Entfernen von Kühlmittel weiterhin gehalten wird.

7. System nach einem der Ansprüche 1 bis 6, wobei der Satz von Abschreckzonen ein Dampfrückgewinnungsmodul umfasst, um feuchte Luft aus mindestens einem Satz an Abschreckzonen zu dem Metallband an einer Stelle stromabwärts des mindestens einen Satzes an Abschreckzonen umzuleiten, und/oder wobei die Stelle stromabwärts des mindestens einen Satzes an Abschreckzonen eine Stelle ist, an der die Temperatur des Metallbandes bei oder unter einem Leidenfrost-Punkt liegt.

8. System nach einem der Ansprüche 1 bis 7, ferner umfassend:

eine Vorabschreckheizeinheit, die stromabwärts der Abwickeleinheit mit niedriger Spannung angeordnet ist; und
einen Regler, der mit der Vorabschreckheizeinheit gekoppelt ist, um das Metallband auf eine Zieltemperatur zu erwärmen, bevor das Metallband in den Satz an Abschreckzonen eintritt.

9. System nach einem der Ansprüche 1 bis 8, wobei die berührungslose Niederhaltevorrichtung so angeordnet ist, dass sie die Kraft auf das Metallband an einer Stelle oder in der Nähe einer Stelle ausübt, an der das Metallband aufgrund von Schwerkraft von der Metallspule abfällt.

10. Verfahren, umfassend:

Abwickeln einer heißen Metallspule unter Ver-

wendung eines Abwicklers mit niedriger Spannung, wobei Abwickeln der heißen Metallspule Aufbringen einer berührungslosen Niederhaltekraft auf die heiße Metallspule und Zulassen, dass das Metallband der heißen Metallspule von der Metallspule abfällt, umfasst;
schnelles Abschrecken des Metallbandes in einem Satz von Abschreckzonen, wobei schnelles Abschrecken des Metallbandes Aufbringen von Kühlmittel auf das Metallband umfasst, um eine Temperatur des Metallbandes mit einer Rate von mindestens 100 °C pro Sekunde zu verringern;
Entfernen des Kühlmittels von dem Metallband, und
Aufbringen einer stromabwärts-gerichteten Spannung auf das Metallband.

11. Verfahren nach Anspruch 10, ferner umfassend Aufrechterhalten einer Anfangstemperatur der heißen Metallspule an dem Abwickler mit niedriger Spannung und/oder Vorheizen des Metallbandes unmittelbar vor einem schnellen Abschrecken des Metallbandes.

12. Verfahren nach Anspruch 10 oder 11, wobei Aufbringen der berührungslosen Niederhaltekraft Erzeugen eines sich ändernden Magnetfeldes durch das Metallband und/oder Blasen erwärmter Luft gegen das Metallband umfasst.

13. Verfahren nach einem der Ansprüche 10 bis 12, ferner umfassend:

Messen der Flachheit des Metallbandes; und
Einstellen einer Zufuhr des Kühlmittels auf der Grundlage der gemessenen Flachheit.

14. Verfahren nach einem der Ansprüche 10 bis 13, ferner umfassend Erzeugen einer Welle in dem Metallband ohne das Metallband zu berühren.

15. Verfahren nach einem der Ansprüche 10 bis 14, ferner umfassend:

Auffangen von Dampf aus mindestens einer der Abschreckzonen; und
Umlenken des aufgefangenen Dampfes in Richtung des Metallbandes,
wobei Umlenken des aufgefangenen Dampfes vorzugsweise Umlenken des aufgefangenen Dampfes in Richtung des Metallbandes an einer Stelle umfasst, an der eine Temperatur des Metallbandes bei oder unter einem Leidenfrost-Punkt liegt.

Revendications

1. Système, comprenant :

une unité de déroulement à faible tension destinée à recevoir et à dérouler une bobine de métal de bande de métal ;
un dispositif de retenue sans contact positionné adjacent à l'unité de déroulement à faible tension pour appliquer une force à la bande de métal en direction du centre de la bobine de métal pendant un déroulement de la bobine de métal ;
un ensemble de zones de trempe destiné à refroidir la bande de métal, dans lequel l'ensemble de zones de trempe fournit suffisamment d'agent de refroidissement pour réduire une température de la bande de métal à une vitesse d'au moins 30 °C par seconde ;
une unité de retrait d'agent de refroidissement positionnée en aval de l'ensemble de zones de trempe ; et
une unité tendeur positionnée en aval de l'unité de retrait d'agent de refroidissement destinée à augmenter une tension dans la bande de métal.

2. Système selon la revendication 1, dans lequel l'unité de déroulement à faible tension comprend une isolation disposée pour retenir de la chaleur à l'intérieur de parties bobinées de la bobine de métal et/ou une source de chaleur destinée à fournir de la chaleur à des parties bobinées de la bobine de métal, dans lequel la source de chaleur est couplée à un contrôleur destiné à maintenir la bobine de métal à une température égale ou supérieure à une température seuil.

3. Système selon la revendication 1 ou 2, dans lequel le dispositif de retenue sans contact comprend un ou plusieurs aimants destinés à générer un champ magnétique variable à travers la bande de métal, dans lequel le champ magnétique variable est de préférence conçu pour répartir la force dans le temps sur une largeur de la bande de métal.

4. Système selon l'une quelconque des revendications 1 à 3, dans lequel le dispositif de retenue sans contact comprend une buse destinée à souffler de l'air chauffé contre la bande de métal.

5. Système selon l'une quelconque des revendications 1 à 4, comprenant en outre :

une unité de mesure de planéité positionnée pour mesurer une planéité de la bande de métal ; et
un organe de commande couplé à l'unité de mesure de planéité et à l'ensemble de zones de trempe pour régler la distribution de l'agent de

refroidissement sur la base de la planéité mesurée de la bande de métal.

6. Système selon l'une quelconque des revendications 1 à 5, comprenant en outre un système de stabilisation positionné en amont de l'ensemble de zones de trempe pour introduire une onde dans la bande de métal, et/ou dans lequel la bande de métal demeure supportée sans contact mécanique entre la bobine de métal et l'unité de retrait d'agent de refroidissement.

7. Système selon l'une quelconque des revendications 1 à 6, dans lequel l'ensemble de zones de trempe comprend un module de récupération de vapeur destiné à rediriger de l'air humide d'au moins une zone de l'ensemble de zones de trempe vers la bande de métal à un emplacement situé en aval de l'au moins une zone de l'ensemble de zones de trempe, et/ou dans lequel l'emplacement situé en aval de l'au moins une zone de l'ensemble de zones de trempe est un emplacement au niveau duquel la température de la bande de métal est une température égale ou inférieure à un point de Leidenfrost.

8. Système selon l'une quelconque des revendications 1 à 7, comprenant en outre :

une unité de préchauffe de trempe positionnée en aval de l'unité de déroulement à faible tension ; et
un organe de commande couplé à l'unité de préchauffe de trempe pour chauffer la bande de métal à une température cible avant que la bande de métal n'entre dans l'ensemble de zones de trempe.

9. Système selon l'une quelconque des revendications 1 à 8, dans lequel le dispositif de retenue sans contact est positionné pour appliquer la force à la bande de métal à un emplacement au niveau duquel, ou adjacent auquel, la bande de métal tombe à l'écart de la bobine de métal du fait de la gravité.

10. Procédé comprenant :

dérouler une bobine de métal chaud au moyen d'un dispositif de déroulement à faible tension, dans lequel le déroulement de la bobine de métal chaud consiste à appliquer une force de retenue sans contact à la bobine de métal chaud et à laisser tomber une bande de métal de la bobine de métal chaud à l'écart de la bobine de métal ;
tremper rapidement la bande de métal dans un ensemble de zones de trempe, dans lequel la trempe rapide de la bande de métal consiste à appliquer un agent de refroidissement à la bande de métal pour réduire une température de la bande de métal à une vitesse d'au moins 100 °C par seconde ;
retirer l'agent de refroidissement de la bande de métal ; et
appliquer une tension en aval à la bande de métal.

11. Procédé selon la revendication 10, comprenant en outre :
maintenir une température initiale de la bobine de métal chaud au niveau du dispositif de déroulement à faible tension et/ou préchauffer la bande de métal immédiatement avant la trempe rapide de la bande de métal.

12. Procédé selon la revendication 10 ou 11, dans lequel l'application de la force de retenue sans contact consiste à générer un champ magnétique variable à travers la bande de métal et/ou à souffler de l'air chauffé contre la bande de métal.

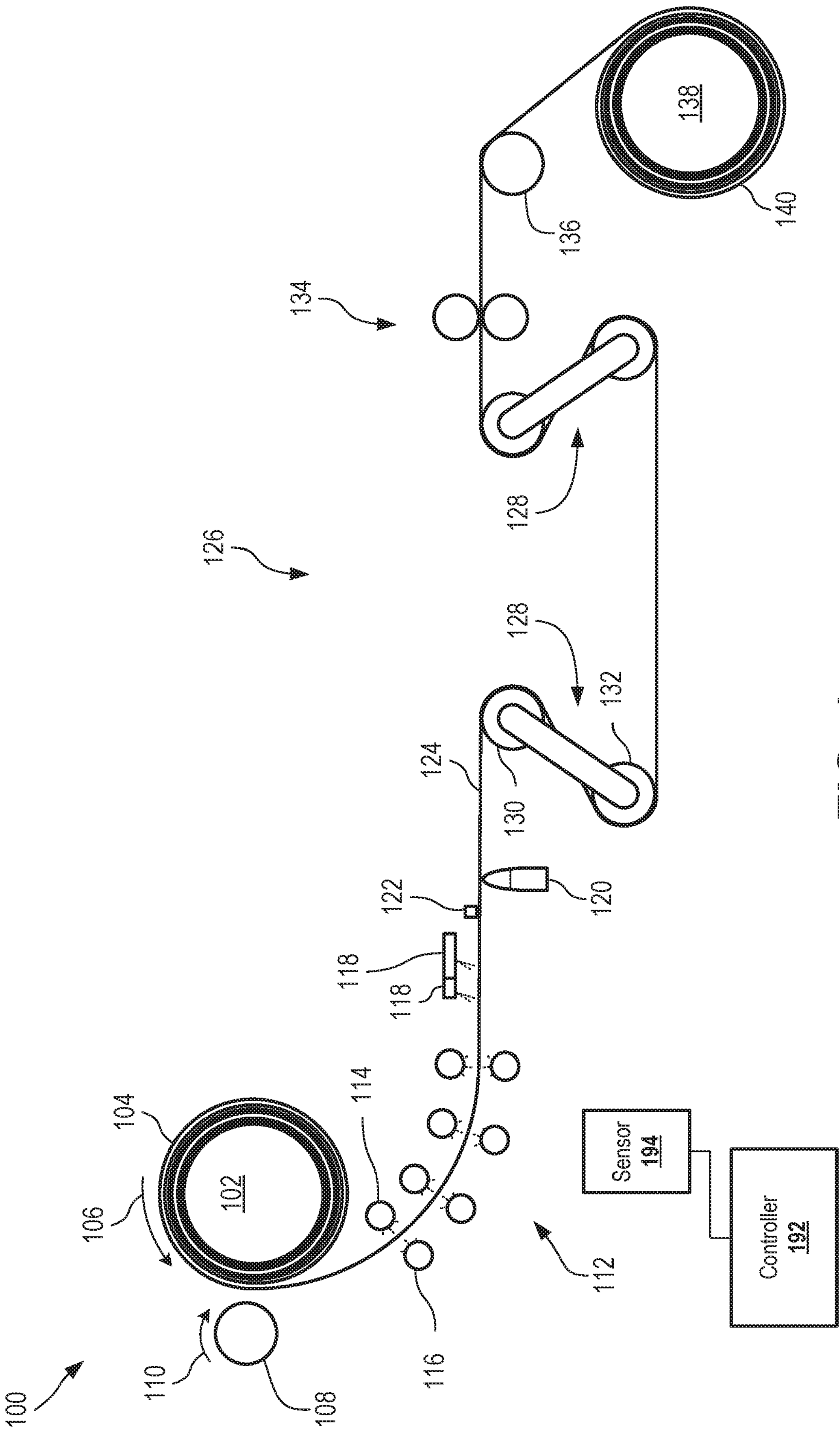
13. Procédé selon l'une quelconque des revendications 10 à 12, comprenant en outre :

mesurer une planéité de la bande de métal ; et
régler une distribution de l'agent de refroidissement sur la base de la planéité mesurée.

14. Procédé selon l'une quelconque des revendications 10 à 13, comprenant en outre :
induire une onde dans la bande de métal sans entrer en contact avec la bande de métal.

15. Procédé selon l'une quelconque des revendications 10 à 14, comprenant en outre :

capturer de la vapeur à partir d'au moins une zone des zones de trempe ; et
rediriger la vapeur capturée en direction de la bande de métal,
dans lequel le fait de rediriger la vapeur capturée consiste de préférence à rediriger la vapeur capturée en direction de la bande de métal au niveau d'un emplacement auquel une température de la bande de métal est égale ou inférieure à un point de Leidenfrost.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104
106
108
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112
114
116
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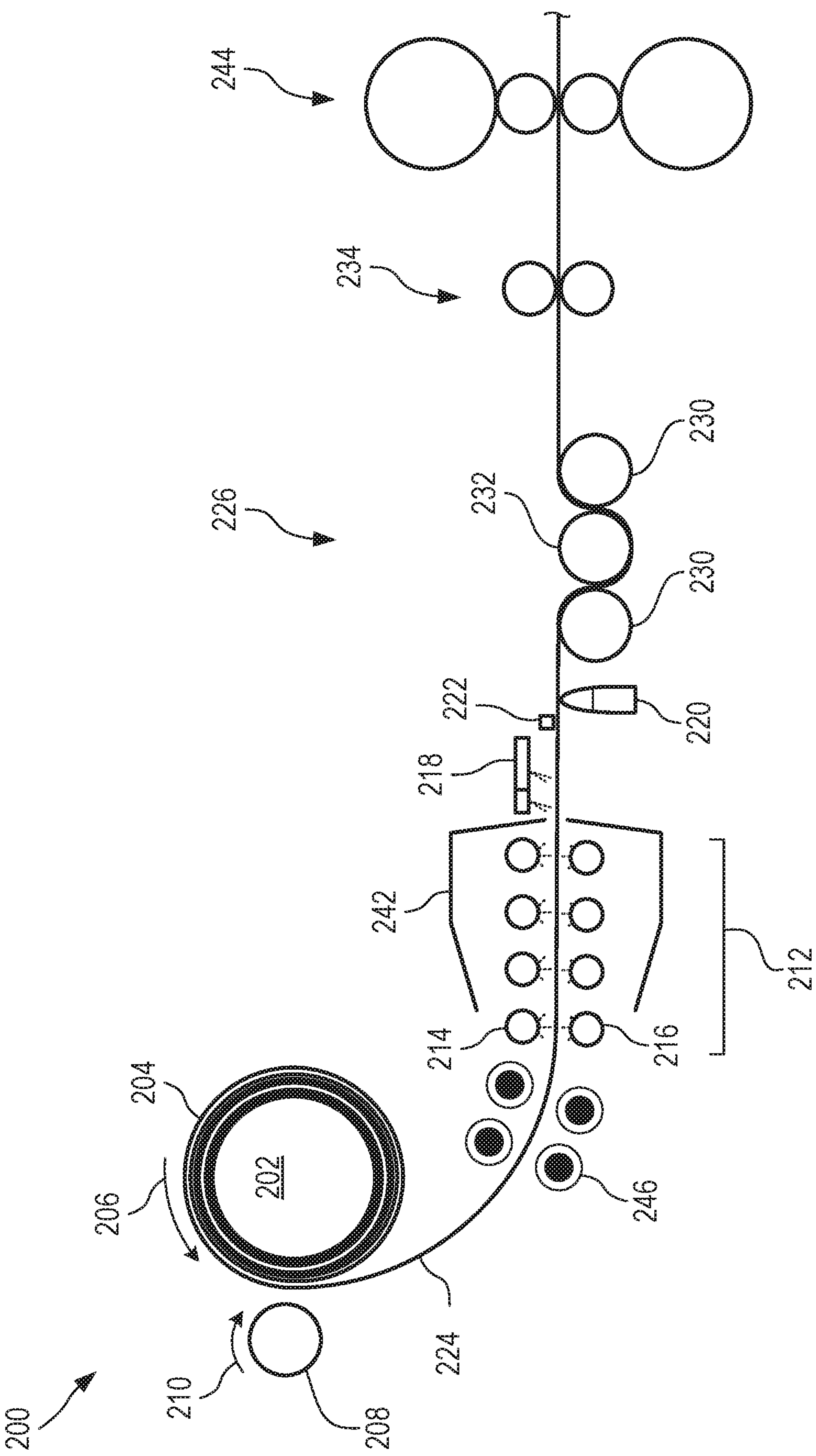
128
128
130
132
134
136
138
140
Sensor
194
Controller
192

FIG. 1


200
208
210
224
206
202
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212
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234
244

FIG. 2

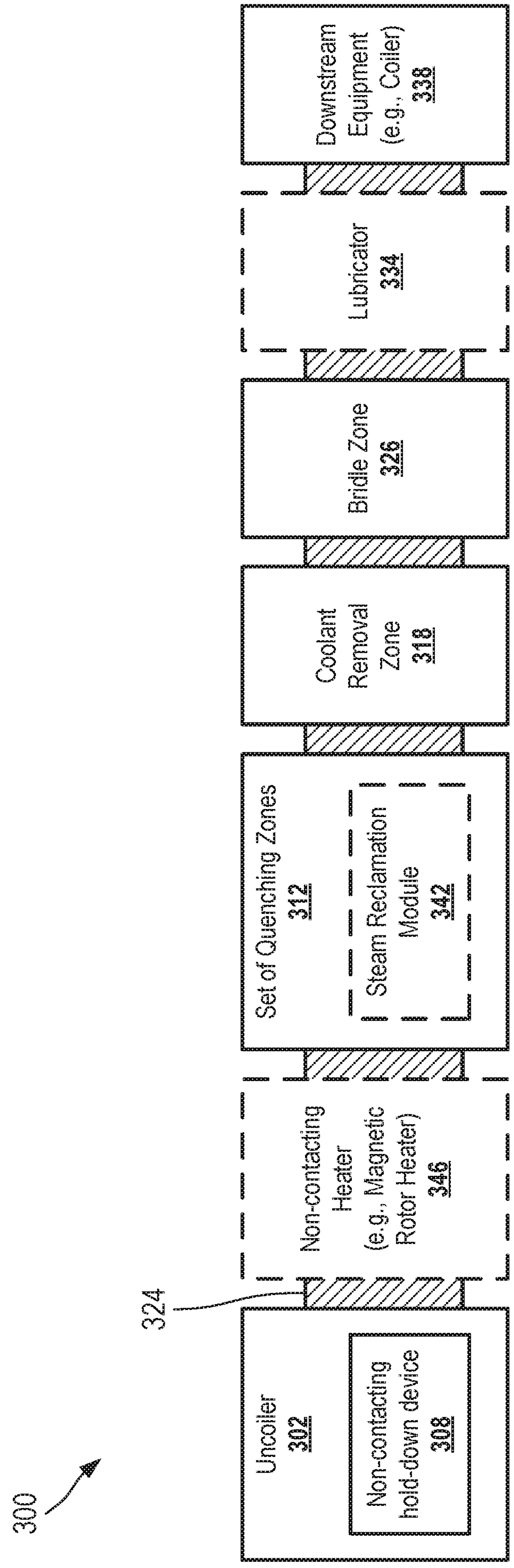
300
Uncoiler 302
Non-contacting hold-down device 308
324
Non-contacting Heater (e.g., Magnetic Rotor Heater) 346
Set of Quenching Zones 312
Steam Reclamation Module 342
Coolant Removal Zone 318
Bridle Zone 326
Lubricator 334
Downstream Equipment (e.g., Coiler) 338

FIG. 3

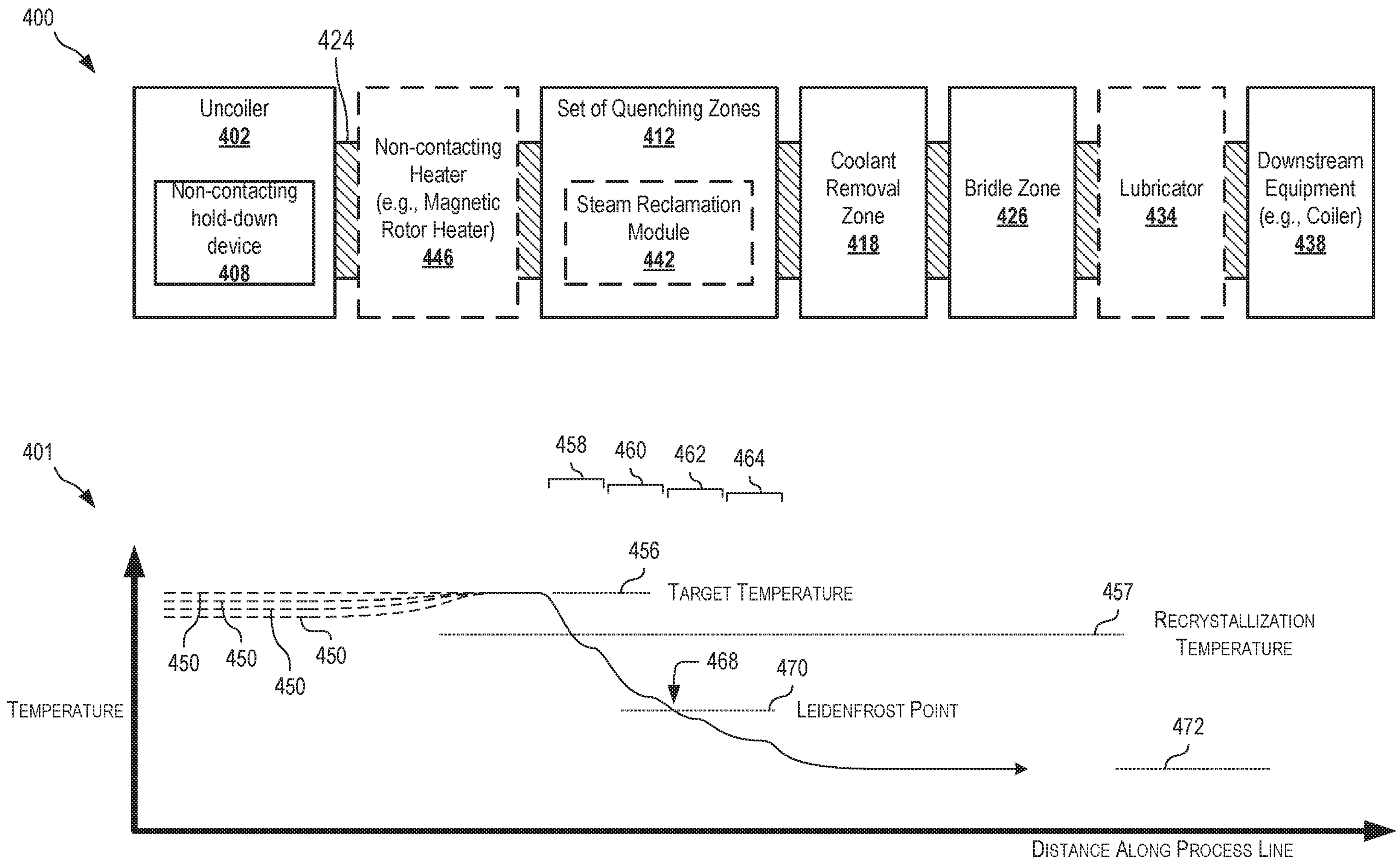
400
424
Uncoiler
402
Non-contacting hold-down device
408
Non-contacting Heater (e.g., Magnetic Rotor Heater)
446
Set of Quenching Zones
412
Steam Reclamation Module
442
Coolant Removal Zone
418
Bridle Zone
426
Lubricator
434
Downstream Equipment (e.g., Coiler)
438
401
458
460
462
464
456
Target Temperature
457
Recrystallization Temperature
450
450
450
450
468
470
Leidenfrost Point
472
Temperature
Distance Along Process Line

FIG. 4

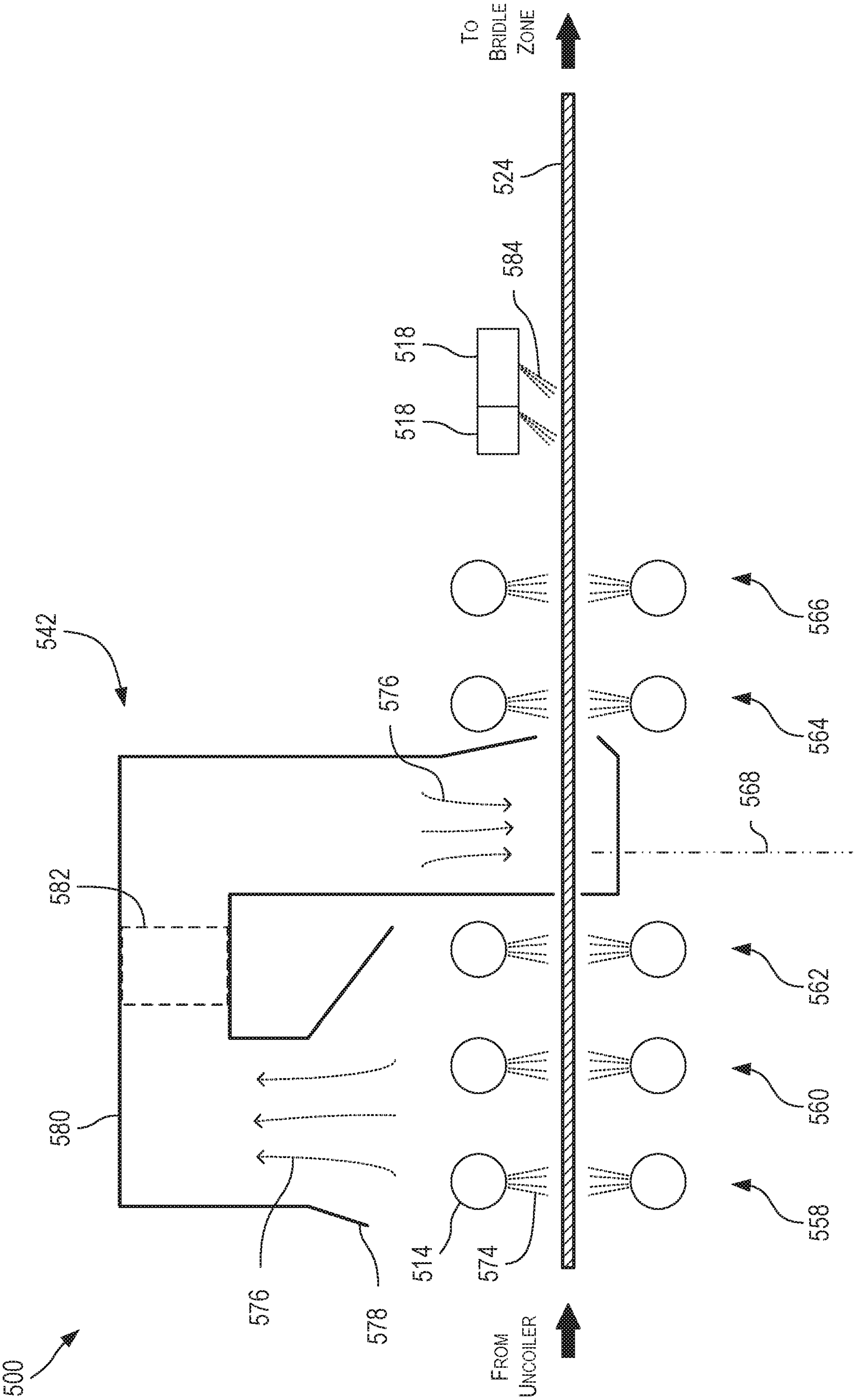
To Bridle Zone
From Uncoiler
500
542
514
524
518
518
558
560
562
564
566
568
574
576
576
578
580
582
584

FIG. 5

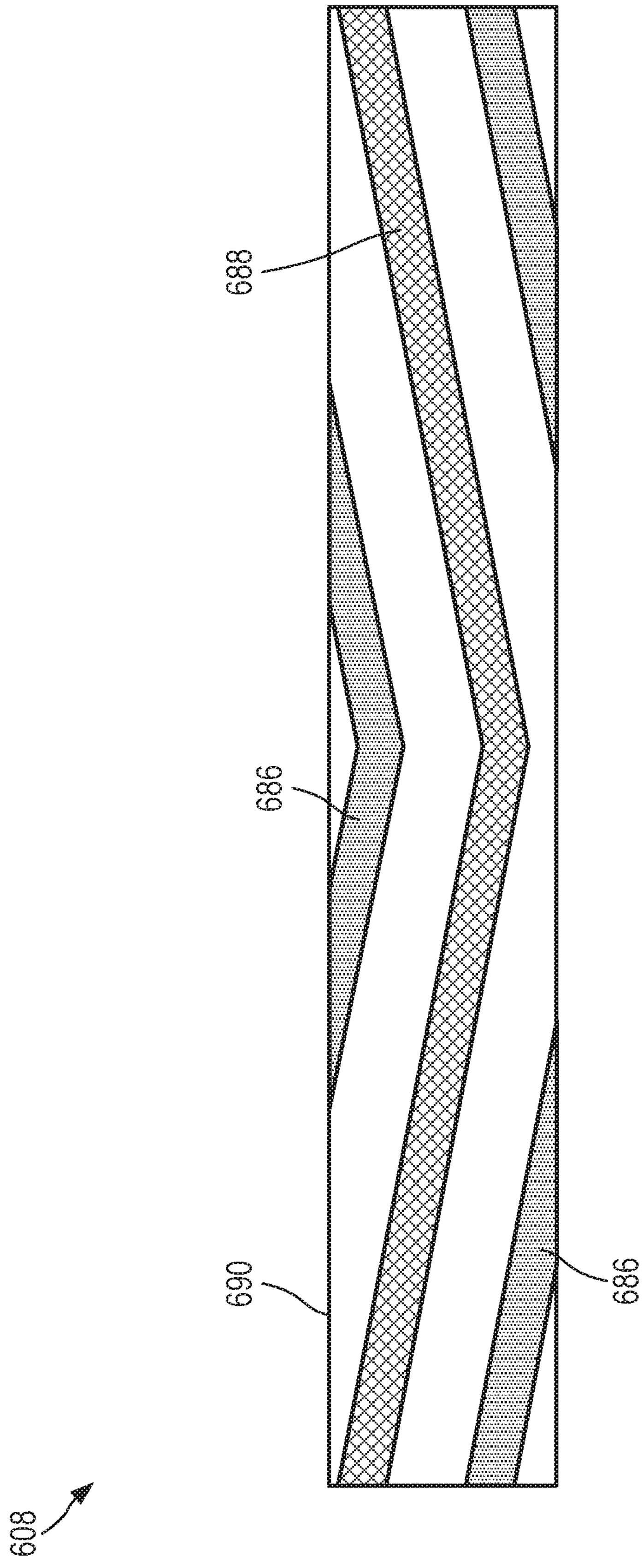

FIG. 6

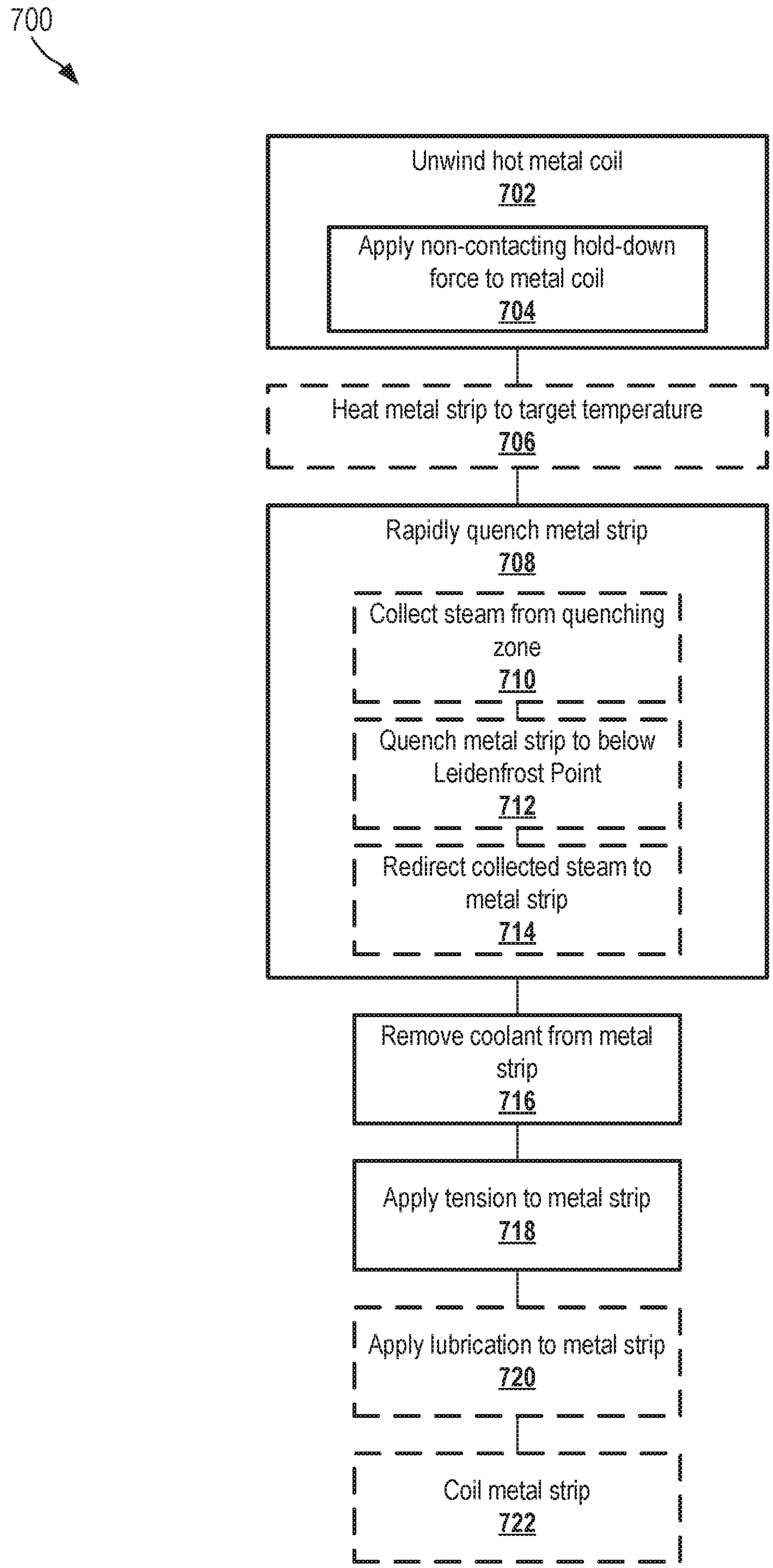
700
Unwind hot metal coil
702
Apply non-contacting hold-down force to metal coil
704
Heat metal strip to target temperature
706
Rapidly quench metal strip
708
Collect steam from quenching zone
710
Quench metal strip to below Leidenfrost Point
712
Redirect collected steam to metal strip
714
Remove coolant from metal strip
716
Apply tension to metal strip
718
Apply lubrication to metal strip
720
Coil metal strip
722

FIG. 7

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2018132604 A **[0006]**