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(54) CASTING ROLL AND METHOD FOR CASTING METAL STRIP WITH CROWN CONTROL

GIESSROLLE UND GIESSVERFAHREN FÜR BLEICHSTREIFEN MIT BALLIGKEITSSTEUERUNG

ROULEAU DE COULÉE ET PROCÉDÉ DE COULÉE D'UNE BANDE MÉTALLIQUE À RÉGLAGE DE COURONNE

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Description

FIELD OF THE INVENTION

[0001] This invention relates to the casting of metal strip by continuous casting in a twin roll caster.

[0002] In particular, the invention relates to a casting roll, for the casting of metal strip by continuous casting in a twin roll caster,

- having a casting surface formed by a substantially cylindrical tube,
- having axially symmetric expansion elements, such as expansion rings, arranged within and adjacent the cylindrical tube, each expansion element spaced from another expansion element, and the expansion elements adapted to increase in radial dimension causing the cylindrical tube to expand changing roll crown of the casting surfaces of the casting rolls and thickness profile of the cast strip during casting.

[0003] The thickness of a casting roll tube often is less than 120 mm, e.g. less than 100 mm or even less than 80 mm. The casting roll tube material usually is selected from the group consisting of copper and copper alloy, optionally with a coating thereon. The casting roll usually has a plurality of longitudinal water flow passages extending through the cylindrical tube.

[0004] The invention also refers to an apparatus for continuously casting thin strip by controlling roll crown and to a method of continuously casting thin strip by controlling roll crown,

- using a pair of counter rotating casting rolls with a nip there between to deliver cast strip downwardly from the nip, each casting roll having a casting surface formed by a substantially cylindrical tube,
- further using a metal delivery system positioned above the nip to form a casting pool supported on the casting surfaces of the casting rolls with side dams adjacent ends of the nip to confine the casting pool,
- at least one casting roll having axially symmetric expansion elements, such as expansion rings, arranged within and adjacent the cylindrical tube, each expansion element spaced from another expansion element, and the expansion elements adapted to increase in radial dimension causing the cylindrical tube to expand changing roll crown of the casting surfaces of the casting rolls and thickness profile of the cast strip during casting.

[0005] In a twin roll caster, molten metal is introduced between a pair of counter-rotated horizontal casting rolls that are cooled so that metal shells solidify on the moving roll surfaces and are brought together at a nip between them to produce a solidified strip product delivered downwardly from the nip between the rolls. The term "nip" is used herein to refer to the general region at which the rolls are closest together. The molten metal may be poured from a ladle into a smaller vessel or series of smaller vessels from which it flows through a metal delivery nozzle located above the nip forming a casting pool of molten metal supported on the casting surfaces of the rolls immediately above the nip and extending along the length of the nip. This casting pool is usually confined between side plates or dams held in sliding engagement with end surfaces of the rolls so as to dam the two ends of the casting pool against outflow.

[0006] The twin roll caster is capable of continuously producing cast strip from molten steel through a sequence of ladles positioned on a turret. Pouring the molten metal from the ladle into a tundish and then a moveable tundish before flowing through the metal delivery nozzle enables the exchange of an empty ladle for a full ladle on the turret without disrupting the production of the cast strip.

PRIOR ART

[0007] In casting thin strip by twin roll caster, the crown of the casting surfaces of the casting rolls varies during a casting campaign. The crown of the casting surfaces of the casting rolls in turn determines the strip thickness profile, i.e., cross-sectional shape, of the thin cast strip produce by the twin roll caster. Casting rolls with convex (i.e. positive crown) casting surfaces produce cast strip with a negative (i.e. depressed) cross-sectional shape; and casting rolls with concave (i.e. negative crown) casting surfaces produce cast strip with a positive (i.e. raised) cross-sectional shape. The casting rolls generally are formed of copper or copper alloy, usually coated with chromium or nickel, with internal passages for circulation of cooling water enabling high heat fluxes for rapid solidification where the casting rolls undergo substantial thermal deformation with exposure to the molten metal during a casting campaign.

[0008] In thin strip casting, a roll crown is desired to produce a desired strip cross-sectional thickness profile under typical casting conditions. It is usual to machine the casting rolls when cold with an initial crown based on the projected crown in the casting surfaces of the casting rolls during casting. However, the differences between the shape of the casting surfaces of the casting rolls between cold and casting conditions are difficult to predict. Moreover, the crown of the casting surfaces of the casting rolls during the casting campaign can vary significantly. The crown of the casting surfaces of the casting rolls can change during casting due to changes in the temperature of the molten metal supplied to the casting pool of the caster, changes in casting speed of the casting rolls, and other casting conditions, such as slight changes in molten steel composition.

[0009] The thickness profile, measured over the strip width, is continuously changing. If the strip profile is measured somewhere between nip of the casting rolls and entrance to the first hot rolling stand shows a variation up to 30 or even 40 micrometers across the strip width. Up to 15-30 peaks and valleys of strip thickness can be found across the whole width of the strip. On the physical strip edge the so called edge drop (= local thickness variation in strip width direction close to strip edge) can even have values of up to 100 micrometer and more.

[0010] Accordingly, there is a need for a reliable and effective way to directly and closely control the shape of the crown in the casting surfaces of the casting rolls during casting, and in turn, the cross-sectional thickness profile of the thin cast strip produced by the twin roll caster.

[0011] WO 2016/083506 A1 discloses a method of controlling casting roll crown and, in turn, the cross-sectional strip thickness profile by controlling the crown in the casting surfaces by expansion rings positioned within and adjacent cylindrical tubes forming the casting rolls. The expansion rings are heated electrically, here at the edges of the casting roll and/or in the center of the casting roll. This method already shows some positive effect to control edge drop.

[0012] Patent documents FR1343136, WO2016/107715 and EP0429385 also disclose a method of controlling the casting roll crown.

SUMMARY OF THE INVENTION

[0013] One object of the present invention is to further reduce the peaks and valleys of the strip surface across the strip width.

[0014] According to the present invention this can be achieved by a casting roll with the features of claim 1.

[0015] Switching electrical power supply from one or more expansion elements to one or more other expansion elements means that electrical power which is fed into one or more expansion elements is reduced, while electrical power which is fed into one or more other expansion elements is increased. The reduction of electrical power for a specific expansion element can, but will in most cases not be, reduced to zero when the electrical power fed into one or more expansion elements is reduced. On the other hand, when starting to increase the electrical power which is fed in one or more other expansion elements, a specific expansion element can at that moment already receive electrical power, or it does at that moment not receive electrical power.

[0016] Since the expansion elements are distributed along the cylindrical tube (which is also referred to as the casting roll sleeve) it is possible to vary the diameter of the casting surface and/or the temperature of the casting surface for the whole casting surface, and not just for the edges or the center. A multitude of expansion elements is necessary to locally vary the diameter of the casting surface and/or the temperature of the casting surface. Although the invention needs at least two expansion elements per casting roll, it is preferred that at least three expansion elements are provided. Still more preferred are more than ten, more than fifteen or even more than twenty expansion elements per casting roll. So a typical number of expansion elements are sixteen to thirty axially symmetric expansion elements, such as expansion rings.

[0017] In a preferred embodiment of the invention the axially symmetric expansion elements, such as expansion rings, are distributed along the entire length of the cylindrical tube including the end portions of the casting surface.

[0018] According to the invention a power switch is situated in or on the casting roll, this in order to distribute the totally available electrical power that is supplied to the casting roll for e.g. expansion element heating to many of the connected expansion elements in equal portions or at different percentages. Each expansion element can be heated separately by using electricity, and thus can be controlled in temperature separately.

[0019] Since such a power switch is integrated in the casting roll there is no need for 10 or more slip rings, for electrical energy supply and sensor signal transmission, with respective control units for each expansion element which slip rings would need a longer shaft of the casting roll hence elongating the casting roll on one end significantly. Due to the power switch only one control wire is needed for leading respective control signals into the casting roll, that is, to the power switch.

[0020] In a preferred embodiment of the invention an expansion element, preferably the multitude of the expansion elements, especially each expansion element, has a width (measured parallel to the axis of the casting roll) between 40 and 150 mm, preferably between 40 and 100 mm, more preferably between 50 and 85 mm. The expansion elements can have the form of a ring which per definition has a central hole, or the expansion elements can have the form of a disk, without a center ring hole. The outer diameter of the expansion element shall in any case be tolerance-fitted with the roll tube inner diameter.

[0021] In a preferred embodiment of the invention each expansion ring is has a radial ring thickness (i.e. the difference between outer and inner diameter of the ring) between 40 and 150 mm, preferably between 40 and 100 mm, more preferably 45 - 75 mm.

[0022] The expansion rings can be mounted on an internal pipe, preferably having a wall thickness of at least 10-50 mm and at least an outer diameter of not less than 110 mm onto which the expansion rings are tolerance fitted. The axial position of the expansion rings on the internal pipe can be fixed by spacers between the rings or by respective press fit tolerances of the rings (e.g. shrinkage mounted rings).

[0023] The outer diameter of the expansion elements is increased by heating. Thus a claimed embodiment of the invention is that each expansion element is equipped with electrical resistance heating elements being able to supply the expansion ring with up to 15 kW, preferably 3-10 kW heating power. The electrical resistance heating elements can be wires or rods in the form of a ring which are in contact with the expansion elements.

[0024] The total electrical energy power provided for all expansion elements together can be up to 70 kW, preferably not more than 35 kW per meter of external circumference of the casting roll.

[0025] A claimed embodiment of the invention is that a centrally mounted expansion element is constructed as to be permanently heated. This assures contact between the outer surface of the expansion element and the inner surface of the cylindrical tube (casting roll sleeve) or even an outward bulging of the cylindrical tube, superposed to the local (thermal) crown. The centrally mounted expansion element may have the same width as most other expansion rings or may have a significantly larger width than all other expansion rings, e.g. up to 150 until 400 mm.

[0026] In addition to that it is preferred that the expansion elements located at the end portions of the casting surface are constructed as to be permanently heated. Again, this assures contact between the outer surface of the two expansion elements and the inner surface of the cylindrical tube (casting roll sleeve) or even an outward bulging of the cylindrical tube, superposed to the local (thermal) crown at the ends of the cylindrical tube.

[0027] A preferred embodiment of the invention is that a controller is constructed to control the radial dimension of each of the expansion elements responsive to at least a temperature process model of the casting roll and/or the expansion rings, or responsive to temperature measurements foreseen within some or all of the expansion elements, by respective temperature sensors. Accordingly, the expansion elements can be equipped with at least one temperature sensor each, for providing respective signals to the controller.

[0028] A preferred embodiment of the invention is that the expansion elements are equipped with at least one RFID-tag each, for identifying the expansion element when sending temperature information to a controller, preferably a controller situated within the casting roll.

[0029] Such a controller, e.g. a microcontroller, can be part of a main controller of the control system and can be connected to the RFID-tags for detecting temperature and evaluating the temperature values. The microcontroller can issue a thermal profile over all expansion elements (i.e. over the width of the casting roll) every two to sixty seconds, preferably every five to thirty seconds, and send it to the main controller which uses this temperature profile (e.g. in combination with a thermal profile computed by a process model) as input for control which expansion elements are to be increased, i.e. heated.

[0030] An apparatus according to the invention for continuously casting thin strip by controlling roll crown comprises

- a pair of counter rotating casting rolls with a nip there between capable of delivering cast strip downwardly from the nip, each casting roll having a casting surface formed by a substantially cylindrical tube,
- a metal delivery system positioned above the nip and capable of forming a casting pool supported on the casting surfaces of the casting rolls with side dams adjacent ends of the nip to confine the casting pool, and is characterized in that at least one casting roll is designed according to the invention.

[0031] The object of the present invention is also achieved by a method of continuously casting thin strip by controlling roll crown disclosed in appended claim 13.

[0032] If the control of which expansion elements are to be increased is done on the basis of the measured temperature of expansion elements, the temperature of two or more expansion elements of one casting roll is measured, or the temperature of two or more expansion elements of both casting rolls is measured.

[0033] So there will be a switching of the electrical power supply among at least some of the expansion elements. Although such switching can be done with high frequency, the switching between different expansion elements is done only every two to sixty seconds, preferably every five to thirty seconds.

[0034] In a preferred embodiment of the invention the temperature profile of one or both of the casting rolls is given by a process model which outputs in real time a two- or three-dimensional temperature field of the interior of the cylindrical tube.

[0035] Alternatively in another preferred, and simpler, embodiment of the invention the temperature profile of one or both of the casting rolls is given by a process model which outputs in real time the average temperature of each expansion element.

[0036] The process model delivers in real time the actual status of the two- or three-dimensional temperature field within the cylindrical tube (casting roll sleeve) and/or the average temperature of each expansion element, e.g. each expansion ring. Additionally the process model delivers strip crown and thermal profile information. Based on these facts the selection of e.g. three, four or five expansion elements which obtain electrical power (= are to be heated) is made. It has to be taken into account that those expansion elements that have been heated before do not immediately cool down.

[0037] The process model is real time calculating the two- or three-dimensional temperature field within the cylindrical tube (casting roll sleeve) and/or the average temperature of each expansion element in calculation cycle which last at least one, two or up to fifteen seconds, as well as the average temperature of the cylindrical tube (casting roll sleeve) in a circular cross section and can hence - by means of a deformation field calculation for the cylindrical tube (casting roll sleeve) and for the expansion elements - forecast which of the expansion elements is touching the cylindrical tube and must be heated and hence dilated more or less to eliminate certain strip profile valleys or strip surface temperature spots.

[0038] The process model for the temperature field within the cylindrical tube (casting roll sleeve) and the process model for the average temperature of each expansion element can be designed as separate models and can therefore be used and calculated separately. The process model for the temperature field within the cylindrical tube (casting roll sleeve) can help save external sensors. The process model for the average temperature of each expansion element can help save the temperature sensors within the expansion elements.

[0039] On top of the physical-mathematical process model also artificial intelligence or machine learning methods and models, e.g. in form of a neural network algorithm or a symbolic regression algorithm and the like, may be used to fine tune the selection of heat rings for heating. Hence a preferred embodiment of the invention is that additionally artificial intelligence, e.g. in form of a neural network algorithm or a symbolic regression algorithm, is used for determining which expansion elements have to be increased, preferably heated.

[0040] It is also preferred that only three to nine, more preferably three to five expansion elements are increased, preferably heated, at a time.

[0041] One preferred embodiment of the invention provides that only a centrally mounted expansion element is permanently increased, preferably heated. In addition it is possible that the expansion elements located at the end portions of the casting surface are permanently increased, preferably heated.

[0042] For the above method it is preferred that at least one of the casting rolls is designed according to the claimed casting roll.

BRIEF DESCRIPTION OF FIGURES

[0043] The invention will be explained in closer detail by reference to a preferred embodiment, which is depicted schematically in the figures.

FIG. 1 is a diagrammatical side view of a twin roll caster of the present disclosure;

FIG. 2A is an enlarged partial sectional view of a portion of the twin roll caster of FIG. 1 including a strip inspection device for measuring strip profile;

FIG 2B is a schematic view of a portion of twin roll caster of Fig. 2A;

FIG. 3A is a cross sectional view longitudinally through a portion of one of the prior art casting rolls of FIG. 2A with an expansion ring corresponding to center portions of the cast strip;

FIG. 3B is a cross sectional view longitudinally through the remaining portion of the prior art casting roll of FIG. 3A joined on line A-A;

FIG. 4 is an end view of the prior art casting roll of FIG. 3A on line 4-4 shown in partial interior detail in phantom;

FIG. 5 is a cross sectional view of the prior art casting roll of FIG. 3A on line 5-5;

FIG. 6 is a cross sectional view of the prior art casting roll of FIG. 3A on line 6-6;

FIG. 7 is a cross sectional view of the prior art casting roll of FIG. 3A on line 7-7;

FIG. 8 is a cross sectional view longitudinally through a portion of one of the prior art casting rolls of FIG. 2 with two expansion rings spaced from the edge portions of the cast strip;

FIG. 9 is a cross sectional view longitudinally through a portion of a prior art casting roll with an expansion ring spaced from the edge portions of the cast strip;

FIG. 10 is a sectional view longitudinally through a portion of one of the prior art casting rolls of FIG. 2 with two expansion rings spaced from the edge portions of the cast strip and an expansion ring corresponding to center portions of the cast strip;

FIG. 11 is a sectional view longitudinally through a casting roll according to the invention, with nineteen expansion rings;

FIG. 12 is a graph of profile correction of half strip thickness vs. length along the cylindrical tube (μm over mm).

WAYS TO IMPLEMENT THE INVENTION

[0044] Referring now to FIGS. 1, 2A, and 2B, a twin roll caster is illustrated that comprises a main machine frame 10 that stands up from the factory floor and supports a pair of counter-rotatable casting rolls 12 mounted in a module in a roll cassette 11. The casting rolls 12 are mounted in the roll cassette 11 for ease of operation and movement as described below. The roll cassette 11 facilitates rapid movement of the casting rolls 12 ready for casting from a setup position into an operative casting position in the caster as a unit, and ready removal of the casting rolls 12 from the casting position when the casting rolls 12 are to be replaced. There is no particular configuration of the roll cassette 11 that is desired, so long as it performs that function of facilitating movement and positioning of the casting rolls 12 as described herein.

[0045] The casting apparatus for continuously casting thin steel strip includes the pair of counter-rotatable casting rolls 12 having casting surfaces 12A laterally positioned to form a nip 18 there between. Molten metal is supplied from a ladle 13 through a metal delivery system to a metal delivery nozzle 17, core nozzle, positioned between the casting rolls 12 above the nip 18. Molten metal thus delivered forms a casting pool 19 of molten metal above the nip 18 supported on the casting surfaces 12A of the casting rolls 12. This casting pool 19 is confined in the casting area at the ends of the casting rolls 12 by a pair of side closure plates, or side dams 20, (shown in dotted line in FIGS. 2A and 2B). The upper surface of the casting pool 19 (generally referred to as the "meniscus" level) may rise above the lower end of the delivery nozzle 17 so that the lower end of the delivery nozzle 17 is immersed within the casting pool 19. The casting area includes the addition of a protective atmosphere above the casting pool 19 to inhibit oxidation of the molten metal in the casting area.

[0046] The ladle 13 typically is of a conventional construction supported on a rotating turret 40. For metal delivery, the ladle 13 is positioned over a movable tundish 14 in the casting position to fill the tundish 14 with molten metal. The movable tundish 14 may be positioned on a tundish car 66 capable of transferring the tundish 14 from a heating station (not shown), where the tundish 14 is heated to near a casting temperature, to the casting position. A tundish guide, such as rails 39, may be positioned beneath the tundish car 66 to enable moving the movable tundish 14 from the heating station to the casting position.

[0047] The movable tundish 14 may be fitted with a slide gate 25, actuable by a servo mechanism, to allow molten metal to flow from the tundish 14 through the slide gate 25, and then through a refractory outlet shroud 15 to a transition piece or distributor 16 in the casting position. From the distributor 16, the molten metal flows to the delivery nozzle 17 positioned between the casting rolls 12 above the nip 18.

[0048] The side dams 20 may be made from a refractory material such as zirconia graphite, graphite alumina, boron nitride, boron nitride-zirconia, or other suitable composites. The side dams 20 have a face surface capable of physical contact with the casting rolls 12 and molten metal in the casting pool 19. The side dams 20 are mounted in side dam holders (not shown), which are movable by side dam actuators (not shown), such as a hydraulic or pneumatic cylinder, servo mechanism, or other actuator to bring the side dams 20 into engagement with the ends of the casting rolls 12. Additionally, the side dam actuators are capable of positioning the side dams 20 during casting. The side dams 20 form end closures for the molten pool of metal on the casting rolls 12 during the casting operation.

[0049] FIG. 1 shows the twin roll caster producing the cast strip 21, which passes across a guide table 30 to a pinch roll stand 31, comprising pinch rolls 31 A. Upon exiting the pinch roll stand 31, the thin cast strip 21 may pass through a hot rolling mill 32, comprising a pair of work rolls 32A, and backup rolls 32B, forming a gap capable of hot rolling the cast strip 21 delivered from the casting rolls 12, where the cast strip 21 is hot rolled to reduce the strip to a desired thickness, improve the strip surface, and improve the strip flatness. The work rolls 32A have work surfaces relating to the desired strip profile across the work rolls 32A. The hot rolled cast strip 21 then passes onto a run-out table 33, where it may be cooled by contact with a coolant, such as water, supplied via water jets 90 or other suitable means, and by convection and radiation. In any event, the hot rolled cast strip 21 may then pass through a second pinch roll stand 91 to provide tension of the cast strip 21, and then to a coiler 92. The cast strip 21 may be between about 0.3 and 2.0 millimeters in thickness before hot rolling.

[0050] At the start of the casting operation, a short length of imperfect strip is typically produced as casting conditions stabilize. After continuous casting is established, the casting rolls 12 are moved apart slightly and then brought together again to cause this leading end of the cast strip 21 to break away forming a clean head end of the following cast strip 21. The imperfect material drops into a scrap receptacle 26, which is movable on a scrap receptacle guide. The scrap receptacle 26 is located in a scrap receiving position beneath the caster and forms part of a sealed enclosure 27 as described below. The enclosure 27 is typically water cooled. At this time, a water-cooled apron 28 that normally hangs downwardly from a pivot 29 to one side in the enclosure 27 is swung into position to guide the clean end of the cast strip 21 onto the guide table 30 that feeds it to the pinch roll stand 31. The apron 28 is then retracted back to its hanging position to allow the cast strip 21 to hang in a loop beneath the casting rolls 12 in enclosure 27 before it passes to the guide table 30 where it engages a succession of guide rollers.

[0051] An overflow container 38 may be provided beneath the movable tundish 14 to receive molten material that may spill from the tundish 14. As shown in FIG. 1, the overflow container 38 may be movable on rails 39 or another guide such that the overflow container 38 may be placed beneath the movable tundish 14 as desired in casting locations. Additionally, an optional overflow container (not shown) may be provided for the distributor 16 adjacent the distributor 16.

[0052] The sealed enclosure 27 is formed by a number of separate wall sections that fit together at various seal connections to form a continuous enclosure wall that permits control of the atmosphere within the enclosure 27. Additionally, the scrap receptacle 26 may be capable of attaching with the enclosure 27 so that the enclosure 27 is capable of supporting a protective atmosphere immediately beneath the casting rolls 12 in the casting position. The enclosure 27 includes an opening in the lower portion of the enclosure 27, lower enclosure portion 44, providing an outlet for scrap to pass from the enclosure 27 into the scrap receptacle 26 in the scrap receiving position. The lower enclosure portion 44 may extend downwardly as a part of the enclosure 27, the opening being positioned above the scrap receptacle 26 in the scrap receiving position. As used in the specification and claims herein, "seal," "sealed," "sealing," and "sealingly" in reference to the scrap receptacle 26, enclosure 27, and related features may not be a complete seal so as to prevent leakage, but rather is usually less than a perfect seal as appropriate to allow control and support of the atmosphere within the enclosure 27 as desired with some tolerable leakage.

[0053] A rim portion 45 may surround the opening of the lower enclosure portion 44 and may be movably positioned above the scrap receptacle 26, capable of sealingly engaging and/or attaching to the scrap receptacle 26 in the scrap receiving position. The rim portion 45 may be movable between a sealing position in which the rim portion 45 engages the scrap receptacle 26, and a clearance position in which the rim portion 45 is disengaged from the scrap receptacle 26. Alternately, the caster or the scrap receptacle 26 may include a lifting mechanism to raise the scrap receptacle 26 into sealing engagement with the rim portion 45 of the enclosure 27, and then lower the scrap receptacle 26 into the clearance position. When sealed, the enclosure 27 and scrap receptacle 26 are filled with a desired gas, such as nitrogen, to reduce the amount of oxygen in the enclosure 27 and provide a protective atmosphere for the cast strip 21.

[0054] The enclosure 27 may include an upper collar portion 43 supporting a protective atmosphere immediately beneath the casting rolls 12 in the casting position. When the casting rolls 12 are in the casting position, the upper collar portion 43 is moved to the extended position closing the space between a housing portion 53 adjacent the casting rolls 12, as shown in FIG. 2, and the enclosure 27. The upper collar portion 43 may be provided within or adjacent the enclosure 27 and adjacent the casting rolls 12, and may be moved by a plurality of actuators (not shown) such as servo-mechanisms, hydraulic mechanisms, pneumatic mechanisms, and rotating actuators.

[0055] The casting rolls 12 are internally water cooled as described below so that as the casting rolls 12 are counter-rotated, shells solidify on the casting surfaces 12A, as the casting surfaces 12A move into contact with and through the casting pool 19 with each revolution of the casting rolls 12. The shells are brought close together at the nip 18 between the casting rolls 12 to produce a thin cast strip product 21 delivered downwardly from the nip 18. The thin cast strip product 21 is formed from the shells at the nip 18 between the casting rolls 12 and delivered downwardly and moved downstream as described above.

[0056] Referring now to FIGS. 3A-B, each casting roll 12 includes a cylindrical tube 120 of a metal selected from the group consisting of copper and copper alloy, optionally with a coating thereon, e.g., chromium or nickel, to form the casting surfaces 12A. In FIG. 3A, according to prior art, an expansion ring 220 may be positioned within and adjacent the cylindrical tube 120 at a position corresponding to center portions of the cast strip formed on the casting surfaces of the casting rolls during casting.

[0057] Each cylindrical tube 120 may be mounted between a pair of stub shaft assemblies 121 and 122. The stub shaft assemblies 121 and 122 have end portions 127 and 128, respectively (shown in FIGS 4-6), which fit snugly within the ends of cylindrical tube 120 to form the casting roll 12. The cylindrical tube 120 is thus supported by end portions 127 and 128 having flange portions 129 and 130, respectively, to form internal cavity 163 therein, and support the assembled casting roll between the stub shaft assemblies 121 and 122.

[0058] The outer cylindrical surface of each cylindrical tube 120 is a roll casting surface 12A. The radial thickness of the cylindrical tube 120 may be no more than 80 millimeters thick. The thickness of the tube 120 may range between 40 and 80 millimeters in thickness or between 60 and 80 millimeters in thickness.

[0059] Each cylindrical tube 120 is provided with a series of longitudinal water flow passages 126, which may be formed by drilling long holes through the circumferential thickness of the cylindrical tube 120 from one end to the other. The ends of the holes are subsequently closed by end plugs 141 attached to the end portions 127 and 128 of stub shaft assemblies 121 and 122 by fasteners 171. The water flow passages 126 are formed through the thickness of the cylindrical tube 120 with end plugs 141. The number of stub shaft fasteners 171 and end plugs 141 may be selected as desired. End plugs 141 may be arranged to provide, with water passage in the stub shaft assemblies described below, in single pass cooling from one end to the other of the roll 12, or alternatively, to provide multi-pass cooling where, for example, the flow passages 126 are connected to provide three passes of cooling water through adjacent flow passages 126 before returning the water to the water supply directly or through the cavity 163.

[0060] The water flow passages 126 through the thickness of the cylindrical tube 120 may be connected to water supply in series with the cavity 163. The water passages 126 may be connected to the water supply so that the cooling water first passes through the cavity 163 and then the water supply passages 126 to the return lines, or first through the water supply passages 126 and then through the cavity 163 to the return lines.

[0061] The cylindrical tube 120 may be provided with circumferential steps 123 at end to form shoulders 124 with the working portion of the roll casting surface 12A of the roll 12 there between. The shoulders 124 are arranged to engage the side dams 20 and confine the casting pool 19 as described above during the casting operation.

[0062] End portions 127 and 128 of stub shaft assemblies 121 and 122, respectively, typically sealingly engage the ends of cylindrical tube 120 and have radially extending water passages 135 and 136 shown in FIGS. 4-6 to deliver water to the water flow passages 126 extending through the cylindrical tube 120. The radial flow passages 135 and 136 are connected to the ends of at least some of the water flow passages 126, for example, in threaded arrangement, depending on whether the cooling is a single pass or multi-pass cooling system. The remaining ends of the water flow passages 126 may be closed by, for example, threaded end plugs 141 as described where the water cooling is a multi-pass system.

[0063] As shown in detail by FIG. 7, cylindrical tube 120 may be positioned in annular arrays in the thickness of cylindrical tube 120 either in single pass or multi-pass arrays of water flow passages 126 as desired. The water flow passages 126 are connected at one end of the casting roll 12 by radial ports 160 to the annular gallery 140 and in turn radially flow passages 135 of end portion 127 in stub shaft assembly 120, and are connected at the other end of the casting roll 12 by radial ports 161 to annular gallery 150 and in turn radial flow passages 136 of end portions 128 in stub shaft assembly 121. Water supplied through one annular gallery, 140 or 150, at one end of the roll 12 can flow in parallel through all of the water flow passages 126 in a single pass to the other end of the roll 12 and out through the radial passages, 135 or 136, and the other annular gallery, 150 or 140, at that other end of the cylindrical tube 120. The directional flow may be reversed by appropriate connections of the supply and return line(s) as desired. Alternatively or additionally, selective ones of the water flow passages 126 may be optionally connected or blocked from the radial passages 135 and 136 to provide a multi pass arrangement, such as a three pass.

[0064] The stub shaft assembly 122 may be longer than the stub shaft assembly 121, and the stub shaft assembly 122 provided with two sets of water flow ports 133 and 134. Water flow ports 133 and 134 are capable of connection with rotary water flow couplings 131 and 132 by which water is delivered to and from the casting roll 12 axially through stub shaft assembly 122. In operation, cooling water passes to and from the water flow passages 126 in the cylindrical tube 120 through radial passages 135 and 136 extending through end portions 127 and 128 of the stub shaft assemblies 121 and 122, respectively. The stub shaft assembly 121 is fitted with axial tube 137, to provide fluid communication between the radial passages 135 in end portions 127 and the central cavity within the casting roll 12. The stub shaft assembly 122 is fitted with axial space tube 138, to separate a central water duct 138, in fluid communication with the central cavity 163, and from annular water flow duct 139 in fluid communication with radial passages 136 in end portion 122 of stub shaft assembly 122. Central water duct 138 and annular water duct 139 are capable of providing inflow and outflow of cooling water to and from the casting roll 12.

[0065] In operation, incoming cooling water may be supplied through supply line 131 to annular duct 139 through ports 133, which is in turn in fluid communication with the radial passages 136, gallery 150 and water flow passages 126, and then returned through the gallery 140, the radial passages 135, axial tube 137, central cavity 163, and central water duct 138 to outflow line 132 through water flow ports 134. Alternatively, the water flow to, from and through the casting roll 12 may be in the reverse direction as desired. The water flow ports 133 and 134 may be connected to water supply and return lines so that water may flow to and from water flow passages 126 in the cylindrical tube 120 of the casting roll 12 in either direction, as desired. Depending on the direction of flow, the cooling water flows through the cavity 163 either before or after flow through the water flow passages 126.

[0066] According to the invention each cylindrical tube 120 is usually provided with more than three expansion rings. As illustrated in FIG. 8, which belongs to prior art, each cylindrical tube 120 may be provided with at least two expansion rings 210 spaced on opposite end portions of the cylindrical tube 120 inward within 450 mm of edge portions of the cast strip formed on opposite end portions of the casting rolls during the casting campaign. FIG. 9, which also belongs to prior art, shows a cross sectional view longitudinally through a portion of a casting roll with an expansion ring 210 spaced from the edge portions of the cast strip.

[0067] Alternatively, as illustrated in FIG. 10, which again belongs to prior art, two expansion rings 210 may be spaced on opposite end portions of the cylindrical tube within 450 mm of edge portions of the cast strip formed on opposite end portions of the casting rolls during the casting campaign and an additional expansion ring 200 may be positioned within and adjacent the cylindrical tube 120 at a position corresponding to center portions of the cast strip formed on the casting surfaces of the casting rolls during casting.

[0068] Power wire 222 and control wire 224 extend from slip ring 220 to each expansion ring. Power wire 222 supplies the energy to electrically power the expansion ring 200, 210. Control wire 224 modulates the energy to electrically power the expansion ring.

[0069] FIG. 11 is a sectional view longitudinally through a casting roll with nineteen expansion rings 101-119 according to the present invention, whereas the inner part of the casting roll 12 has been omitted. In this example expansion rings 101-119 have approximately the same width and the same ring thickness. Expansion rings 101 and 119 are located at the edge of the casting surface 12A. Seen in axial direction, part of the expansion ring 101, 119 is located within the casting surface 12A and part of the expansion ring 101, 119 is located outside the casting surface 12A. The distance of an expansion ring 101, 119 at the edge of the casting surface 12A to the next expansion ring 102, 118 is here larger than the distance between two adjacent inner expansion rings 102-118. The distance of an expansion ring 101, 119 at the edge of the casting surface 12A to the next expansion ring 102, 118 in this example is between 1,0 and 1,5 the width of one expansion ring 101-119. The distance between two adjacent inner expansion rings 102-118 is less than the width of one expansion ring 101-119, here approximately between 0,5 and 0,8 the width of one expansion ring 101-119.

[0070] The expansion rings 101-119 are mounted on the outer surface of an internal pipe 180, e.g. by shrinkage mounting. This internal pipe 180 can contain the wires or cables for providing electrical energy from the wires 181 to each of the expansion rings 101-119. Also a power switch can be situated in the internal pipe 180 in order to switch electrical power supply from one or more expansion rings to one or more other expansion rings. The internal pipe 180 can also contain part of the water cooling, similar to FIG. 4-7.

[0071] The centrally mounted expansion ring, which would be expansion ring 110 in this case, could be permanently connected to the wires 181 so as to be heated permanently, or the power switch is constructed or programmed or controlled as to permanently heat the centrally mounted expansion ring 110. The same could apply to the expansion rings 101 and 119 which are located at the edge of the casting surface 12A.

[0072] Each expansion ring 101-119 is equipped with electrical resistance heating elements which supply each expansion ring with up to 15 kW, preferably 3-10 kW heating power via wires 181 leading to and from a slip ring (not to be seen here). The total electrical power provided through the slip ring of one casting roll may total up to 70, preferably up to 35 kW per meter of external circumference of the respective casting roll.

[0073] A controller can be situated outside the casting roll 12 and can be connected via control wires (not shown) with the heating elements of the expansion rings 101-119 or the power switch in the internal pipe 180. The controller controls the radial dimension of each of the expansion rings 101-119 by controlling the electrical energy provided to each expansion ring 101-119, e.g. responsive to at least a temperature process model of the casting roll 12 and/or the expansion rings 101-119 and/or responsive to a measured expansion ring temperature.

[0074] Deformation of the crown of the casting surfaces may be controlled by regulating the radial dimension of the respective expansion rings 101-119 located inside the cylindrical tube 120. The radial dimension of the expansion rings 101-119 may be controlled by regulating the temperature of the expansion ring. In turn, the thickness profile of cast strip may be controlled with the control of the crown of the casting surfaces 12A of the casting rolls 12. Since the circumferential thickness of the cylindrical tube 120 normally is made to a thickness of no more than 120 mm, the crown of the casting surfaces 12A may be deformed responsive to changes in the radial dimension of the expansion rings 101-119.

[0075] Each expansion ring 101-119 is adapted to increase in radial dimension causing the cylindrical tube 120 to expand changing the crown of the casting surfaces 12A and the thickness profile of the cast strip 21 during casting.

[0076] Each expansion ring is electrically heated increasing in radial dimension. Each expansion ring 101-119 may provide a heating input of up to 15 kW; preferably, of 3-10 kW. The force generated from the increase in radial dimension will be applied on the cylindrical tube 120 causing the cylindrical tube to expand changing the crown of the casting surfaces and the thickness profile of the cast strip. FIG. 12 shows the effect of expansion ring temperature on the cast strip thickness profile. Fig. 12 is a graph of the profile correction of half strip thickness versus the length along the cylindrical tube (mm) for expansion temperatures from 40°C to 200°C. To achieve a desired thickness profile via control of the radial dimension of the expansion rings 101-119 and control of the casting speed, a strip thickness profile sensor 71 may be positioned downstream to detect the thickness profile of the cast strip 21 as shown in FIGS. 2 and 2A. The strip thickness sensor 71 is provided typically between the nip 18 and the pinch rolls 31A to provide for direct control of the casting roll 12. The sensor may be an x-ray gauge or other suitable device capable of directly measuring the thickness profile across the width of the strip periodically or continuously. Alternatively, a plurality of non-contact type sensors are arranged across the cast strip 21 at the roller table 30 and the combination of thickness measurements from the plurality of positions across the cast strip 21 are processed by a controller 72 to determine the thickness profile of the strip periodically or continuously. The thickness profile of the cast strip 21 may be determined from this data periodically or continuously as desired.

[0077] The radial dimension of each expansion ring 101-119 may be independently controlled from the radial dimension of the other expansion rings. The sensor 71 generates signals indicative of the thickness profile of the cast strip 21. The radial dimension of each expansion rings 101-119 is controlled according to the signals generated by the sensor, which in turns control roll crown of the casting surfaces 12A of the casting rolls 12 during the casting campaign.

[0078] Furthermore, the casting roll drive may be controlled to vary the speed of rotation of the casting rolls while also varying the radial dimension of the expansion ring 101-119 responsive to the electrical signals received from the sensor 71 controlling in turn the roll crown of the casting surfaces of the casting rolls during the casting campaign.

[0079] In each embodiment, the expansion rings may be made of an austenitic stainless steel such as 18/8 austenitic stainless steel. Each expansion ring may have an annular dimension between 40 to 100 millimeters. Each expansion ring 101-119 may have a width of up to 200 millimeters, preferably between 50 and 100 mm, more preferably between 60 and 85 mm. However, the centrally mounted expansion ring 110 may have a larger width than all other expansion rings, e.g. up to 150 until 400 mm.

Claims

1. A casting roll (12), for the casting of metal strip (21) by continuous casting in a twin roll caster,

- having a casting surface (12A) formed by a substantially cylindrical tube (120),
- having axially symmetric expansion elements, such as expansion rings (101-119), arranged within and adjacent the cylindrical tube (120), each expansion element spaced from another expansion element, and the expansion elements adapted to increase in radial dimension causing the cylindrical tube to expand changing roll crown of the casting surfaces of the casting rolls and thickness profile of the cast strip during casting,
- having a multitude of axially symmetric expansion elements, such as expansion rings (101-119), are distributed along the entire length of the cylindrical tube (120) and a power switch is situated in or on the casting roll (12) in order to switch electrical power supply of the expansion elements (101-119) from one or more expansion elements to one or more other expansion elements by use of a power wire (181), that each expansion element (101-119) is equipped with electrical resistance heating elements being able to supply the expansion element with up to 15 kW, preferably 3-10 kW heating power and that a centrally mounted expansion element (110) is constructed as to be permanently heated, **characterized in that** the power switch is constructed to switch power supply between different expansion elements (101-119) every two to thirty seconds preferably every five to fifteen seconds.

2. A casting roll (12) according to claim 1, **characterized in that** an expansion element (101-119) has a width between 40 and 150 mm, preferably between 40 and 100 mm, more preferably between 50 and 85 mm.

3. A casting roll (12) according to claim 1 or 2, **characterized in that** each expansion ring (101-119) has a radial ring thickness between 40 and 150 mm, preferably between 40 and 100 mm.

4. A casting roll (12) according to one of the preceding claims, **characterized in that** the expansion elements have the form of a ring (101-119) or of a disk.

5. A casting roll according to claim 1, **characterized in that** the total electrical energy power provided for all expansion elements (101-119) together is up to 70 kW, preferably not more than 35 kW, per meter of external circumference of the casting roll (12).

6. A casting roll (12) according to one of the preceding claims, **characterized in that** more than fifteen, preferably sixteen to thirty, axially symmetric expansion elements, such as expansion rings (101-119), are arranged within and adjacent the cylindrical tube (120).

7. A casting roll (12) according to one of the preceding claims, **characterized in that** a multitude of axially symmetric expansion elements, such as expansion rings (101-119), are distributed along the entire length of the cylindrical tube (120) including the end portions of the casting surface (12A).

8. A casting roll (12) according to claim 1, **characterized in that** the expansion elements (101, 119) located at the end portions of the casting surface (12A) are constructed as to be permanently heated.

9. A casting roll (12) according to one of the preceding claims, **characterized in that** the expansion elements (101 -119) are equipped with at least one temperature sensor each, for providing respective signals to a controller.

10. A casting roll (12) according to one of the preceding claims, **characterized in that** the expansion elements (101 -119) are equipped with at least one RFID-tag each, for identifying the expansion element when sending temperature information to a controller, preferably a controller situated within the casting roll (12).

11. A casting roll (12) according to one of the preceding claims, **characterized in that** a controller is constructed to control the radial dimension of each of the expansion elements (101-119) responsive to at least a temperature process model of the casting roll (12) and/or a temperature process model of the expansion elements (101-119) and/or to temperature changes measured for the expansion elements (101-119).

12. An apparatus for continuously casting thin strip by controlling roll crown comprising

- a pair of counter rotating casting rolls (12) with a nip (18) there between capable of delivering cast strip (21) downwardly from the nip, each casting roll having a casting surface (12A) formed by a substantially cylindrical tube (120),
- a metal delivery system positioned above the nip (18) and capable of forming a casting pool (19) supported on the casting surfaces of the casting rolls (12) with side dams (20) adjacent ends of the nip to confine the casting pool,

characterized in that at least one casting roll (12) is designed according to one of the claims 1-11.

13. A method of continuously casting thin strip by controlling roll crown,

- using a pair of counter rotating casting rolls (12) with a nip (18) there between to deliver cast strip (21) downwardly from the nip, each casting roll having a casting surface (12A) formed by a substantially cylindrical tube (120),
- further using a metal delivery system positioned above the nip (18) to form a casting pool (19) supported on the casting surfaces (12A) of the casting rolls (12) with side dams (20) adjacent ends of the nip to confine the casting pool,
- at least one casting roll (12) having axially symmetric expansion elements, such as expansion rings (101-119), arranged within and adjacent the cylindrical tube (120), each expansion element spaced from another expansion element, and the expansion elements adapted to increase in radial dimension causing the cylindrical tube (120) to expand changing roll crown of the casting surfaces of the casting rolls and thickness profile of the cast strip (21) during casting
- -at least one expansion element is increased in radial dimension, preferably by heating, causing the cylindrical tube (120) to expand while at least one other expansion element is not increased in radial dimension, whereas control of which expansion elements are to be increased is done on the basis of
- the recorded temperature profile of the cast strip (21), and/or
- the measured strip thickness profile of the cast strip (21), and/or
- the measured hot crown of the casting rolls (12), and/or
- the temperature profile of one or both of the casting rolls (12), and/or
- the measured temperature of expansion elements, **characterized in that** switching between different expansion elements (101-119) is done every two to sixty seconds, preferably every five to thirty seconds.

14. Method according to claim 13, **characterized in that** the temperature profile of one or both of the casting rolls (12) is given by a process model which outputs in real time a two- or three-dimensional temperature field of the interior of the cylindrical tube (120).

15. Method according to any of claims 13 or 14, **characterized in that** the temperature profile of one or both of the casting rolls (12) is given by a process model which outputs in real time the average temperature of each expansion element (101-119).

16. Method according to any of claims 13 to 15, **characterized in that** additionally artificial intelligence, e.g. in form of a neural network algorithm or a symbolic regression algorithm, is used for determining which expansion elements (101-119) have to be increased, preferably heated.

17. Method according to any of claims 13 to 16, **characterized in that** only three to nine, preferably three to five expansion elements are increased, preferably heated, at a time.

18. Method according to any of claims 13 to 17, **characterized in that** only a centrally mounted expansion element (110) is permanently increased, preferably heated.

19. Method according claim 18, **characterized in that** the expansion elements (101, 119) located at the end portions of the casting surface (12A) are permanently increased, preferably heated.

20. Method according to any of claims 13 to 19, **characterized in that** at least one of the casting rolls (12) is designed according to one of the claims 1 to 11.

Patentansprüche

1. Gießwalze (12) zum Gießen eines Metallbands (21) durch Stranggießen in einer Zweiwalzen-Gießanlage,

- mit einer Gießoberfläche (12A), die von einem im Wesentlichen zylindrischen Rohr (120) gebildet wird,
- mit axialsymmetrischen Expansionselementen wie Expansionsringen (101 bis 119), die in und neben dem zylindrischen Rohr (120) angeordnet sind, wobei jedes Expansionselement in einem Abstand zu einem anderen Expansionselement liegt und die Expansionselemente so ausgelegt sind, dass sich ihre radiale Abmessung vergrößert, so dass das zylindrische Rohr expandiert und sich dadurch die Walzenballigkeit der Gießoberflächen der Gießwalzen und das Dickeprofil des gegossenen Bands beim Gießen verändert,
- mit einer Vielzahl axialsymmetrischer Expansionselemente wie Expansionsringe (101 bis 119), die über die gesamte Länge des zylindrischen Rohrs (120) verteilt sind, und einem Stromversorgungsschalter, der sich in oder an der Gießwalze (12) befindet und die elektrische Stromversorgung der Expansionselemente (101 bis 119) mithilfe einer Stromleitung (181) von einem oder mehreren Expansionselementen auf ein oder mehrere andere Expansionselemente umschaltet, wobei jedes Expansionselement (101 bis 119) mit Widerstandsheizelementen ausgestattet ist, die in der Lage sind, das Expansionselement mit einer Heizleistung

von bis zu 15 kW, vorzugsweise 3 bis 10 kW, zu versorgen, und ein mittig angebrachtes Expansionselement (110) so konstruiert ist, dass es dauerhaft beheizt wird,
dadurch gekennzeichnet, dass der Leistungsschalter so konstruiert ist, dass er eine Stromversorgung alle zwei bis dreißig Sekunden, vorzugsweise alle fünf bis fünfzehn Sekunden, zwischen verschiedenen Expansionselementen (101 bis 119) umschaltet.

2. Gießwalze (12) nach Anspruch 1, **dadurch gekennzeichnet, dass** ein Expansionselement (101 bis 119) eine Breite zwischen 40 und 150 mm, vorzugsweise zwischen 40 und 100 mm, besonders bevorzugt zwischen 50 und 85 mm, aufweist.

3. Gießwalze (12) nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** jeder Expansionsring (101 bis 119) eine radiale Ringdicke zwischen 40 und 150 mm, vorzugsweise zwischen 40 und 100 mm, aufweist.

4. Gießwalze (12) nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Expansionselemente die Form eines Rings (101 bis 119) oder einer Scheibe aufweisen.

5. Gießwalze nach Anspruch 1, **dadurch gekennzeichnet, dass** die für alle Expansionselemente (101 bis 119) bereitgestellte elektrische Gesamtenergie insgesamt bis zu 70 kW, vorzugsweise maximal 35 kW, pro Meter Außenumfang der Gießwalze (12) beträgt.

6. Gießwalze (12) nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** mehr als fünfzehn, vorzugsweise sechzehn bis dreißig axialsymmetrische Expansionselemente, wie Expansionsringe (101 bis 119), in und neben dem zylindrischen Rohr (120) angeordnet sind.

7. Gießwalze (12) nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** eine Vielzahl axialsymmetrischer Expansionselemente, wie Expansionsringe (101 bis 119), über die gesamte Länge des zylindrischen Rohrs (120) einschließlich der Endabschnitte der Gießoberfläche (12A) verteilt sind.

8. Gießwalze (12) nach Anspruch 1, **dadurch gekennzeichnet, dass** die Expansionselemente (101, 119) an den Endabschnitten der Gießoberfläche (12A) so konstruiert sind, dass sie dauerhaft beheizt werden.

9. Gießwalze (12) nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Expansionselemente (101 bis 119) jeweils mit mindestens einem Temperatursensor zum Liefern von jeweiligen Signalen für eine Steuerung ausgestattet sind.

10. Gießwalze (12) nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Expansionselemente (101 bis 119) jeweils mit mindestens einem RFID-Tag zum Kennzeichnen des Expansionselements beim Senden von Temperaturangaben zu einer Steuerung, vorzugsweise einer Steuerung in der Gießwalze (12), ausgestattet sind.

11. Gießwalze (12) nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** eine Steuerung so konstruiert ist, dass sie die radiale Abmessung jedes Expansionselements (101 bis 119) gemäß einem Temperaturprozessmodell für die Gießwalze (12) und/oder einem Temperaturprozessmodell für die Expansionselemente (101 bis 119) und/oder gemäß für die Expansionselemente (101 bis 119) gemessenen Temperaturänderungen regelt.

12. Vorrichtung zum Stranggießen dünner Bänder durch Steuern der Walzenballigkeit, die Folgendes umfasst:

- zwei gegenläufig rotierende Gießwalzen (12) mit einem Spalt (18) dazwischen, die in der Lage sind, abwärts von dem Spalt gegossene Bänder (21) abzugeben, wobei jede Gießwalze eine Gießoberfläche (12A) aufweist, die von einem im Wesentlichen zylindrischen Rohr (120) gebildet wird,
- ein Metallabgabesystem, das oberhalb des Spalts (18) angeordnet und in der Lage ist, einen auf den Gießoberflächen der Gießwalzen (12) gehaltenen Gießtümpel (19) zu bilden, wobei an Enden des Spalts seitliche Dämme (20) angrenzen, die den Gießtümpel begrenzen,

dadurch gekennzeichnet, dass mindestens eine Gießwalze (12) einem der Ansprüche 1 bis 11 entsprechend aufgebaut ist.

13. Verfahren zum Stranggießen dünner Bänder durch Steuern der Walzenballigkeit

- unter Verwendung von zwei gegenläufig rotierenden Gießwalzen (12) mit einem Spalt (18) dazwischen zum Abgeben von gegossenen Bändern (21) abwärts von dem Spalt, wobei jede Gießwalze eine Gießoberfläche (12A) aufweist, die von einem im Wesentlichen zylindrischen Rohr (120) gebildet wird,
- ferner unter Verwendung eines Metallabgabesystems, das oberhalb des Spalts (18) angeordnet und in der Lage ist, einen auf den Gießober-

flächen (12A) der Gießwalzen (12) gehaltenen Gießtümpel (19) zu bilden, wobei an Enden des Spalts seitliche Dämme (20) angrenzen, die den Gießtümpel begrenzen,
- wobei mindestens eine Gießwalze (12) axialsymmetrische Expansionselemente wie Expansionsringe (101 bis 119) aufweist, die in und neben dem zylindrischen Rohr (120) angeordnet sind, wobei jedes Expansionselement in einem Abstand zu einem anderen Expansionselement liegt und die Expansionselemente so ausgelegt sind, dass sich ihre radiale Abmessung vergrößert, so dass das zylindrische Rohr (120) expandiert und sich dadurch die Walzenballigkeit der Gießoberflächen der Gießwalzen und das Dickeprofil des gegossenen Bands (21) beim Gießen verändert,
- wobei die radiale Abmessung mindestens eines Expansionselements, vorzugsweise durch Erhitzen, vergrößert wird, wodurch das zylindrische Rohr (120) expandiert, während die radiale Abmessung mindestens eines anderen Expansionselements nicht vergrößert wird, wobei die Regelung, welche Expansionselemente vergrößert werden sollen, auf folgender Grundlage erfolgt:
- aufgezeichnetes Temperaturprofil für das gegossene Band (21) und/oder
- gemessenes Banddickeprofil für das gegossene Band (21) und/oder
- gemessene thermische Balligkeit der Gießwalzen (12) und/oder
- Temperaturprofil einer der oder beider Gießwalzen (12) und/oder
- gemessene Temperatur von Expansionselementen,

dadurch gekennzeichnet, dass ein Wechsel zwischen unterschiedlichen Expansionselementen (101 bis 119) alle zwei bis sechzig Sekunden, vorzugsweise alle fünf bis dreißig Sekunden erfolgt.

14. Verfahren nach Anspruch 13, **dadurch gekennzeichnet, dass** das Temperaturprofil einer der oder beider Gießwalzen (12) von einem Prozessmodell geliefert wird, das in Echtzeit ein zwei- oder dreidimensionales Temperaturfeld vom Innern des zylindrischen Rohrs (120) ausgibt.

15. Verfahren nach Anspruch 13 oder 14, **dadurch gekennzeichnet, dass** das Temperaturprofil einer der oder beider Gießwalzen (12) von einem Prozessmodell geliefert wird, das in Echtzeit die Durchschnittstemperatur jedes Expansionselements (101 bis 119) ausgibt.

16. Verfahren nach einem der Ansprüche 13 bis 15, **dadurch gekennzeichnet, dass** zum Festlegen, welche Expansionselemente (101 bis 119) vergrößert, vorzugsweise erhitzt werden müssen, zusätzlich künstliche Intelligenz, z.B. in Form eines Algorithmus für neuronale Netze oder zur symbolischen Regression, verwendet wird.

17. Verfahren nach einem der Ansprüche 13 bis 16, **dadurch gekennzeichnet, dass** nur drei bis neun, vorzugsweise drei bis fünf Expansionselemente gleichzeitig vergrößert, vorzugsweise erhitzt werden.

18. Verfahren nach einem der Ansprüche 13 bis 17, **dadurch gekennzeichnet, dass** nur ein mittig angebrachtes Expansionselement (110) dauerhaft vergrößert, vorzugsweise erhitzt wird.

19. Verfahren nach Anspruch 18, **dadurch gekennzeichnet, dass** die Expansionselemente (101, 119) an den Endabschnitten der Gießoberfläche (12A) dauerhaft vergrößert, vorzugsweise erhitzt werden.

20. Verfahren nach einem der Ansprüche 13 bis 19, **dadurch gekennzeichnet, dass** mindestens eine der Gießwalzen (12) einem der Ansprüche 1 bis 11 entsprechend aufgebaut ist.

Revendications

1. Rouleau de coulée (12) pour la coulée d'une bande métallique (21) par coulée continue dans une machine de coulée entre cylindres,

ayant une surface de coulée (12A) formée par un tube sensiblement cylindrique (120),
ayant des éléments d'expansion axialement symétriques, tels que des bagues d'expansion (101-119), agencés dans et de manière adjacente au tube cylindrique (120), chaque élément d'expansion étant espacé d'un autre élément d'expansion, et les éléments d'expansion étant adaptés pour augmenter en dimension radiale, amenant le tube cylindrique à expanser la cambrure de rouleau de changement des surfaces de coulée des rouleaux de coulée et le profil d'épaisseur de la bande coulée pendant la coulée,
ayant une multitude d'éléments d'expansion axialement symétriques, telles que des bagues d'expansion (101-119), qui sont répartis le long de toute la longueur du tube cylindrique (120) et un interrupteur d'alimentation est situé dans ou sur le rouleau de coulée (12) afin de commuter l'alimentation électrique des éléments d'expansion (101-119) d'un ou de plusieurs éléments d'expansion aux un ou plusieurs autres éléments d'expansion en utilisant un fil d'alimentation (181), de sorte que chaque élément d'ex-

pansion (101-119) est équipé d'éléments chauffants à résistance électrique qui peuvent fournir à l'élément d'expansion jusqu'à 15 kW, de préférence 3-10 kW de puissance de chauffage et en ce qu'un élément d'expansion (110) monté de manière centrale est construit afin d'être chauffé en permanence, **caractérisé en ce que** l'interrupteur d'alimentation est construit pour commuter la puissance d'alimentation entre différents éléments d'expansion (101-119) toutes les deux à trente secondes, de préférence toutes les cinq à quinze secondes.

2. Rouleau de coulée (12) selon la revendication 1, **caractérisé en ce qu'**un élément d'expansion (101-119) a une largeur comprise entre 40 et 150 mm, de préférence entre 40 et 100 mm, encore de préférence entre 50 et 85 mm.

3. Rouleau de coulée (12) selon la revendication 1 ou 2, **caractérisé en ce que** chaque bague d'expansion (101-119) a une épaisseur de bague radiale comprise entre 40 et 150 mm, de préférence entre 40 et 100 mm.

4. Rouleau de coulée (12) selon l'une des revendications précédentes, **caractérisé en ce que** les éléments d'expansion ont la forme d'une bague (101-119) ou d'un disque.

5. Rouleau de coulée selon la revendication 1, **caractérisé en ce que** la puissance électrique totale fournie pour tous les éléments d'expansion (101-119) ensemble va jusqu'à 70 kW, de préférence non supérieure à 35 kW, par mètre de circonférence externe du rouleau de coulée (12).

6. Rouleau de coulée (12) selon l'une des revendications précédentes, **caractérisé en ce que** plus de quinze, de préférence de seize à trente éléments d'expansion axialement symétriques, telles que des bagues d'expansion (101-119), sont agencés à l'intérieur de et de manière adjacente au tube cylindrique (120) .

7. Rouleau de coulée (12) selon l'une des revendications précédentes, **caractérisé en ce qu'**une multitude d'éléments d'expansion axialement symétriques, telles que des bagues d'expansion (101-119), sont répartis le long de toute la longueur du tube cylindrique (120) comprenant les parties d'extrémité de la surface de coulée (12A).

8. Rouleau de coulée (12) selon la revendication 1, **caractérisé en ce que** les éléments d'expansion (101, 119) positionnés au niveau des parties d'extrémité de la surface de coulée (12A), sont construits afin d'être chauffés en permanence.

9. Rouleau de coulée (12) selon l'une des revendications précédentes, **caractérisé en ce que** les éléments d'expansion (101-119) sont équipés avec au moins un capteur de température chacun, pour fournir des signaux respectifs à un organe de commande.

10. Rouleau de coulée (12) selon l'une des revendications précédentes, **caractérisé en ce que** les éléments d'expansion (101-119) sont équipés avec au moins une étiquette RFID chacun, pour identifier l'élément d'expansion lors de l'envoi de l'information de température à un organe de commande, de préférence un organe de commande situé à l'intérieur du rouleau de coulée (12).

11. Rouleau de coulée (12) selon l'une des revendications précédentes, **caractérisé en ce qu'**un organe de commande est construit pour contrôler la dimension radiale de chacun des éléments d'expansion (101-119) en réponse à au moins un modèle de traitement de température du rouleau de coulée (12) et/ou un modèle de traitement de température des éléments d'expansion (101-119) et/ou aux changements de température mesurés pour les éléments d'expansion (101-119).

12. Appareil pour couler, en continu, une fine bande en commandant la cambrure d'un rouleau, comprenant :

une paire de rouleaux de coulée contrarotatifs (12) avec une ligne de contact (18) entre eux pouvant délivrer la bande coulée (21) vers le bas à partir de la ligne de contact, chaque rouleau de coulée ayant une surface de coulée (12A) formée par un tube sensiblement cylindrique (120),
un système de distribution de métal positionné au-dessus de la ligne de contact (18) et pouvant former un bassin de coulée (19) supporté sur les surfaces de coulée des rouleaux de coulée (12) avec des barrages latéraux (20) adjacents aux extrémités de la ligne de contact pour confiner le bassin de coulée,
caractérisé en ce qu'au moins un rouleau de coulée (12) est conçu selon l'une des revendications 1 à 11.

13. Procédé pour couler, en continu, une bande fine en commandant une cambrure d'un rouleau, comprenant les étapes consistant à :

utiliser une paire de rouleaux de coulée contrarotatifs (12) avec une ligne de contact (18) entre eux pour délivrer une bande coulée (21) vers le bas à partir de la ligne de contact, chaque rouleau de coulée ayant une surface de coulée

(12A) formée par un tube sensiblement cylindrique (120),
utiliser en outre un système de distribution de métal positionné au-dessus de la ligne de contact (18) afin de former un bassin de coulée (19) supporté sur les surfaces de coulée (12A) des rouleaux de coulée (12) avec des barrages latéraux (20) adjacents aux extrémités de la ligne de contact afin de confiner le bassin de coulée, au moins un rouleau de coulée (12) ayant des éléments d'expansion axialement symétriques, telles que des bagues d'expansion (101-119), agencés à l'intérieur et de manière adjacente au tube cylindrique (120), chaque élément d'expansion étant espacé d'un autre élément d'expansion, et les éléments d'expansion étant adaptés pour augmenter en dimension radiale, amenant le tube cylindrique (120) à expanser la cambrure d'un rouleau de changement des surfaces de coulée des rouleaux de coulée et le profil d'épaisseur de la bande coulée (21) pendant la coulée,
au moins un élément d'expansion est augmenté en dimension radiale, de préférence par chauffage, amenant le tube cylindrique (120) à s'expanser alors qu'au moins un autre élément d'expansion n'augmente pas en dimension radiale, tandis que la commande de ces éléments d'expansion qui doivent être augmentés, est réalisée sur la base de :

le profil de température enregistré de la bande coulée (21), et/ou
le profil d'épaisseur de bande mesuré de la bande coulée (21), et/ou
la couronne chaude mesurée des rouleaux de coulée (12), et/ou
le profil de température d'un ou des deux des rouleaux de coulée (12), et/ou
la température mesurée des éléments d'expansion,

caractérisé en ce que la commutation entre différents éléments d'expansion (101-119) est réalisée toutes les deux à soixante secondes, de préférence toutes les cinq à trente secondes.

14. Procédé selon la revendication 13, **caractérisé en ce que** le profil de température d'un ou des deux rouleaux de coulée (12) est donné par un modèle de traitement qui produit en temps réel un champ de température en deux ou trois dimensions de l'intérieur du tube cylindrique (120).

15. Procédé selon l'une quelconque des revendications 13 ou 14, **caractérisé en ce que** le profil de température d'un ou de deux des rouleaux de coulée (12) est donné par un modèle de traitement qui produit en temps réel la température moyenne de chaque élément d'expansion (101-119).

16. Procédé selon l'une quelconque des revendications 13 à 15, **caractérisé en ce que** l'on utilise de plus l'intelligence artificielle, par exemple sous la forme d'un algorithme de réseau neural ou d'un algorithme de régression symbolique, pour déterminer quels éléments d'expansion (101-119) doivent être augmentés, de préférence chauffés.

17. Procédé selon l'une quelconque des revendications 13 à 16, **caractérisé en ce qu'**uniquement trois à neuf, de préférence trois à cinq éléments d'expansion sont augmentés, de préférence chauffés, à la fois.

18. Procédé selon l'une quelconque des revendications 13 à 17, **caractérisé en ce qu'**uniquement un élément d'expansion (110) monté de manière centrale est augmenté en permanence, de préférence chauffé.

19. Procédé selon la revendication 18, **caractérisé en ce que** les éléments d'expansion (101, 109) positionnés au niveau des parties d'extrémité de la surface de coulée (12A) sont augmentés en permanence, de préférence chauffés.

20. Procédé selon l'une quelconque des revendications 13 à 19, **caractérisé en ce qu'**au moins l'un des rouleaux de coulée (12) est conçu selon l'une des revendications 1 à 11.

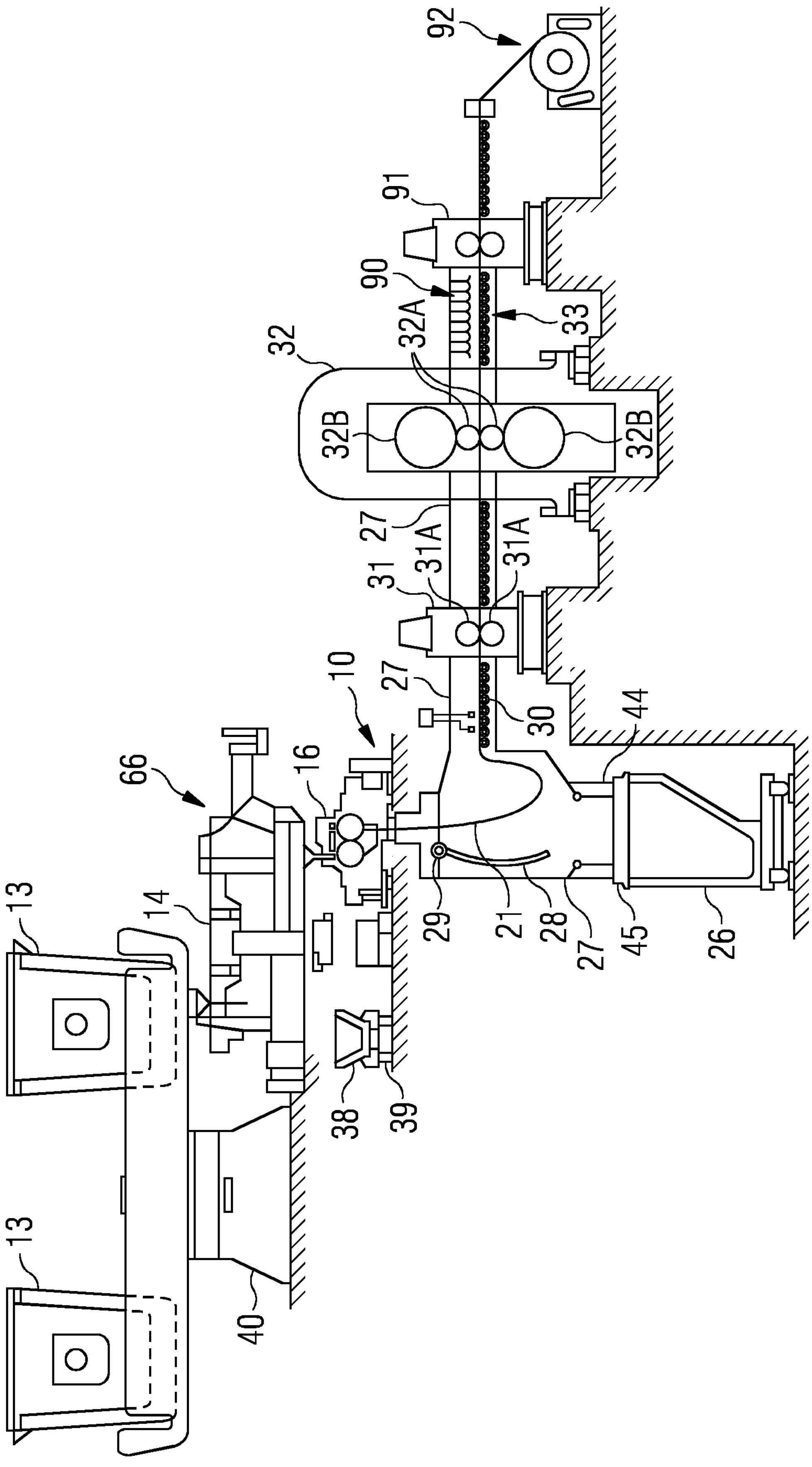
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FIG 1

FIG 2A

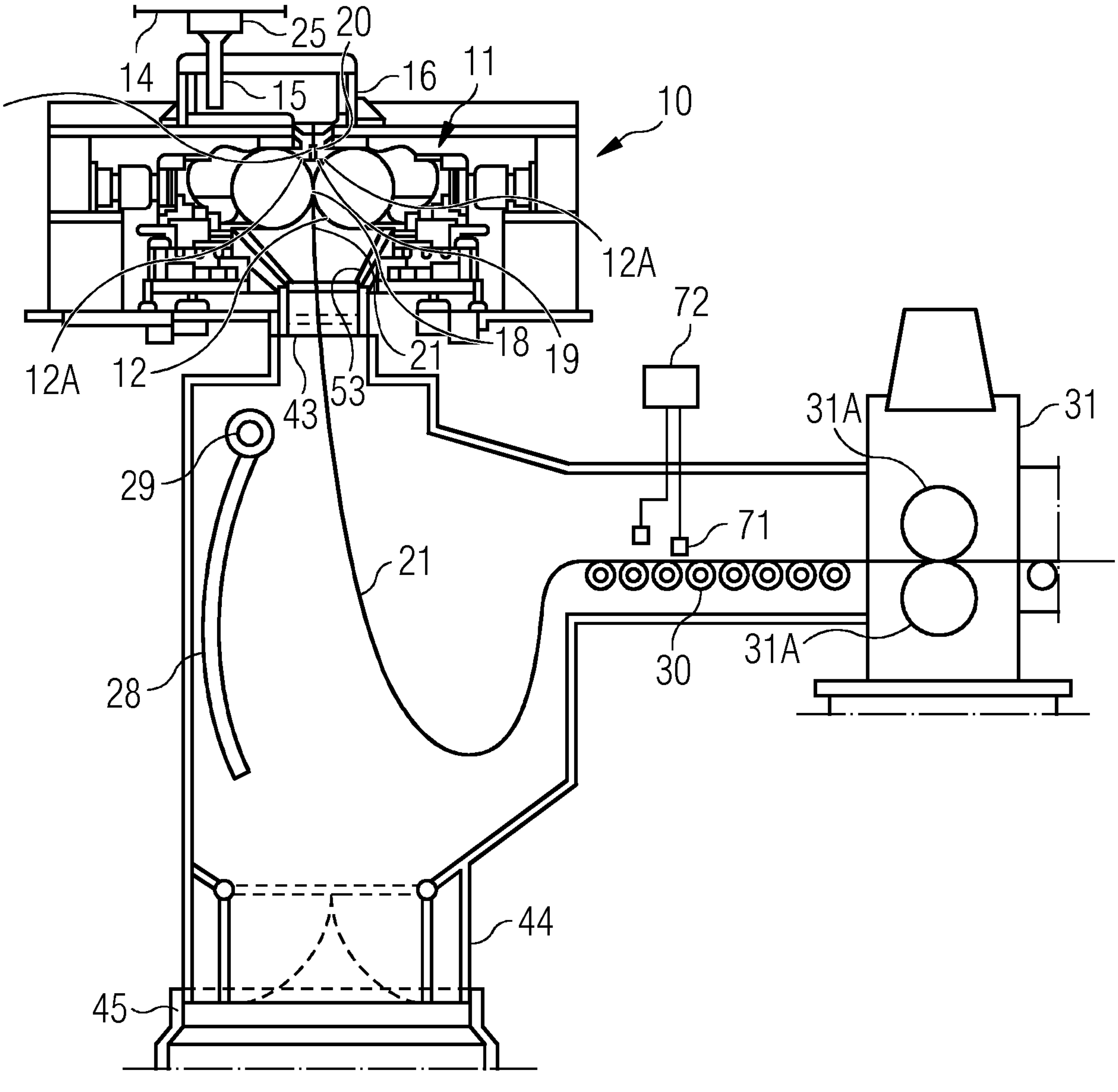
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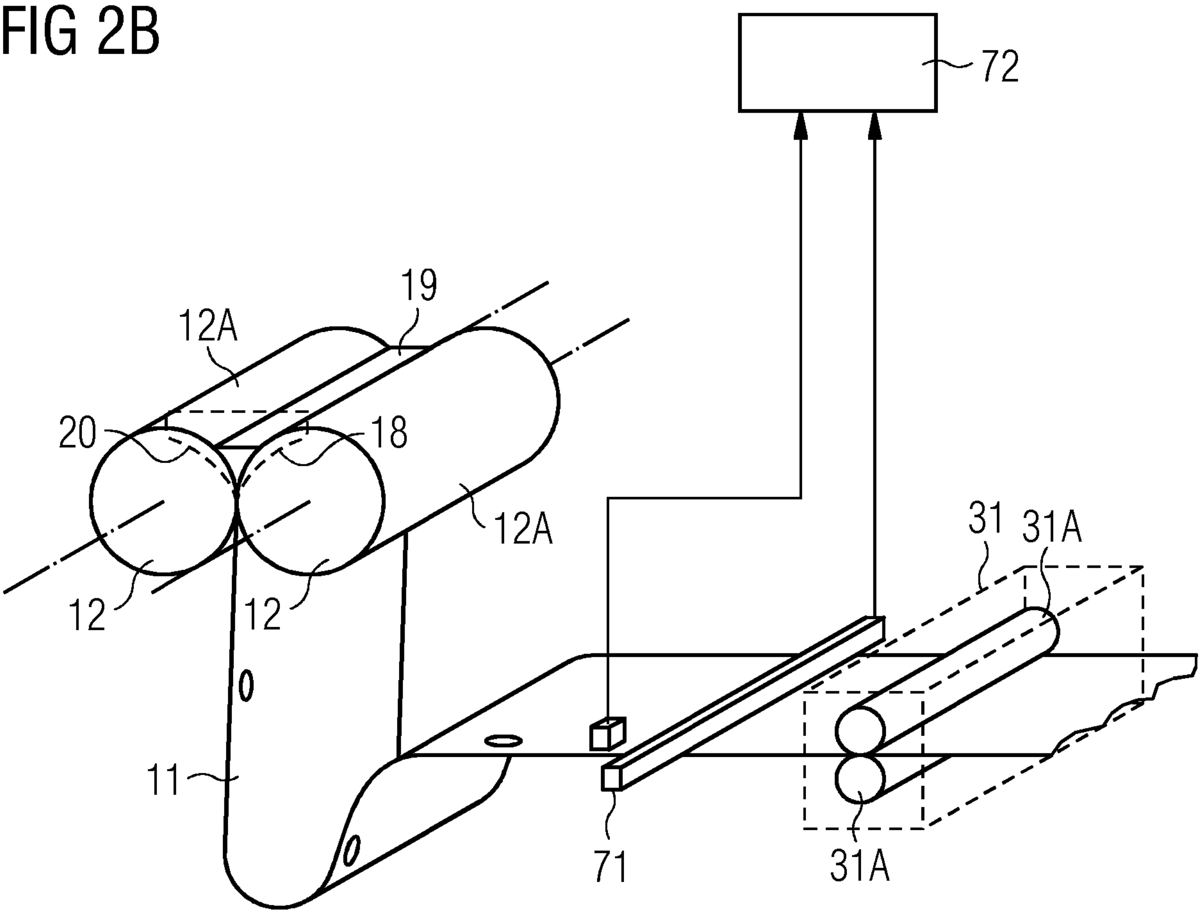
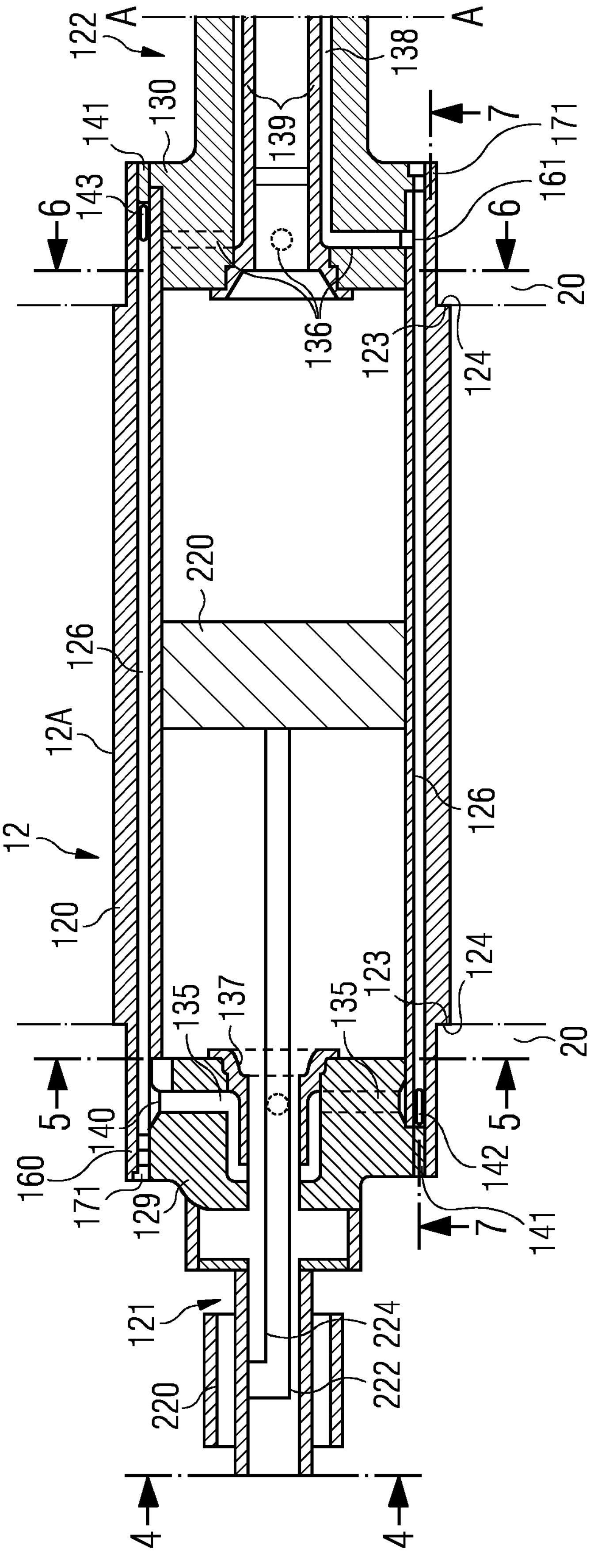
FIG 2B

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12A
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FIG 3A

FIG 3B

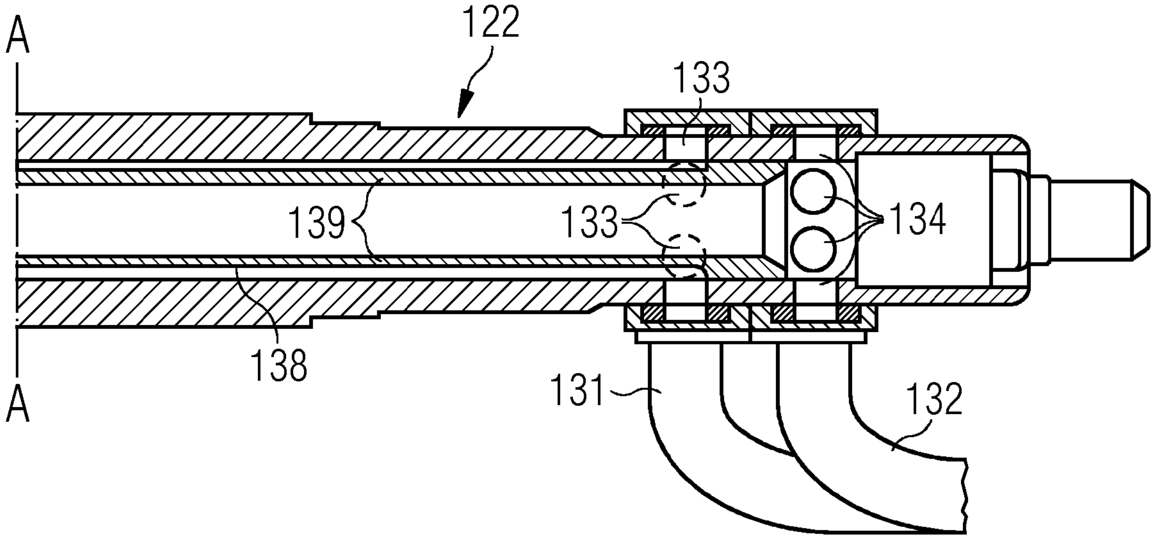
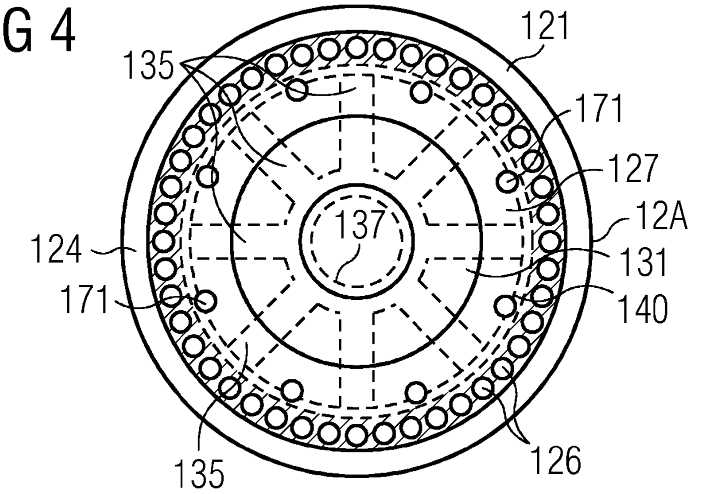


FIG 4



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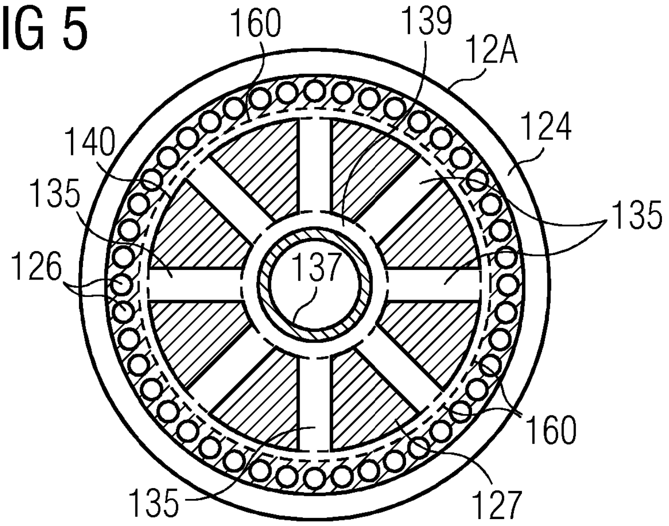

FIG 6

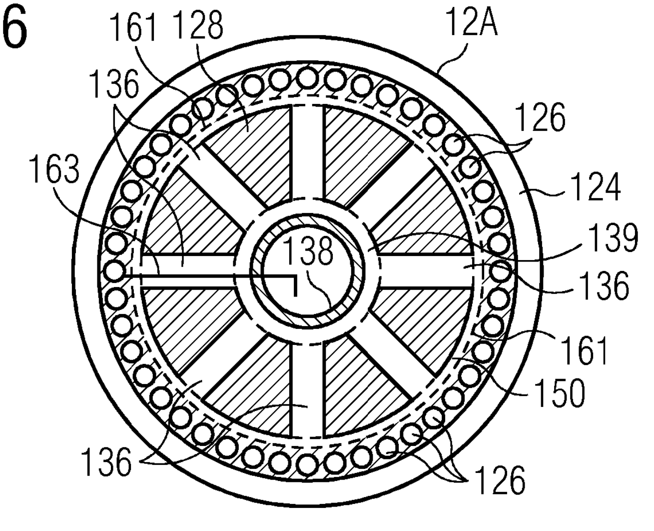

FIG 7

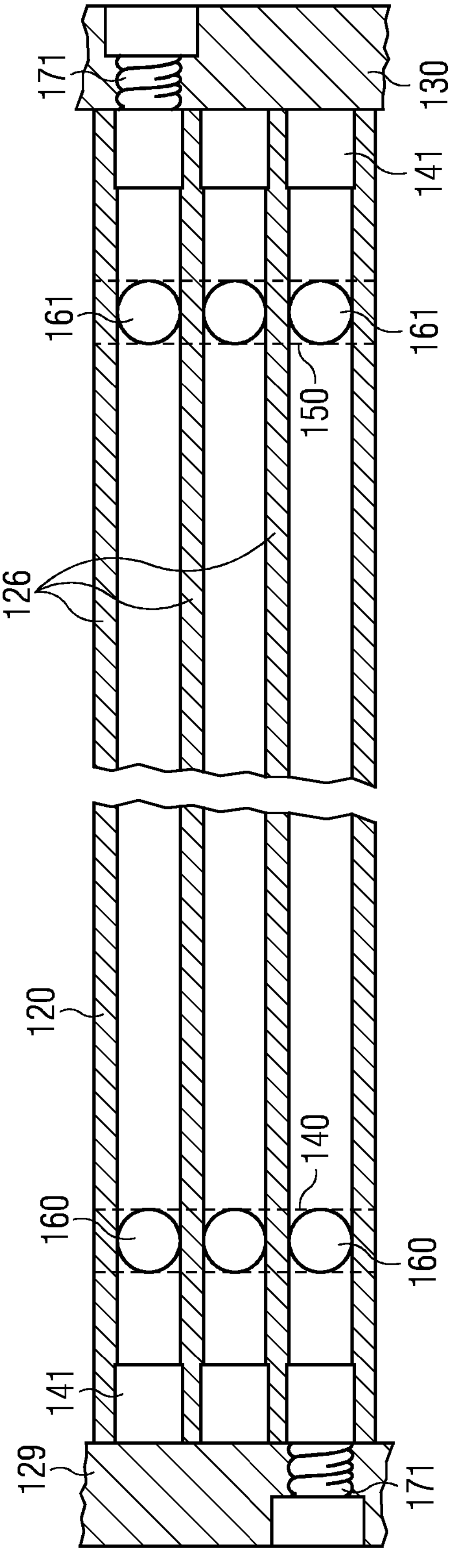

FIG 8

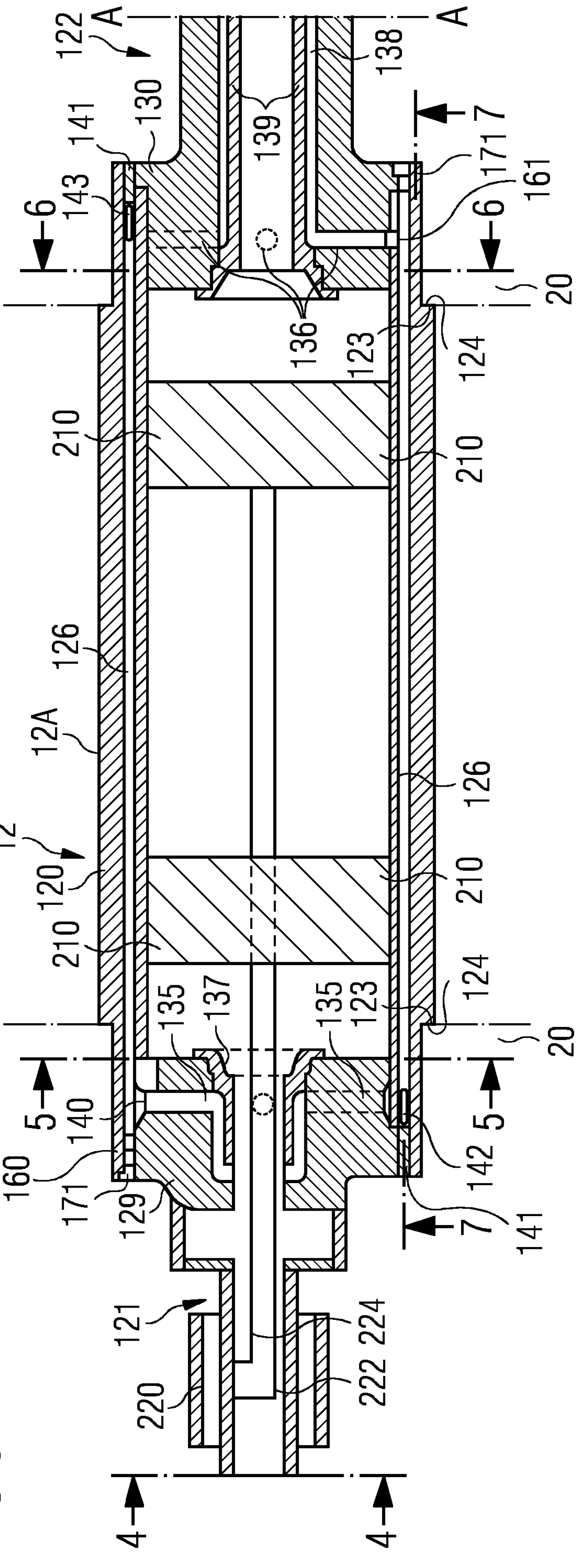
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FIG 9

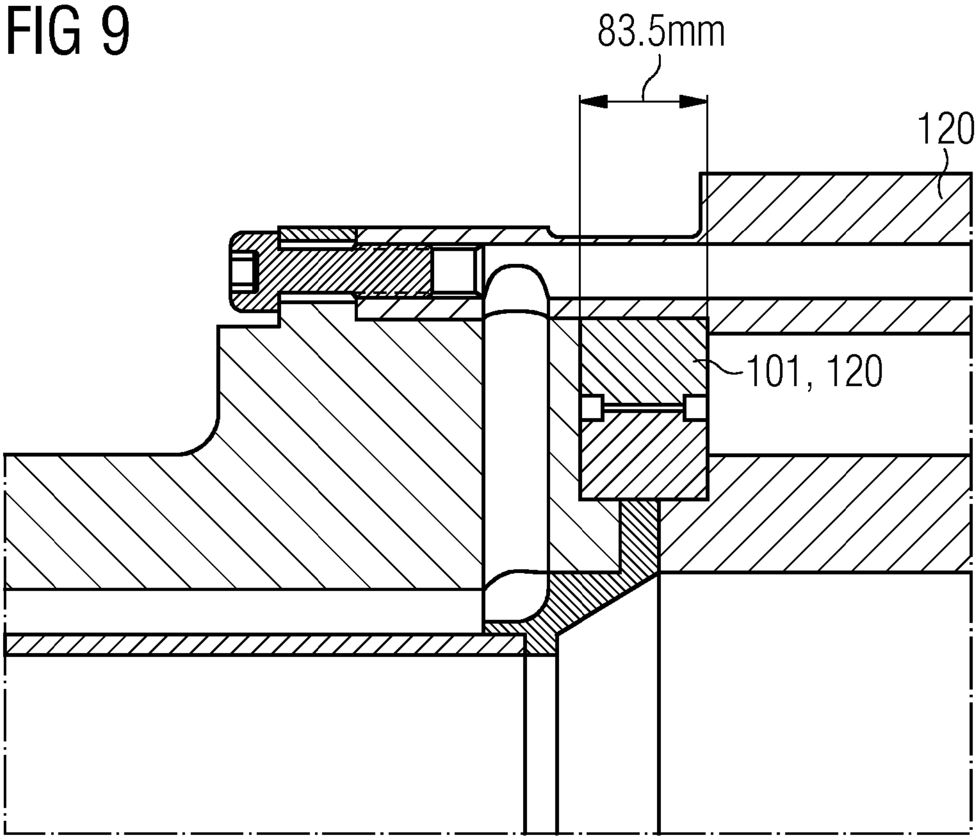

FIG 10

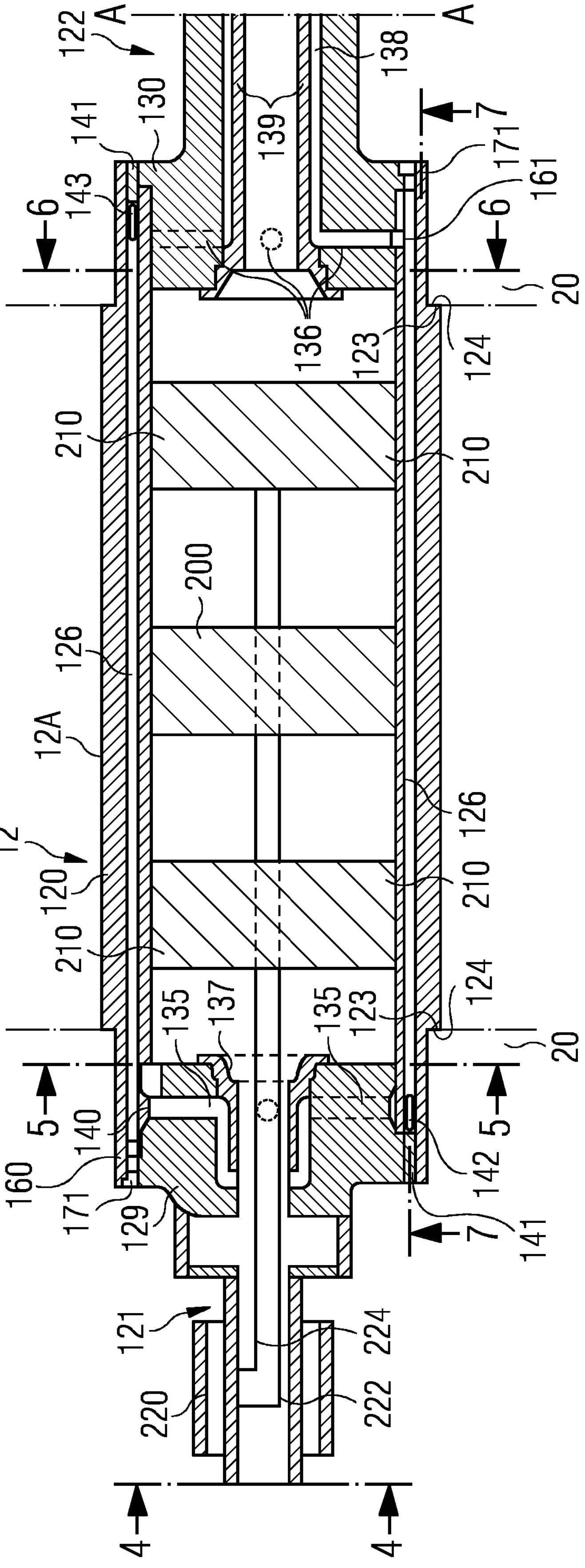
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FIG 11

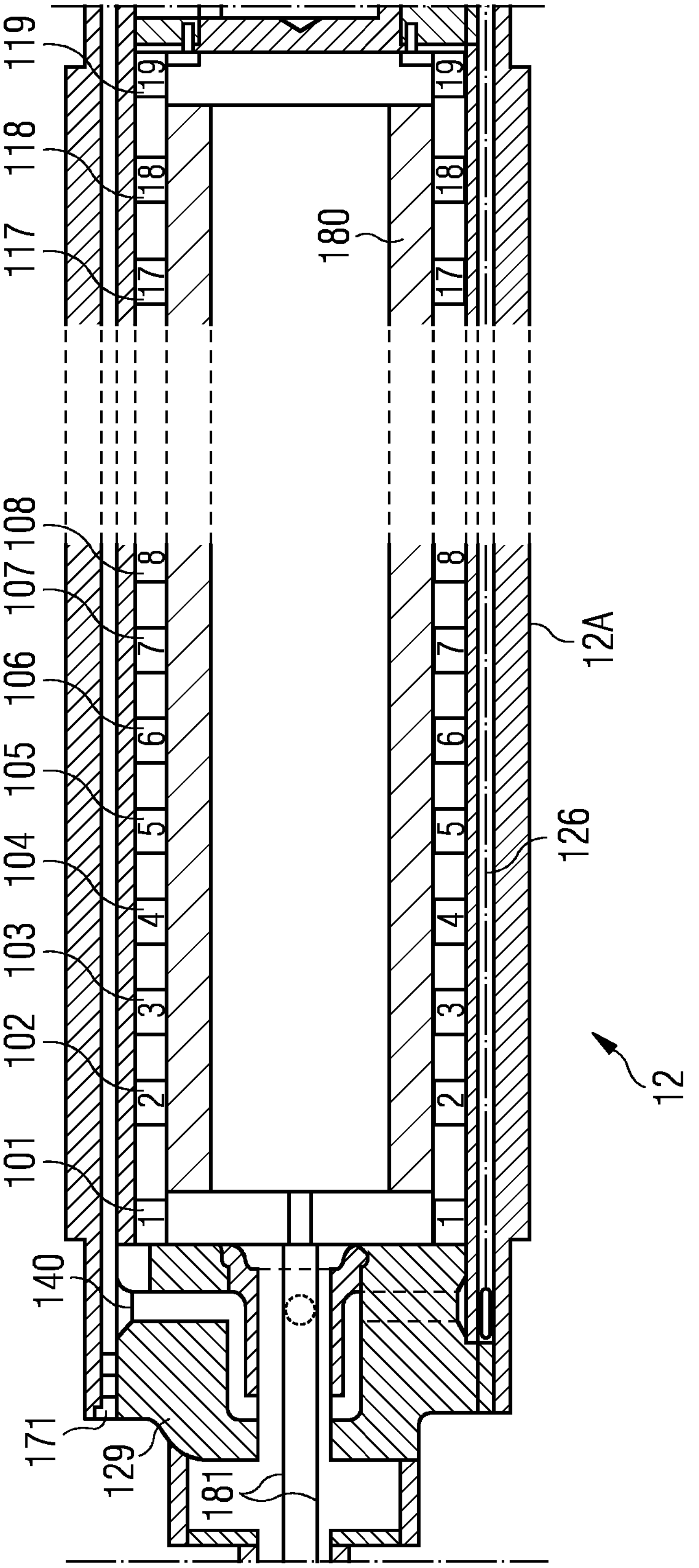
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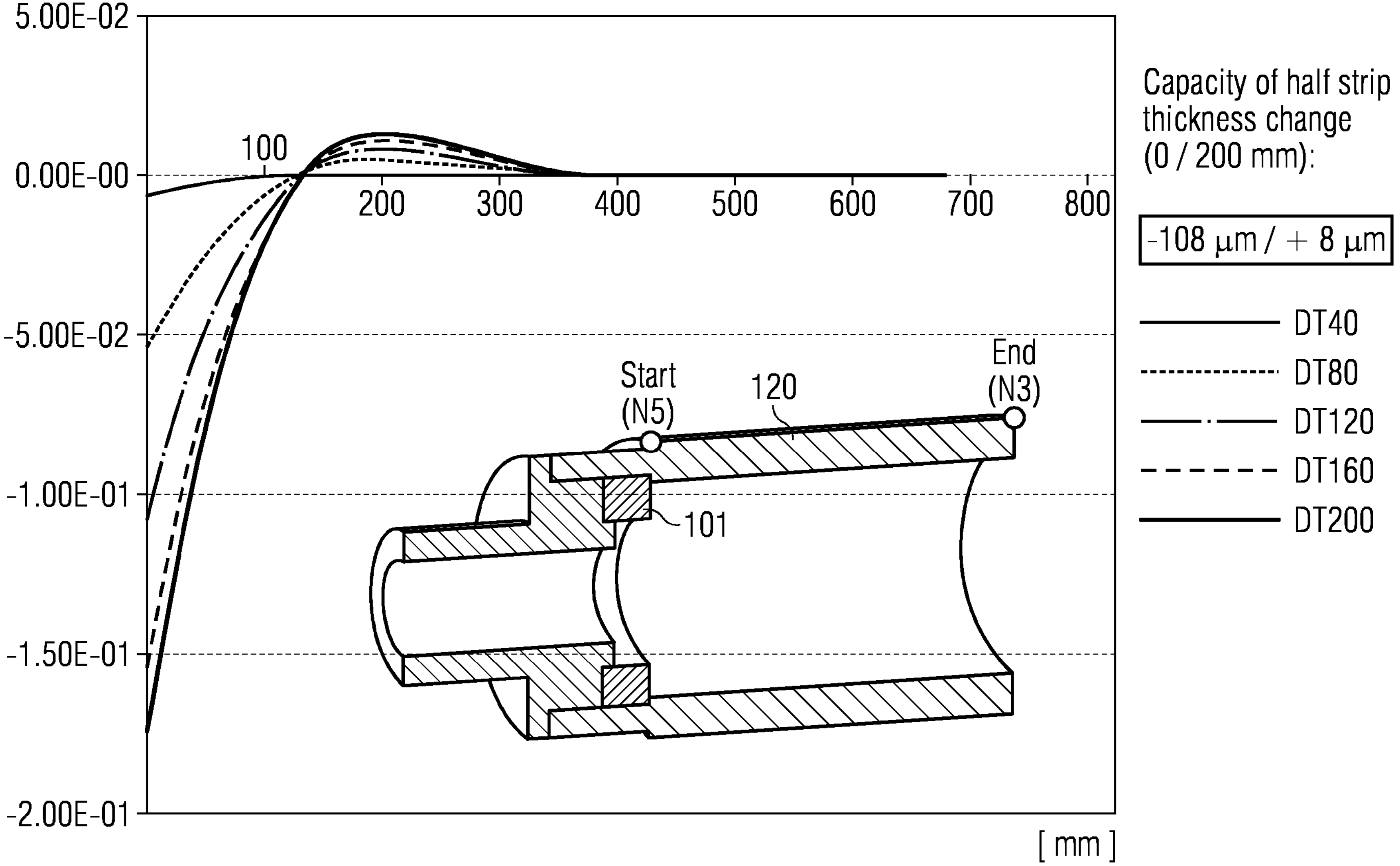
FIG 12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-1.00E-01
-1.50E-01
-2.00E-01
100
200
300
400
500
600
700
800
[mm]
Start
(N5)
120
End
(N3)
101
Capacity of half strip thickness change (0 / 200 mm):
-108 µm / + 8 µm
DT40
DT80
DT120
DT160
DT200

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO 2016083506 A1 **[0011]**
- FR 1343136 **[0012]**
- WO 2016107715 A **[0012]**
- EP 0429385 A **[0012]**