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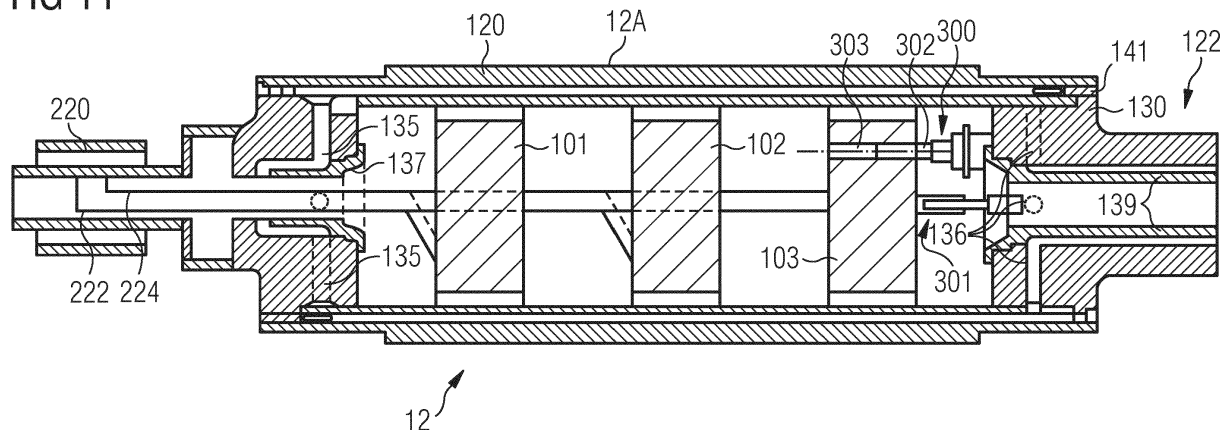
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(54) **CASTING ROLL AND METHOD FOR CASTING METAL STRIP WITH CROWN CONTROL**

(57) The invention relates to 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 at least one substantially axially symmetric expansion element, e.g. an expansion ring (101-103), arranged within the cylindrical tube (120), and the expansion element adapted to increase in radial dimension causing the cylindrical tube to expand changing roll

crown of the casting surfaces (12A) of the casting rolls and thickness profile of the cast strip during casting, whereas at least one expansion element is movable in axial direction of the casting roll (12). The method of continuously casting thin strip by controlling roll crown is characterized in that at least one expansion element is moved in axial direction of the casting roll (12) to an axial position where the strip thickness of the cast metal strip (21) shall be reduced.

FIG 11



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 at least one substantially axially symmetric (also called axis-symmetric) expansion element, e.g. an expansion ring, arranged within 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 to the ends of the nip to confine the casting pool,
- at least one casting roll having at least one substantially axially symmetric expansion element, such as an expansion ring, arranged within the cylindrical tube, and the expansion element 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 produced by the twin roll caster. Casting rolls with convex (i.e. positive crown) casting surfaces produce cast strip with a negative (i.e. depressed, concave) cross-sectional shape; and casting rolls with concave (i.e. negative crown) casting surfaces produce cast strip with a positive (i.e. raised, convex) 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. Other factors influencing the shape of the casting rolls at the nip and/or the end point of solidification, and thus influencing the shape and thickness profile of the cast strip, are total solidification over time,

varying liquid molten metal flow onto the casting rolls, varying surface conditions on the casting rolls due to oxidation and scale deposition effects, varying cleaning of rolls, or the like.

[0009] Generally, the casting rolls are heavily charged, e.g. by external solidification heat, thermo-shock, internal cooling, edge forces from the side dams, cleaning brushes and by separation forces at the nip. Due to this large number of variabilities it is very difficult to forecast before a casting process start on which spot of the strip width the darkest lines and thus coolest areas (stripes) of strip will occur and where the brightest and thus hottest areas (stripes).

[0010] 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 it 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.

[0011] 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.

[0012] WO 2016/083506 A1, corresponding to US 2017341134 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 and global strip crown.

[0013] Another invention by the same inventor suggests to use a multitude of expansion rings distributed along the entire length of the cylindrical tube whereas a power switch is situated in or on the casting roll in order to switch electrical power supply of the expansion elements from one or more expansion elements to one or more other expansion elements. Since the expansion elements are distributed along the cylindrical tube 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 at least two expansion elements are needed 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 would be sixteen to thirty axially symmetric expansion

elements, such as expansion rings.

[0014] Apart from edge drop, there is still an issue of fluctuation of the thickness profile of up to 20 micrometer. In particular in an area of 150 to 300 mm from the strip edge into the strip and also in the inner bulk area of the strip farther than 300 mm from the edge, thickness depressions or protrusion up to 40 micrometer occur in rare cases since the influence area of any expansion ring is normally not wider than 150 mm from the edges of the expansion ring in both directions, based on a half-value decay model. Additionally, having more than 5 or 7 expansion rings is rather complex due to interactions between the expansion rings and control effort.

15 SUMMARY OF THE INVENTION

[0015] One object of the present invention is to further reduce the peaks and valleys of the strip surface across the strip width, and at the same time keeping the number of expansion elements as low as possible.

[0016] According to the present invention this can be achieved by a casting roll when at least one expansion element is movable in axial direction of the casting roll.

[0017] The at least one movable expansion element, e.g. an expansion ring, can be shifted axially and on-line during strip casting and can be expanded, e.g. heated, at its new position. An embodiment of the invention is that the operator now can position the movable expansion element into that area of the casting roll which is directly associated to the thickest stripes of the cast strip, hence reducing the produced as cast strip thickness at this location and in this way generating higher casting (separation) forces there. This will relatively reduce the specific casting roll separation force on a neighboring area which has exhibited thinner stripes. Accordingly, force distribution and thickness distribution is homogenized over the whole strip width. This helps in achieving better the required rectangular or parabolic strip thickness profile.

[0018] The expansion element is also moved to a new position if at its actual position the strip thickness is too low even if the expansion element is not heated and does not influence the form of the casting roll. Because if the expansion element would be heated at its actual position (where strip thickness is too low) one would have to wait until the expansion element has cooled down and has shrunk to see if the strip thickness has increased or the local strip thickness differences have been reduced.

[0019] Of course one or more movable expansion elements can be combined with one or more of the known fixed expansion elements. So a casting roll could have one movable expansion element, e.g. in the middle of the casting roll, and two fixed expansion elements, e.g. on either side of the movable expansion element. For reasons of symmetry one could use two movable expansion elements whose areas of possible positions are symmetric to the middle of the casting roll.

[0020] One embodiment of the present invention is that

the expansion element is movable in axial direction by 1-250 mm, preferably by 10-100 mm. This is sufficient for many applications and keeps the inner construction of the casting roll simple and fail-safe.

[0021] One embodiment of the present invention is that the expansion element is movable to axial positions which are more than 120 mm away from the wet ends of the cylindrical tube of the casting roll (which corresponds to more than 120 mm away from the strip edge). The wet end of the cylindrical tube is to be understood as the end of the area where liquid metal wets the cylindrical tube. The cylindrical tube of course projects beyond that area which area is called wetting area or solidification area. With this embodiment the task of dynamically reducing the strip thickness apart from the edge region of the strip can be solved. Especially if the possible axial positions are more than 300 mm away from the ends of the cylindrical tube thickness deviations in the inner bulk region of the strip can be homogenized, and at the same time not influencing the as cast strip edge thickness at all.

[0022] One embodiment of the present invention is that the expansion element is movable to axial positions which are between 120 mm and 350 mm away from the wet ends of the cylindrical tube of the casting roll. With this embodiment the so called dog-bone region of the strip can be homogenized, especially if two movable expansion elements are used and one movable expansion element is situated near each wet end in the area between 120 mm and 350 mm away from the wet ends.

[0023] One embodiment of the present invention is that an actuator is situated within the casting roll and that the actuator is constructed to move the expansion element in axial direction of the casting roll. The actuator is preferably driven electrically. Normally each movable expansion element will have its own actuator. If two or more movable expansion elements are near enough to each other one actuator, e.g. one electric drive can move both or more expansion elements.

[0024] The actuator will preferably contain two guiding elements, e.g. in the center (seen in radial direction) of the casting roll. One guiding element can be a pipe which is arranged concentrically or near to the axis of the casting roll, the expansion elements being supported on this pipe. One option for mounting the expansion elements on the guiding element would be a thread on the guiding element with a corresponding thread on the expansion element. Preferably the expansion elements are locked against rotation. The second guiding element can be combined with the drive that moves the expansion element.

[0025] A possible solution for the actuators is that the actuator contains a spindle drive. The spindle can then act as the second guiding element.

[0026] One embodiment of the present invention is that the casting roll comprises a sensor for measuring the axial position of the at least one movable expansion element with relation to the cylindrical tube of the casting roll. Thus it can be checked if the expansion ring is po-

sitioned correctly.

[0027] The positioning of the movable expansion elements will normally be controlled by a controller, e.g. comprising a microprocessor. The controller will be connected to the sensor for measuring the axial position of the expansion element and to the actuator of the expansion element. The controller is favourably constructed to control the position of the movable expansion element in axial direction of the casting roll responsive to the strip profile, and/or to the casting roll hot profile, and/or to the temperature profile of the strip, and/or to the temperature profile of the casting roll, in width direction of the cast metal strip. In other words the controller receives information of e.g. the strip profile and will compute which expansion element shall be shifted and to which extent to level out thickness deviations, e.g. local minima and maxima of the strip profile.

[0028] Similar to existing solutions one embodiment of the invention consists in that a multitude of substantially axially symmetric expansion elements (both movable and fixed expansion elements) are distributed along the length of the cylindrical tube, each expansion element being spaced from another expansion element, whereas at least one expansion element is not movable in axial direction of the casting roll.

[0029] An embodiment of the invention, especially an option for the preceding embodiment, consists in that a multitude of substantially axially symmetric expansion elements (either only movable expansion elements or both movable and fixed expansion elements) are distributed along the length of the cylindrical tube, each expansion element being spaced from another expansion element, a power switch being situated in or on the casting roll in order to switch electrical power supply of the expansion elements from one or more expansion elements to one or more other expansion elements.

[0030] 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.

[0031] 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 normally needs at least two expansion elements per casting roll, it is preferred that at least three expansion elements are provided whereas at least one is movable, preferably all three. Four or five expansion elements, at least two of them movable, are also advantageous. Even more than five or seven expansion rings can be used per casting roll, but a bigger number of expansion rings makes control and construction complicated.

[0032] It is possible that expansion elements, especially fixed expansion elements, are situated near the end portions of the casting surface.

[0033] A possible power switch can be 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.

[0034] Since such a power switch is integrated in the casting roll there is no need for one slip ring per expansion ring, 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.

[0035] 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.

[0036] A typical 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. However, one embodiment of the present invention is that at least one expansion element has a contacting width with the cylindrical tube (= casting sleeve) of less than 40 mm (e.g. less than 35, 30, 25 or 20 mm), preferably below 15 mm. This can be particularly advantageous for a movable expansion element because then smaller axial areas can be heated and only a local high strip thickness can be reduced without influencing neighboring areas too much.

[0037] 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 hole. The outer diameter of the expansion element shall in any case be tolerance-fitted with the roll tube inner diameter. For movable expansion elements it has to be guaranteed that they can be moved axially within the cylindrical tube of the cast roll, at least in their cold state.

[0038] A typical expansion ring, movable or fixed, 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 130 mm, more preferably 45 - 75 mm.

[0039] The expansion rings can be mounted on an internal pipe, preferably having a wall thickness of at least

3-50 mm and at least an outer diameter of not less than 25 mm, preferably less than 250 mm, onto which the fixed expansion rings are tolerance fitted, or the movable expansion rings are mounted slideable, respectively. The axial position of the fixed 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).

[0040] The outer diameter of the expansion elements can be increased by heating. Thus a preferred 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.

[0041] 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.

[0042] An 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.

[0043] An 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.

[0044] 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.

[0045] 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 to the 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. Normally both casting rolls will be designed according to the invention.

[0046] The object of the present invention is also achieved by 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 to the ends of the nip to confine the casting pool,
- at least one casting roll having at least one substantially axially symmetric expansion element, such as an expansion ring, arranged within the cylindrical tube, the expansion element 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,

whereas at least one expansion element is moved in axial direction of the casting roll to an axial position where the strip thickness of the cast metal strip shall be reduced.

[0047] Preferably at least one of the casting rolls used for the method is designed according to one of the claims for the casting roll.

[0048] One embodiment of the method is that the target axial position of the expansion element is determined, e.g. calculated, by detection of the brightness of the cast strip in width direction in that the target axial position of the expansion element corresponds to the position of a brighter area of the cast strip which area is adjacent to a darker area of the cast strip. This is a possible solution where no exact strip profile of the cast strip is needed.

[0049] One embodiment of the method is that the target axial position of the expansion element is determined by detection of the surface temperature of the as cast strip in that the target axial position of the expansion element corresponds to the position of an area of the cast strip with higher temperature which area is adjacent to an area with lower temperature.

[0050] One embodiment of the method is that the expansion element is moved to a target axial position corresponding to a position in width direction of the as cast strip where the measured or computed actual strip thickness is higher than a predefined strip thickness, or where the measured or computed actual strip thickness is a local maximum. For this solution the strip profile can be measured or computed using models for the strip casting process. According to prior art the strip profile (=strip

thickness profile) is needed as a basis for expanding the expansion rings.

[0051] As soon as the expansion element has reached the axial position where the strip thickness of the cast metal strip shall be reduced the expansion element can be heated.

[0052] So often at least one expansion element is increased in radial dimension, preferably by heating, causing the cylindrical tube to expand, whereas control of which expansion elements are to be increased is done on the basis of the current axial position of the at least one movable expansion element and on the basis of

- the recorded temperature profile of the cast strip, and/or
- the measured strip thickness profile of the cast strip, and/or
- the measured hot crown of the casting rolls, and/or
- the temperature profile of one or both of the casting rolls, and/or
- the measured temperature of expansion elements.

[0053] In this respect it is possible that at least one expansion element is increased in radial dimension, preferably by heating, causing the cylindrical tube 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 again done on the basis of

- the recorded temperature profile of the cast strip, and/or
- the measured strip thickness profile of the cast strip, and/or
- the measured hot crown of the casting rolls, and/or
- the temperature profile of one or both of the casting rolls, and/or
- the measured temperature of expansion elements.

[0054] 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.

[0055] So there can 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 it is preferred that switching between different expansion elements is done only every two to sixty seconds, preferably every five to thirty seconds.

[0056] 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.

[0057] 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.

[0058] 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 instantaneously cool down, but cooling down takes some time.

[0059] 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 a calculation cycle which lasts not longer than 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.

[0060] 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.

[0061] 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, or to determine the target axial position for a movable expansion element. 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, and/or which expansion element shall be axially re-positioned and to which axial position.

[0062] It is also preferred that only three to nine, more preferably three to five expansion elements are radially increased, preferably heated, at a time.

[0063] One embodiment of the method according to the invention is that the target axial position for a movable expansion element is defined by detecting one or a combination of the following items:

- the strip thickness profile of the as cast strip,
- the temperature versus width profile of the as cast strip,
- the casting roll cross shape profile,
- the casting roll cross shape temperature profile,
- the casting roll surface oxidation profile,
- the casting roll surface roughness profile over width.

[0064] The target axial position for a movable expansion element can be determined by using a series of measurements of one or more items mentioned above and by evaluating the measurements with mathematical, statistical and/or artificial intelligence methods. Artificial intelligence methods include machine learning methods and deep learning methods.

[0065] By using a casting roll with movable expansion elements, e.g. movable expansion rings, it is possible to decrease local thickness variations in width direction of the cast strip by 5-30%. There normally are 15-30 local minima (valleys) and maxima (peaks) with a thickness variation of about 15 micrometers between two neighboring peaks, in rare cases of up to 40 micrometers. The mean value of thickness variation lies between 4 and 12 micrometers. Using one movable expansion ring will at least level out one local peak whereas neighboring local peaks will be reduced.

[0066] An improvement of more than 10% or even more than 20% of the mean value of thickness variation can be reached if exactly two movable expansion elements are used which are situated between 120 and 350 mm from the strip edge, i.e. from the wet ends of the cylindrical tube of the casting roll. The expansion elements thus can be used in the so called dog-bone region of the strip and can yield four effects at a time: decreasing the surplus thickness of the local dog-bone region, better distribution of the roll force separation in the dog-bone region, homogenization of the oxide layer on the casting roll and decreasing chatter tendency.

[0067] With the present invention also a slightly wrong or unfavourable cold crown of the casting roll can be compensated for. The cold crown is the profile of the casting roll before or after it is coated with a metallic wearing layer (e.g. containing nickel or chromium), which layer usually is thinner than 2 mm, e.g. is only 90 micrometer of thickness. So there is no need for unmounting the casting roll, removing the metallic wearing layer, grinding the casting roll, adding a new metallic wearing layer and mounting the casting roll.

BRIEF DESCRIPTION OF FIGURES

[0068] 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. 2 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 2A is a schematic view of a portion of twin roll caster of Fig. 2;

FIG. 3A is a cross sectional view longitudinally through a portion of one of the prior art casting rolls of FIG. 2 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 differently 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 three expansion rings, one of them is axially movable;

FIG. 12-14 are graphs of radial expansion (dilation) (in mm) of the casting roll sleeve vs. half length along the cylindrical tube (in mm) measured from the casting edge (= wet edge) inwardly, for three different axial positions of expansion rings.

WAYS TO IMPLEMENT THE INVENTION

[0069] Referring now to FIGS. 1, 2, and 2A, 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.

[0070] 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. 2 and 2A). 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.

[0071] 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.

[0072] 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.

[0073] 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 ca-

pable 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.

[0074] 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.

[0075] 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.

[0076] 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.

[0077] 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.

[0078] 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.

[0079] 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.

[0080] 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.

[0081] 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 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.

[0082] 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.

[0083] 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.

[0084] 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.

[0085] 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.

[0086] 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.

[0087] 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.

[0088] 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.

[0089] 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.

[0090] 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.

[0091] 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.

[0092] 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.

[0093] 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.

[0094] FIG. 11 is a sectional view longitudinally through a casting roll with three expansion rings 101-103 accord-

ing to the present invention. In this example expansion rings 101-103 have approximately the same width and the same ring thickness. Expansion rings 101 and 103 are located near the edge of the casting surface 12A. The distance between neighboring expansion rings 101-103 here is equal, the distance of one expansion ring 101-103 to the next in this example is between 1,0 and 1,5 the width of one expansion ring 101-103.

[0095] The expansion rings 101-103 are mounted on the outer surface of an internal pipe (not shown) so that they can slide along the internal pipe. The internal pipe is concentric to the axis of the casting roll 12. This internal pipe can contain the power wire 222 or cables for providing electrical energy to each of the expansion rings 101-103. It can also contain a control wire 224. Also a power switch can be situated in the internal pipe in order to switch electrical power supply from one or more expansion rings to one or more other expansion rings. The internal pipe can also contain part of the water cooling, similar to FIG. 4-7.

[0096] The expansion rings 101-103 are arranged concentrically to the cylindrical tube 120. They have a radial distance to the inner surface of the cylindrical tube 120 in order to be shifted along the axis of the cylindrical tube 120.

[0097] Only for the expansion ring 103 on the right side possible actuators for axially moving the expansion ring 103 are shown, only one of them will be realized in practice. The first actuator 300 comprises a spindle 302 which is driven by an electric motor. Expansion ring 103 has a bore 303 corresponding to the spindle 302. The second actuator 301 comprises an element mounted at the side face of the expansion ring 103 which contains a bore and a spindle corresponding to the bore.

[0098] Each expansion ring 101-103 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 222 leading to and from a slip ring 220. 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.

[0099] A controller can be situated outside the casting roll 12 and can be connected via control wires 224 with the heating elements of the expansion rings 101-103 or the power switch in the internal pipe. The controller controls the radial dimension of each of the expansion rings 101-103 by controlling the electrical energy provided to each expansion ring 101-103, e.g. responsive to at least a temperature process model of the casting roll 12 and/or the expansion rings 101-103 and/or responsive to a measured expansion ring temperature.

[0100] The radial dimension of the expansion rings 101-103 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 radial thickness of the cylindrical tube 120 normally

is made to a thickness of no more than 120 mm, preferably not more than 80 mm, the crown of the casting surfaces 12A may be deformed responsive to changes in the radial dimension of the expansion rings 101-103.

[0101] FIG. 12-14 show the effect of the axial position of one expansion ring on the contour of the cylindrical tube 120 and its casting surface 12A. Fig. 12-14 each is a graph of the radial expansion of the cylindrical tube 120 versus the length along the cylindrical tube in mm when expanding one single expansion element located at different axial positions from the casting edge. The different curves refer to different temperatures of the expansion ring, each curve is labelled with the temperature in °C of the expansion ring. The temperatures range between 30°C and 190°C and even 290°C. The width of the expansion ring here is 67 mm. The maximum of local peaks was between 50 and 100 micrometers.

[0102] In FIG. 12 the expansion ring is situated at the edge of the casting surface 12A which corresponds to 0 mm on the horizontal axis. Up to 150 mm, measured from the edge of the casting surface 12A, an expanding effect can be seen.

[0103] In FIG. 13 the expansion ring is situated at a position of 160 mm, measured from the edge of the casting surface 12A which again corresponds to 0 mm on the horizontal axis. Up to approximately 250 mm on both sides of the expansion ring position of 160 mm, an expanding effect can be seen.

[0104] In FIG. 14 the expansion ring is situated at the center of the casting surface 12A, which is a position of 640 mm, measured from either edge of the casting surface 12A since the casting surface 12A here has a length of 1280 mm. Again, up to approximately 250 mm on both sides of the expansion ring position of 640 mm, an expanding effect can be seen.

[0105] To achieve a desired thickness profile via control of the radial dimension of the expansion rings 101-103 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.

[0106] The radial dimension of each expansion ring 101-103 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 ring 101-103 is controlled according to the signals generated by the sensor, which in turn controls roll crown of the casting surfaces 12A of the casting rolls 12 during the casting campaign.

[0107] 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 rings 101-103 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.

[0108] 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 170 millimeters, preferably between 60 and 140 millimeters.

[0109] Each expansion ring 101-103 may have a width of up to 200 millimeters, preferably between 50 and 100 mm, more preferably between 60 and 85 mm. In case only smaller axial areas need to be heated, i.e. only a local high strip thickness has to be reduced without influencing neighboring areas too much, a movable expansion ring 103 can have a contacting width with the cylindrical tube 120 of less than 40 mm (e.g. less than 35, 30, 25 or 20 mm), preferably below 15 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 at least one substantially axially symmetric expansion element, e.g. an expansion ring (101-103), arranged within the cylindrical tube (120), and the expansion element 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,
 characterized in that at least one expansion element is movable in axial direction of the casting roll (12).
2. A casting roll (12) according to claim 1, characterized in that the expansion element is movable in axial direction by 1-250 mm, preferably by 10-100 mm.
3. A casting roll (12) according to claim 1 or 2, characterized in that the expansion element is movable to axial positions which are more than 120 mm away from the wet ends of the cylindrical tube (120) of the casting roll (12).

4. A casting roll (12) according to one of the preceding claims, **characterized in that** the expansion element is movable to axial positions which are between 120 mm and 350 mm away from the wet ends of the cylindrical tube (120) of the casting roll (12). 5
5. A casting roll (12) according to one of the preceding claims, **characterized in that** an actuator (300, 301) is situated within the casting roll (12) and that the actuator (300, 301) is constructed to move the expansion element in axial direction of the casting roll (12). 10
6. A casting roll (12) according to claim 5, **characterized in that** the actuator (300, 301) contains a spindle drive. 15
7. A casting roll (12) according to one of the preceding claims, **characterized in that** it comprises a sensor for measuring the axial position of the at least one movable expansion element with relation to the cylindrical tube (120) of the casting roll (12) 20
8. A casting roll (12) according to one of the preceding claims, **characterized in that** a controller is constructed to control the position of the movable expansion element in axial direction of the casting roll (12) responsive to the strip profile, and/or to the casting roll hot profile, and/or to the temperature profile of the strip, and/or to the temperature profile of the casting roll, in width direction of the cast metal strip (21). 25 30
9. A casting roll (12) according to one of the preceding claims, **characterized in that** a multitude of substantially axially symmetric expansion elements are distributed along the length of the cylindrical tube (120), each expansion element being spaced from another expansion element, whereas at least one expansion element is not movable in axial direction of the casting roll (12) . 35 40
10. A casting roll (12) according to one of the preceding claims, **characterized in that** a multitude of substantially axially symmetric expansion elements are distributed along the length of the cylindrical tube (120), each expansion element being spaced from another expansion element, a power switch being situated in or on the casting roll (12) in order to switch electrical power supply of the expansion elements from one or more expansion elements to one or more other expansion elements. 45 50
11. A casting roll (12) according to one of the preceding claims, **characterized in that** at least one expansion element, preferably a movable expansion element, has a contacting width with the cylindrical tube (120) of less than 40 mm, preferably below 15 mm. 55
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 to the 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 to the ends of the nip to confine the casting pool,
 - at least one casting roll (12) having at least one substantially axially symmetric expansion element, such as an expansion ring (101-103), arranged within the cylindrical tube (120), the expansion element 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, **characterized in that** at least one expansion element is moved in axial direction of the casting roll (12) to an axial position where the strip thickness of the cast metal strip (21) shall be reduced.
14. Method according claim 13, **characterized in that** the target axial position of the expansion element is determined by detection of the brightness of the cast strip in width direction **in that** the target axial position of the expansion element corresponds to the position of a brighter area of the cast strip which area is adjacent to a darker area of the cast strip.
15. Method according claim 13, **characterized in that** the target axial position of the expansion element is determined by detection of the surface temperature of the as cast strip **in that** the target axial position of the expansion element corresponds to the position

of an area of the cast strip with higher temperature which area is adjacent to an area with lower temperature.

16. Method according to claim 13, **characterized in that** the expansion element is moved to a target axial position corresponding to a position in width direction of the as cast strip where the measured or computed actual strip thickness is higher than a predefined strip thickness, or where the measured or computed actual strip thickness is a local maximum. 5 10
17. Method according to any of claims 13 to 16, **characterized in that** the expansion element is heated when it has reached the target axial position where the strip thickness of the cast metal strip (21) shall be reduced. 15
18. Method according to any of claims 13 to 17, **characterized in that** at least one expansion element is increased in radial dimension, preferably by heating, causing the cylindrical tube (120) to expand, whereas control of which expansion elements are to be increased is done on the basis of the current axial position of the at least one movable expansion element and on the basis of 20 25
 - the recorded temperature profile of the cast strip (21), and/or
 - the measured strip thickness profile of the cast strip (21), and/or 30
 - 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 35
 - the measured temperature of expansion elements.
19. Method according to any of claims 13 to 18, **characterized in that** at least one of the casting rolls (12) is designed according to one of the claims 1 to 11. 40
20. Method according to any of claims 13 to 19, **characterized in that** the target axial position for a movable expansion element is defined by detecting one or a combination of the following items: 45
 - the strip thickness profile of the as cast strip,
 - the temperature versus width profile of the as cast strip, 50
 - the casting roll cross shape profile,
 - the casting roll cross shape temperature profile,
 - the casting roll surface oxidation profile,
 - the casting roll surface roughness profile over width. 55
21. Method according to claim 20, **characterized in that**

the target axial position for a movable expansion element is determined by using a series of measurements of one or more items of claim 20 and by evaluating the measurements with mathematical, statistical and/or artificial intelligence methods.

FIG 1

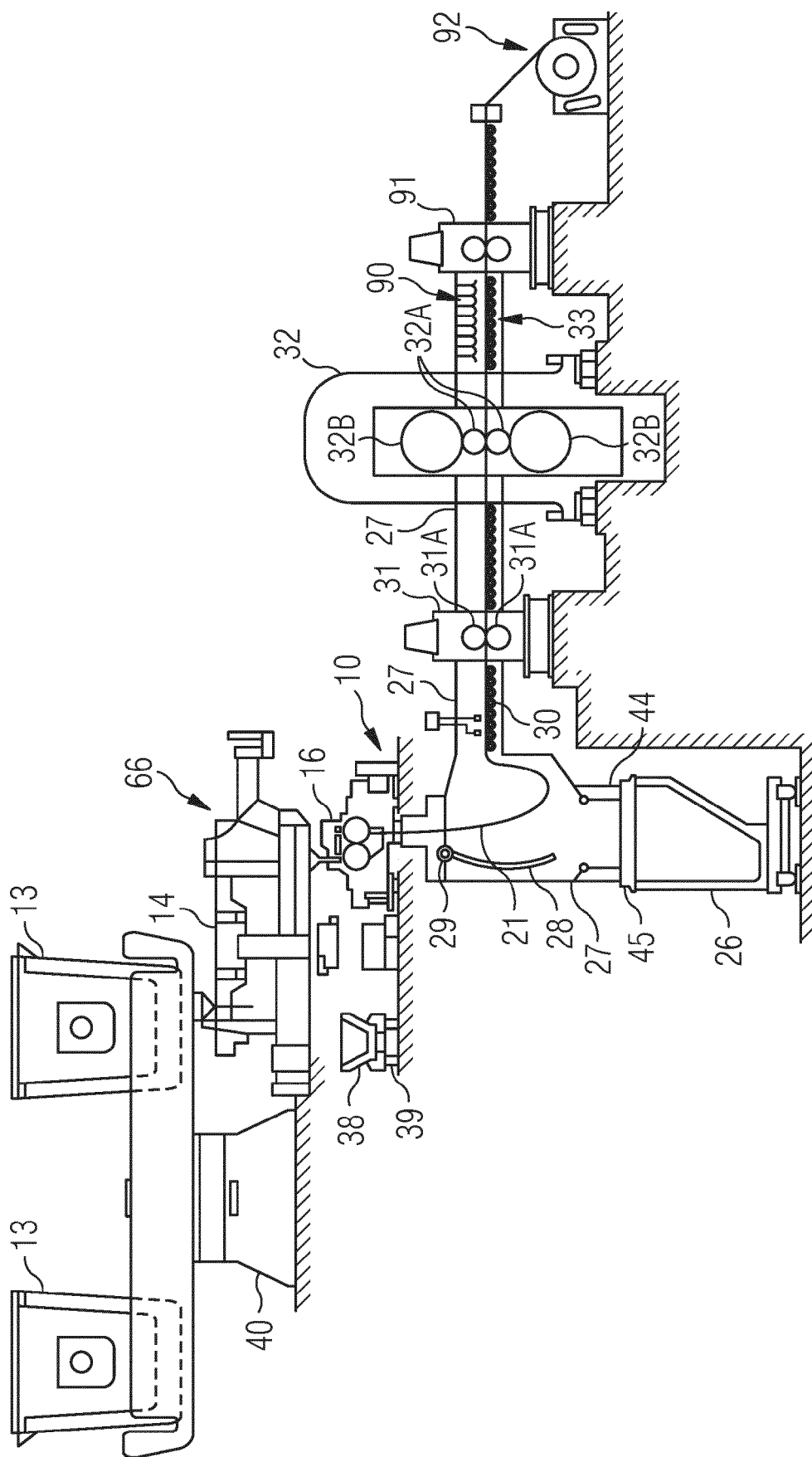


FIG 2

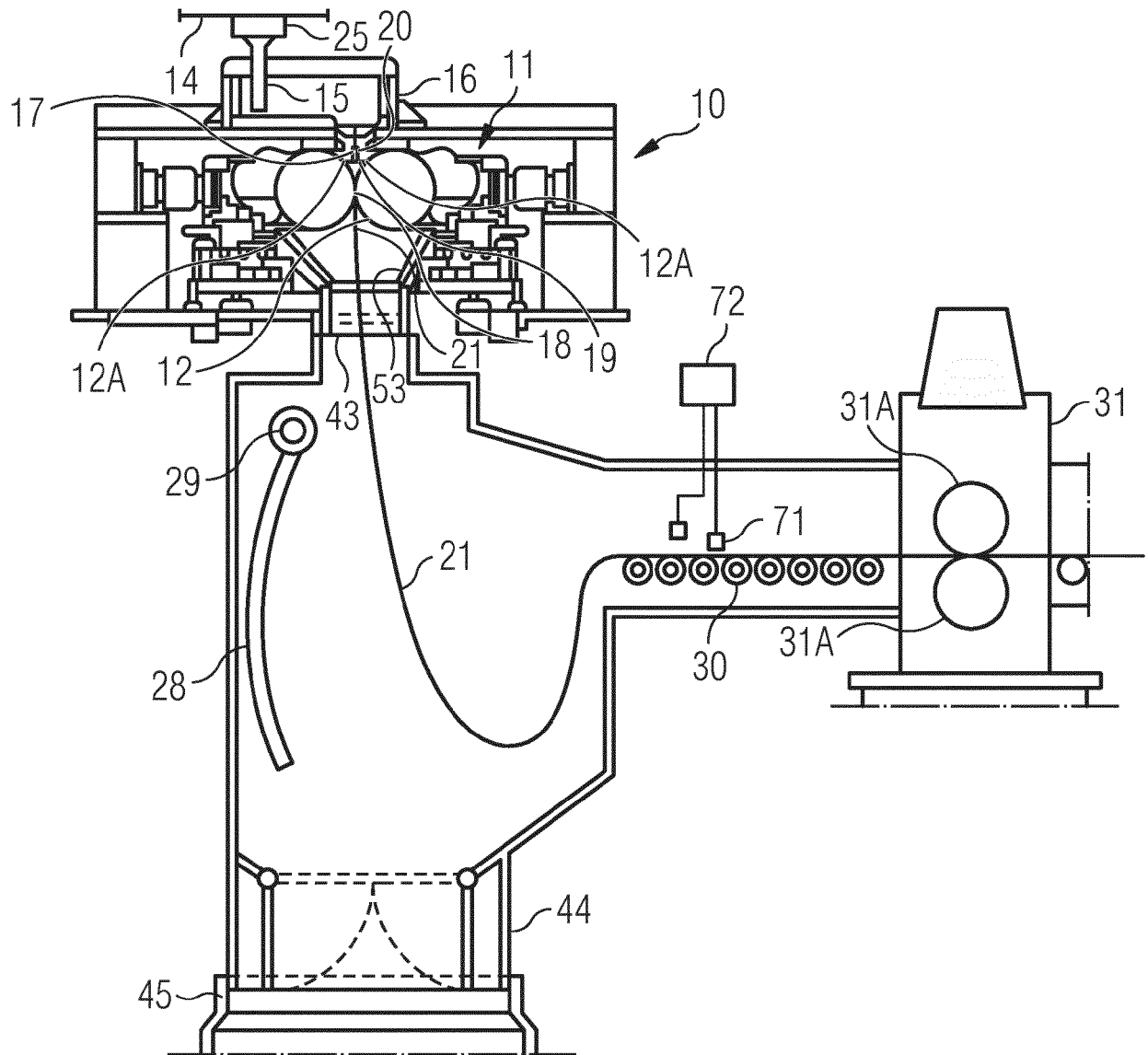


FIG 2A

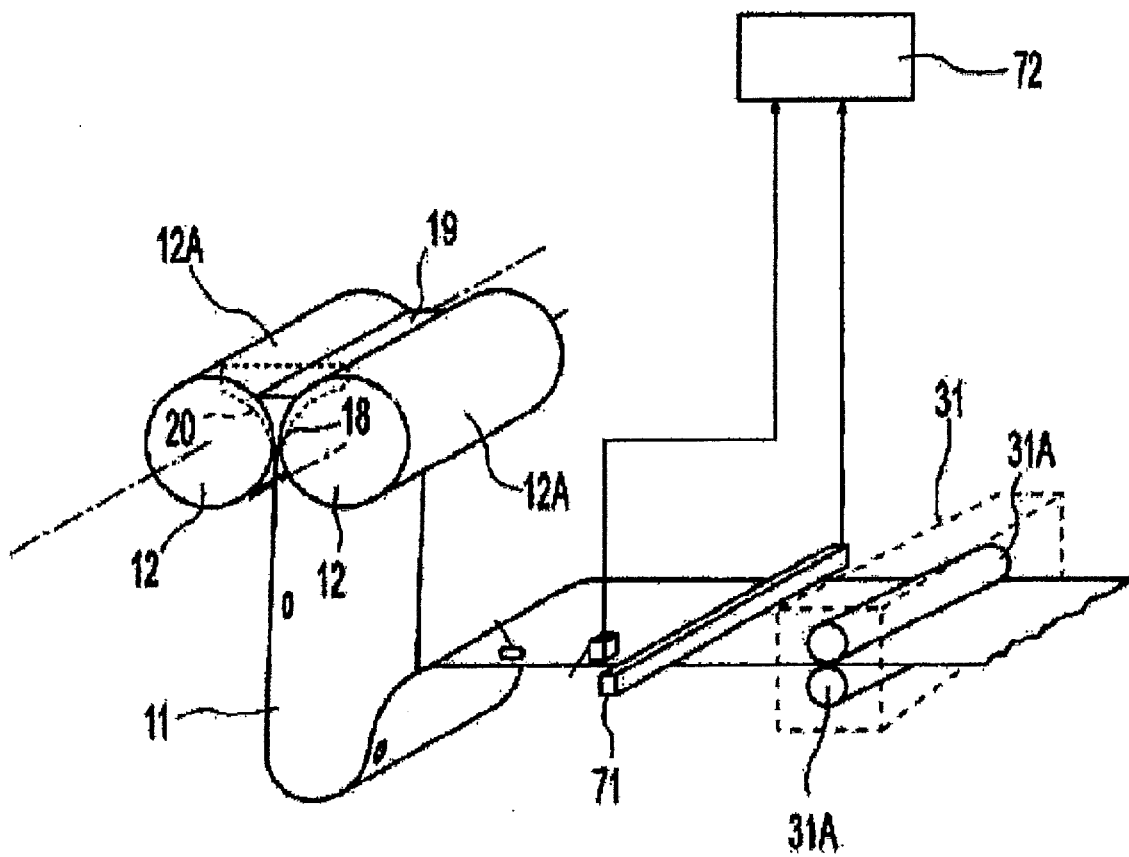


FIG 3A

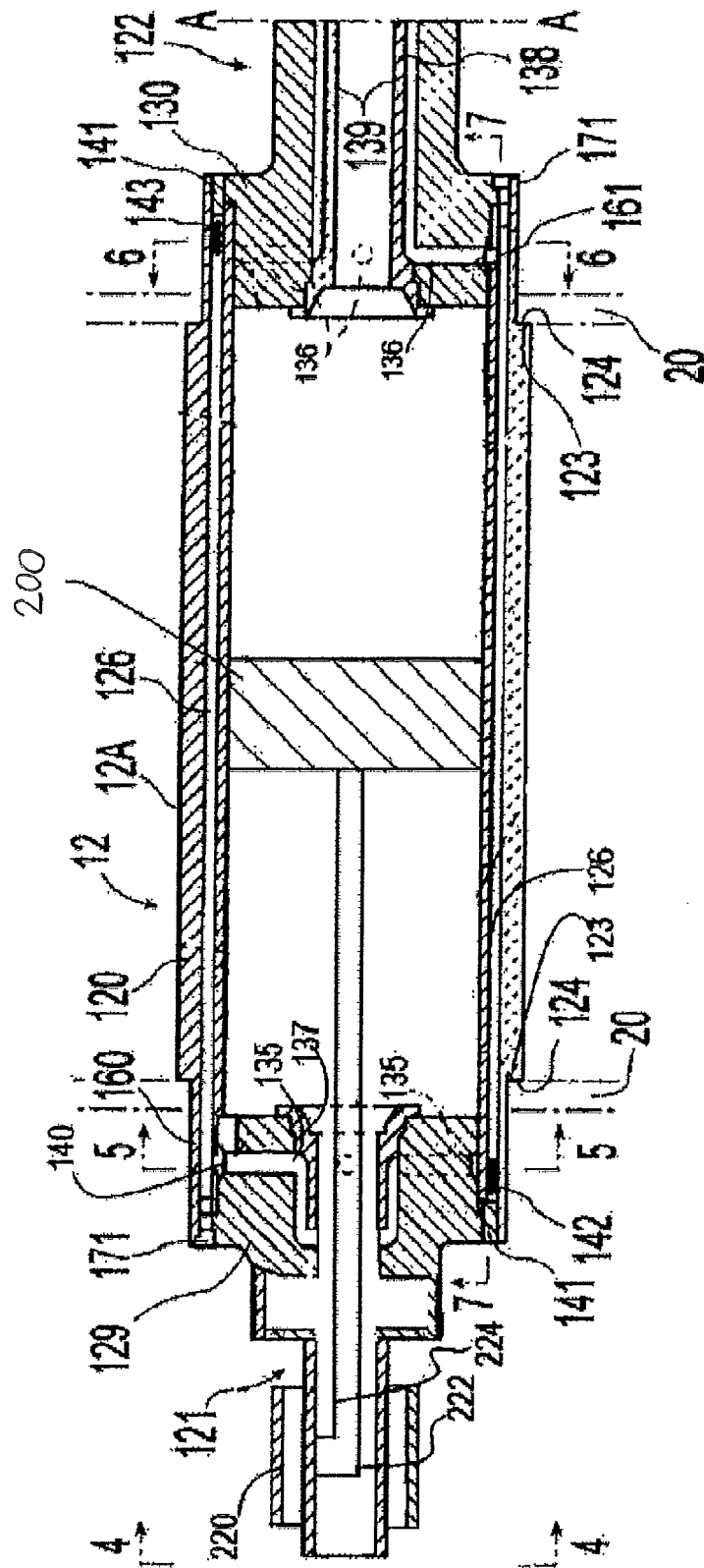


FIG 3B

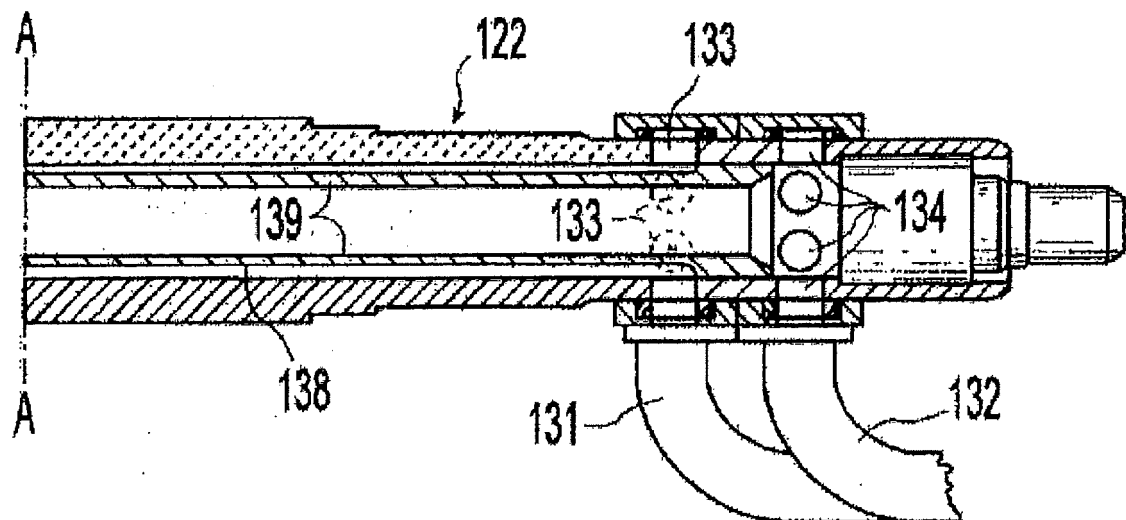


FIG 4

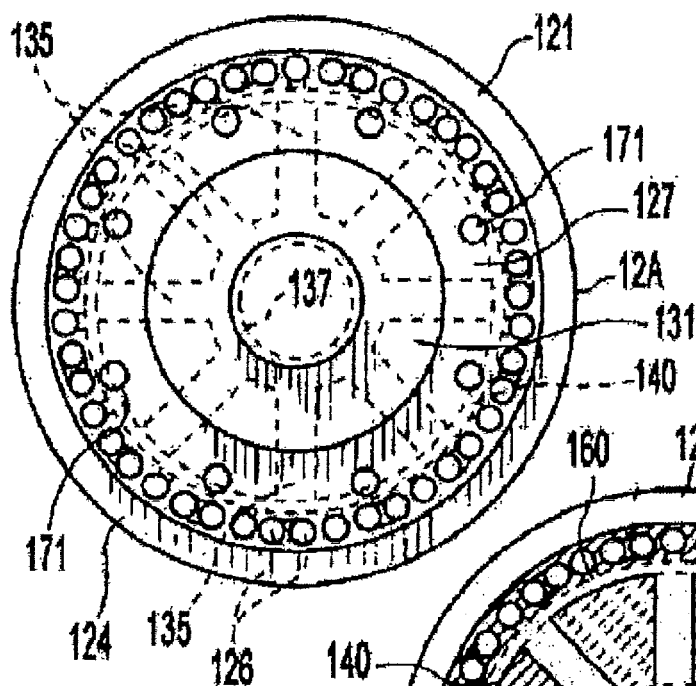


FIG 5

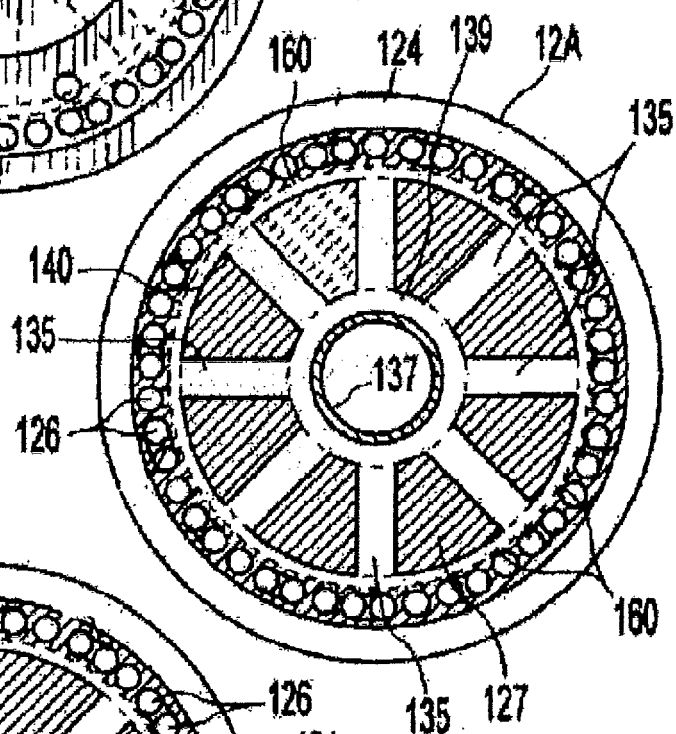


FIG 6

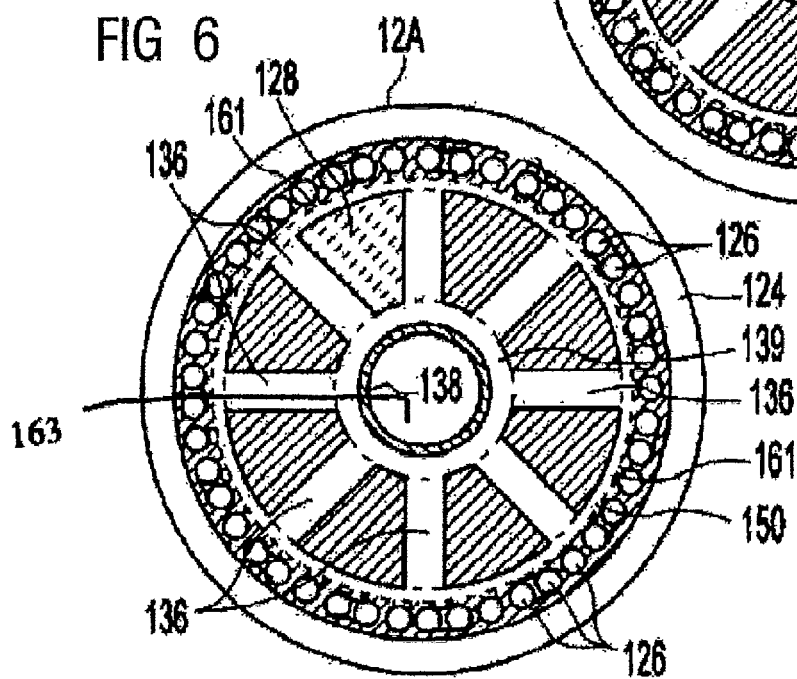


FIG 7

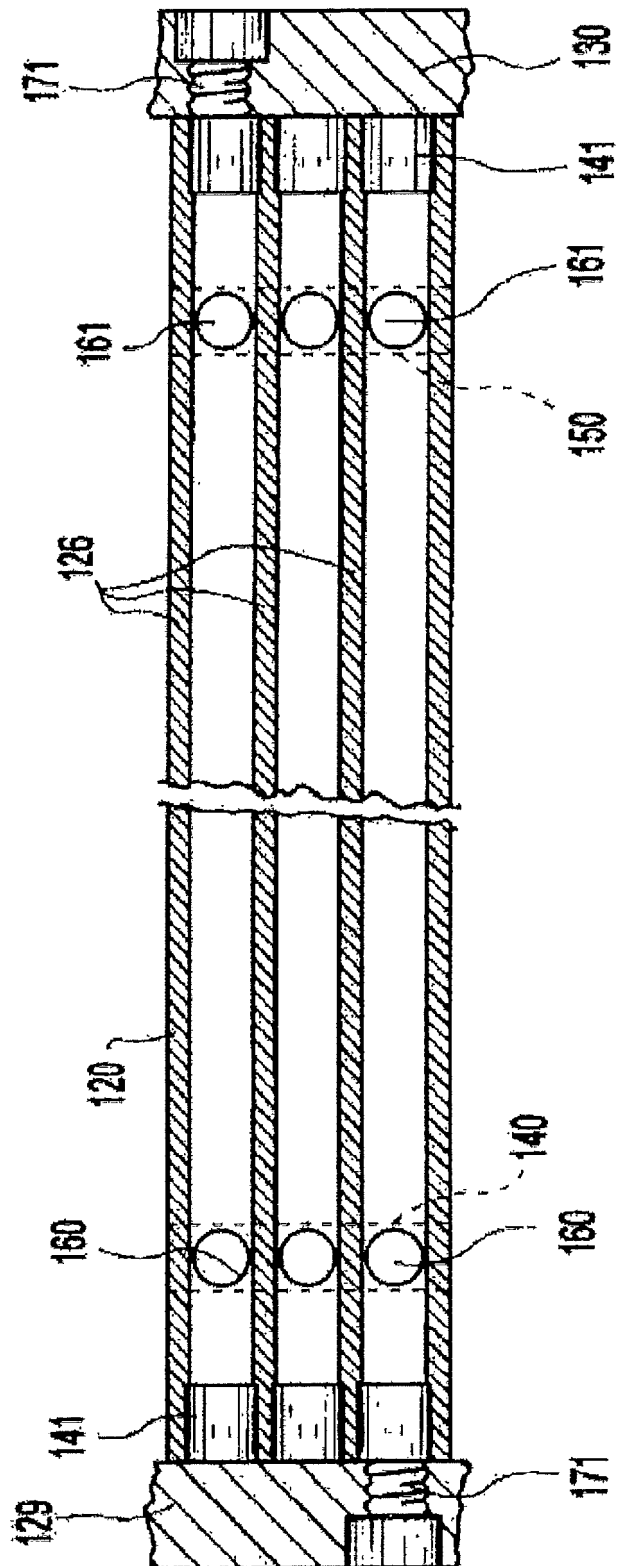
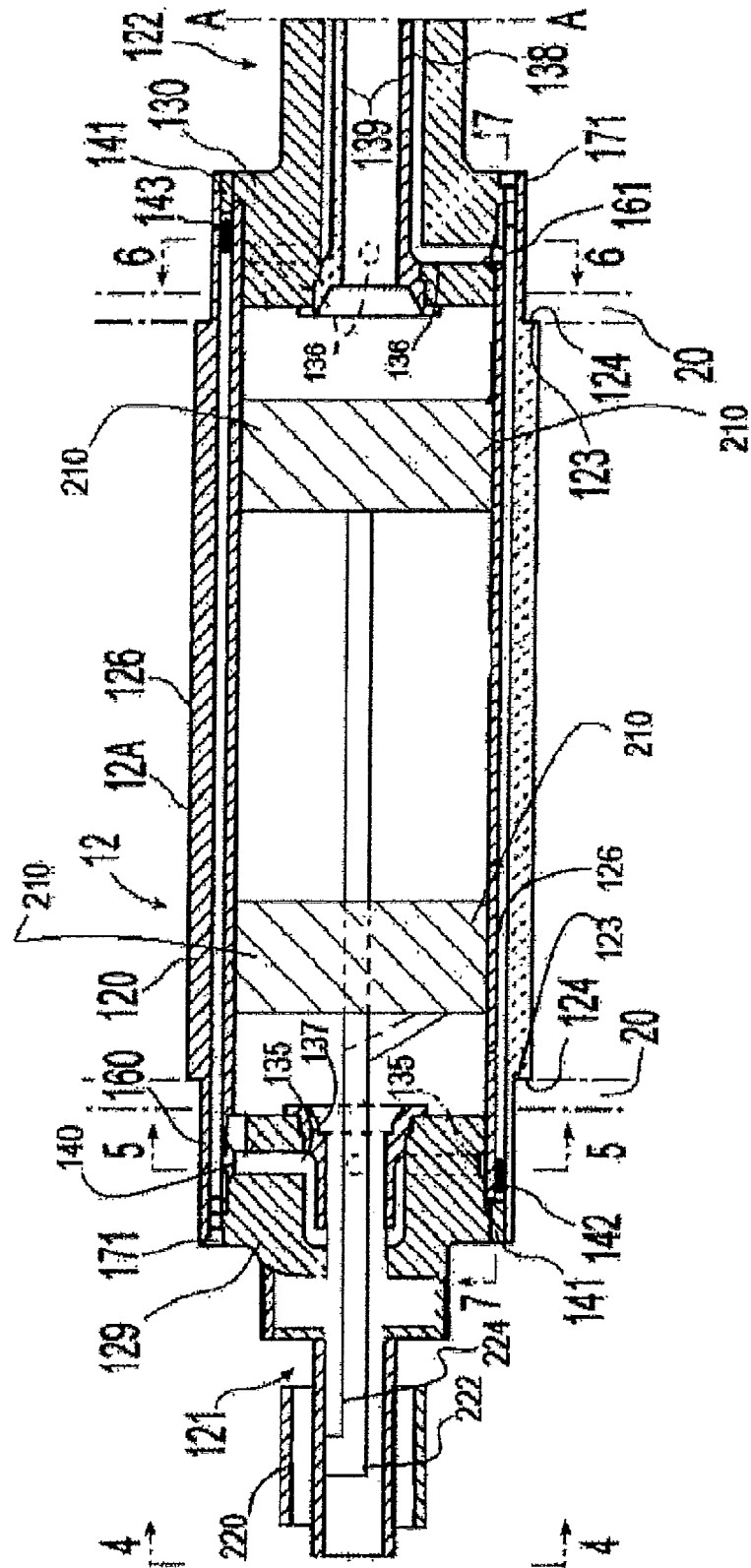


FIG 8



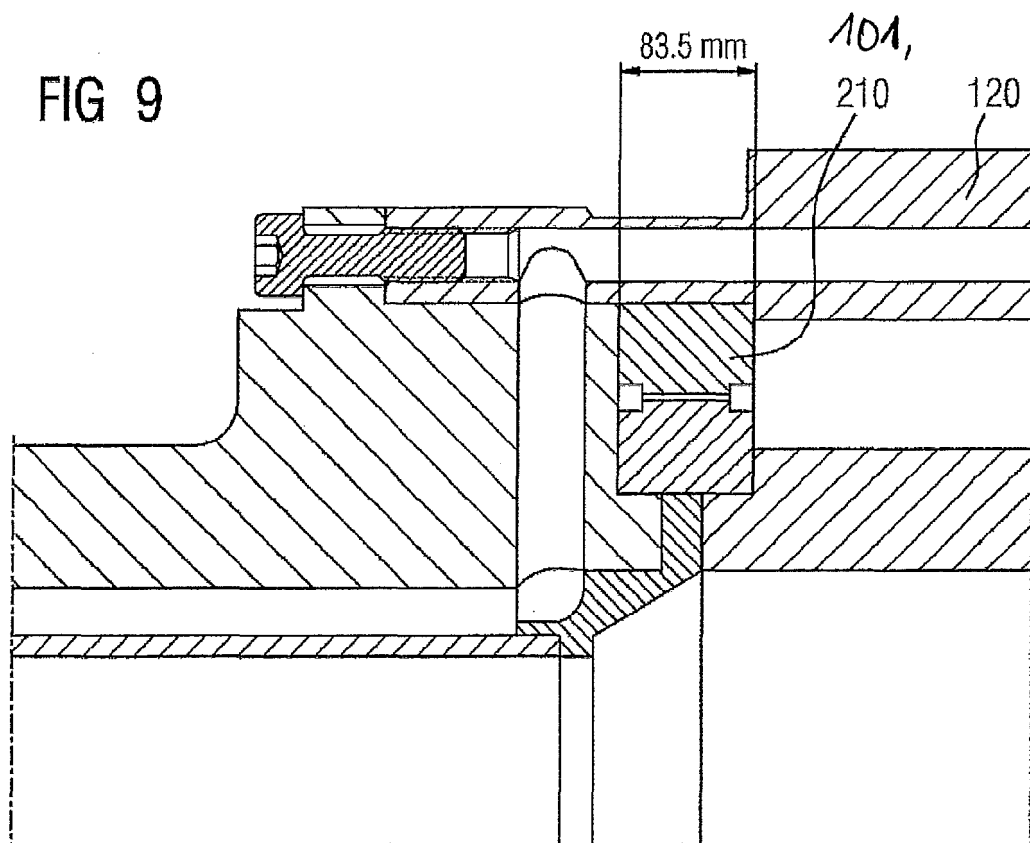


FIG 10

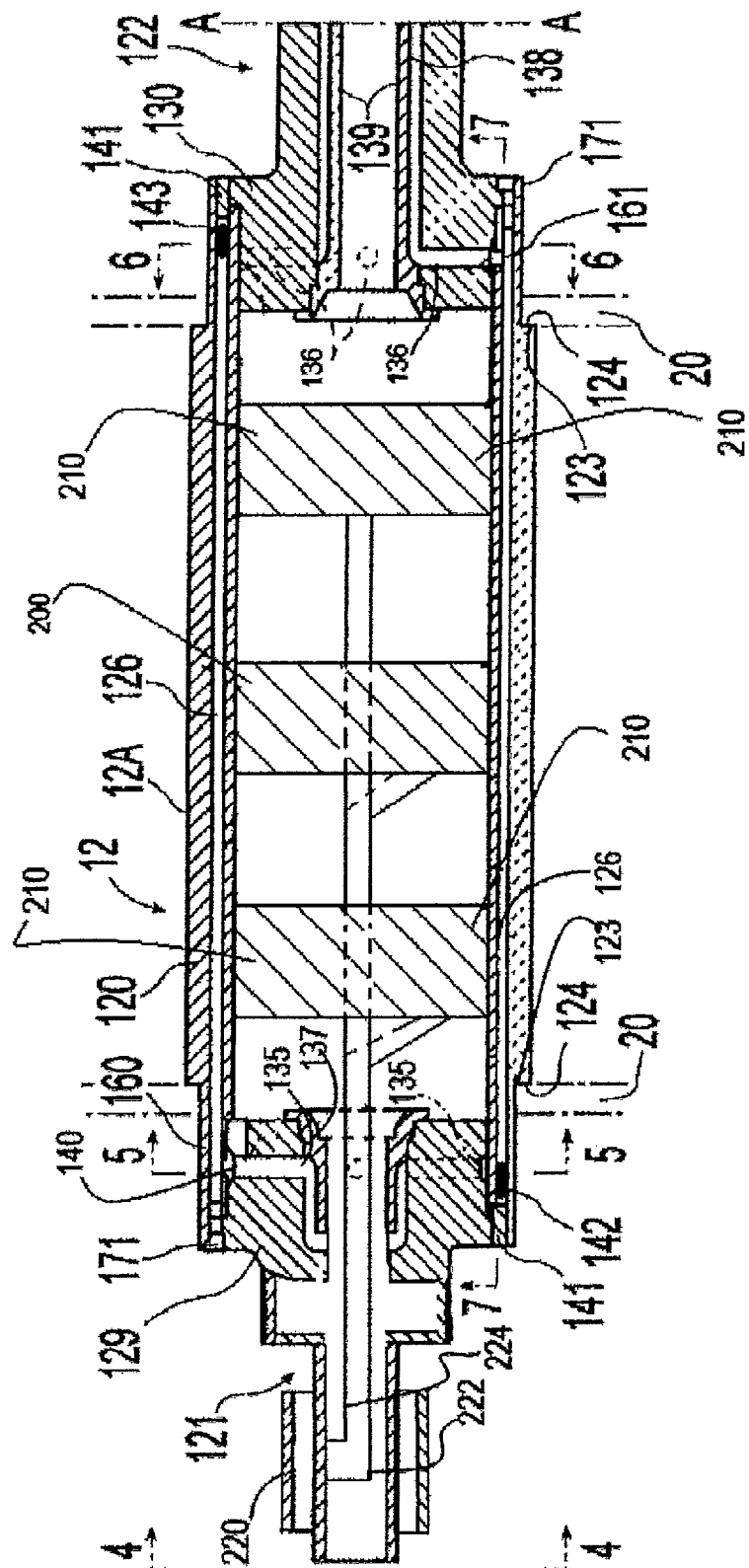
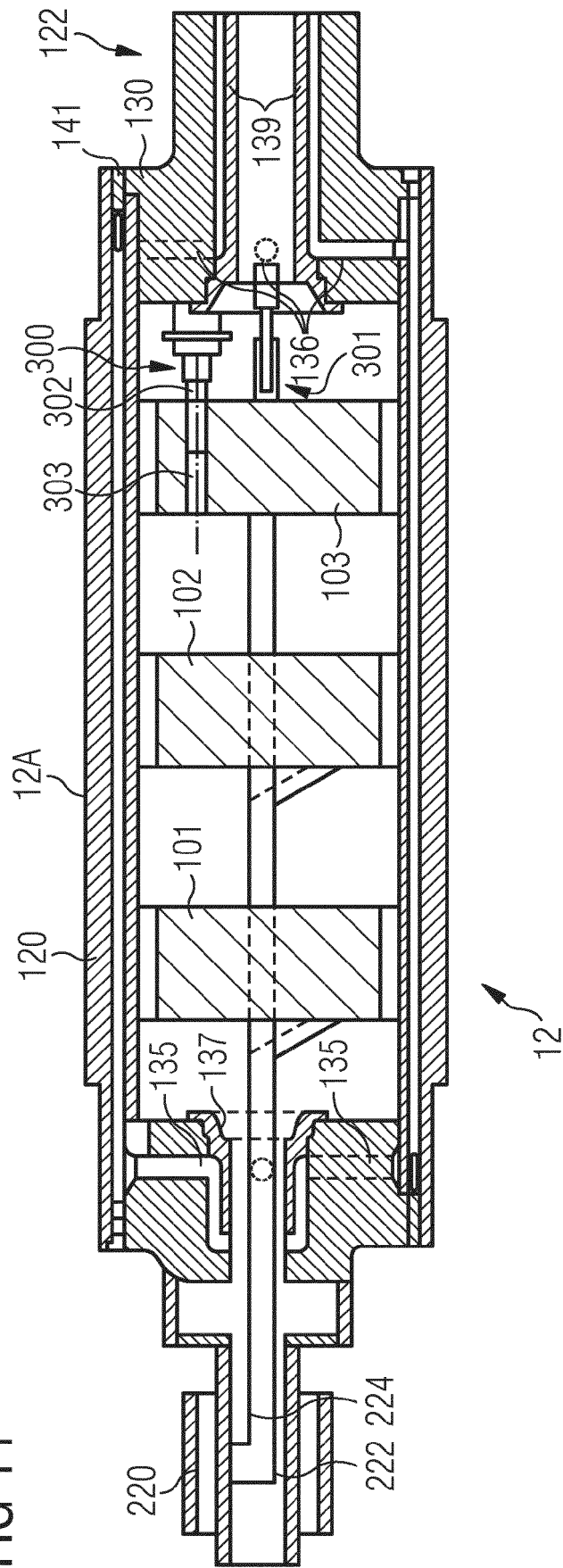


FIG 11



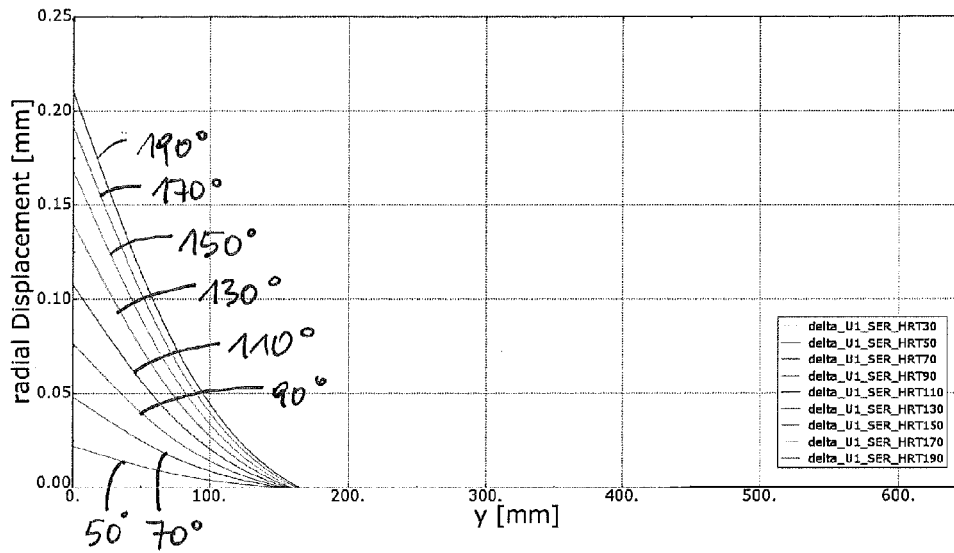


Fig. 12

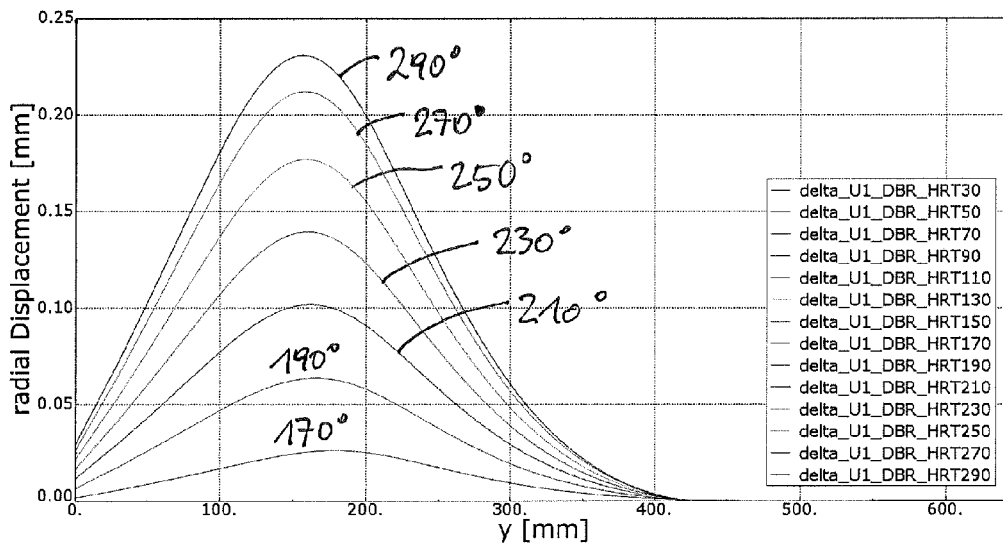


Fig. 13

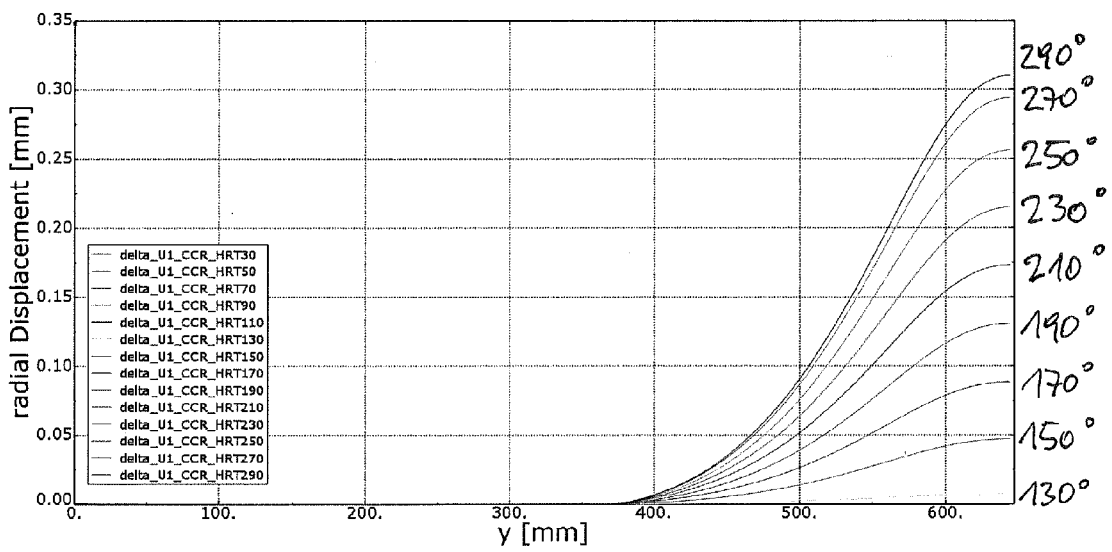


Fig. 14



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