(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 808 501 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
18.07.2007 Bulletin 2007/29

(51) Int Cl.:
C21D 9/573 *(2006.01)*

(21) Application number: **07007266.5**

(22) Date of filing: **06.04.2007**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC MT NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR MK YU

(30) Priority: **22.05.2006 EP 06010511**

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(54) **Method and apparatus for cooling a strip**

(57) The invention relates to a method for cooling a flexible strip, wherein the strip (1) is brought in contact with at least one rotating cooling roll (2; 102; 202) for transferring heat from the strip (1) to the wall (2a, 102a, 202a) of said cooling roll, the cooling roll having an interior space (3; 103; 203) at a predetermined pressure.

According to the invention, the interior space comprising at least one evaporation zone (EZ) containing a cooling medium in a liquid state, wherein the temperature of said liquid cooling medium is substantially the temperature of the liquid/gas phase change of that cooling medium at the predetermined pressure, such that the liquid cooling medium is partially evaporated by the heat received from the strip (1) via the cooling roll wall.

The invention also relates to an apparatus for the implementation of the method.

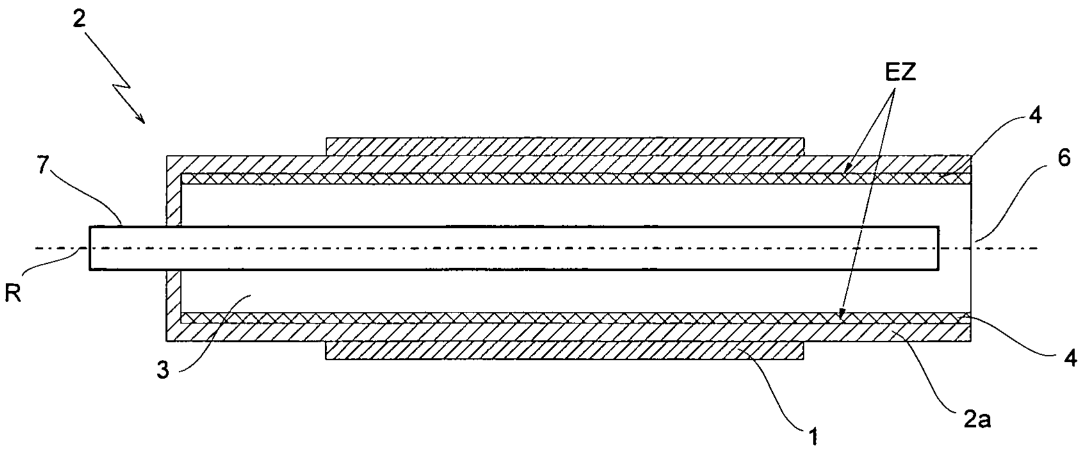

Fig. 1

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Description

[0001] The invention relates to a method for cooling a flexible strip, wherein the strip is brought in contact with at least one rotating cooling roll for transferring heat from the strip to the wall of said cooling roll, the cooling roll having an interior space at a predetermined pressure. The invention also relates to an apparatus for implementing this method.

[0002] Current available technologies to cool (metal) strip are:

Gas Jet Cooling (GJC): strip is cooled by blowing cooled protective HN_x gas against the strip (convection) in a cooling box. When the HN_x gas is heated up it is taken out of the furnace, lead to a heat exchanger with cooling water and transported back into the cooling box again.

Mist Cooling: works like GJC method but water (mist) is used to cool the strip. Water will evaporate when it is heated by the strip. Because of the high evaporation heat of water the strip will cool down faster as with GJC.

Spray Cooling: strip is cooled by spraying water onto it. Part of the water will evaporate giving a high cooling rate of the strip.

Roller Quench (RQ): this is a contact cooling method (conduction). Strip is cooled by bringing it into contact with a cooling roll, while the strip stays in the protective HN_x atmosphere. Heat flows from the strip to the roll by contact thermal conductance. The cooling roll itself is cooled by cooling water that flows just below the roll surface.

Water Quench: strip is cooled by leading it through a water tank. When the strip comes into contact with the water some part of the water will start to evaporate. By circulating the water in the tank over a cooling tower, the water temperature is kept well below the evaporation temperature of water.

HOWAQ: this HOt WAter Quench is similar to the water quench method, but uses hot water and water jets to get a better temperature uniformity and a better controllable process.

[0003] With the current available technologies, the following difficulties occur:

Cooling capacity: Low cooling rate and cooling capacity, especially when the strip is on low temperature. This leads to a long necessary strip and line length in the cooling section, which leads to high investment and operational costs. This is especially valid for the GJC method, where no water evaporation occurs.

Cooling uniformity: A bad cooling uniformity over the width of the strip leads to problems with strip shape in the furnace (of which buckling and pinching are examples). Methods like GJC, mist and spray cool are normally optimised for this but changes in strip width will always have a negative effect. The Roller Quench (RQ) method has also difficulties in this area because the outside of the roll is never uniform in temperature (the inside of the roll is only uniform in the temperature range of the cooling water). Variations in incoming strip temperature over the width automatically leads to variation in outside roll temperature and therefore in cooling rate with the RQ method.

Strip surface: For an optimal strip surface of the product, the strip should stay in an inert/protective HN_x atmosphere. When the strip surface comes into contact with water or water vapour the strip surface will oxidise. Even if the strip surface is reduced afterwards the strip surface condition will have changed. This is the main difficulty with cooling methods like mist and spray cooling as well as with water quench and HOWAQ.

[0004] It is an object of the invention to provide an improved method and apparatus for cooling a flexible strip.

[0005] It is a further object of the invention to provide a method and apparatus for cooling a flexible strip in which the above difficulties are avoided or at least reduced.

[0006] It is still further an object of the invention to provide a method and apparatus, with which a substantially uniform cooling over the width of the strip is achieved.

[0007] It is moreover an object of the invention to provide a method and apparatus for cooling a strip that is faster that the presently known non-oxidising methods and apparatus.

[0008] According to an aspect of the invention, there is provided a method for cooling a flexible strip, wherein the strip is brought in contact with at least one rotating cooling roll for transferring heat from the strip to the wall of said cooling roll, the cooling roll having an interior space at a predetermined pressure, the interior space comprising at least one evaporation zone containing a cooling medium in a liquid state, wherein the temperature of said liquid cooling medium is substantially the temperature of the liquid/gas phase change of that cooling medium at the predetermined pressure, such that the liquid cooling medium is partially evaporated by the heat received from the strip via the cooling roll wall.

[0009] Using this method, the temperature of the cooling roll can be kept relatively uniform, so the strip can be cooled relatively uniform. Particularly, the present invention is based on the inventive notion that evaporative heat transfer is high compared to convective and conductive heat transfer. Because use is made of the liquid/gas phase change of the cooling medium, the evaporation rate is highly temperature sensitive. For evaporation a high amount of energy is needed, and thus temperature variations of the cooling roll are smoothed automatically by compensating changes in the evaporation rate of the liquid cooling medium. Thus, the liquid cooling medium is held substantially at the temperature of the liquid/gas phase change of the cooling medium. Also, the cooling roll cools the strip without bringing the strip in contact with the cooling medium. In this way an undesired oxidation or other surface reaction of the strip surface by cooling medium is prevented.

[0010] It should be noted that for this invention with flexible strip is meant a material having a width of a few tens of centimetre to more than one metre, having a thickness of at most approximately 5 mm, and having a length of hundred to thousands of metres.

[0011] Preferably said liquid cooling medium is present at an inner contour of the cooling roll wall. In this way the cooling of the strip by the evaporation is the most effective.

[0012] According to a preferred embodiment, the evaporated cooling medium flows from said evaporation zone to at least one condensation zone, in which condensation zone heat is removed from the evaporated cooling medium by condensation thereof. Thus, the heat is transferred from the strip to the condensation zone.

[0013] According to a very efficient embodiment, condensed cooling medium returns from said condensation zone to said evaporation zone. In this way, the cooling fluid is recycled from the evaporation zone to the condensation zone and back. Preferably, said cooling medium is substantially retained in said cooling roll, so the cooling roll is closed for the cooling medium.

[0014] Preferably, the evaporated cooling medium is condensed by a condenser. The condenser can be outside the cooling roll, but when the cooling roll is closed for the cooling medium, the condenser is present in the cooling roll.

[0015] According to a preferred embodiment, the condenser is cooled by a condensation medium. The condensation medium can be provided from outside the cooling roll and is separated from the cooling medium. Preferably the condensation medium is water, but other condensation fluids are possible.

[0016] Preferably said condenser extends through said interior space of said cooling roll. The condensation medium can thus be transported through the cooling roll.

[0017] According to a preferred embodiment, said evaporated cooling medium is condensed on an outer contour of said condenser, the condenser being rotated together with the cooling roll, such that the condensed cooling medium is removed from said outer contour at least under influence of centrifugal force. In this way a simple and efficient way is provided for transporting the condensed cooling medium to the evaporation zone.

[0018] According to another efficient embodiment, the evaporated cooling medium is removed from the cooling roll to an environment of the cooling roll. The cooling medium is thus not recycled , but removed to the environment.

[0019] Using this embodiment, preferably the liquid cooling medium in the evaporation zone is continuously replenished from outside the cooling roll.

[0020] In all embodiments, the cooling medium can be water. Water is a simple and effective cooling medium, which is especially usable when the cooling medium is removed to the environment.

[0021] According to a preferred embodiment, the pressure in the interior space is atmospheric pressure. This makes the use of the cooling roll relatively easy.

[0022] However, for special purposes it is preferable when the pressure in the interior space is above or below atmospheric pressure. Low pressures in the cooling roll can be useful to provide a lower temperature for the liquid/gas phase change of the cooling medium, to provide an efficient cooling when the strip is relatively cool.

[0023] Another way the provide an efficient cooling for strip having a relatively low temperature is the use of a fluid having an evaporation temperature below 100° C at 1 atmosphere as cooling medium.

[0024] According to a preferred embodiment, the strip is a steel strip. For steel strip a good cooling is often needed, as elucidated in the introduction.

[0025] Preferably the steel strip has at least been heated, and/or been held at a suitable annealing temperature in an annealing process before the steel strip is being cooled using said at least one cooling roll. Especially after annealing steel strip has to be cooled uniformly and with predetermined velocity.

[0026] According to a preferred embodiment, provided is a method comprising:

- at least a first cooling step, wherein the strip is cooled by at least one first of said cooling roll to a first temperature; and
- at least a second cooling step, wherein the strip is cooled by at least one second of said cooling roll to a second temperature.

[0027] In this way, the cooling can be effected with more than one cooling roll in at least two steps.

[0028] Preferably the strip is continuously transported along said cooling roll, for continuously cooling the strip. Continuous cooling of a (semi) endless strip is used in many industries, such as the steel industry, but also during the fabrication of paper, plastic and the like.

[0029] According to a second aspect of the invention there is provided an apparatus for cooling a hot steel strip, for instance an apparatus specifically adapted for use in a method according to any of the preceding claims, wherein the apparatus comprises at least one rotatable cooling roll for receiving heat from the strip, wherein an interior space of said cooling roll comprises at least one evaporation zone for containing a liquid cooling medium, to be partially evaporated during use. This apparatus provides the cooling to fulfil one or more of the objects of the invention.

[0030] Further, preferred embodiments of the apparatus are given in the dependent apparatus claims. The effects with be clear from the discussion of the method according to the invention above, or the description of the examples.

[0031] The invention will now be explained below by way of non-limitative examples, with reference to the accompanying schematic drawings. Therein shows:

Fig. 1 a longitudinal cross-section of a first embodiment of the invention;
Fig. 2 a transversal cross-section, over line II-II, of Fig. 1;
Fig. 3 a cross-section similar to Fig. 2 of a second embodiment of the invention;
Fig. 4 a longitudinal cross-section of a third embodiment of the invention; and
Fig. 5 a longitudinal cross-section of a fourth embodiment of the invention.

[0032] In the present embodiment, equal or corresponding features are referred to by equal or corresponding reference signs.

[0033] Fig. 1 and 2 show a first embodiment of the invention. The first embodiment is an apparatus for cooling a hot steel strip 1. The apparatus comprises a cylindrical cooling roll 2, having a cylindrical wall 2a with a cylindrical outer contour for receiving heat from the strip 1. The cooling roll 2 has a circular cross-section (see Fig. 2). The cooling roll 2 is rotatable about a rotation axis R, which axis is the centre line of the roll 2. An optional, suitable drive for rotating the cooling roll 2 with a desired rotation speed is not shown in the figures. To the skilled person, it will be clear how such a drive can be arranged and constructed, for instance comprising one or more motors, shafts, coupling means, control means and/or the like.

[0034] Particularly, said cooling roll wall 2a surrounds a cylindrical interior space 3, having an cylindrical evaporation zone EZ of suitable thickness. This evaporation zone EZ extends along the inner surface of the wall 2a. Preferably, as is shown in fig. 1, said evaporation zone EZ extends at least over the full width of said strip 1 during use, overlapping said strip 1. Then, heat only has to flow over a relatively short distance from the strip 1 through the cylindrical wall 2a to the evaporation zone EZ during use.

[0035] The interior space 3 of said cooling roll 2 comprises a substantially cylindrical, porous holder or wick 4, having a suitable thickness, for holding a liquid cooling medium at the inner contour of the cooling roll 2, in said evaporation zone EZ, such that this cooling medium can be partly evaporated during use. The cooling medium may be, for instance, water, which is cheap and safe to use.

[0036] The cooling medium holder 4 may be arranged in various ways, as is clear to the skilled person. For instance, the holder 4 may at least comprise suitable porous material or wick, having a capillary structure, for retaining the liquid cooling medium in contact with the wall 2a of the cooling roll 2.

[0037] Besides, the cooling roll 2 comprises an exhaust 6 for removing evaporated cooling medium from said interior space 3. In the present embodiment, said exhaust 6 simply is an open end of the cooling roll, for ventilating the evaporated cooling medium from the hollow part of the interior space 3 to ambient air.

[0038] Alternatively, the exhaust of the cooling roll 2 may be coupled to an external collector for collecting the evaporated cooling medium. The exhaust may also be coupled to a separate condenser for condensing the cooling medium vapour. Such collector and condenser are not shown in Fig. 1 and 2. To the skilled person, is will be clear how to implement such means in the present embodiment.

[0039] Besides, the first embodiment comprises a cooling medium supply 7 for supplying the cooling roll 2 with liquid cooling medium. In the present embodiment, the pressure inside the cooling roll is atmospheric pressure, since the cooling roll interior is in connection with the atmospheric environment via the exhaust 6.

[0040] During use of the first embodiment of Fig. 1 and 2, the cooling roll 2 is rotated about the rotation axis R, whilst the hot steel strip 1 is continuously transported, in a direction T, around the cooling roll 2. Herein, the strip 1 is in contact with the outer contour of the cooling roll 2. The temperature of the strip 1 is higher than the temperature of the outer contour of the cooling roll. Since the strip 1 is in contact with the cooling roll 2, heat flows from the strip into the cooling roll 2, leading to a cooling of the strip 1.

[0041] During use, said interior space 3 is only partially filled with said liquid cooling medium for removing heat from the cooling roll 2. For clarity, the liquid cooling medium is not shown in the figures. Preferably, during use, the cooling medium holder 4 contains a major part of said liquid cooling medium, wetting the inner surface of the wall 2a of the cooling roll 2 substantially with the liquid cooling medium. This liquid cooling medium is held substantially at the temperature of the liquid/gas phase change of that cooling medium at the respective pressure in said interior space 3. During use, this can simply be achieved under influence of the heat received from the steel strip 1 via the cooling roll 2.

[0042] The heat, which the cooling roll 2 receives from the steel strip 1, flows to the liquid cooling medium which is held by the holder 4 in the evaporation zone EZ. This heat not only keeps the cooling medium at said desired temperature, but also leads to evaporation of the liquid cooling medium. Since the evaporation rate is strongly dependent on temperature, the outer surface of the cooling roll 2 is automatically kept at a substantially uniform temperature. Thus, the cooling of the strip 1 is substantially uniform, so that deformation of the strip is prevented.

[0043] The evaporation zone EZ is preferably continuously supplied with fresh liquid cooling medium by the supply pipe 7, such that drying out of the cooling medium holder 4 is being prevented. For instance, liquid cooling medium may be sprayed onto the cooling medium holder 4 by the supply pipe 7. Such spraying may be effected, for example, by a suitable supply pressure and/or centrifugal force for the case that the supply pipe is also rotated about the rotation axis R, and the-like.

[0044] Particularly, the components of the cooling roll 2 are preferably arranged such, and the amount of fresh liquid cooling medium supplied to the cooling medium holder 4 is preferably such, that drying out of the cooling medium holder 4 is prevented during use, which also depends on the temperature of the hot strip 1 to be cooled by the apparatus. Then, a continuous uniform cooling of relatively long steel strips 1 can be sustained.

[0045] Fig. 3 shows a second embodiment of the invention. Herein, the hot strip 1 is fed along at least one pair of opposite cooling rolls 2. Each cooling roll is arranged, for example, as shown in Fig. 1 and 2, or alternatively as embodiments shown in Fig. 4 or 5. By using a plurality of cooling rolls 2, the cooling power can be increased substantially, if desired.

[0046] Fig. 4 shows a third embodiment of the invention. The third embodiment differs from the first embodiment, in that the cooling roll 102 is a heat pipe. Herein, the interior space 103 of the cooling roll 102 is closed by side walls 102b for retaining the cooling medium in the cooling roll 102, such that the cooling medium can be cycled between a liquid phase and an vapour phase -in the cooling roll 102- during use. The pressure in the interior space 103 may be substantially atmospheric pressure, or a different pressure, during use. In this third embodiment, the interior space 103 of the cooling roll 102 also comprises a holder 104 for holding said liquid cooling medium along the inner surface of the wall 102a of the roll 102, to provide an evaporation zone EZ. This cooling medium holder 104 can be constructed, for instance, the same as the holder 4 of the above-described first embodiment.

[0047] In the third embodiment, of Fig. 4, the cooling roll 102 further comprises a condenser 105 for condensing said evaporated cooling medium. During use, a condensation zone CZ for condensation of evaporated cooling medium extends around the condenser 105, so that the condensation zone CZ is located within said cooling roll 102. The condenser 105 can be arranged in various ways. In the present embodiment, said condenser is a tube 105, which is cooled by a condensation medium during use. The condensation medium flows through the condenser tube 105 shown in Fig. 4. The condenser tube 105 extends centrally through said interior space 103 of said cooling roll 102, and concentrically with respect to the evaporation zone EZ. The opposite ends of the condenser 105 are connected to a condensation medium supply 118 and outlet 119, respectively, which extend through the side walls 102b of the cooling roll 102. The condenser tube 105 is preferably rotatable about the rotation axis R of the cooling roll 102, for removing the condensed cooling medium from the condenser 105 by centrifugal force. For instance, the condenser 105 may or may not be integrally connected to the cooling roll 102.

[0048] In the third embodiment, the outer surface of said condenser 105 has divergent sections 105', when viewed -starting from a virtual transversal plane- in directions parallel to the rotation axis R. Therefore, the radius of the condenser 105 increases from the middle towards the sides. In the present embodiment, said virtual plane intersects the strip 1 to be cooled during use. Each of the divergent sections 105' can have several shapes, for instance conical, trumpet-shaped and/or the-like.

[0049] The use of the third embodiment is similar to the use of the first embodiment. However, in the third embodiment, the evaporated cooling medium remains inside the cooling roll 102 during use. The vapour is condensed in the condensation zone CZ by the condenser 105, which removes heat from the vapour. To this aim, the condenser 105 is being cooled by the condensation medium, passing there-through.

[0050] The condenser 105 is preferably being rotated, for instance via the rotation of the cooling roll 102. By rotating the condenser 105, the condensed cooling medium flows along said divergent condenser sections 105' under the influence of centrifugal force, towards the side walls 102b of the cooling roll, and for example along the side walls 102b back to the cooling medium holder 104. The cooling medium holder 104 then distributes the cooling medium evenly along the surface of the cylindrical wall 102a of the roll 102, for instance using capillary action and centrifugal force, so that the liquid cooling medium can be evaporated again. In this embodiment, the components of the cooling roll 102 are preferably arranged such, and the condensation rate provided by the condenser 105 is preferably such, that drying out of the cooling medium holder 104 is prevented during use, at a respective temperature of the hot strip 1.

[0051] Also during use of the third embodiment, the condensation medium does not undergo a phase transformation in the cooling roll 102; it only heats up. An advantage of the third embodiment is, that different media can be used at various pressures. Since the condensation medium does not come in contact with the steel strip 1, and/or with the outside world, there is a large freedom of choice of using for instance alcohol or refrigerator coolant as a cooling or condensation medium. This opens opportunities to use various temperature levels in the cooling roll 102, for controlling the heat flows and thus the cooling rate of the strip 1. Besides, the cooling medium is simply retained in the cooling roll 102, providing a relatively simple, cheap and compact cooling construction. For example, in the third embodiment, application of complex means for transporting the cooling medium to and from the rotating cooling roll 102 is avoided. Besides, since the cooling roll is a heat pipe, having a condenser 105 which is cooled by the condensation medium for condensing the cooling medium, the cooling roll can remove large amounts of heat from the hot steel strip in an uniform manner, leading to high cooling rates, high throughput, where deformation of the steel strip 1 is avoided.

[0052] Fig. 5 shows a fourth embodiment of the invention, which differs from the third embodiment, in that the condenser tube 205 is a substantially cylindrical rotatable tube. In the fourth embodiment, the condenser tube 205 has an outer surface which is corrugated. For instance, the condenser tube 205 may comprise suitable fins, grooves, ribs 209 and/or the-like. During use, the condenser tube 205 is being rotated, so that condensed cooling medium is forced from tops of the corrugations of the condenser 205 back to the cooling medium holder 204 by centrifugal force. In this way, the condensed cooling medium can simply be sprayed back onto the surrounding cooling medium holder 204, to be evaporated again. Said corrugations can be arranged and shaped in various ways, as will be clear to the skilled person.

[0053] Clearly, combinations of the above described four embodiments of the invention also fall within the scope of the present application. For instance, the third embodiment may also comprise a corrugated condenser.

Claims

1. Method for cooling a flexible strip, wherein the strip (1) is brought in contact with at least one rotating cooling roll (2; 102; 202) for transferring heat from the strip (1) to the wall (2a, 102a, 202a) of said cooling roll, the cooling roll having an interior space (3; 103; 203) at a predetermined pressure, the interior space comprising at least one evaporation zone (EZ) containing a cooling medium in a liquid state, wherein the temperature of said liquid cooling medium is substantially the temperature of the liquid/gas phase change of that cooling medium at the predetermined pressure, such that the liquid cooling medium is partially evaporated by the heat received from the strip (1) via the cooling roll wall.

2. Method according to claim 1, wherein said liquid cooling medium is present at an inner contour of the cooling roll wall.

3. Method according to claim 1 or 2, wherein the evaporated cooling medium flows from said evaporation zone (EZ) to at least one condensation zone (CZ), wherein in the condensation zone (CZ) heat is removed from the evaporated cooling medium by condensation thereof, preferably wherein condensed cooling medium returns from said condensation zone (CZ) to said evaporation zone (EZ).

4. Method according to any one of the claims 1 to 3, wherein said cooling medium is substantially retained in said cooling roll (2; 102; 202).

5. Method according to any one of the preceding claims, wherein the evaporated cooling medium is condensed by a condenser, preferably wherein the condenser is cooled by a condensation medium, preferably wherein said condenser extends through said interior space (103; 203) of said cooling roll.

6. Apparatus for cooling a hot steel strip, for instance an apparatus specifically adapted for use in a method according to any of the preceding claims, wherein the apparatus comprises at least one rotatable cooling roll (2; 102; 202) for receiving heat from the strip (1), wherein an interior space (3; 103; 203) of said cooling roll (2; 102; 202) comprises at least one evaporation zone (EZ) for containing a liquid cooling medium, to be partially evaporated during use, preferably wherein a surface of the interior space (3; 103; 203) of said cooling roll comprises a holder (4; 104; 204) for holding said liquid cooling medium in said evaporation zone (EZ), such that the liquid cooling medium can be evaporated from the evaporation zone (EZ) during use, preferably wherein said holder (4; 104; 204) at least comprises porous material or wick, having a capillary function.

7. Apparatus according claim 6, comprising at least one condensation zone (CZ) for condensation of evaporated cooling medium, preferably wherein said condensation zone (CZ) is present within said cooling roll (102; 202).

8. Apparatus according to claim 6 or 7, wherein said interior space (103; 203) of said cooling roll (102; 202) is arranged for retaining said cooling medium therein, such that the cooling medium is cycled between a liquid phase and an vapour phase in the cooling roll (2; 102; 202), during use.

9. Apparatus according to any one of the claims 6 to 8, wherein said cooling roll (102; 202) comprises at least one condenser (105; 205) for condensing said evaporated cooling medium.

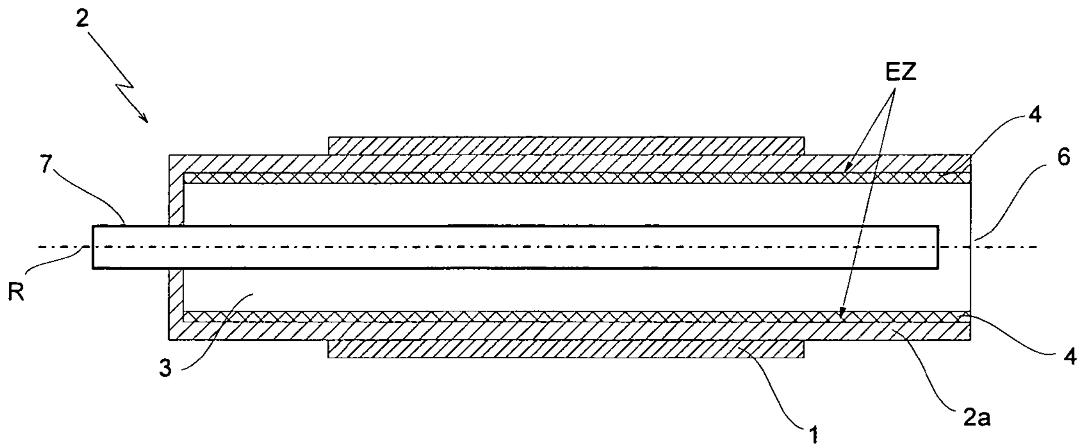

Fig. 1

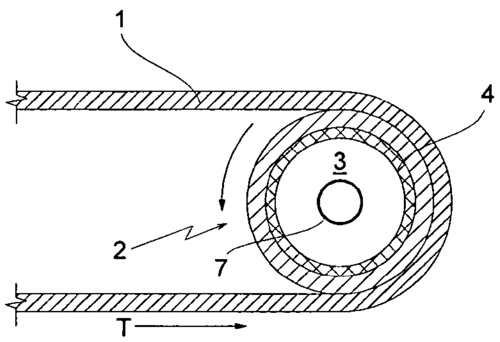

Fig. 2

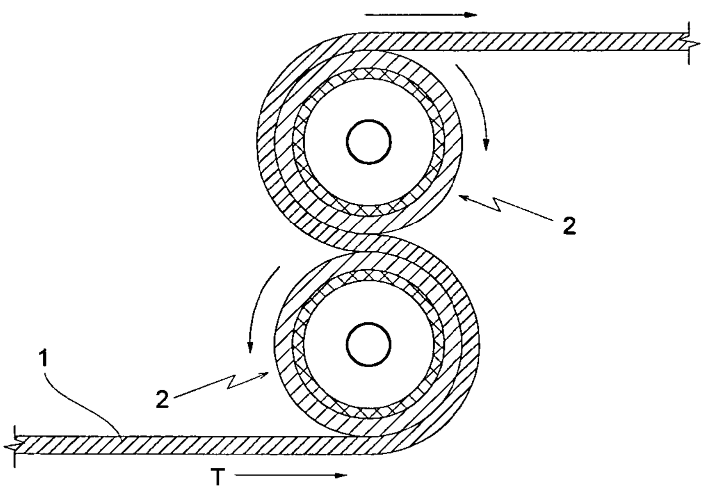

Fig. 3

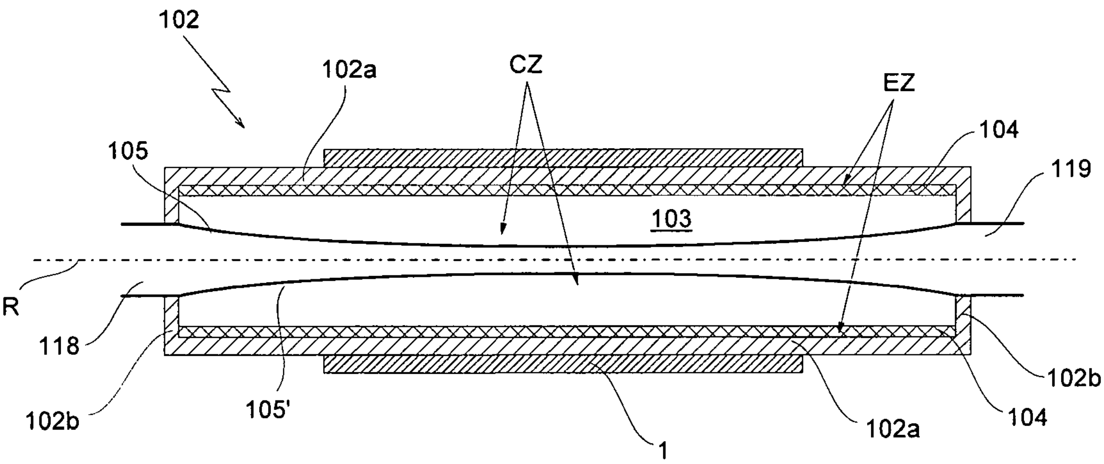
102
102a
CZ
EZ
104
105
119
103
R
118
102b
105'
1
102a
104
102b

Fig. 4

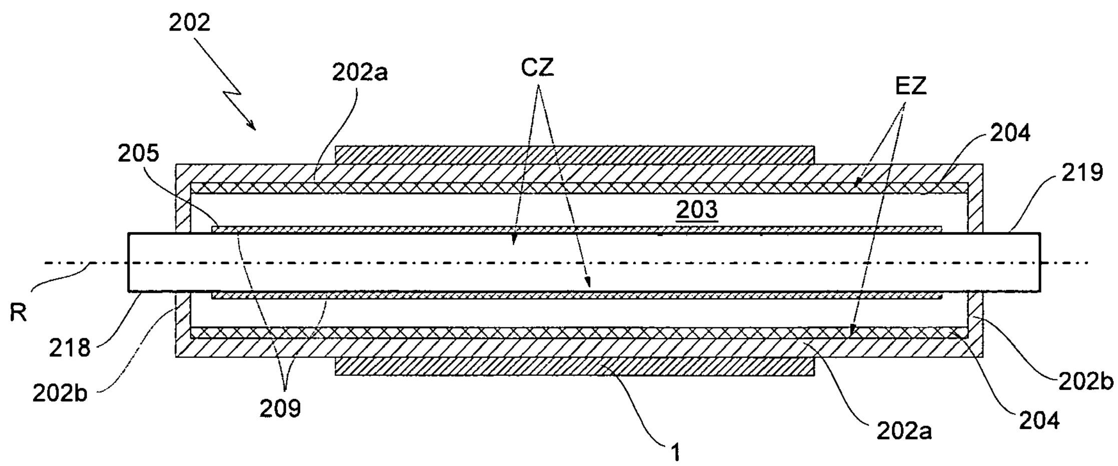
202
202a
CZ
EZ
204
205
219
203
R
218
202b
209
1
202a
204
202b

Fig. 5