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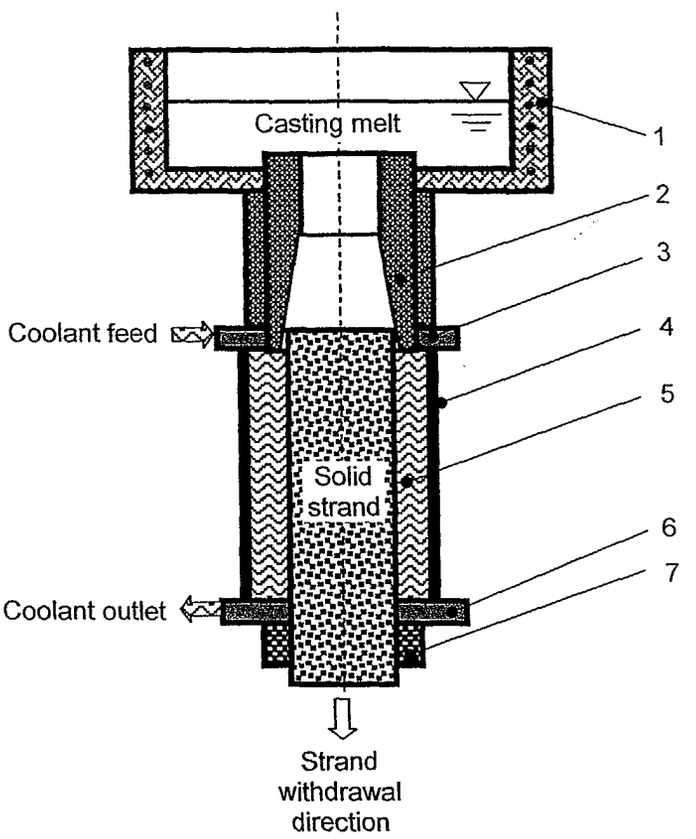
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(54) Continuous casting method

(57) The invention concerns the continuous casting of metals of all kinds.

The invention is characterised in that liquid metal is used as coolant, especially for direct cooling of the strand. The invention further includes a casting device.

Figure 1:



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Description

[0001] The invention concerns the continuous casting of metals of all kinds.

[0002] The introduction of continuous casting is a very effective way of producing semi-finished products. Products are rolling ingots, extrusion billets, strips and wires, sometimes also pipes, furthermore forging feedstock and in small amounts also thixotropic pre-material. Cast materials are aluminium, copper, magnesium, nickel and their alloys as well as steel. The high number of parameters influencing the casting process has led to the development of many different designs of moulds.

[0003] Usually the casting melt is cooled indirect by a mould as far as it is necessary to solidify a shell strong enough to carry the stresses at the mould exit and to resist a breakout of liquid casting melt. Short behind the mould exit the strand is cooled directly by water realised as film cooling or as spray cooling or a two phase cooling with water and air. The direct cooling stage ensures the solidification of the liquid core of the strand. Sometimes the second cooling stage is followed by a third one, a submerging in a water bath or a soft cooling stage by a flow of air.

[0004] The process variant with an indirect cooling stage in the mould and a following direct cooling stage with water or water and air is state of the art, but the disadvantage of this cooling concept is that friction between mould and strand causes damage of the new formed surface. Furthermore, the reheating of the strandshell induced by the arising air gap between mould and strand as consequence of solidification shrinkage is disadvantageous too. These two events are leading to defects like surface cracks (in case of too high friction), segregations and cell size variations, shell bending significant for the subsurface layer of a continuous cast strand. In any case the subsurface is very different from the core of the strand and therefore has to be machined off especially from rolling ingots. This means that an additional process step is necessary which leads to additional costs. One approach to reduce the thickness of the subsurface layer is the application of lubricant. Many different lubrication systems have been developed applying lubricant but also lubricant/gas mixtures to reduce the friction and the heat withdrawal in the mould, but a fully elimination of the subsurface layer was not possible. Another approach was to reduce the mould length in order to decrease the thickness of the subsurface layer requiring a better and therefore costlier process control system.

[0005] For the production of single crystals, a heated mould is used in the so called Ohno continuous casting process (OCC), the mould temperatures are higher than the melting point of the cast material in order to prevent nucleation at the mould wall and to ensure axial directional solidification. The necessary heat removal for this process is realised by direct cooling at only one position at a defined distance from the mould exit. Strands produced in this process are always single crystals with a very smooth surface. But the production of single crystals is not the aim of usual continuous casting, since the produced strands should be formable by rolling, extruding or forging with isotropic properties.

[0006] Between these two process types (casting with cooled mould and casting with heated mould) lays the possibility to work with an insulating mould and to cool the strand by direct cooling only. This also promises a smooth, subsurface layer free strand when working with correct process parameters. Since the active mould length is very short, this process requires a very fast, accurate process control system.

[0007] One feature all above described processes have in common, the use of water as coolant, induces a more or less stable steam film on the cooled surface, depending on the surface temperature and the cooling water supply density. This leads to a very strong variable heat transfer coefficient during the direct cooling stage. Depending on the cooling concept, the properties of the cast material, the roughness of the strand surface, water supply density and water velocity as well as water temperature are decisive. But these parameters are influencing hot tearing, surface crack development and possible casting rate. Since parameters may change during the casting process, also the quality of the product may change.

[0008] The EP 063 832 discloses a concept for the "casting" of a probe which gets solidified in its mould and is therefore no real casting process, even less a continuous casting process.

[0009] The DE 41 27 792 discloses to cast a problematic probe into a pre-heated mould with special geometric properties, where a special form of solidification takes place. This is a casting process, but has nothing to do with a continuous casting process.

[0010] As one may see, there exists a great interest in a simple, reliable continuous casting process which avoids the mentioned disadvantages without loosing the advantages of the known processes.

[0011] In order to achieve this aim, the invention proposes to use liquified metal as cooling medium and, advantageously, an insulated mould. This makes sure that no steam film exists at the surface of the strand. This, in turn, guarantees that the cooling properties and characteristics are well defined and controllable.

[0012] The mould consists preferably of an insulating mould, which enables a solidification of the strand shell in the near vicinity of the mould exit. This is responsible for the prevention of many surface defects and the prevention of an unwanted subsurface layer. Solidification occurs by the influence of the direct cooling. The direct cooling uses a liquid metal like lead, tin, bismuth, gallium, indium or alloys of them as well as other liquid metals or alloys being liquid below the solidification temperature of the cast metal or alloy.

[0013] The feature of direct cooling in continuous casting with liquid metal ensures a very constant cooling

behaviour, prevents oxidation of the new formed strand surface and eliminates the danger of explosions as a consequence of the use of water as coolant fully. Furthermore the hot tearing and cold tearing may be eliminated by the choice of the cooling metal and cooling metal temperature at the cooler entry and cooler exit. The produced strand is free of the well known subsurface layer usually found in conventional continuous casting processes. The grain structure of the produced strands can be controlled by adjusting the coolant temperature.

[0014] Furthermore, it is possible to attach the casting machine to a rolling unit, since the strand exit temperature can be adjusted and hence will safe energy costs for reheating. In this process type no lubricant is necessary, this makes the process easier, cheaper but also increases the quality of the produced strand, since it is known that the lubricant also interacts and reacts with the hot strand surface leading to hydrogen enrichment and other surface defects.

[0015] The liquid metal as coolant can be directed onto the hot strand surface as continuous film or as drops. The coolant distribution unit can be realised by a continuous slot around the strand perimeter but also may consist of slotted segments at different angles to the strand withdrawal direction. In order to increase the heat withdrawal it is possible to add direct cooling stages to ensure a higher heat transfer area leading to higher possible casting rates. The mould itself can be cylindrical or conical getting wider in casting direction. For lower casting rates it is also possible to realise the direct cooling step by submerging the hot strand into a bath of liquid cooling metal.

[0016] In general it also is possible to operate a conventional mould with a first indirect cooling step and a secondary direct cooling step with liquid metal as coolant, but in order to prevent known surface defects and the inhomogeneous subsurface layer the cooled mould length has to be very short.

[0017] It is possible to use the casting process according to the invention for vertical and horizontal continuous casting. This invention was successful applied for casting of copper, magnesium and aluminium showing that it can applied for all nonferrous metals and alloys as well as for steel.

[0018] Advantages of the new cooling concept are:

- Easier cooling control, since the heat transfer number is very constant in comparison to that of a direct cooling with water.
- No oxidation of the new formed strand surface
- Smooth surface without surface defects
- No inhomogeneous subsurface layer of the cast strand - (no machining off necessary)
- Grain structure can be controlled by adjusting the coolant temperature
- Hot and cold tearing can be eliminated by adjusting and controlling the coolant temperature in the different stages of the cooling stages as well as by the choice of the liquid metal (or alloy) as coolant
- Inline rolling of the cast strand is possible and would safe energy costs for reheating
- No lubricant necessary
- Easier mould design

[0019] The invention will be described in greater detail under reference to the drawing. The drawing shows in:

- Fig. 1 a mould according to the invention in a vertical cross section,
- Fig. 2 an other embodiment of the invention in a similar view,
- Fig. 3 a third embodiment of the invention in a similar view,
- Fig. 4 a fourth embodiment of the invention in a similar view,
- Fig. 5 a fifth embodiment of the invention in a similar view,
- Fig. 6 a sixth embodiment of the invention in a similar view and
- Fig. 7 a principal view of the cooling system.

[0020] Figure 1 shows a strand with vertical withdrawal direction. The cooling is done in a totally new way, using a complete filled strand cooler which is operated similar to heat exchanger known from chemical industry. The melt is sucked from the tundish 1 (which can be heated) into the mould 2 and solidifies at the mould exit since the strand is cooled by a liquid metal coolant over the entire length of a cooling unit 4. The temperature of the strand decreases during its movement through the strand cooler until its end is reached. A strand cleaning unit 7 ensures the slip off of the coolant from the strand.

[0021] The cold coolant is fed into the strand cooler 4 and is distributed as it is required for the cast shape by a coolant distribution unit 3. From the mould exit to a coolant collecting unit 6, the coolant takes up heat from the hot strand, thereby heating up. The coolant collecting 6 unit ensures the required coolant distribution along the strand perimeter. This process type enables highest cooling rates but needs an accurate pressure control in the coolant feed.

[0022] Figure 2 represents a process type, in which the cast strand is cooled softer than in the process type of figure 1. The casting melt is sucked from the tundish 1 (which can be heated) into the mould 2 and solidifies at the mould exit since the heat is withdrawn by the coolant in direct contact with the strand 4. Instead of a strand cooler, a cooling box 5 is provides around the area where the strand solidifies during its movement. At the bottom end of the cooling box 5 a strand cleaning unit 6 is fixed, it ensures that no coolant is remaining on the strand surface. The "cold" coolant is distributed along the strand perimeter how it is required for the cast strand shape by a coolant distribution unit 3. After getting in contact with the strand, the now hot coolant flows down

to the bottom of the cooling box 5 and then leaves it through the coolant outlet.

[0023] Figure 3 represents a casting process according to the invention, and mould, respectively, with a heat withdrawal rate between the two aforementioned ones. The casting melt in the tundish 1 (which can be heated) is sucked into the mould 2 and solidifies at the mould exit. The axial heat removal in the strand is, in a first cooling stage, similar to that according to Fig. 2 but gets increased by a second cooling stage in a cooling unit 7, which is similar to the cooling unit shown in Fig. 1. The device for the first cooling stage consists of a coolant distributor 3 which produces a coolant film 4. The device for the second cooling stage consists of a coolant distribution unit 5 and an attached heat exchanger tube 7, which ensures a higher heat removal than cooling stage one. The strand is cleaned from the remaining coolant on the surface by the cleaning unit 8.

[0024] The figures 4, 5 and 6, respectively, show devices similar to those shown in figures 1, 2 and 3, respectively, but with horizontal withdrawal of the strand. Continuous casting with horizontal withdrawal is well known in the art, for the person skilled in the art, there is no problem to adapt the invention to this version of casting. The only difference that should be mentioned is, that the liquid metal has a much higher densitythan the water which has been used in the prior art. Therefore, the free applied liquid in the devices according to Fig. 5 and the first cooling stage of Fig. 6 must be differently pressurised on the top-side and the down-side of the strand.

[0025] Figure 7 shows the flow sheet for the whole casting plant: The liquid metal used as coolant is stored in a tank 7, which needs to be heated by a heating unit 5 before starting the casting process. The liquid coolant is pumped by the pump 7 into the cooling unit 3. In the cooling unit 3, it picks up heat from the hot strand, then the hot coolant leaves the cooling unit and gives up this heat in the heat exchanger 8. Then the cold coolant flows back into the coolant tank 7. The heat withdrawn in heat exchanger 8 can be used for different things in any case it may help to safe costs for energy in a firm. The coolant tank as well as the whole cooling system needs to be free from air and especially from oxygen, this is ensured by flushing the coolant tank 7 and the cooling unit 3 with inert-gas. As inert-gas, all such gases known in the art are usable, they have to stay inert at the given temperatures at contact with the coolant and the material of the strand. It is, of course, advantageous to use the same inert-gas in the storage tank 7 and the cooling unit 3.

[0026] In order to come to defined and repeatable conditions in the cooling unit 3, it is preferred to have sensors for the temperature TIC, the flow rate FIC and the pressure PIC at least near the entrance of the cooling agent into the cooling unit 3. It is of course advantaguous to have further measuring points within this system.

[0027] The invention is not restricted to the shown and described embodiments.

[0028] Coolant can be a liquid metal like lead, tin, bismuth, gallium, indium or alloys of them as well as metals or alloys, which are having a melting point lower equal 60% of the melting point of the casting material. Further, it is possible to use non-metallic liquids, namely any liquid medium, which does not react with the material of the strand at the relevant temperatures and which stays in a liquid state at all temperatures involved in the cooling process. This may be some organic compounds, especially for strands of low-melting alloys.

[0029] It is not necessary that the storage tank is arranged at lower level than the mould, but for safety reasons, this arrangement is preferred. If an other arrangement is provided, the pump and other armatures have to be put to other positions, but this brings no problem to the man skilled in the art.

[0030] The pipes, the pump, the armatures, the sensors, the cooling box, the pipe-like heat exchanger and other equipment for the coolant are, given the disclosure of the invention, readily available for the man skilled in the art of casting metal, may it be ferrous or not.

[0031] Finally, the described method and apparatus is useful for other casting methods too, one need only think of the coquille-casting process.

[0032] Some additional features and advantages of the invention are: The casting process can apply one or more direct cooling steps. The use of liquid metal as coolant prevents the formation of oxide layers on the strand surface. The adjustment of the coolant feed temperature and coolant flow rate allows good control of the cooling rate and hence the formation of grain structure. The use of an insulating mould prevents the formation of surface defects and inhomogeneous subsurface layers. The use of liquid metal for the direct cooling in continuous casting eliminates the danger of explosions known from the conventional process using water as coolant. This increases the safety in cast shops enormous. For this continuous casting process no lubricant is necessary. Applying one of the above described process types in horizontal continuous casting enables inline rolling of the cast ingots in order to safe energy costs for the reheating of the ingot. The process eliminates hot tearing and cold tearing when operating at optimum process parameter (coolant temperatures at different stages of the cooling unit). The process has no restrictions concerning the shape of the cast strand or the number of parallel cast strands.

[0033] The existing plants may easily be adapted to the invention, existing cooling systems using water my be stripped and replaced by the new system. The mould itself hardly needs any adaptation, it is only necessary to have the freezing area at the end of the mould, therefore, insulated moulds or very short cooled moulds may be best used.

Claims

1. A process for continuous casting of metals, **characterised in that** liquid metal is used as coolant, especially for direct cooling of the strand.

2. Process according to claim 1, **characterised in that** the coolant is chosen from the group consisting of: lead, tin, bismuth, gallium, indium or alloys of them.

3. Process according to claim 1, **characterised in that** the coolant has, in Centigrade Celsius, a melting point which is lower or equal 60% of the melting point of the casting material.

4. Process according to claim 1, **characterised in that** the coolant is directed in one or more free streams or jets onto the strand directly beneath the mould exit.

5. Process according to claim 1, **characterised in that** the coolant is brought into a pipe which surrounds the strand and fills the entire gap-like room between the surface of the strand and the inner surface of the pipe.

6. Process according to claim 5, **characterised in that** the coolant flows essentially in the direction into which the strand is moving.

7. Process according to claim 5, **characterised in that** the coolant flows essentially in the direction opposite to the direction into which the strand is moving.

8. Device for the process according to any of the claims 1 to 7, characterised that it includes a storage tank (7) for the cooling medium, with a heating element (5) and a pump (6), pipes which connect the storage tank with the cooling device (3) and a heat exchanger (8) which is located in the pipe transporting the coolant from the cooling device (3) to the storage tank (7).

9. Device according to claim 8, **characterised in that** the cooling device (3) includes a cooling box (5) with at least one nozzle which directs the cooling liquid directly onto the strand, preferably in near vicinity of the mould exit.

10. Device according to claim 8, **characterised in that** the cooling device (3) includes a cooling box (6) and a pipe-like device (7) arranged around the strand or its path, respectively, and forming a gap-like room around the strand which is filled with cooling liquid.

11. Device according to claim 10, **characterised in that** the coolant feed is located in near vicinity of the mould exit.

12. Device according to claim 9 and 10, **characterised in that** at least one nozzle is provided in near vicinity of the mould exit, combined with a pipe like device arranged in some distance from the at least one nozzle in the direction of the movement of the strand.

13. Device according to any of the claims 8 to 12, **characterised in that** a cleaning unit (7) is provided outside the cooling box (5) in order to clean the strand from drops or particles of the coolant.

14. Device according to any of the claims 8 to 13, **characterised in that** the mould is an insulated mould.

Figure 1:

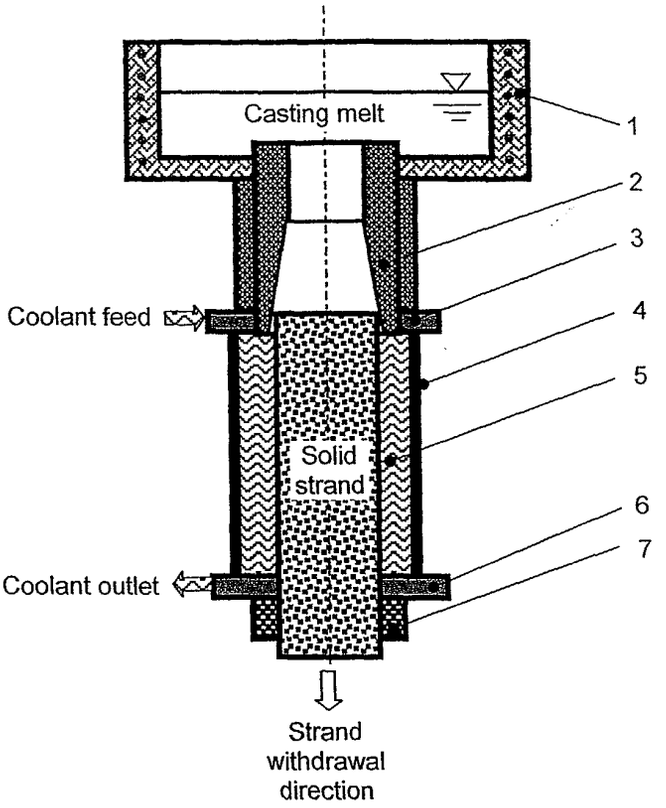


Figure 2:

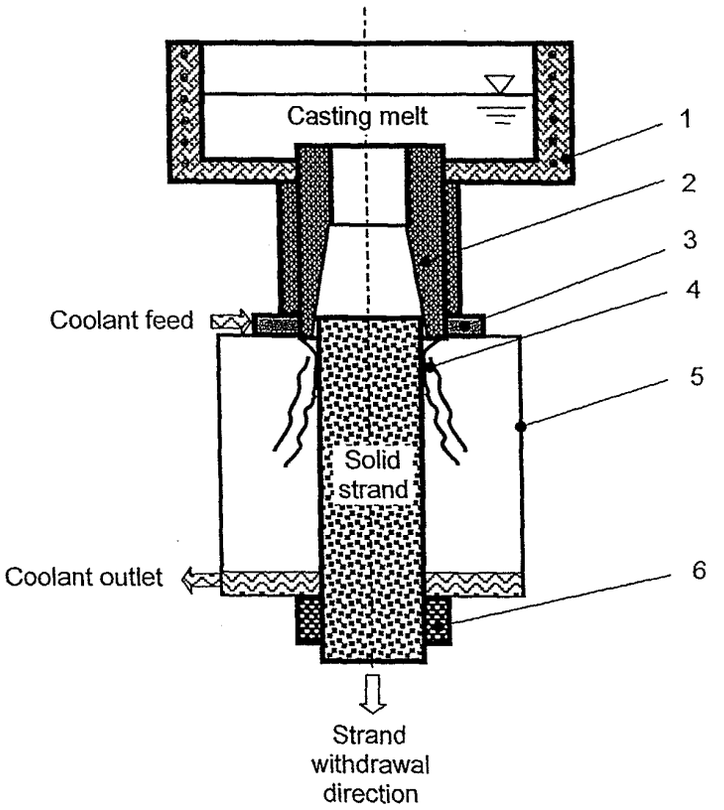


Figure 3:

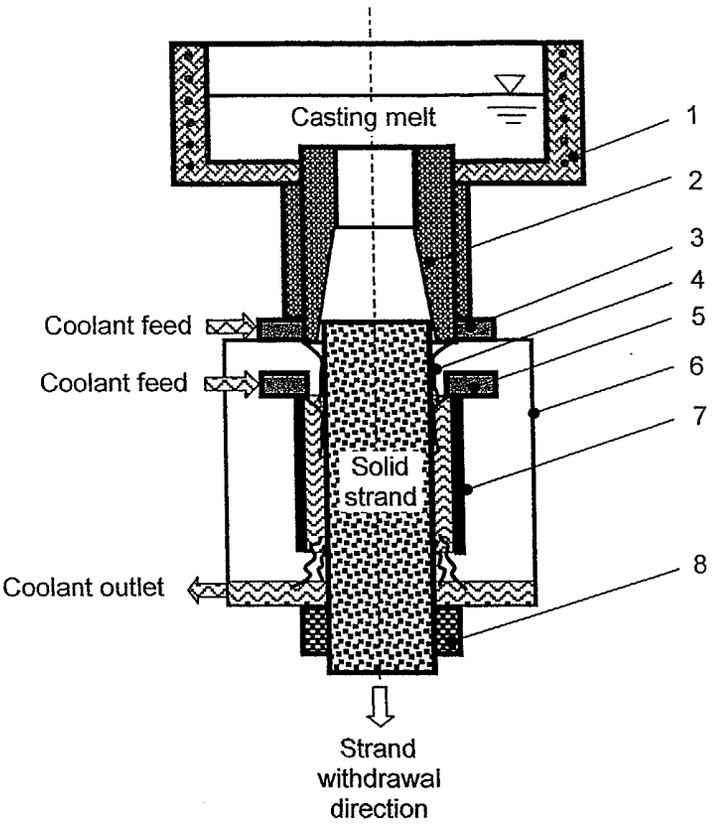


Figure 4:

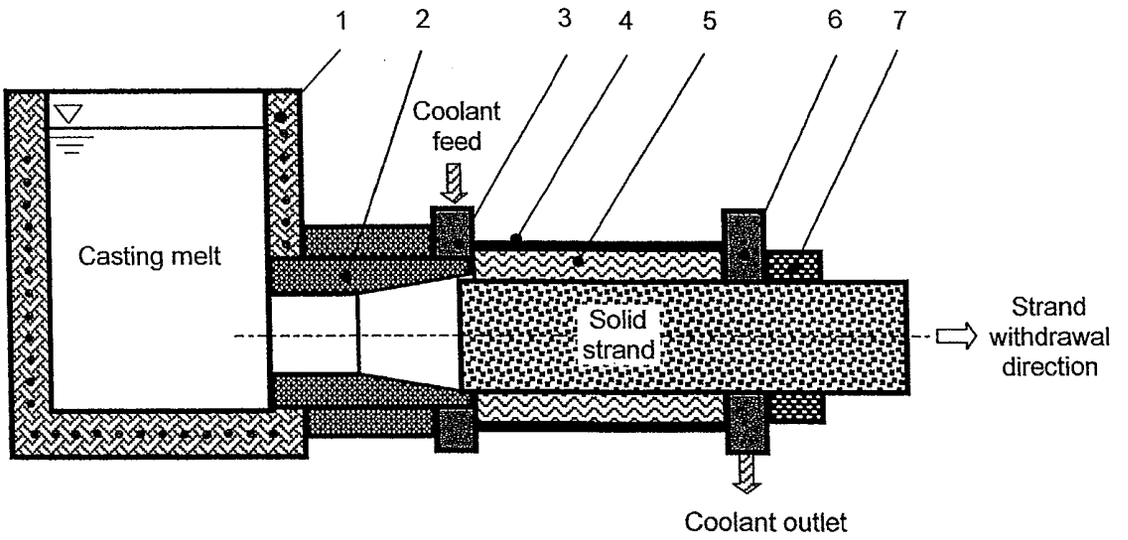


Figure 5:

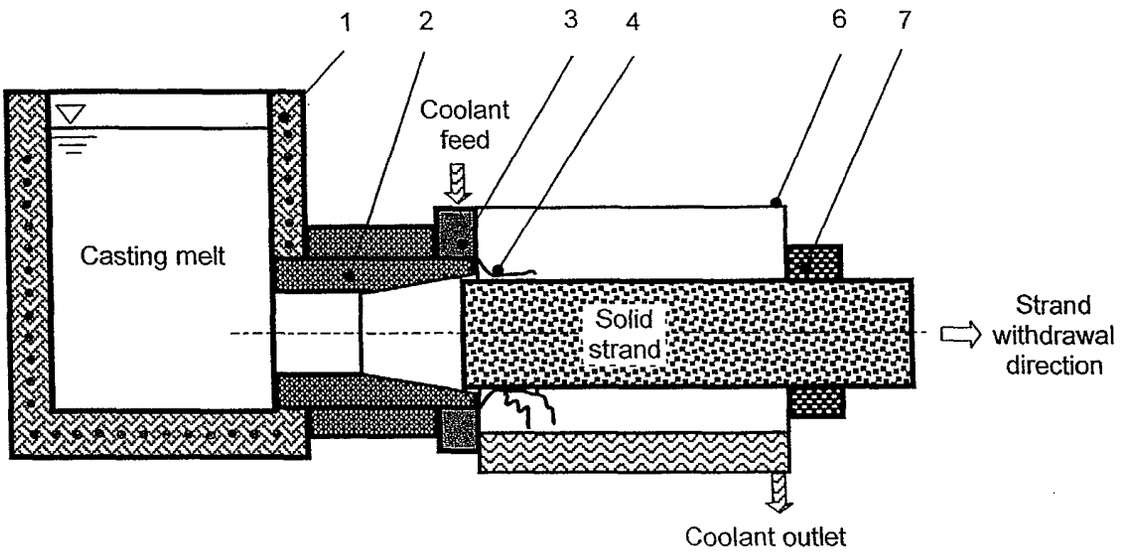


Figure 6:

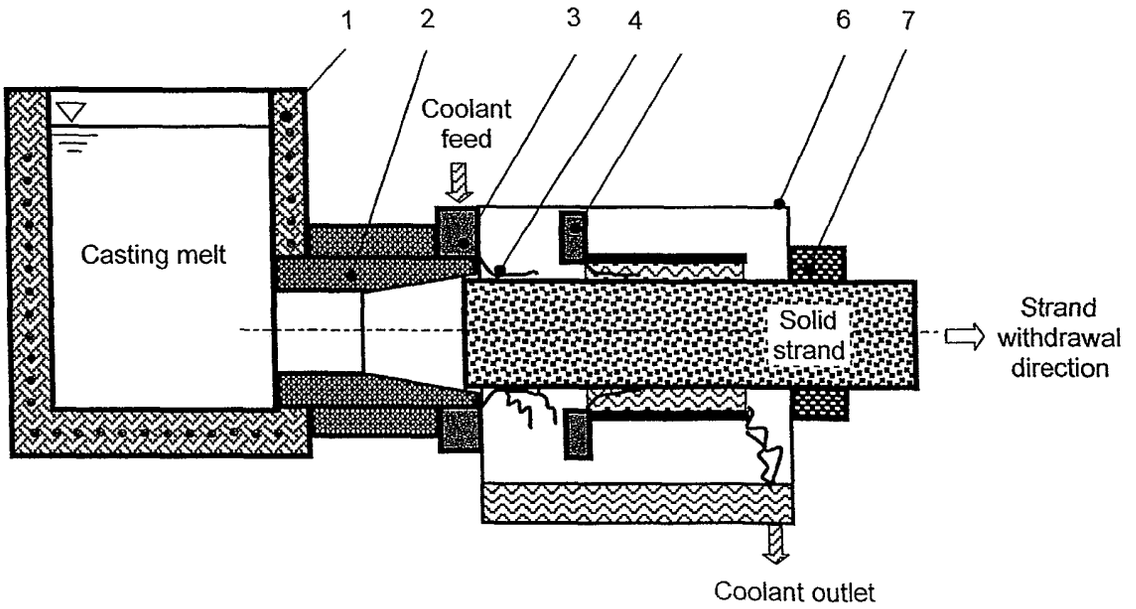
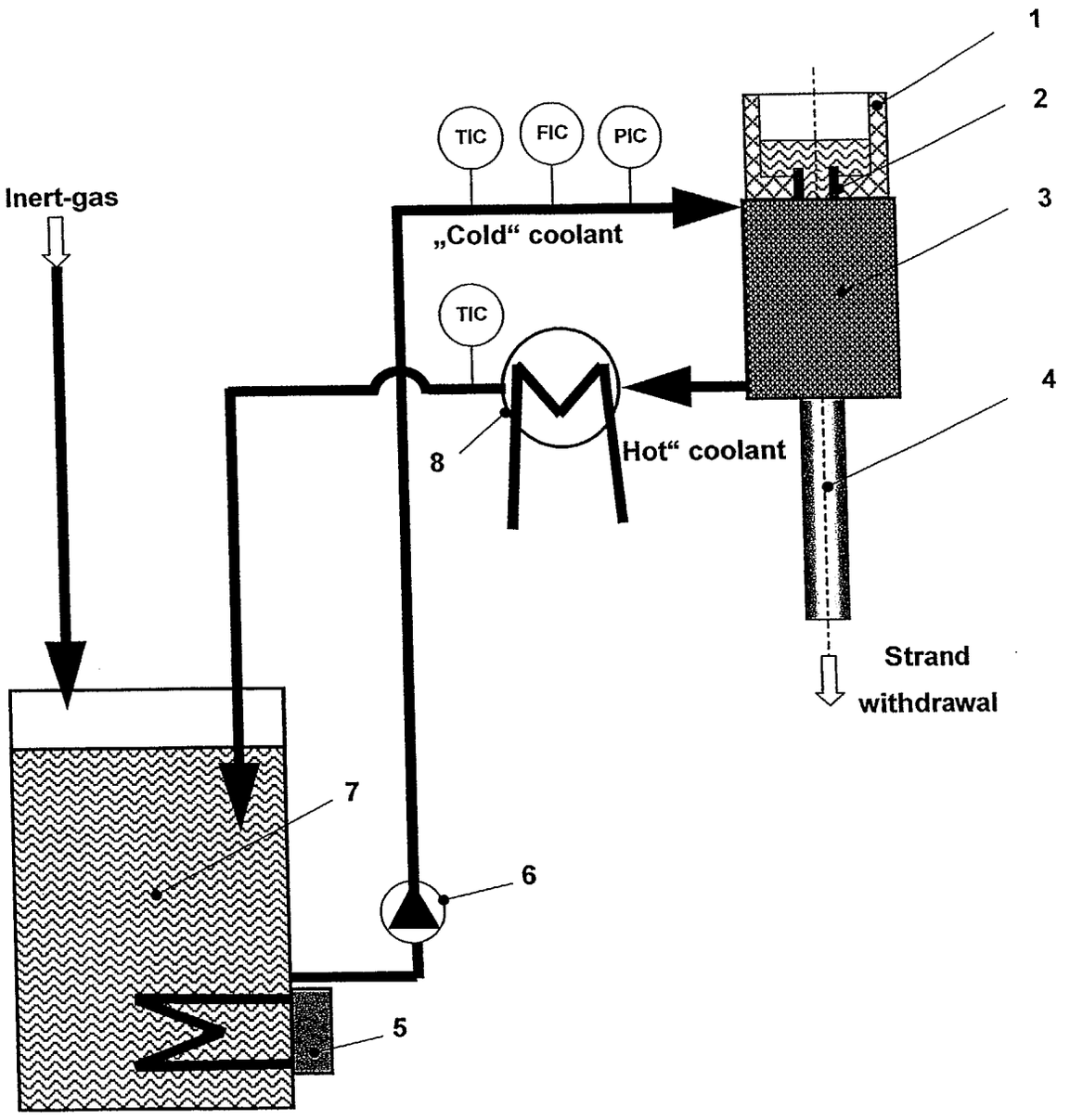


Figure 7:


1
2
3
4
TIC
FIC
PIC
Inert-gas
„Cold“ coolant
TIC
8
Hot“ coolant
Strand
withdrawal
7
6
5

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EUROPEAN SEARCH REPORT

Application Number
EP 03 45 0060

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	4 February 2004	Bergman, L

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EUROPEAN SEARCH REPORT

Application Number
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A	US 3 128 513 A (CHARLTON JOSEPH W ET AL) 14 April 1964 (1964-04-14) * the whole document * ---	1	
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