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ABSTRACT

COOLING STAVE FOR A METALLURGICAL FURNACE

A cooling stave (100) for a metallurgical furnace, in particular for a blast furnace, has a metallic plate body (110) with a front face (112) and a rear face (114), and at least one internal coolant passage (120). A set of heat pipes (130) is associated to the coolant passage in the plate body (110) to improve heat transfer from the front face (112) to the associated coolant passage (120). According to the invention, each heat pipe (130) of the set is arranged within the plate body (110) with its condensation end portion (132) enclosed in metallic material of the plate body (110) contiguous to the associated coolant passage (120). Heat transfer from the condensation end portion (132) to the associated coolant passage (120) occurs through this region of metallic material.

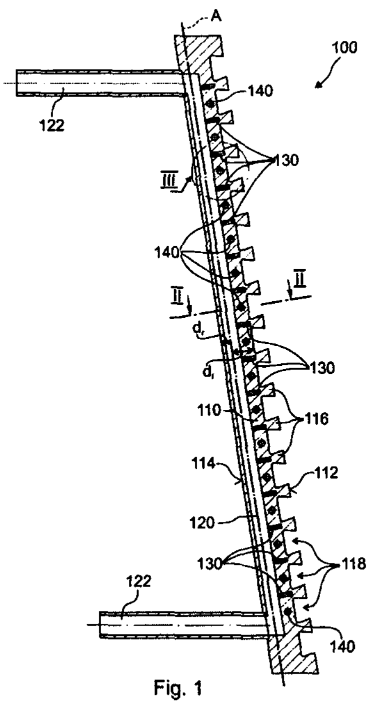

Fig. 1

Claims

1. A cooling stave for a metallurgical furnace, in particular for a blast furnace, said cooling stave comprising:

   a plate body made of metallic material and having:

   a front face for facing the interior of said metallurgical furnace,

   an opposite rear face, and

   at least one internal coolant passage within said plate body, said coolant passage having a main portion with a longitudinal axis; and

   a set of heat pipes associated to said coolant passage, each heat pipe having:

   an evaporation end portion and

   a condensation end portion,

   said set of heat pipes being arranged in said plate body to improve heat transfer from said front face to said associated coolant passage;

   characterized in that

   each heat pipe of said set of heat pipes is arranged within said plate body with its condensation end portion enclosed in metallic material of said plate body contiguous to said associated coolant passage so that heat transfer from said condensation end portion to said associated coolant passage occurs through said metallic material contiguous to said associated coolant passage.

2. The cooling stave according to claim 1, characterized in that said set of heat pipes comprises pairs of heat pipes arranged in layers at regular intervals along said longitudinal axis of said associated coolant passage.

3. The cooling stave according to claim 2, characterized in that the condensation end portions of both heat pipes of each pair are arranged on opposite sides of said main portion of said associated coolant passage.

4. The cooling stave according to claim 2 or 3, characterized in that the heat pipes of each pair are arranged obliquely with respect to a front-to-rear

direction with their evaporation end portions spaced apart further than their condensation end portions.

5. The cooling stave according to any one of claims 1 to 4, wherein said front face of said stave comprises alternating retaining ribs and retaining grooves for retaining refractory material, characterized in that said heat pipes are arranged in layers at the level of said retaining ribs.

6. The cooling stave according to claim 5, characterized in that said heat pipes are arranged with their evaporation end portion enclosed within a retaining rib.

7. The cooling stave according to any one of claims 1 to 6, characterized in that each heat pipe of said set of heat pipes is arranged to extend within said plate body from near said front face to near said associated coolant passage, preferably along a direction perpendicular to said longitudinal axis.

8. The cooling stave according to any one of claims 1 to 7, characterized in that each heat pipe of said set of heat pipes is arranged with its evaporation end portion enclosed in metallic material contiguous to said front face so that heat transfer from said front face to said evaporation end portion occurs through said metallic material contiguous to said front face.

9. The cooling stave according to any one of claims 1 to 8, characterized in that said cooling stave further comprises a first group of auxiliary heat pipes arranged in said plate body so as to extend perpendicularly to said longitudinal axis of said coolant passage and in parallel to said front face for improving thermal distribution along the width direction of said plate body.

10. The cooling stave according to any one of claims 1 to 9, characterized in that said cooling stave further comprises a second group of auxiliary heat pipes arranged in said plate body so as to extend in parallel to said longitudinal axis of said coolant passage for improving thermal distribution along the length direction of said plate body.

11. The cooling stave according to any one of claims 1 to 10, characterized in that said plate body comprises a plurality of parallel internal coolant passages, each coolant passage having a respectively associated set of heat pipes and

said coolant passages having their longitudinal axis arranged closer to the rear face than to the front face of said plate body..

12. The cooling stave according to any one of claims 1 to 11, characterized in that said heat pipes of said set of heat pipes each comprise an internal working agent and an internal wick arrangement, in particular a sintered metal wick arrangement or an internal groove arrangement, for returning said working agent from said condensation end portion to said evaporation end portion by capillary action.

13. The cooling stave according to any one of claims 1 to 12, characterized in that said metallic plate body comprises, for each heat pipe of said set of heat pipes, a corresponding blind bore drilled from said rear face and terminating short of said front face, each heat pipe being fixed in thermally conductive manner within its corresponding blind bore, preferably by means of a tight fit.

14. The cooling stave according to any one of claims 1 to 12, characterized in that said plate body is made of cast metal and comprises, for each heat pipe of said set of heat pipes, a corresponding calibrated steel blind tube cast-in said plate body and extending from said rear face and terminating short of said front face, each heat pipe being fixed in thermally conductive manner within its corresponding blind tube, preferably by means of a tight fit.

15. The cooling stave according to any one of claims 1 to 12, characterized in that said plate body is made of cast metal and in that each heat pipe of said set of heat pipes is cast-in in said metallic plate body.

16. The cooling stave according to any one of claims 1 to 15, characterized in that each heat pipe of said set of heat pipes is arranged with its condensation end portion at a distance in the range of 2 to 15 mm, more preferably 5 to 10 mm, from an outer envelope of said associated coolant passage.

17. The cooling stave according to any one of claims 1 to 16, characterized in that said plate body is made of ferrous metal, in particular of cast iron or steel.

18. Blast furnace comprising a plurality of cooling staves according to any one of the preceding claims.

19. Blast furnace according to claim 18, characterized in that said cooling staves are made of cast iron or steel and installed at the level of the belly and/or of the bosh of said blast furnace.

Dated this the 8th day of June 2012.

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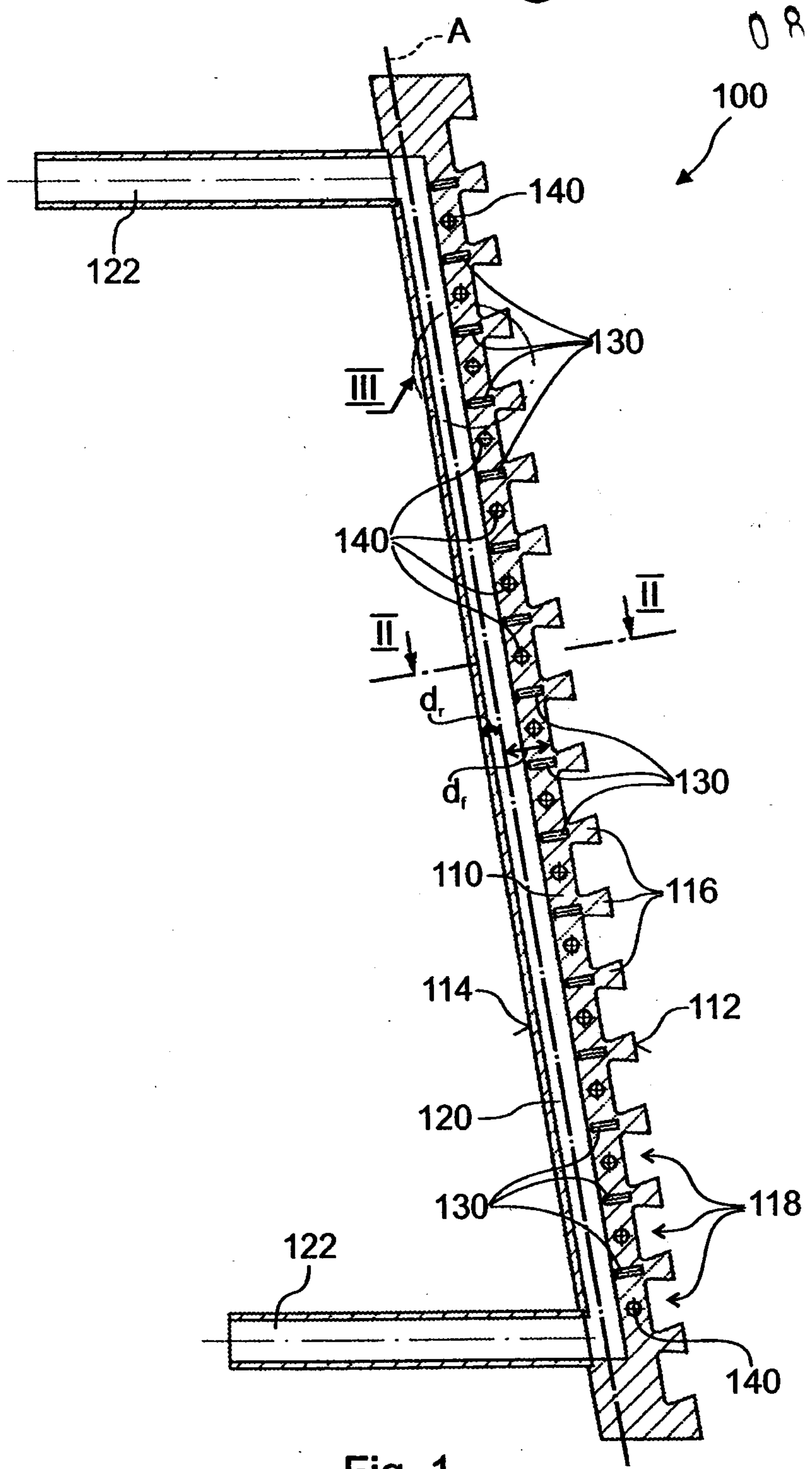

Fig. 1

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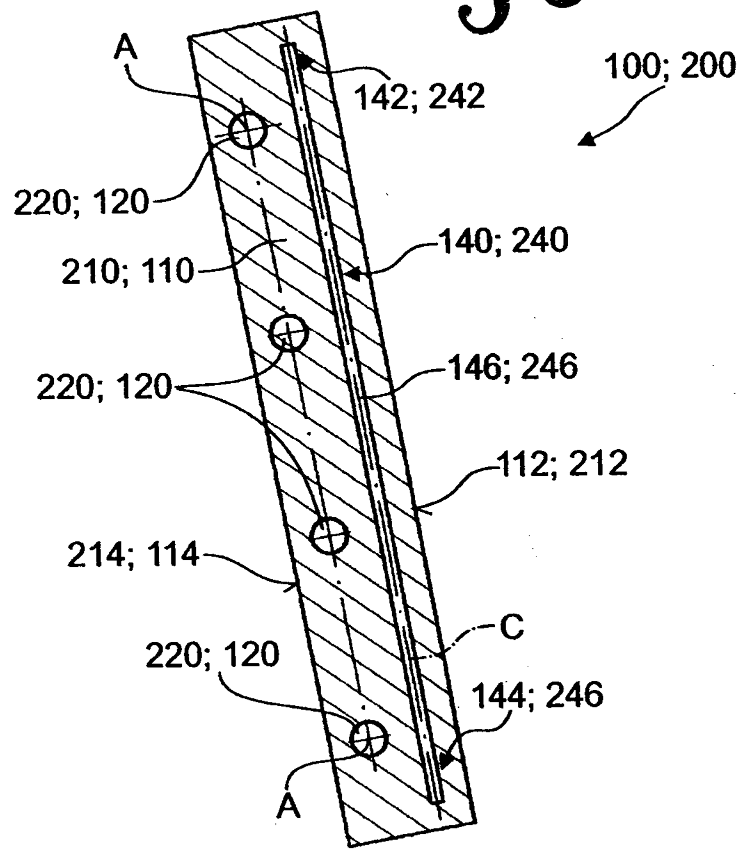

Fig. 2

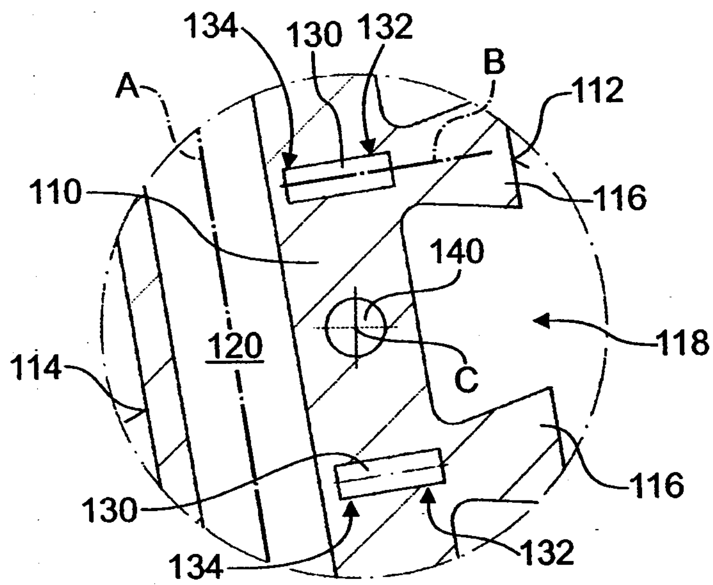

Fig. 3

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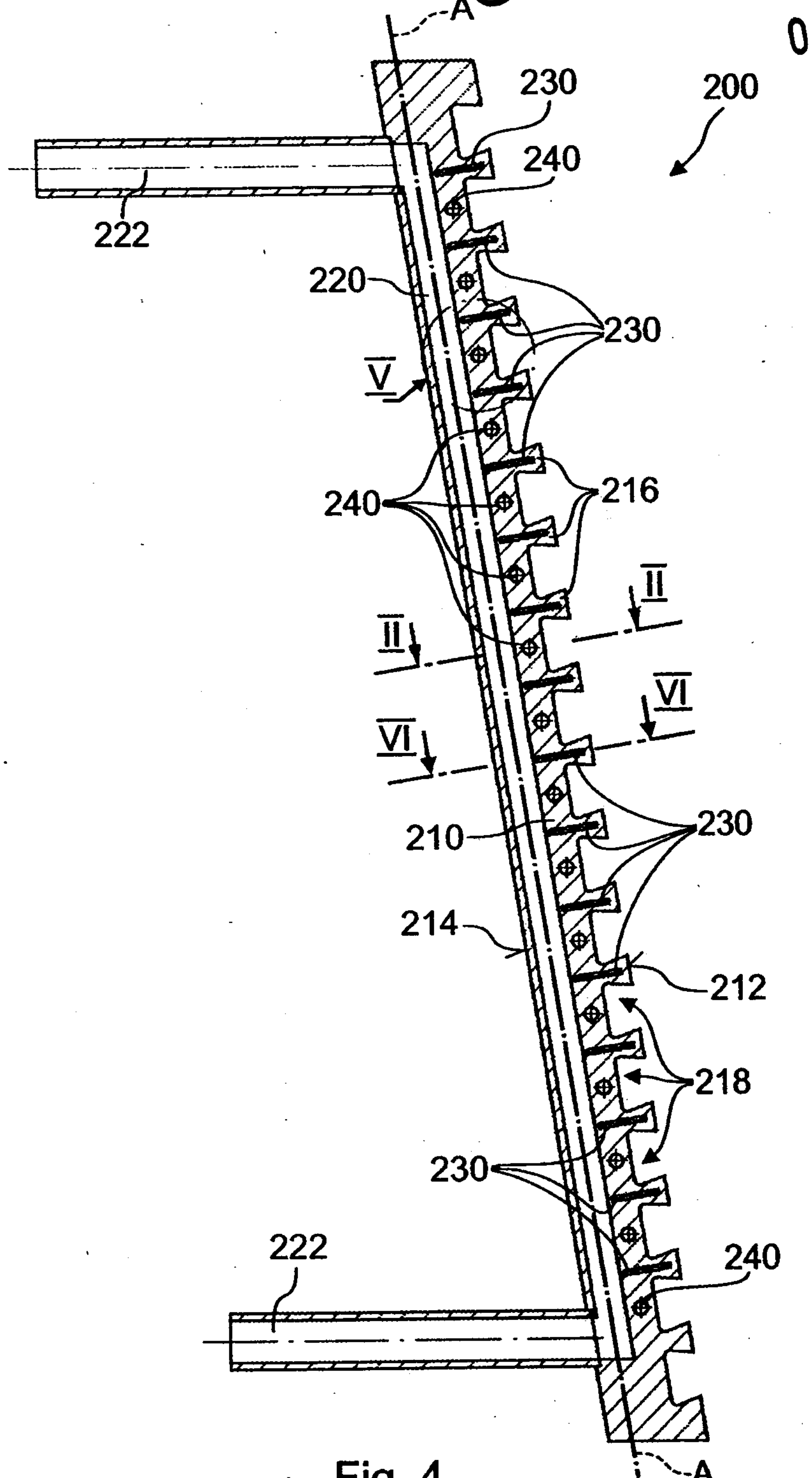

Fig. 4

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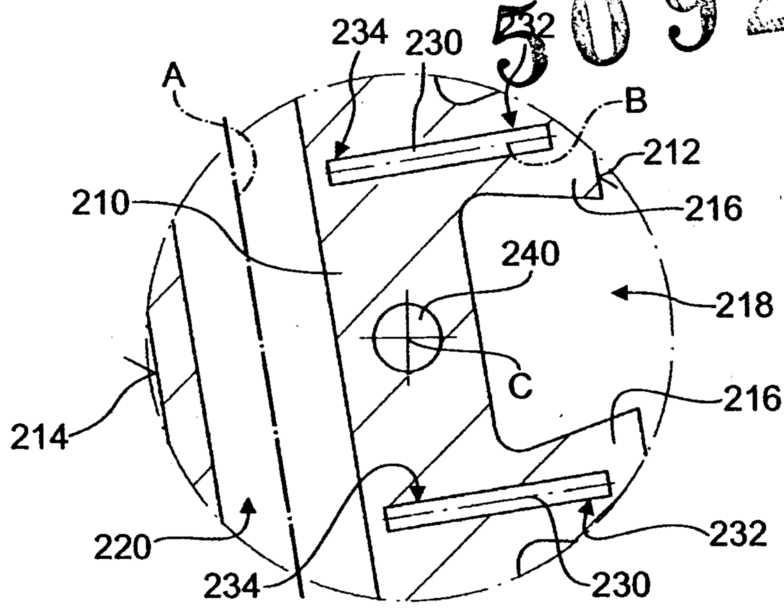

Fig. 5

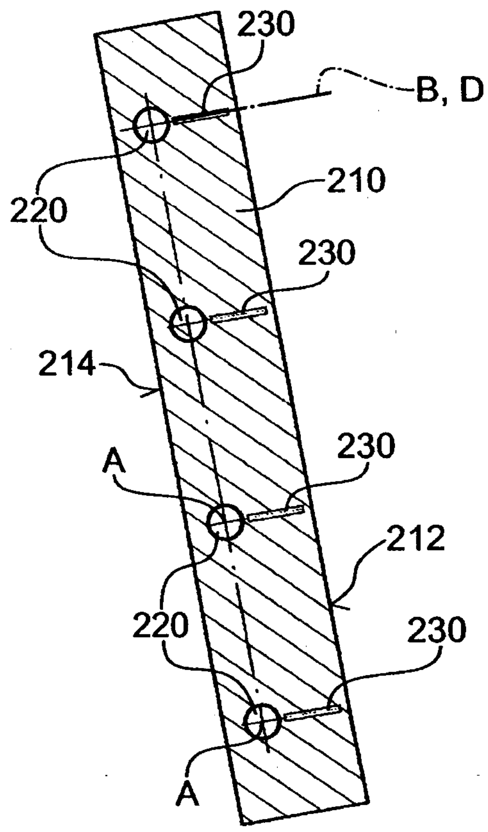

Fig. 6

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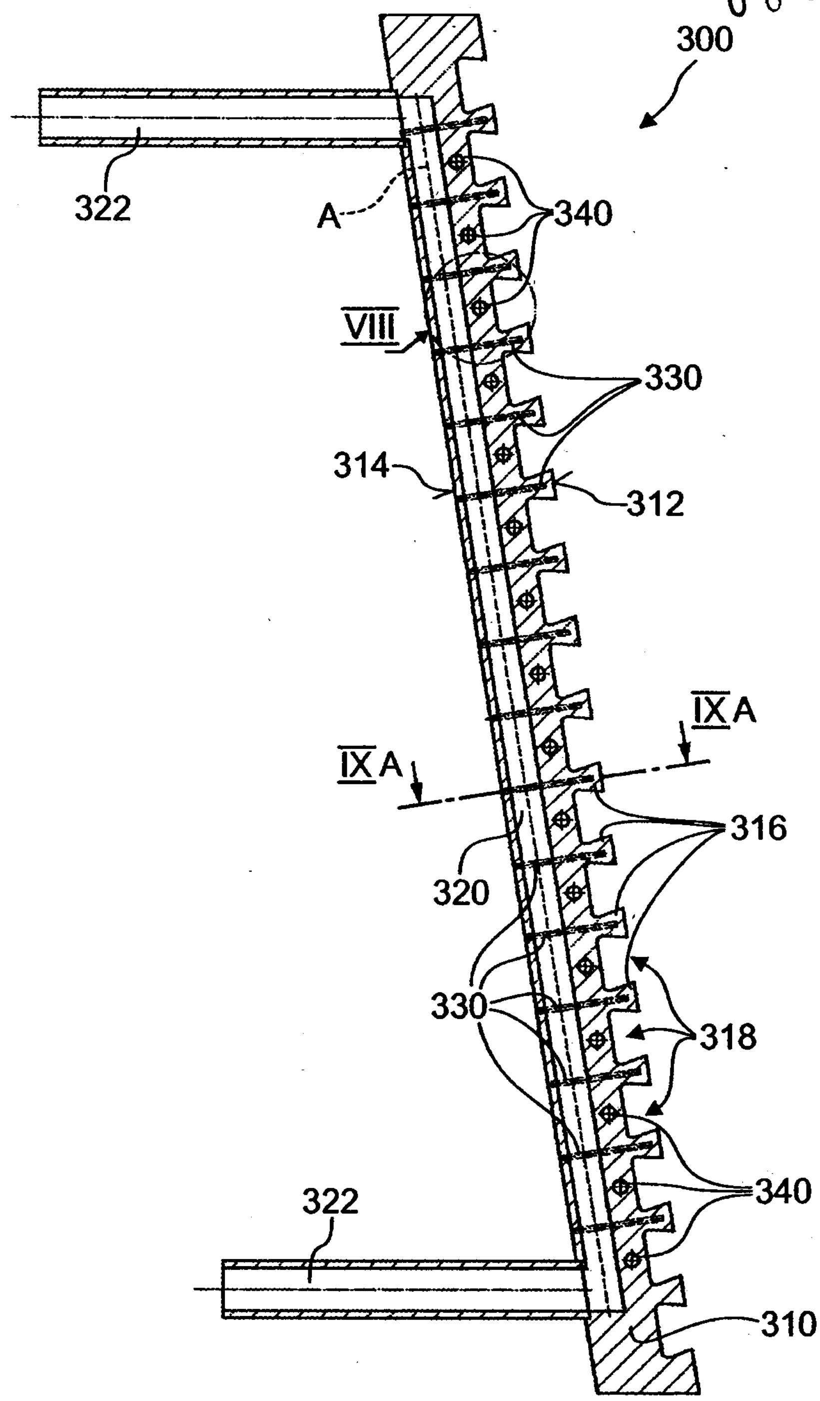

Fig. 7

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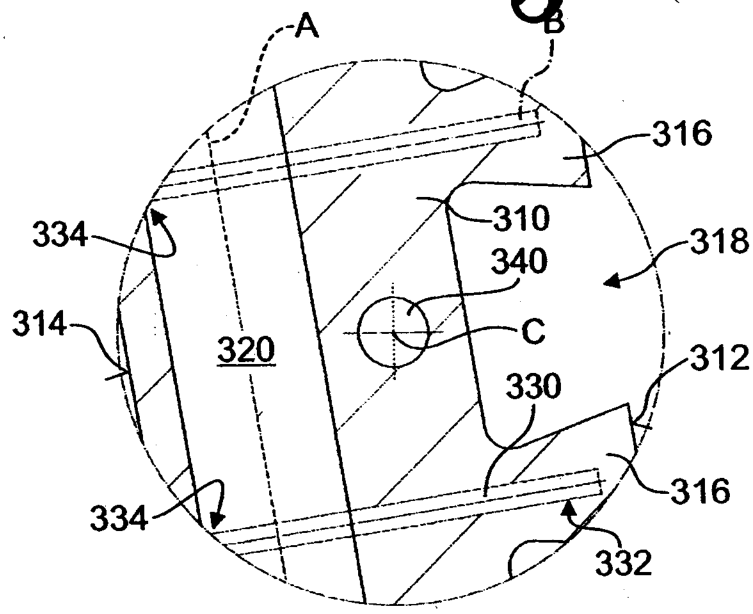

Fig. 8

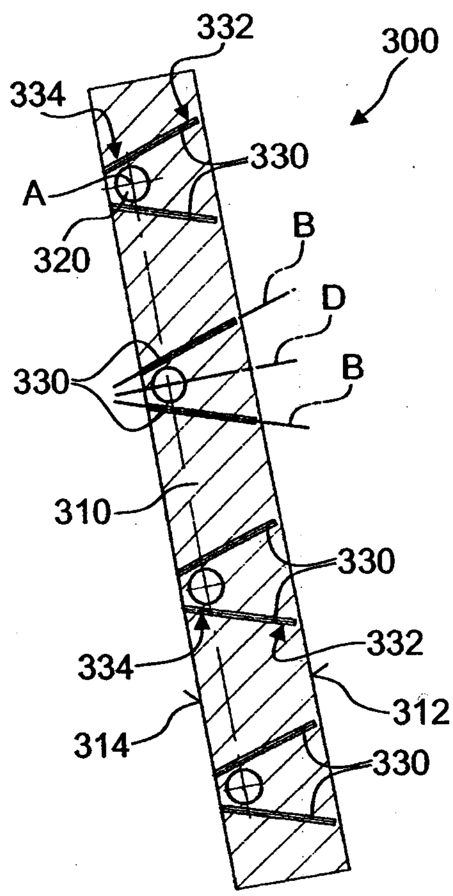

Fig. 9A

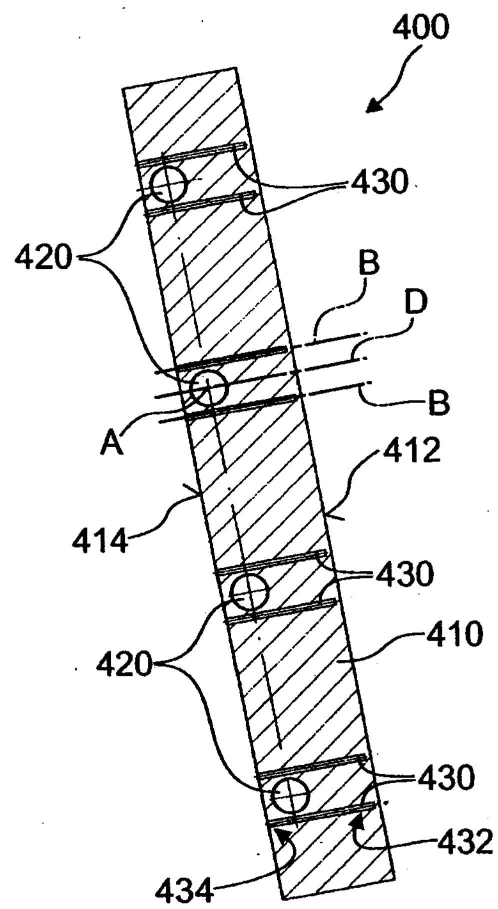

Fig. 9B

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COOLING STAVE FOR A METALLURGICAL FURNACE

Technical Field

[0001] The present invention generally relates to cooling equipment for furnaces, and more specifically to cooling staves for use in a metallurgical furnace. The invention relates to a cooling stave intended in particular but not exclusively for use in a shaft furnace, especially in a blast furnace for pig iron production.

Background Art

[0002] Cooling staves, also called "stave coolers", "cooling plates" or simply "staves", have been used in blast furnaces for decades to protect the furnace armor. They are arranged on the inside of the furnace armor, i.e. the furnace shell, and typically have internal coolant ducts, which are connected to the cooling system of the furnace. The coolant ducts are usually formed either by separate cast-in coolant pipes or, to reduce thermal resistance at the interface, by drilled-in or cast-in internal passages. The "hot face", i.e. the stave surface facing the interior of the furnace, is typically lined with a refractory material to isolate the stave from the process environment. The original intention for stave cooling was that refractories could be worn off and that the staves could, theoretically, operate with no refractory on the hot face. This situation will however subject the staves to considerable wear due to the process environment and, ultimately, lead to failure even though cooling of the stave encourages formation of protective accretions ("scaffold") on the hot face.

[0003] Initially and still nowadays, most widely used are cooling staves that have a cast iron plate body. More recently, cooling staves with a plate body made of copper or steel have been proposed and successfully used. While copper cooling staves generally have a far better thermal conductivity than cast iron or steel cooling staves, the former have a far lower wear resistance than the latter. Thus, furnace zones in which the cooling plates are exposed to severe mechanical stresses cannot readily be equipped with copper cooling plates. Furthermore, copper cooling staves are normally more expensive than cast iron cooling staves.

[0004] Due to their higher thermal conductivity copper staves are nowadays mainly used in lower region of the furnace, in the belly and in the bosh, where higher heat loads must be met and formation of a protective "scaffold" is highly desirable. Cast iron (or steel) staves on the other hand have often proved not sufficiently conductive to be used in the lower region of today's high-capacity furnaces, where very high heat loads must be met. Nevertheless cast iron (or steel) staves, have significantly higher mechanical wear resistance than copper staves. In fact, copper staves can be badly damaged by abrasive unreduced burden in case neither their refractory lining nor a protective scaffold is intact. Moreover, copper staves are more prone to deformation due to uneven thermal loads, such deformation increasing the risk of damage to the stave.

[0005] As will be understood, mechanical damage of the stave, irrespective of whether it is made of copper or ferrous metal, may lead to a rupture of its inherent internal coolant passages. Such rupture leads to a considerable risk of explosion due to formation of explosive hydrogen resulting from a coolant water leakage into the high temperature furnace interior. In case such leakages occur to an unacceptable degree, a very costly interruption of furnace operation becomes necessary, since cooling staves cannot be replaced during operation.

[0006] In an attempt to reduce the likelihood of a coolant leakage into the furnace and to minimize related risk and costs, U.S. patent application 2008/0111287 proposes a modified stave design, in which the stave is devoid of usual internal coolant passages (that are connected to the cooling circuit). As opposed to conventional staves, US 2008/0111287 proposes to install an arrangement of heat pipes that extend from inside the stave plate body to a heat sink outside the furnace shell, where the heat pipe is safely connected to the coolant circuit. Accordingly, in such a stave, the condensation end portion of the heat pipes is arranged outside the furnace shell, while only their evaporation end portion is arranged within the plate body of the stave. Similar designs have been proposed in German laid open publication no. DE 28 04 282, Japanese patent application no. JP 54 050 477 and in Soviet Union inventor's certificate SU 499300. As will be noted, compared to conventional staves, the latter designs entirely avoid passage of water coolant of the cooling circuit inside the stave.

While these designs thus considerably reduce the risk of a "hydrogen explosion" due to water leakage and while they might provide similar or even improved heat removal capacity, their main drawback resides in that considerable modification of the existing cooling circuit infrastructure and of the furnace shell is required. In other words, the above designs are not readily suitable for retrofitting existing blast furnaces, i.e. for on-site installation at an existing furnace without additional installation costs.

[0007] A similar approach of reducing the danger of ingress of coolant water into the furnace interior is proposed in international patent application no. WO 80/01000 and U.S. patent no. 4'561'639, and, similarly, in international patent application no. WO 80/01201.

[0008] The stave designs according to WO 80/01000 and US 4'561'639 also comprise a plate body made of metallic material with a front face facing the interior of the furnace. As opposed to the previous designs and in a manner similar to conventional cooling staves, these staves still include an internal (water) coolant passage within the plate body, the passage being connected to the furnace cooling circuit in typical manner. However, as an improvement over conventional staves, a set of heat pipes is associated to the coolant passage, the heat pipes being arranged in the plate body to improve heat transfer from the front face ("hot face") to the internal coolant passage. Accordingly, heat conductivity is improved, so that a risk of mechanical failure is reduced. Moreover the heat pipes, which bear little if any unsafe cooling agent, are more exposed to mechanical failure than the coolant passages. While they would allow straightforward retrofitting and connection to existing coolant circuits, the designs according WO 80/01000 or U.S. 4'561'639, still present a substantial risk of coolant leakage.

Technical Problem

[0009] It is a first object of the present invention to provide a cooling stave, having a general configuration of the type set out above, which presents a reduced risk of coolant leakage compared to conventional cooling staves while being readily suitable for installation in existing metallurgical furnaces without the need for major constructional modifications. A cooling stave as claimed in claim 1 achieves this object.

General Description Of The Invention

[0010] The present invention relates to a cooling stave (in short "stave") for protecting the shell of metallurgical furnace, in particular of a blast furnace. In known manner, the cooling stave comprises a plate body made of metallic material. The plate body has a front face and an opposite rear face, the faces respectively facing the interior of the metallurgical furnace and facing the shell when the stave is installed. Also in known manner, at least one internal coolant passage is provided within the plate body, the coolant passage having a main portion, which is usually but not necessarily rectilinear and of cylindrical cross-section. According to the invention, a set of heat pipes is associated to at least one of the coolant passages, typically to each coolant passage. Each heat pipe has an evaporation end portion and a condensation end portion. The set of heat pipes is arranged in the plate body to improve heat transfer from the front face, i.e. from the "hot face" to the opposite "cold face" in general, and more specifically to the associated coolant passage.

[0011] To achieve the above-mentioned first object and according to the presently claimed invention, each heat pipe of the set of heat pipes is arranged within the plate body, i.e. without protruding notably from the plate body, and further arranged with its condensation end portion partially enclosed or fully enclosed in plate material contiguous to the associated coolant passage. That is to say the condensation end portion of each heat pipe is either partially surrounded or wholly contained (embedded) in the plate material without, in either case, protruding into the coolant passage. Accordingly, during operation, heat transfer from the condensation end portion to the coolant passage occurs through the metallic material contiguous to the coolant passage. In other words, the condensation end portions are cooled, indirectly, by means of thermal conduction through an interface of metallic material of the plate body between the heat pipe and the associated coolant passage.

[0012] By integrating comparatively small heat pipes, the global thermal conductivity of a stave can be significantly improved, especially in case of a stave made of ferrous metal but also in case of a stave made of copper. Finite element calculations predict, for a cast iron stave an increase of >30% compared to a conventional cast iron stave and for a copper stave an increase of >10% compared to a conventional copper stave. Moreover the thermal distribution is enhanced, thus reducing a risk of plastic deformations due to excessive and non-uniform temperatures in the stave body. Eventually, by providing heat pipes according to the invention, the lifetime of the stave is increased.

[0013] Compared to staves equipped with heat pipes according to US 2008/0111287, DE 28 04 282, JP 54 050 477 or SU 499300, the staves according to the presently claimed invention have the notable benefit of being compatible with existing designs. In fact the presently proposed staves enable installation in existing furnaces (retrofitting), without major changes to the cooling installation if any, without the need to connect heat pipes to a modified cooling circuit, and without the need of creating heat pipe vacuum on-site (as probably inherently necessary with the mentioned prior art staves).

[0014] Compared to staves equipped with heat pipes according to WO 80/01000 and US 4'561'639, the staves according to the presently claimed invention have the important benefit of further reducing the risk of coolant leakage into the furnace. In fact, according to WO 80/01000 and US 4'561'639 cavities are provided in the stave body that communicate with the coolant passages to receive heat pipes that have their condensation end portion arranged within the coolant passage. These cavities inevitably create channels from the associated coolant passage to a portion near the front face of the stave, which channels must be reliably sealed to avoid any leakage through this channel in case of a mechanical failure, e.g. a rupture or fissure, through the cavity. Accordingly, with progressing wear, leakage of coolant from a stave according to WO 80/01000 and US 4'561'639 cannot reliably be excluded. In the staves according to the presently claimed invention, this drawback is eliminated by the barrier of metallic material of the plate body remaining between the condensation end portion of the heat pipe and the associated coolant passage.

[0015] A beneficial increase in thermal conductivity is achieved in case the plate body is made of ferrous metal, in particular of cast iron or steel. Accordingly, a stave having the combined benefits of mechanical robustness of a cast iron or steel stave together with higher thermal efficiency is obtained. . Nevertheless, a notable increase in thermal conductivity can also be achieved with copper staves.

[0016] Preferably, each set of heat pipes comprises pairs of heat pipes arranged along the longitudinal axis of the main portion of the associated coolant passage, preferably in layers at regular intervals. Whereas each layer may alternatively comprise a single heat pipe, pairs of heat pipes further improve the overall thermal conductance. In the latter case, the condensation end portions of both heat pipes of each pair are advantageously arranged on opposite sides of the main portion of the associated coolant passage. Furthermore, in order to increase the heat pipe length and thus the effective "thermal short" and at the same time achieve more uniform cooling of the front face, the heat pipes of each pair are preferably arranged obliquely with respect to a front-to-rear direction and with their evaporation end portions spaced apart further than their condensation end portions.

[0017] In case the front face of the stave comprises alternating retaining ribs and retaining grooves for retaining refractory material, the heat pipes are preferably arranged in layers at the level of the retaining ribs in order to enhance mechanical protection of the heat pipes within the plate body. In the latter embodiment of the presently claimed invention, the heat pipes may be arranged with their evaporation end portion enclosed within a retaining rib in order to further reduce overall thermal conductance. Alternatively, the heat pipes may be arranged so at to not protrude into the retaining ribs for minimal exposure to mechanical stress.

[0018] In a further preferred embodiment, each heat pipe of the set of heat pipes extends fully within the plate body, from near the front face to near the associated coolant passage, and preferably along a direction perpendicular to the longitudinal axis of the main portion of the associated coolant passage. Preferably, each heat pipe of a set of is also arranged with its evaporation end portion enclosed in metallic material contiguous to the front face. Accordingly, heat transfer from the front face to the evaporation end portion occurs through this interface of metallic material contiguous to the front face, so that the evaporation end portion are protected from mechanical wear.

[0019] In another preferred embodiment, a first group of auxiliary heat pipes is arranged in the plate body so as to extend perpendicularly to the longitudinal axis of the coolant passage and in parallel to the front face. Such auxiliary heat pipes improve thermal distribution along the width direction of the plate body. To increase thermal distribution along the length direction of the plate body, a second group of auxiliary heat pipes may be arranged in the plate body so as to extend in parallel to the longitudinal axis of the coolant passage.

[0020] Typically, the plate body comprises a plurality of parallel internal coolant passages, each coolant passage having a respectively associated set of heat pipes according to the presently claimed invention. In the latter case, the coolant passages beneficially have their longitudinal axis arranged closer to the rear face than to the front face, in particular within the rearmost 40% of the base wall thickness of the plate body. In this construction the water carrying passages (integrally formed channels or inserted pipes) in the stave are further away from the inside of the furnace. The risk of a breakthrough is thereby further reduced, and, in certain cases of a fatal failure on the front side of the stave, this design may nevertheless warrant that no water enters the furnace. Accordingly, the risk of a hydrogen explosion is lowered even further.

[0021] Preferably, in order to warrant operation in any orientation, the heat pipes preferably an internal wick arrangement, e.g. a sintered metal wick arrangement or an internal groove arrangement, for returning the heat pipe working agent from the condensation end portion to the evaporation end portion by capillary action.

[0022] Depending on the chosen mode of manufacturing, the metallic plate body may comprise:

- for each heat pipe of the set of heat pipes, a corresponding blind bore drilled from the rear face and terminating short of the front face, each heat pipe being fixed in thermally conductive manner within its corresponding blind bore, preferably by means of a tight fit; or
- for each heat pipe of the set of heat pipes, a corresponding calibrated steel blind tube cast-in the plate body and extending from the rear face and terminating short of the front face, each heat pipe

being fixed in thermally conductive manner within its corresponding blind tube, preferably by means of a tight fit.

[0023] In an alternative mode of manufacturing, wherein the plate body is made of cast metal and in that each heat pipe of the set of heat pipes is cast-in in the metallic plate body.

[0024] Irrespective of manufacturing, in a preferred embodiment, each heat pipe of a set of heat pipes is beneficially arranged with its condensation end portion at a distance of at least 2 mm, preferably a distance in the range of 2 to 15 mm, from an outer envelope of the associated coolant passage.

[0025] As will be appreciated, the presently claimed staves are particularly adapted for industrial application in blast furnace cooling systems. In a preferred application, the proposed staves are made of cast iron or steel and are installed at the level of the belly and/or of the bosh of the blast furnace.

Brief Description Of The Drawings

[0026] Further details and advantages of the present invention will be apparent from the following detailed description of several not limiting embodiments with reference to the attached drawings, wherein:

FIG.1 is a longitudinal cross-sectional view of a cooling stave according to a first embodiment;

FIG.2 is a lateral cross-sectional view according to line II-II of FIG.1 and FIG.4;

FIG.3 is an enlarged view of region III in FIG.1;

FIG.4 is a longitudinal cross-sectional view of a cooling stave according to a second embodiment;

FIG.5 is an enlarged view of region V in FIG.4;

FIG.6 is a lateral cross-sectional view according to line VI-VI of FIG.4;

FIG.7 is a longitudinal cross-sectional view of a cooling stave according to a third embodiment;

FIG.8 is an enlarged view of region VIII in FIG.7;

FIG.9A is a lateral cross-sectional view according to line IX A-IX A of FIG.7, illustrating the third embodiment of a cooling stave;

FIG.9B is a lateral cross-sectional view illustrating a fourth embodiment of a cooling stave.

[0027] In these drawings identical reference signs or reference signs with incremented hundreds digit are used to identify identical or functionally similar components throughout.

Detailed Description With Respect To The Drawings

[0028] In FIG.1, a first embodiment of a cooling stave 100 (hereinafter "stave") is shown in longitudinal cross-sectional view. The stave 100 comprises a plate body 110 made of metallic material e.g. of a ferrous metal such as cast iron, typically spheroidal graphite cast iron (ductile C.I., DIN "GGG" type) or lamellar graphite cast iron (grey iron, DIN "GGL" – type). As will be understood, the plate body 110 may also be made of another metal, e.g. of copper. The metallic plate body 110 has the general form of a parallelepiped, with a front face and an opposite rear face respectively indicated at 112 and 114. The front face 112 ("hot face") of the plate body 110 is advantageously provided with a series of alternating and regularly spaced parallel retaining ribs 116 and retaining grooves 118. The ribs 116 and grooves 118 are preferably dovetail shaped in lateral cross-section, as best seen in FIG.3. Accordingly, as shown in FIG.1, the front face 112 is corrugated to increase the heat exchange surface and improve adherence of a refractory lining typically provided on the front face 112. The stave 110 is to be arranged on the inside of the shell of a metallurgical furnace, e.g. a blast furnace (not shown), with the front face 112 facing the interior reaction space of the furnace. Typically the plate body 110 has dimensions in the following ranges: length: 500-5000mm, width: 200-2000mm, plate thickness: (smallest dimension, i.e. base wall thickness excluding ribs 116) 40-500mm.

[0029] Reference number 120 identifies a generally straight, cylindrical coolant passage, e.g. in the form of an internal channel integrally formed during casting of the plate body 110 – as seen in FIG.1 – or, alternatively a channel machined by subsequent drilling. As best seen in lateral cross-section of the stave in FIG.2, the plate body 110 includes several such coolant passages 120, which are normally parallel to one another. The coolant passages 120 extend inside and within the metallic plate body 110 in between the front face 112 and the rear face 114. The cross-section of each coolant passage 120 is normally circular, but a different, e.g. oval section is not excluded. As further seen in FIG.1, the internal coolant passages are connected to connection pipe portions 122. The connection pipe portions 122 of FIG.1 are welded transversely to the integrally formed channels that form the coolant passages 120, or alternatively, may be formed by bent portions of a coolant pipe, which is either inserted into a bore or cast-in into the plate body 110, and that forms the coolant passage (non-illustrated alternative). The connection pipe portions 122 respectively form an inlet and outlet for connecting the internal coolant passages 120 to the cooling circuit (not shown) of the blast furnace. While not necessarily being entirely straight and rectilinear, each coolant passage 120 normally has at least a rectilinear main portion, with a longitudinal axis A, as best seen in FIG.1 & FIG.2.

[0030] As is apparent from FIG.1, a main set of heat pipes 130 is associated to each coolant passage 120. As is well known, heat pipes have very high effective thermal conductance often several hundred times higher than that of copper, and can thus be considered as "thermal shorts". Suitable configurations for the heat pipes 130 are per se well known. Further details may be found e.g. in Reay, David and Peter Kew "Heat Pipes, Fifth Edition: Theory, Design and Applications" Butterworth-Heinemann publisher; 5 ed. (2006); ISBN 978-0750667548.

[0031] Each heat pipe 130, as best indicated in FIG.3, has an evaporation end portion 132 (typically called "evaporator section") and a condensation end portion 134 (typically called "condenser section"). As may be noted, for use in a stave 100 according to the present invention, the heat pipes 130 have an internal working agent (working fluid), as well as a container material, suitable for temperatures of >760°C. Suitable working agents are for example water or mercury. The heat pipes 130 normally have an internal wick arrangement, e.g. a sintered metal wick arrangement or internal grooves, for returning the working agent from the condensation end portion 134 to the evaporation end portion 132 by capillary action, irrespectively of the orientation of the heat pipes 130. Alternatively or in addition, provided an orientation with adequate slope from the condensation end portion 134 to the evaporation end portion 132 is warranted (see e.g. second auxiliary group of heat pipes below), return of the working agent may be caused or assisted by gravity, thus enabling the use of less expensive heat pipes 130. Whereas cylindrical container geometry is most practical, the heat pipes 130 may in principle have any, generally elongated geometry.

[0032] As best seen in the enlarged view of FIG.3, the condensation end portion 134 of each heat pipe is arranged in proximity of the associated coolant passage 120 whereas the evaporation end portion 132 is arranged in proximity of the front face 112 of the plate body 110. Accordingly, each heat pipe 130 of the main set is arranged in the plate body 110 in a manner that improves heat transfer from the front face 112 ("hot face") to the rear face 114 ("cold face") in general, and in particular to the associated internal coolant passage 120. As seen in FIG.1, within a set of heat pipes 130 associated to a given coolant passage 120, the heat pipes 130 are arranged in layers at regular intervals along the longitudinal axis, in set preferably covering substantially the full length of the associated coolant passage 120. In the stave 100 of FIGS.1-3, each heat pipe 130 is arranged to extend from the vicinity of the associated coolant passage 120 to the vicinity of the front face 112 without protruding into the retaining ribs 116. Accordingly, the heat pipes 130 of FIGS.1-3 are embedded within the core parallelepiped-shaped part of the stave body 110 without passing into the ribs 116 so as to avoid exposure to higher mechanical stress to which the ribs 116 are typically subjected, among others due to temperature gradients and their refractory-supporting function. In addition, preferably the heat pipes 130 are arranged to approximately cover the length of the associated coolant passage 120 within a central region excluding the uppermost and lowermost longitudinal extremities of the plate body 110, which are also subjected to considerable stress and wear.

[0033] Preferably, as seen in FIGS.1&3, the heat pipes 130 are arranged in layers that correspond to the retaining ribs, with their longitudinal axes B approximately coinciding with the plane of symmetry of the corresponding retaining rib 116. The heat pipes 130 may also be arranged differently, e.g. without their longitudinal axes B located exactly mid-plane of the retaining ribs 116. As best seen in FIG.3, the heat pipes 130 are preferably arranged with their longitudinal axis B oriented substantially perpendicular to the longitudinal axis A. In the stave 100 of FIG.1, each layer comprises a single heat pipe 130 having its axis B arranged to cross the axis A of the associated coolant passage. The number of heat pipes 130 associated per set to a coolant passage 120 approximately corresponds to the number of retaining ribs 116, subtracting 2-4 for one or two uppermost and lowermost retaining ribs 116, as illustrated in FIG.4.

[0034] As will be appreciated and as best illustrated in FIG.3, each main heat pipe 130 is embedded within the metallic plate body 110 with its condensation end portion 134 enclosed in a "cooled" portion of the metallic material of the plate body 110, which portion is contiguous to the associated coolant passage 120. Accordingly, in operation, heat transfer occurs from the condensation end portion 134 to the respective coolant passage through the "cooled" portion of plate material adjoining the coolant passage 120. In other words, the heat pipes 130 do not protrude into the coolant passages 120 nor out of the plate body 110. Consequently, the heat pipes 130 are safely encapsulated within the material of the plate body 110 and wear- or stress induced damage to any one of the heat pipes 130 cannot cause a leakage from the associated coolant passage 120 due to the remaining barrier of metallic material between the heat pipe 130, especially its condensation end portion 134 and the coolant passage 120. Preferably, each heat pipe 130 is arranged so that the shortest distance between its condensation end portion 134 and the outer, e.g. cylindrical, envelope of the associated coolant passage 120 is greater than 2mm, preferably in the range of 2mm to 15mm, more preferably in the range of 5 to 10mm, in order to warrant practical safety at low thermal resistance.

[0035] For additional protection of the heat pipes 130 from stress and wear to which the front face 112 (hot face) is subjected, each heat pipe 130 is arranged with its evaporation end portion 132 enclosed in a "heated" portion of metallic material of the plate body 110 contiguous to the front face 112. Accordingly, heat transfer from the front face 112 to the evaporation end portion 132 will occur through the corresponding "heated portion" of plate material adjoining to the front face 112.

[0036] As will further be appreciated, besides achieving a considerable reduction of the leakage risk, the proposed configuration of heat pipes 130 considerably increases the overall heat conductivity in front-to-rear direction, from the "hot" front face 112 to the "cold" rear face 114. Accordingly, it also allows positioning each of the coolant passages 120 closer to the rear face 114 than typically recommended in conventional staves. Preferably, the coolant passages 120 thus have their longitudinal axis A, arranged closer to the rear face 114 than to the front face 112 i.e. at a ratio $dr / df << 1$. Preferably $dr / df \leq 0.8$, more preferably $dr / df \leq 0.7$, with dr being the distance of the axis A to the rear face and df that to the front face 112 (at the level of a groove 118), as seen in FIG.1. The coolant passages 120 are configured such that the remaining thickness of material of the plate body 110 between the coolant passages 120 and the rear face 114 is minimized, being preferably in the range of 5 to 50mm. As a result, the risk of stress-induced failure of the coolant passages 120 causing a leakage is further reduced since the rear face 114 is least exposed to mechanical stress.

[0037] FIG.1 illustrates a first group of parallel auxiliary heat pipes 140 which are embedded in the plate body 110 with a different orientation. As best seen in FIG.2, each of the plurality of first auxiliary heat pipes 140 is arranged with its longitudinal axis C extending perpendicularly to the longitudinal axis A of the parallel coolant passages 120 and generally in parallel to the front face 112. The heat pipes 140 have their end portions 142, 144 located within plate material contiguous to the opposite lateral edges of the plate body 110. Accordingly, depending on the temperature distribution within the plate body 110, the end portions 142, 144 are operating either as condenser or evaporator section. Due to their comparatively long length, the heat pipes 140 are normally equipped with an adiabatic central section 146, through which the end portions 142, 144 communicate. As seen in FIG.1, the heat pipes 140 are preferably arranged mid-plane of a corresponding retaining groove 118, a heat pipe 140 being provided for each retaining groove 118 except for the uppermost and lowermost grooves 118. As best seen in FIG.3, the heat pipes 140 are arranged with their longitudinal axis C located approximately centrally on the shortest distance between the cylindrical envelope of the cooling passages 120 and the surface of the front face 112 at the bottom of corresponding groove 118. As will be appreciated, the first group of auxiliary heat pipes 140 increases thermal distribution along the width direction of the plate body 110 and thereby also distributes the thermal load more equally between the coolant passages 120. Preferably, the auxiliary heat pipes 140 are regularly spaced, in altemation with the main heat pipes 130, as a group substantially covering the length of the coolant passages 120. In addition, although not shown in the drawings, a second group of auxiliary heat pipes may be provided in similar manner for improving thermal distribution along the length direction of said plate body and thus reducing wrapping of the stave. Such heat pipes can be embedded in the plate body 110 so as to extend in parallel to the longitudinal axes C of the coolant passages 120.

[0038] FIGS.4-6 illustrate a second embodiment of a stave 200. For conciseness, only the difference of the stave 200 of FIGS.4-6 with respect to the stave 100 of FIGS.1-3 is detailed below. Other features, as identified by incremented hundreds digit, are identical or analogous to those described above.

[0039] As best seen in FIG.5, and in contrast to the stave 100, the evaporation end portion 232 of a main heat pipe 230 in the stave 200 is enclosed within the plate material forming the corresponding retaining rib 216. With the heat pipes 230 protruding partially into the retaining ribs 216, the thermal conductivity is further increased since the evaporation end portions 232 are located closer to the front-most plane of the corrugated front face 212. Accordingly, depending on their required length, the heat pipes 230 may be provided with an intermediate adiabatic section. Safety distances between the condensation end portion 234 and the associated coolant passage 220 are preferably chosen similar to those set out above with respect to FIGS.1-4. In addition, and even though failures, e.g. breakage of a heat pipe 230 is uncritical, each heat pipe 230 is preferably arranged so that the shortest distance between its evaporation end portion 232 and the surface of the front face 212 at the tip of the corresponding rib 216 is in the range of 5 mm to 50 mm to minimize exposure to mechanical stress and wear so as to warrant sufficient lifetime of the heat pipes 230.

[0040] As may be noted and shown in lateral cross-section in FIG.2, the stave 200 of FIGS.4-6 is also equipped with auxiliary heat pipes 240 configured and arranged as detailed further above in relation to FIG.2. Furthermore, the axis B of each heat pipe 230 is also parallel to the front-to-rear direction, indicated by line D in FIG.6.

[0041] FIGS.7-9A illustrate a third embodiment of a cooling stave, identified by reference 300. Only the differences with respect to the stave 100 of FIG.1-3 and the stave 200 of FIGS.4-6 are detailed below. Other features are identical or analogous to those described above.

[0042] In the stave 300 of FIGS.7-9A, the main set of heat pipes 330 is configured differently as regards the amount of heat pipes 330 used and as regards their orientation within the plate body 310. As best seen in FIG.9A (taken along line IXA-IXA in FIG.7), each set associated to a given coolant passage 320 comprises a pair of heat pipes 330 in each layer, with layers corresponding to the retaining ribs 316 (except for one or two upper- and lowermost ribs). Accordingly, in the embodiment of FIGS.7A-9, the total number of heat pipes 330 is approximately equal to the number of coolant passages 320 multiplied by the number of ribs 316 multiplied by two, thus amounting e.g. to several tens of heat-pipes. Consequently, an additional increase in thermal conductivity in the front-to-rear direction is achieved when compared to FIGS.1-6 by the pairs of heat pipes 330 that are arranged at regular intervals along the longitudinal axis A of the associated coolant passage 320. Thus, a stave 300 according to FIGS.7-9A has even higher thermal efficiency and is even less prone to premature failure. As further seen in FIG.9A, the two heat pipes 330 of each pair are arranged obliquely and mirror-symmetrically with respect to the transverse front-to-rear direction D. More specifically, their evaporation end portions 332 close to the front face 312 are spaced apart to a greater extent than their condensation end portions 334 adjacent the associated coolant passage 320. In other words, the longitudinal axes B of the heat pipes 330 in a pair are at an angle with respect to the transverse front-to-rear direction D. This arrangement allows doubling the number of "thermal shorts" from near the front face 312 to near the associated coolant passage 320, while at the same time warranting, along the width direction of the plate body 310, an approximately uniform distribution of the evaporation end portions 332 in the plate material contiguous to the front face 312. Similar to FIGS.1-6, the condensation end portions 334 on the other hand, are enclosed in respective "cooled region" of material of the plate body 310. In the stave 300 however, the "cooled region" is respectively contiguous to opposite sides of the main portion of the associated coolant passage 320, with – as above – heat transfer between the evaporation end portions 332 and the associated coolant passage 320 occurring through this protective "cooled region".

[0043] Furthermore, the main heat pipes 330 are longer than those used in FIGS.1-6. In fact, the configuration of FIG.9A allows for a maximum heat pipe length while maintaining a uniform distribution of the evaporation end portions 332 along the width of the front face 312. The condensation end portions 334 are located closer to the rear face 314 of the plate body 310. As best seen in FIG.9A, the heat pipes 330 of each set go by closely and laterally of the associated coolant passage 320, on opposite sides of the passage main portion with respect to the front-to-rear direction D. Accordingly, a greater extent of the condensation end portions 334 is arranged in vicinity of the coolant passage 320 to improve cooling when compared to FIGS.1-6. For simplified manufacturing, the heat pipes 330 are installed, e.g. by tight-fit, in a corresponding blind hole. The blind holes extend obliquely along axis B from the rear face 314 toward the front face 312 and terminate short of the front face 312, e.g. at distance in the range of 5mm to 50 mm. The terminal faces of the condensation end portions 334 are preferably flush or nearly flush with the rear face 314. While the lateral surface of the condensation end portions 334 is fully surrounded by plate material contiguous to the associated coolant passage 320, their front faces need not be (as enabled by larger exposure to cooling on the lateral surfaces). In other words, as opposed to the previous embodiments, the heat pipes 330 of the stave 300, while also being arranged within the plate body 310 without protruding there from, are not completely embedded within the material of the plate body 310.

[0044] FIG.9B illustrates a fourth embodiment of a stave, identified by reference 400. The stave 400 is substantially identical to that of FIGS.7-9A and differs only in that, for further simplified manufacture, the blind holes, in which the main heat pipes 430 are installed, are provided in the plate body 410 in parallel to the front-to-rear direction D. Accordingly, the heat pipes 430 are arranged within the plate body 410 with a longitudinal axis B that is both perpendicular to the axis A of the coolant passages 420 and perpendicular to the plane of the front face 412 / rear face 414.

[0045] To conclude, some preferred ways of manufacturing cooling staves 100, 200, 300, 400 as described above are summarized below:

[0046] As will be noted, the main heat pipes 130, 230 of FIGS.1-6, as well as the auxiliary heat pipes 140, 240 are completely embedded in the metallic material of the plate body 110, 210. In case the plate body 110, 210 is manufactured by casting, a method suitable for complete embedding is:

(a) casting-in the heat pipes 130, 230; 140; 240 during the casting operation of the plate body, preferably using heat pipes with a steel container.

[0047] In alternative methods, which are suitable for manufacturing staves 300, 400 according to FIGS.7-9B (in which the heat pipes 330, 430; 340; 440 may have an end face not enclosed by the plate material properly speaking) the heat pipes 330, 330; 340; 440 can be installed by:

(b) for a cast plate body: providing, during the casting operation of the plate body, a cylindrical sand core as a placeholder at the final location of the heat pipes 330, 430; 340; 440, and, after casting, removal of the sand core and boring up of the thus obtained cavities, followed by tight-fitting the heat pipes 330, 430; 340; 440 therein for sufficient thermal contact (optionally adding a thermal grease at the interface);

(c) for a cast plate body: casting-in a calibrated blind tube, preferably made of steel, during the casting operation of the plate body 310, 310, which will have an end face flush with a surface of the plate body 310, 410 and have good thermal contact with the plate material due to carburization, followed after casting by insertion, e.g. by tight-fit or screwed connection, of the heat pipes 330, 430; 340; 440 and, if required, adding a protective filling material in a manner avoiding air inclusion in residual empty portions of the blind tube; or by

(d) for any kind of plate body: drilling and, if required, boring out receiving holes at the appropriate locations after (cast or non-cast) manufacture of the plate body 310, 410 and subsequently inserting the heat pipes 330, 430; 340; 440, e.g. by tight-fit or screwed connection.

[0048] As may further be noted, the plate body 110, 210, 310, 410 may also be manufactured of a non-ferrous metal, in particular of copper. In copper staves the plate body 110, 210, 310, 410 is usually either cast, e.g. according to US 6'470'958, or produced by machining a rolled slab. In such copper staves, the heat pipes 130, 230; 140; 240 can also be installed by:

(e) in case of cast copper staves: casting-in the heat pipes 130, 230; 140; 240 during the casting operation of the copper plate body 110, 210, preferably using heat pipes with a steel container provided with a suitable coating.

(f) in case of copper stave: drilling and, if required, boring out receiving holes at the appropriate locations after casting and subsequently inserting and fitting heat pipes 330, 430; 340; 440, e.g. e.g. by tight-fit or screwed connection, in thermally conductive manner.

[0049] Whereas the staves 100, 200 of FIGS.1-3&4-6 are preferably manufactured e.g. by method (a) or (e) set out above, the cooling staves 300, 400 of FIGS.7-9A&9B can be manufactured by any one of the methods (b), (c), (d) above. As will be understood, methods (a) or (e) can also be used to manufacture cooling staves 300, 400 according to FIGS.7-9A&9B or similar staves, in which the condensation end portions are embedded laterally of the coolant channels.

Legend / List of reference signs:

FIGS.1-3

100	stave
110	plate body
112	front face
114	rear face
116	retaining ribs
118	retaining grooves
120	coolant passage
A	longitudinal axis of 120
122	connection pipe portions
130	(main) heat pipes
132	evaporation end portion
134	condensation end portion
B	longitudinal axis of 130
140	auxiliary heat pipes
142, 144	end portions (evaporation/condensation)
146	adiabatic section
C	longitudinal axis of 140
D	front-to-rear direction
df	distance from A to 112
dr	distance from A to 114

FIGS.4-6 & FIG.2

200	stave
210	plate body
212	front face
214	rear face
216	retaining ribs
218	retaining grooves
220	coolant passage
A	longitudinal axis of 220
222	connection pipe portions
230	(main) heat pipes
232	evaporation end portion
234	condensation end portion
B	longitudinal axis of 230
240	auxiliary heat pipes
242, 244	end portions (evaporation/condensation)
246	adiabatic section
C	longitudinal axis of 240
D	front-to-rear direction

FIGS.7-9A

300	stave
310	plate body
312	front face
314	rear face
316	retaining ribs
318	retaining grooves
320	coolant passage
A	longitudinal axis of 320
322	connection pipe portions
330	(main) heat pipes
332	evaporation end portion
334	condensation end portion
B	longitudinal axis of 330
340	auxiliary heat pipes
C	longitudinal axis of 340
D	front-to-rear direction

FIG.9B

400	stave
410	plate body
412	front face
414	rear face
420	coolant passage
A	longitudinal axis of 420
430	(main) heat pipes
432	evaporation end portion
434	condensation end portion
B	longitudinal axis of 430
D	front-to-rear direction