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(54) **Crystalliser for the continuous casting of thin slabs**

(57) Crystalliser (10) for the continuous casting of thin and medium slabs with a thickness of between 30 and 150 mm, the crystalliser (10) including wide walls (15), movable narrow sides (13) to adjust the width of the slab and a through casting chamber (11) extending for the length of the crystalliser (10), there being included containing means (24) and transverse rollers (18) immediately downstream of the ingot mold (10), the liquid metal defining a meniscus (20), the casting chamber (11) being defined by an enlargement, substantially central, achieved on at least one wide wall (15), by a curved segment (23) connecting at the sides with substantially straight segments (123), the curved segment (23a) at the inlet (16) being defined by a width "L" taken on the axis (x) of at least 500 mm, with a value of the lateral half-enlargement "A" taken on the axis (y) of between 30 and 90 mm, the casting chamber (11) decreasing lengthwise along the axis (z) of the crystalliser (10) and including at the outlet another substantially central enlargement with a value "B" of between 1 and 15 mm and defined by a curved segment (23b) connected at the sides to substantially straight segments, the curved segment (23a) which constitutes the substantially central enlargement of the casting chamber (11) being defined, at least around the nominal value of the meniscus (20), by a curve with a sinusoidal development.

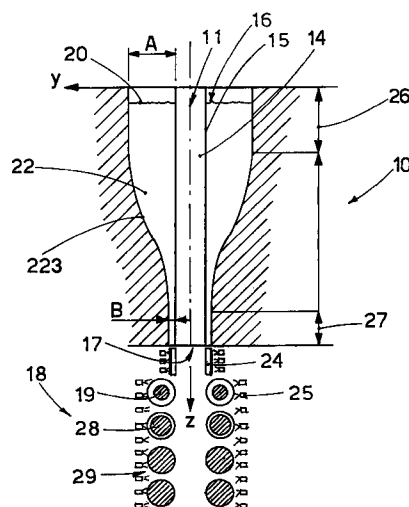


fig.3

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Description

[0001] This invention refers to a crystalliser, whether it be straight or curved, for the continuous casting of thin or medium slabs as set forth in the main claim.

[0002] The crystalliser according to the invention is used to obtain slabs suitable for subsequent rolling to produce strip or sheet.

[0003] The crystalliser according to the invention serves to produce slabs from 500 to more than 3000 mm wide, with a thickness of 150 mm to 30 mm and with casting speeds of even more than 10÷12 metres per minute.

[0004] The state of the art includes crystallisers for the continuous casting of thin slabs.

[0005] US-A-2.564.723 teaches to include a casting chamber in an intermediate position of the wide sides, the casting chamber having a surface conformed like a rhombus.

[0006] Apart from providing a reserve of liquid metal which can feed the area of the narrow sides, the casting chamber enables the nozzle to be introduced so that it can discharge the liquid metal below the meniscus.

[0007] When rolling strip or sheet, it is necessary to carry out rolling campaigns with different widths so as to satisfy the requirements of the market. Thus, US-A-4.134.441 teaches to displace the narrow sides during the casting process so as to have programmed widths of thin slabs.

[0008] In order to avoid lengthwise cracks caused by the sliding of the solidifying skin, which before it reaches the outlet section is subject to extensive shrinkage, SU-A-143.215 and JP-A-51-112730 teach to include casting chambers with a curved peripheral development.

[0009] EP-C-149.734 re-uses the teachings of all these prior art documents and proposes them in an organic manner to serve the same purposes.

[0010] In the case of thin slabs, that is to say, when the slab has an average thickness of 50÷60 mm, all these prior art documents, and the state of the art as it stands, teach that the casting chamber should extend vertically for about 1/4÷1/3, at most 1/2, of the length of the ingot mold.

[0011] However, this condition retains considerable problems of stress and deformation of the skin as it leaves the casting chamber, and the problem of the adaptation of the skin to the surrounding walls.

[0012] In order to partly reduce these problems, very large connecting portions have been included in the area where the casting chamber changes direction.

[0013] These proposed solutions, however, have not solved the considerable metallurgical problems which reduce the speed of extraction and the quality of the product caused by the lateral thrusts against the skin, the danger of the skin itself becoming detached and the turbulence encouraged by the limited size of the casting chamber.

[0014] In JP-A-51-112730 the casting chamber is pro-

gressively reduced practically along the whole length of the ingot mold so that, at the outlet of the mold, the slab has the desired nominal measurements with the sides perfectly straight.

[0015] Nor does this proposal, which is positive in itself, solve all the problems of productivity and of the surface quality of the thin slab, which is not always of the best with whatever type of steel is cast.

[0016] DE-A-2034762 teaches to include an ingot mold with a casting chamber which has a through development; also, to pre-roll the enlargements which are formed in the slab as it leaves the ingot mold so as to make it flat when it reaches the end of the discharge rollerway.

[0017] This document includes through casting chambers with constant dimensions which, however, create problems with the surface continuity of the skin due to the shrinkage thereof.

[0018] WO-A-89/12516 substantially includes two solutions.

[0019] The first solution, already included in EP-A-230.886, includes a casting chamber with a rectangular plan and with the sides tapering until they reach the nominal section of the slab at an intermediate position in the length of the crystalliser.

[0020] This solution, in practice, has the same problems, though attenuated, as in US-A-2.564.723.

[0021] The second solution includes a through casting chamber with a constant width which tapers in such a way that the sides at the centre line of the casting chamber reach the dimensions of the slab outside the ingot mold.

[0022] This second solution includes a long and important pre-rolling process immediately downstream of the ingot mold in order to gradually reduce the convex section.

[0023] This second solution does not make it possible to obtain a skin which is sufficiently smooth and without cracks, and above all it is not possible, with this solution, to proceed at present required casting speeds.

[0024] Furthermore, it makes it difficult to align the outlet of the crystalliser and the containing foot means, and it makes the start-up of continuous casting difficult.

[0025] Also, in the area of maximum thermal stress for the slab, that is to say, in the area of transition between conduction cooling and convection cooling, there is a component of thrust against the centre of the slab which causes detachment of the skin, combined bending and compressive stresses, deformation of the skin and the formation of hollows.

[0026] The present applicants, in patent US-A-5.460.220, have proposed a crystalliser wherein the casting chamber is progressively reduced from the inlet to the outlet both in width and in depth, maintaining at the outlet a central enlargement which causes a rounding of the slab leaving the crystalliser; this rounding is progressively pre-rolled by pre-rolling rolls which are included at the outlet of the crystalliser. The pre-rolling

rolls also induce in the slab a process of soft-reduction which reduces the thickness of the slab by as much as 30 mm or more.

[0027] This solution is very efficient in itself but it has had problems with the quality of the product and with standardisation for every type of steel; to be more exact, these problems occur when there are high speeds of extraction, that is to say, speeds of more than 6 metres per minute and up to speeds of around 12 metres per minute and more, and also in the high speed casting of particular steels, such as for example peritectic steels. In such cases, the compensation for the differing shrinkage of the slab as it solidifies - compensation which is closely connected with the maximum speed of extraction and with the type of steel - is obtained by intervening from time to time practically in an empirical manner on the geometry of the narrow side of the crystalliser.

[0028] This kind of solution does not guarantee efficient results, since it is gauged on a restricted range of speeds and not on the whole range of speeds; moreover, it is not easily repeated, given the variables at work, and therefore it cannot be standardised, since it is closely connected to the experience and the skill of the individual workman.

[0029] This represents a constraint which prevents the desired speeds of extraction being achieved, and limits the quality of the results which can be obtained, whatever the type of steel cast.

[0030] The present applicants have designed, tested and embodied this invention to overcome the shortcomings of the state of the art.

[0031] The invention is set forth and characterised in the main claim, while the dependent claims describe variants of the idea of the main embodiment.

[0032] The purpose of the invention is to obtain a crystalliser which, starting from the teachings of US'220, will allow the geometry of the casting chamber to be standardised and reproduced so that it will be possible to guarantee optimum and repeatable quality results no matter what the speed of extraction, that is to say even when the speed is of around 12 metres per minute and more, and no matter what type of steel is cast, including peritectic steels and micro-alloy peritectic steels.

[0033] The casting chamber of the crystalliser according to the invention is defined by an enlargement made in at least one of the wide walls of the crystalliser in a substantially central position; the enlargement connects at the sides with two substantially straight segments.

[0034] The casting chamber defined by this enlargement passes through the length of the crystalliser and, in one embodiment of the invention, is progressively reduced from the inlet to the outlet.

[0035] Inlet, in this case, means the value which the casting chamber has at a desired position around the nominal level of the meniscus of the liquid metal inside the crystalliser.

[0036] To be more exact, the substantially central enlargement, at the inlet, has a width of at least 500 mm

and a depth, referred to a single wide wall of the crystalliser, of between about 30 and 90 mm.

[0037] At the outlet, the substantially central enlargement has a depth, referred to a single wide wall of the crystalliser, of between about 1 and 15 mm.

[0038] According to the invention, the curves which define the geometry of the casting chamber and which connect the casting chamber to the straight segments of the wide walls of the crystalliser, both in a transverse direction to the direction of casting and also lengthwise thereto, are defined by equations whose parameters are functionally correlated at least to the type of steel cast.

[0039] The equations, apart from allowing the geometry of the casting chamber to be repeated, also make it possible to adapt the shape to the different behaviour of the cast steel and particularly to the different shrinkage which the skin is subjected to in the first stage of solidification.

[0040] The geometry is therefore a function of the range of products, that is to say, a geometric description is determined which is the closest possible to the various optimum surfaces and obtains a characteristic configuration for a desired range of products.

[0041] With the crystalliser according to the invention it is possible to increase the speed of extraction up to more than 10÷12 metres per minute.

[0042] This is because the problems relating to cracks and fissures in the surface, caused by the uncompensated shrinkage of the skin of the slab, are greatly attenuated and eliminated by the precise and specific adaptation, both autonomous and continuous, of the skin to the walls of the crystalliser which support and guide the skin continuously.

[0043] The casting chamber is moreover wider than that of US'220 and of a greater height, so that the liquid bath and the surface of the meniscus increase though the width of the slab does not vary.

[0044] It is therefore possible to contain a greater quantity of lubricating powder and the increased hot surface in contact with the lubricating powder makes available a greater quantity of melted powder which cooperates between the skin and the wall of the crystalliser.

[0045] Moreover, with the crystalliser according to the invention it is possible to cast steels such as peritectic steels at high speed; until now it was possible to cast such steels with good quality results only with the crystalliser as in US'220 and with a casting speed of not more than 6 metres per minute.

[0046] According to the invention, the substantially central enlargement around the nominal value of the meniscus at at least one of the two wide walls defining the casting chamber is made according to a curve with a sinusoidal development.

[0047] This sinusoidal curve is connected laterally and naturally to the straight segments of the walls whose extensions lie on the plane tangent to the sinusoidal curve.

[0048] The use of a sinusoidal curve, defined by a precise and univocal equation, not only guarantees that the parameters can be reproduced, but also makes possible a greater central space, both in width and in height; on the one hand, this enables the nozzle to be inserted deep into the casting chamber, and on the other hand enables the casting speed to be increased.

[0049] Moreover, the sinusoidal curve guarantees a continuous and constant dimensional progression, perfectly controlled and able to be reproduced, which prevents anomalous and uncontrolled stresses, and also the stress of the skin both during shrinkage at the time of solidification and also during the vertical and horizontal flow.

[0050] This is possible thanks to the shape of the casting chamber which has no sharp angles or surfaces with a sudden change of direction, either in a lengthwise or in a transverse direction.

[0051] The central enlargement at the meniscus is progressively reduced, in a desired and controlled manner, which can be reproduced even on the machine, along the height of the crystalliser, until it assumes a desired depth and with a reduced value at the outlet of the crystalliser.

[0052] According to a variant, all the curves taken on a plane transverse to the casting direction and defining the enlargements in each section of the crystalliser are defined by sinusoidal curves characterised by a specific equation.

[0053] The sinusoidal development of the curved segments which connect the central enlargement and the straight segments makes it possible to prevent, in all the sections of the crystalliser, critical loads from forming on the skin, with negative effects such as the detachment of the skin and the formation of hollows.

[0054] According to another variant, the crystalliser has a central enlargement defined, lengthwise to the crystalliser, by a first segment with a constant depth, by a second segment with a progressively decreasing depth and by a third segment with a constant depth.

[0055] According to the invention, the curved segment, taken lengthwise to the crystalliser, which connects the two enlargements with a constant depth is a sinusoidal curve.

[0056] According to another variant, the central enlargement of the crystalliser progressively decreases in depth in a longitudinal direction to the crystalliser and the terminal segment has a constant depth.

[0057] The curve defining the progressive reduction in the depth of the enlargement as taken lengthwise to the crystalliser is defined, according to the invention, by at least a sinusoidal curve.

[0058] This makes it possible to avoid sharp corners and surfaces with a change of direction which is not uniform, in the profile of the crystalliser, in the direction of flow of the metal; it also allows a greater volume in the casting chamber, improves the fluid-dynamical behaviour and reduces the possibility of bridges of solidified

steel forming between the nozzle and the crystalliser.

[0059] The terminal segment with the constant depth covers a length equal to $1/4 \div 1/6$ of the total length of the crystalliser and includes substantially parallel walls which allow the casting to be started with the insertion of the starter bar, thus facilitating alignment and reducing the transitional heat stress.

[0060] The upper enlargement with the constant depth according to the invention covers a length of the crystalliser equal to about $1/9 \div 1/6$ of the total length.

[0061] With the crystalliser according to the invention, the slab is taken to its final form with a drastic reduction in friction and lateral thrusts and therefore with far fewer possibilities of the skin breaking. The progressive reduction, according to a sinusoidal development, of the angle which defines the progressive dimensional reduction of the casting chamber minimises the possibility of surface hollows forming on the skin of the forming slab.

[0062] Moreover, the behaviour of the crystalliser can be predicted on the drawing board, or verified and composed experimentally and repeated indefinitely for all crystallisers, since all the curves are obtained in a descriptive manner.

[0063] With reference to the attached Figures, given as a non-restrictive example,

- Fig. 1 shows a linear crystalliser with a casting chamber which decreases in section lengthwise and with a constant terminal segment;
- Fig. 2 shows a variant of Fig. 1 in which the crystalliser has a first segment with a casting chamber with a constant section, a second segment with a casting chamber which progressively decreases and a terminal segment with a casting chamber with a constant section;
- Fig. 3 shows a longitudinal cross section, taken on a plane orthogonal to the plane on which the wide walls lie, of a crystalliser of the type as in Fig. 2;
- Fig. 4 shows a type of enlargement and curved connection of the casting chamber according to the invention.

[0064] With reference to the attached Figures, the crystallisers 10 are shown diagrammatically, and only the essential parts are shown, particularly the profile of the section of the crystalliser 10.

[0065] The crystalliser 10 can be made of copper or copper alloy or other material and includes chambers with circulating cooling water as are known to the state of the art.

[0066] The crystalliser 10, again as is known to the state of the art, is subject to longitudinal to-and-fro movements, that is, substantially along the axis of flow of the liquid metal and therefore of the slab.

[0067] The crystalliser 10 includes wide walls 15 and narrow walls 14. The narrow walls 14 are defined by the

movable sides 13 which, as they move, define the width of the slab as it leaves the crystalliser; this width can vary from about 500 mm to 3000 mm.

[0068] At an intermediate position between the wide walls 15 there is the casting chamber 11 inside which there is the nozzle 12 which delivers the molten metal below the meniscus 20.

[0069] At the outlet 17 of the ingot mold 10 there are containing means 24, in this case plates, followed by the transverse rollers 18 which act on the wide sides of the slab.

[0070] The containing means 24 define a transit section which is substantially equal to the outlet section of the terminal segment 27 of the crystalliser, and can be equipped with means to adapt them elastically to the surface of the slab in transit.

[0071] The whole cooperates with cooling means 25 of a type as are known to the state of the art.

[0072] The transverse rollers 18, in this case (Figs. 1 and 3), have a first assembly of rollers 19, which have a profile coordinated with the outlet section of the crystalliser 10, which defines a transit section which is in fact the same as the outlet section of the terminal segment 27.

[0073] The rollers 18 then have a second assembly of rollers 28 whose profile is progressively modified so as to take the section of the slab, which leaves the crystalliser with the enlargements on the wide sides defined by the outlet section of the terminal segment 27, to have the wide sides without any enlargements and parallel, so that the slab can cooperate with the third assembly of rollers 29 which are cylindrical or possibly rounded.

[0074] According to the invention, as shown in Fig. 1, the casting chamber 11 has a first segment 26 with a width, taken on the axis x, which is progressively and continuously reduced along the axis z, followed by a terminal segment 27 with a substantially constant section with a constant width "l".

[0075] The first segment 26 has at least an initial segment wherein the enlargement has a constant depth taken on the axis y; this depth is then progressively reduced until it again has a constant value in the terminal segment 27.

[0076] The first segment which has the enlargement with a substantially constant depth covers about $1/9$ to $1/6$ of the total length of the crystalliser 10, while the terminal segment 27, with a width "l", covers about $1/4$ to $1/6$ of the total length.

[0077] According to a variant, the first segment 26 has a depth which is progressively reduced immediately from the inlet and until the terminal segment 27 which has a constant section.

[0078] The casting chamber 11, in correspondence with the inlet 16 taken as around the nominal value of the meniscus 20, has a width "L", defined by a curve 23 which constitutes the substantially central enlargement on the wide walls 15.

[0079] The casting chamber 11 also has a depth

defined by the nominal width of the movable sides 13 to which the enlargement with the value of "2A" at the inlet 16 is added.

[0080] In the drawings, "A" is the value of the lateral half-enlargement at the inlet 16 to the casting chamber 11 relative to one wall of the crystalliser and measured substantially along the median plane of the crystalliser along the axis y.

[0081] The curve 23 defining this lateral half-enlargement, which at the inlet 16 has a maximum depth of "A", is a sinusoid defined by a specific equation.

[0082] The sinusoid connects at the sides with the segments 123 to the straight segments 21 of the wide walls 15 whose extensions are tangent to the sinusoid. In the first segment 26 the section of the casting chamber 11 is progressively reduced, so that every transverse section of the crystalliser 10 is defined by its own enlargement described by a specific curve 23 with a sinusoidal development.

[0083] Fig. 4 shows the curve 23a in correspondence with the inlet 16 and the curve 23b in correspondence with the outlet 17, all the intermediate curves between the inlet 16 and the outlet 17 being defined by specific sinusoids whose parameters are functionally correlated at least to the type of steel cast and to the speed of extraction.

[0084] According to a variant, the parameters of the sinusoids are also functionally correlated to the nominal width of the movable sides 13 and/or the value of the width and/or depth of the enlargement in the relative section of the crystalliser 10.

[0085] The value of the enlargement "A" according to the invention can vary from about 30 to 90 mm.

[0086] In the variant shown in Figs. 2 and 3, the casting chamber 11 has a first segment 26 with a constant section, a second segment 22 with a section which is progressively reduced in width and depth, and a third segment 27, or terminal segment, with a constant section which has a width "l".

[0087] The connecting curved portion 223 which connects the end of the first segment 26 with the beginning of the terminal segment 27 in the case of Figs. 2 and 3, or the curved portion 223 which defines the progressive reduction of the first segment 26 in the case of Fig. 1 is, according to the invention, a sinusoid defined by a specific equation. This equation has parameters which are functionally correlated at least to the speed of extraction and to the type of steel cast.

[0088] This equation, according to a variant, has parameters which are functionally correlated also to the value of the initial depth A and/or the final depth B, and/or to the height of the decreasing segment 22 or 26 and/or the height of the segment 26 with constant section if present.

[0089] The transit section of the terminal segment 27 is constant and facilitates the extraction of the slab which leaves the crystalliser with its sides substantially parallel and with its central rounded part having a width

"B" at a central position on its wide sides. This value "B" is between about 1 and 15 mm.

[0090] The connections with a sinusoidal development included at the changes in direction, both in a transverse direction between the central enlargements and the straight segments, and also in a longitudinal direction between the segment with the decreasing section and the segments with a constant section, greatly reduce the formation of surface hollows, allow a progressive and continuous adaptation to the differentiated shrinkage of the skin and minimise the formation of cracks and fissures, reducing the stress on the skin as it forms. Moreover, the sinusoidal connections, which guide and support the skin continuously during the progressive shrinkage caused by solidification, can be reproduced perfectly on the machine and can be controlled experimentally.

[0091] It is understood that the measures indicated by 26, 27, "L" and "I" identify the beginning and the end of the connecting curved portions in a longitudinal and lateral direction.

Claims

1. Crystalliser for the continuous casting of thin and medium slabs with a thickness of between 30 and 150 mm, the crystalliser (10) including wide walls (15), movable narrow sides (13) to adjust the width of the slab and a through casting chamber (11) extending for the length of the crystalliser (10), there being included containing means (24) and transverse rollers (18) immediately downstream of the ingot mold (10), the liquid metal defining a meniscus (20), the casting chamber (11) being defined by an enlargement, substantially central, achieved on at least one wide wall (15), by a curved segment (23) connecting at the sides with substantially straight segments (123), the curved segment (23a) at the inlet (16) being defined by a width "L" taken on the axis (x) of at least 500 mm, with a value of the lateral half-enlargement "A" taken on the axis (y) of between 30 and 90 mm, the casting chamber (11) decreasing lengthwise along the axis (z) of the crystalliser (10) and including at the outlet another enlargement substantially central with a value "B" of between 1 and 15 mm and defined by a curved segment (23b) connected at the sides to substantially straight segments, the crystalliser being characterised in that the curved segment (23a) which constitutes the substantially central enlargement of the casting chamber (11) is defined, at least around the nominal value of the meniscus (20), by a curve with a sinusoidal development.
2. Crystalliser as in Claim 1, in which the curved segment (23b) which constitutes the substantially central enlargement of the casting chamber (11) at the outlet (17) is a curve with a sinusoidal development.
3. Crystalliser as in Claim 1 or 2, in which the curved segments (23) defining the substantially central enlargement of the casting chamber (11) in each transverse section of the crystalliser (10) are curves with a sinusoidal development.
4. Crystalliser as in any claim from 1 to 3 inclusive, which includes lengthwise a first segment (26) with a casting chamber (11) progressively decreasing in width and a terminal segment (27) with a substantially constant section.
5. Crystalliser as in Claim 4, in which the first segment (26) includes a first segment with a constant depth and a second segment with a decreasing depth.
6. Crystalliser as in Claim 4, in which the first segment (26) has a decreasing depth.
7. Crystalliser as in any claim from 1 to 3 inclusive, which has lengthwise a first segment (26) with a casting chamber (11) with a constant section, a second segment (22) with a casting chamber (11) with a progressively decreasing section in width and in depth, and a terminal segment (27) with a substantially constant section.
8. Crystalliser as in any claim hereinbefore, in which the terminal segment (27) corresponds to about $1/4 \div 1/6$ of the total length of the crystalliser (10).
9. Crystalliser as in Claim 7, in which the first segment (26) with the substantially constant section corresponds to about $1/6 \div 1/9$ of the total length of the crystalliser (10).
10. Crystalliser as in any claim hereinbefore, in which the curved segments (223) which connect lengthwise the segments with a constant section (26,27) and which define segments (26,22) with a decreasing section are curves with a sinusoidal development.
11. Crystalliser as in any claim hereinbefore, in which the equations of the curves with the sinusoidal development defining the curved connecting segments both in a transverse direction (23) and in a lengthwise direction (223) include parameters which are functionally correlated at least to the type of steel cast.
12. Crystalliser as in any claim hereinbefore, in which the equations of the curves with the sinusoidal development defining the curved connecting segments both in a transverse direction (23) and in a lengthwise direction (223) include parameters which are functionally correlated at least to the speed of extraction.

13. Crystalliser as in any claim hereinbefore, in which the equations of the curves with the sinusoidal development defining the curved connecting segments in a transverse direction (23), for each section of the crystalliser (10), include parameters which are functionally correlated to the nominal width of the movable sides (13) and/or the value of width and/or depth of the enlargement in the relative section of the crystalliser (10).

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14. Crystalliser as in any claim hereinbefore, in which the equations of the curves with the sinusoidal development defining the curved connecting segments in a lengthwise direction (223) include parameters which are functionally correlated to the value of the initial depth ("A") and/or the final depth ("B"), and/or to the height of the decreasing segment (22,26) and/or the height of the segment with the constant section (26).

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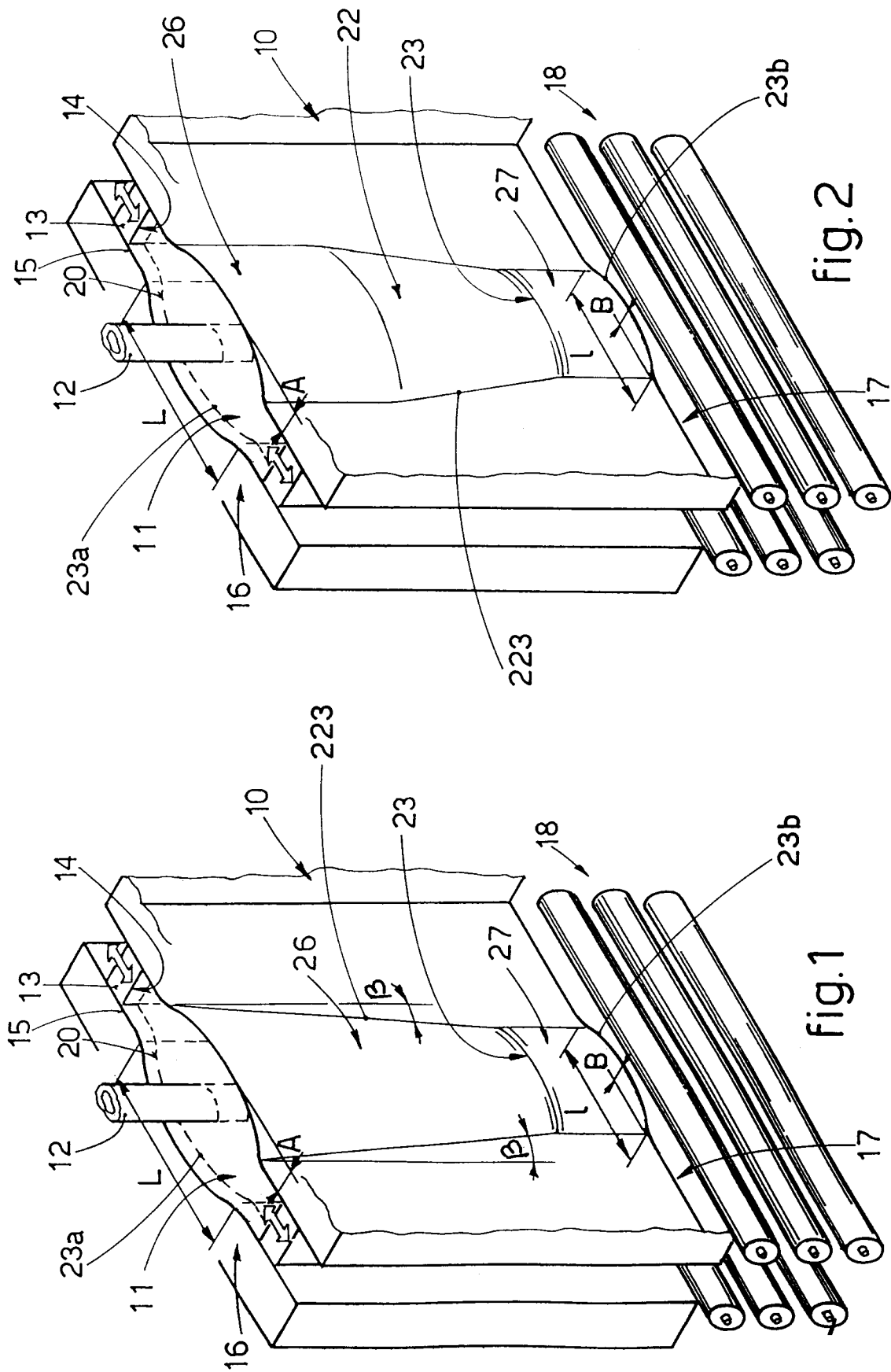
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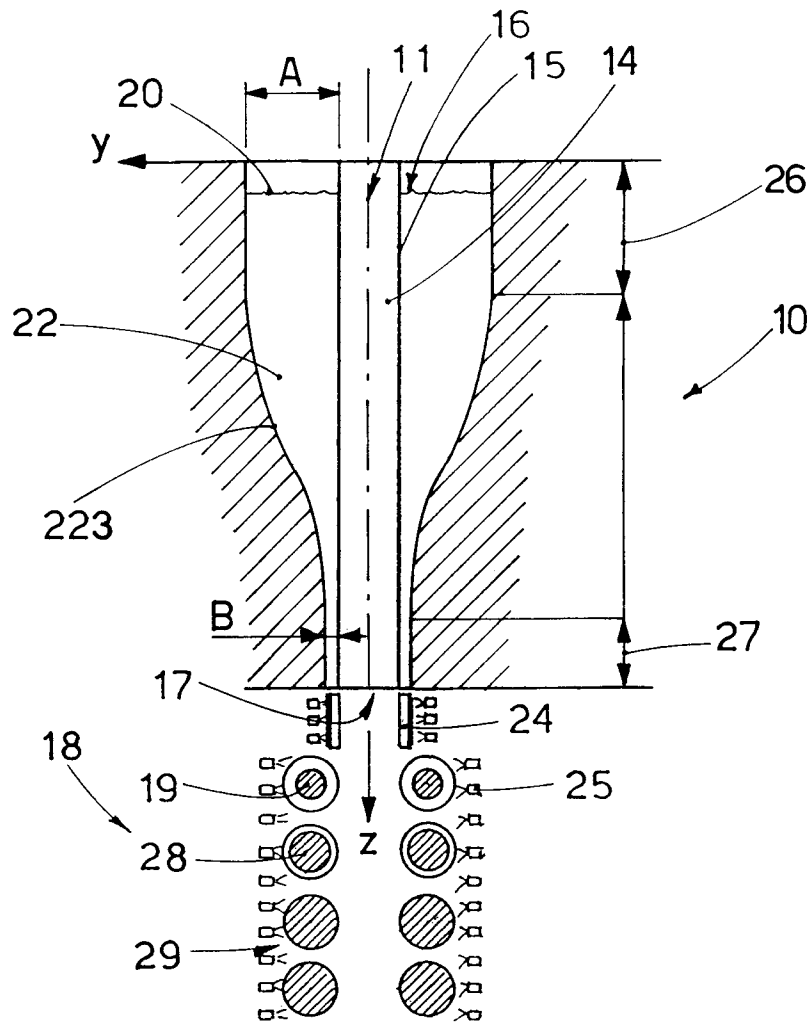


fig.3

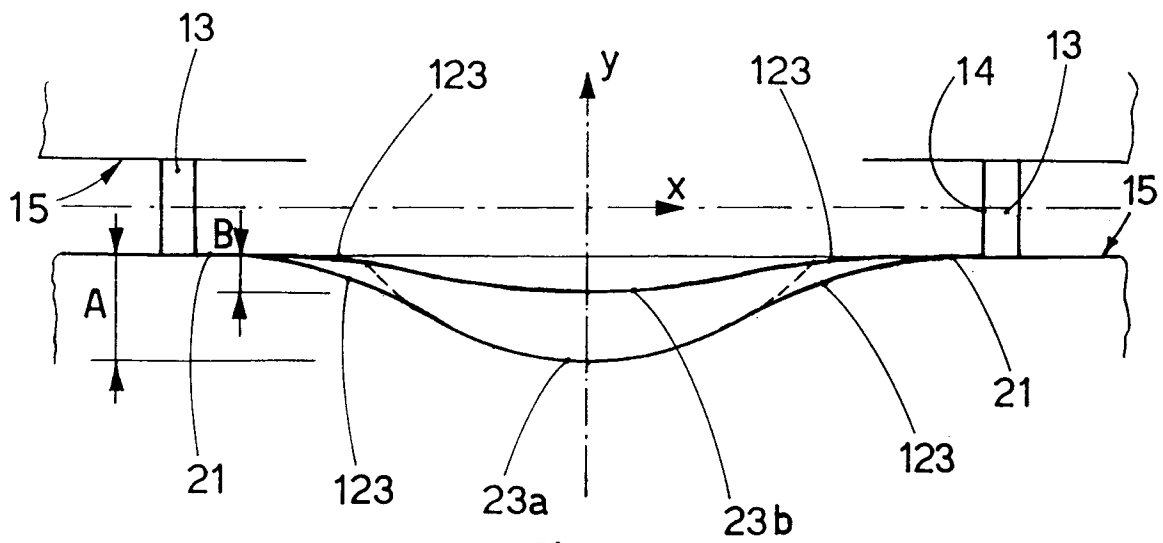


fig.4



European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 98 10 1945

DOCUMENTS CONSIDERED TO BE RELEVANT			
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The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 23 December 1998	Examiner Mailliard, A
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 98 10 1945

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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