(12) **EUROPEAN PATENT APPLICATION**

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(54) **Improved submerged nozzle for steel continuous casting**

(57) A submerged nozzle (1) feeding by gravity with a molten metal or alloy (2) from a container (3) a slab (4) that is under formation in a mould (5) with cooling walls, comprises a form of a vertical tube (6) connected to the overhanging container (3) and terminates at the bottom with a flat diffuser (8) having two outlet ports (9,9') having rectangular cross-section and with an ogivally shaped central divider baffle (14) having a symmetrical contour without corners and adapted to define two passage channels (16,16') for the stream which correspond to said two outlet holes (9,9'). The cross-section (10) for the passage of the fluid at the highest point of the diffuser is narrower than the passage section (11) of the tube (6) according to a ratio 0,6-0,8. In addition the inner side walls (12,12') of the diffuser which are directed towards the narrow sides of the thin mould diverge symmetrically downwards from the median vertical axis (13). Further geometric and functional parameters to be fulfilled by the nozzle are mentioned.

Fig.1

EP 1 657 009 A1

Description

[0001] The present invention relates to a feed pipe or submerged nozzle for the continuous casting of semifinished steel products such as slabs, either thin (50-70 mm thick) or almost thin (70-120 mm thick) or conventional (120-450 mm thick) ones, and for steel flows up to 8 ton/min as required for example in continuous casting for thin slabs at high speed (>5 m/min) and in continuous casting/roughing processes, wherein it is desired to solidify a flow rate of steel as above indicated and comparable to that of a continuous heat laminating-finishing train for strips, so as to line up both processes without any interruption in the material.

[0002] The present invention relates more particularly to a submerged entry nozzle (SEN in the following) suitable to convey in the best way the molten metal or alloy from a container with nearly constant head, or "tundish", in order to feed it with a minimum of turbulence or undertows to a position underlying the head or meniscus of a slab being formed within a cooling-mould in which said slab is formed by solidification.

[0003] Moulds for slabs are known, formed of four walls extending vertically with horizontal cross-section in which two sides are longer than the other two. It is also known that to introduce molten metal, in particular steel, fed from an overhanging vessel named "tundish", into the mould, a connection conduit is used, also named "dip pipe" because of its lower mouth that is dipped or submerged in the molten mass within the mould and fitted as fairly as possible to the size of the latter, so as to keep an adequate distance from the cooling walls. Accordingly there are normally used in the technique submerged nozzles (SENs) for slabs having at the bottom a horizontal section rectangularly, polygonally or elliptically shaped with outlet ports directed towards the narrow sides and/or the lower part of the mould.

[0004] These known SENs do not meet however the various typical problems of this technology, widely described in the pertinent literature and imputable to various causes. In particular the fluid stream discharged from the SEN has the tendency to circulate within the liquid mass in the heart of the slab being formed which is hardened on the outside only. Thereby it is likely that the stream comes out again on the surface so as to produce nearly stationary waves on the free surface of the molten bath, in particular near the narrow faces of the thin mould. As a consequence, the liquid lubricating slag that is artificially produced through the melting of a special powder on the surface or "meniscus" of the building slab tends to collect in the most depressed parts of the wavy meniscus, thus leaving exposed its peaks, with a resulting null or poor distribution of lubrication. This gives rise to the mould being worn as well as to a poor surface quality of the slab and incorrect heat exchange between the slab being formed and the mould, which is a possible cause of cracks. The amount of the peak height of said waves as referred to the central zone of wavy meniscus can be

taken as an estimate of the extent of the problem and gives an idea of the minimum thickness of liquid slag available on the meniscus, increased by a fraction as a consequence of the oscillatory movement vertically applied to the mould.

[0005] In addition, the points where the fluid vortexes enter again into the liquid body are at high meniscus curvature, in which points the particles of powder and lubricating slag are easily entrapped in the slab being formed, this being a further cause of cracks and other surface flaws. Therefore, also the size of peaks height of waves as referred to said re-entering zones of vortexes and depressed zones of meniscus may be taken as a value characterizing the extent of the problem.

[0006] Furthermore the turbulence existing at the meniscus in a mould is an important cause of the unstable control of the level position in the mould, as well as of fluid friction wear on the refractory material that forms the SEN, thus reducing the duration thereof. For the latter aspect, linked to the previous ones, it may be assumed, as a value characterizing the extent of the problem, the horizontal velocity of recirculating flows measured in given positions and at a certain depth (about 30-60 mm) under meniscus (submeniscus velocity), and a convenient upper limiting value thereof not to be exceeded may be imposed.

[0007] On the contrary, an excessively stagnant meniscus without a continuous supply of novel metal at higher temperature could bring about a premature hardening and a difficult melting of the artificial powders which generate the liquid slag. Due to this, for said value of submeniscus velocity also a convenient lower limit is usually stated.

[0008] With regard to the solidification occurring within the slab, possible swirls and recirculations of the liquid mass flowing from the SEN affect adversely the process, that must be progressive and homogeneous as much as possible in a direction parallel to the narrow faces of the mould. It would be advisable to have a feed stability without varying flows within the hardening slab and a distribution of the fluid mass as much as possible symmetrical with respect to the longitudinal axis of the slab, with wide and foreseeable recirculations without dead zones, in order to have the maximum thermal homogeneity in the horizontal sections. From this standpoint it appears to be advantageous to have a so-called quadruple recirculation within the liquid mass in the slab being formed without stagnant zones, with the outgoing stream from each of both ports of the SEN that advances towards the narrow face, bifurcates then in two wide vortexes: one running up again along the narrow face and exiting at meniscus, and another one that goes down and comes back towards the center of the slab where it runs upward.

[0009] With a view to overcome the above named inconveniences closely bound to the dissipation of kinetic energy of the flow entering the mould, it is possible to use the so-called "electromagnetic brakes" applied to the moulds. These brakes, based on the Lorentz force that

is applied on moving molten metal or alloy particles leading the electrical current and subjected to a steady magnetic field that passes through the mould, slow down the recycling streams in the solidifying slab. It is however a matter of hardly controllable equipments: in fact, when adjusted to excessive magnetic field intensities, they cause an undesirable reflecting effect on the streams oriented towards the braked zone, or otherwise they tend to generate an excessively stagnant meniscus with the already mentioned problems. These are in addition expensive equipments that require to properly function special moulds being also very expensive. It is finally to be mentioned a further inconvenience due to the fact that within the molten metal or alloy bodies are present oxides which tend to settle on the inner surfaces of the SEN, thus changing its geometry and adversely affecting the repeatability of the feed till to restrict or totally prevent its flowing.

[0010]   With the exception of the last named inconvenience which get worse in the case of low flow rates in the various passage cross-sections and in case of low turbulence (Reynolds number under certain values), all those previously mentioned become worse with the increasing flow of molten metal or alloy, namely with higher drawing speeds of the slab being formed in the mould and/or larger slab cross-sections, and consequently with higher flow rates at the different passage sections, particularly in correspondence of the outlet holes.

[0011]   At any rate, all these above named inconveniences are present in all known embodiments of SENs, adversely and variously affecting the correct progress of the casting and cooling process of the slab being formed, with the consequence of a poor quality final product.

[0012]   The problem solution disclosed and claimed in EP 0925132 provides a good slowing down of flow and shows concurrently properties of reduced sensitivity to the obstruction phenomenon due to the oxides, through the accomplishment of the double stream diffusion. Some restrictions however persist depending on the shape of the flow dividing baffle that at high rates, greater than 2,5 ton/min, leads to the onset of vortexes which trouble the flow itself along the contours of the flow divider until a vein partition phenomenon arises. These vortexes have the tendency to be dragged by the stream within the mould and to cause an excessive fluid friction between the opposed narrow surfaces of both obtained exiting flows with consequences of instability and rapid recirculation of flows towards the meniscus without the possibility to penetrate the liquid mass.

[0013]   In addition there are limits bound to a pressure drop in the region of the flow regulating valve, down to so low absolute values as to jeopardize in consequence of oscillatory phenomena the stability of said regulation and to bring about a rapid dissolution (vaporization) of the flow regulating surfaces formed of refractory material. In stagnant conditions with closed regulating valve and gas-tight SEN theoretically dipped in a mould and filled with molten steel, if the distance between closed valve

and free surface in the mould exceeds 1,4 m, then vacuum conditions would be realized and a meniscus formed within the SEN (steel-based barometer). The dynamic casting process by gravity with open control valve barely differs from this static condition, but is however controlled by the total hydraulic head resulting from the level difference between free surface in the tundish and free surface in the mould, this head normally exceeding in industrial applications the value of 1,4 m. The most critical section of the controlling valve is the variable and reduced one in which a sudden flow acceleration takes place with a consequent increase of turbulence and an important dissipative phenomenon. The result is a sudden pressure drop just in such regulation region. The pressure value is as lower as the length of SEN is larger; the larger is the flow rate of steel, the lower is the hydraulic leakage in the SEN and lower the outflow from the outlet ports and consequently as the flow diffusion increases.

[0014]   It is in principle convenient to have a SEN as short as possible, but this need is in contrast with the practical plant requirements, particularly in the presence of a large sized tundish, like those really needed for steel flow rates of up to 8 ton/min and for requirements of mounting a SEN to the tundish. It is therefore difficult to limit the length of a SEN to less than 1000-1100 mm.

[0015]   In addition the increase of the kinetic term in the Bernoulli's equation for high flow rate SENs as those of the present invention necessarily reduces further the value of absolute pressure.

[0016]   It is therefore an object of the present invention to provide a SEN that even at the highest flow rates (up to 8 tons of steel per minute) avoids the above mentioned inconveniences by reducing as much as possible and progressively the flow speed in sections gradually approaching the outlet ports, so as to obtain two slow and steady fluid streams, possibly with the same flow rate, without breaking down of the fluid vein and without vortexes, whose residual kinetic energy is more easily dispersable within the liquid body of the slab being formed, thus giving rise to non-swinging recirculation vortexes symmetrical with respect to the vertical axis, and having reduced dead zones, with minimal wave peaks at meniscus, with respect to both its center and the more depressed regions, to under-meniscus velocities within an optimal range and to reduction of vortexes and turbulences at meniscus to a minimum.

[0017]   Furthermore the present invention aims at rendering superfluous or not strictly required the use of electromagnetic brakes, while having shown an optimal working capability even in combination with such apparatus and with different arrangements thereof.

[0018]   These objects are achieved by a SEN having the features set forth in claim 1.

[0019]   The subsequent claims relate to preferred and alternative embodiments of the SEN according to particular aspects of the present invention.

[0020]   A further object is to raise as much as possible, and in line with the flow regulation, the absolute pressure

in the region of valve in order to stabilize the control thereof and reduce the vaporization phenomenon of the refractory surfaces controlling the stream.

[0021] This further object is achieved by means of a SEN with a reduced total length in which, according to claim 8, in the zone of the pipe under the flow regulating valve a further narrowing is formed with a resulting head restriction suitable to increase the absolute pressure level in the region of the valve.

[0022] These and other objects, advantages and characteristics of the SEN according to the invention will be better understood by those skilled in the art when reading the following description of a preferred non limiting embodiment of the invention, given with reference to the drawings in which:

Fig. 1 shows a longitudinal sectional view of a submerged nozzle (SEN) according to the invention when dipped in a mould for slabs, taken along a middle plane parallel to the wide faces of the mould itself; Fig. 2 shows a longitudinal sectional view of the SEN of Fig. 1 when dipped in the mould, taken along a vertical plane II-II comprising the main axis of the continuous casting machine that is parallel to the narrow faces of the same mould;
Fig. 3 shows a sectional view along line III-III of Fig. 2; and
Fig, 4 shows a schematic sectional view similar to that of Fig. 1 of a preferred embodiment of the nozzle (SEN) according to the present invention.

[0023] With reference to Fig. 1, as already shown in EP 0925132, a dip feed pipe or SEN 1 feeds by gravity with a molten metal or alloy 2, from an upper vessel or tundish 3 with a nearly constant head, a slab being formed within a thin slab mould 5 having cooling walls and comprising four vertical walls wherein two sides in horizontal section are longer than the other two. While shown in Fig 3 with a perfectly rectangular cross-section, the mould may have slightly convex or polygonal walls, or show a development slightly different from the perfectly vertical one shown in Fig. 2, without bringing about any changes in the features of the SEN according to the invention.

[0024] The SEN comprises a length of vertical tube 6, not necessarily cylindrical with circular section, joined in a known manner to the upper vessel 3. It may be provided on the top with a flow control surface or regulation valve 7, whereas on the bottom it extends, through a connection zone 18, with a distributing flat portion, named later on as diffuser 8, having bottom outlet ports 9, 9'. The diffuser 8 allows to feed molten material under head 17 within the slab being formed 4 in the mould 5, while maintaining a certain distance from the walls thereof. The slab being formed 4 has been shown with solid walls having an increasing thickness from the top to the bottom, whereas the inner volume is to be regarded as still liquid or anyhow not yet fully hardened.

[0025] In the region of diffuser 8, there is also provided a central flow divider 14 integral with both wider walls of the diffuser and adapted to divide the flow into two separate channels 16, 16' terminated at the bottom by two outlet ports 9, 9' discharging downwards.

[0026] The cross-section 10 for the passage of the flow in the higher portion of diffuser 8, at the end of connection 18 with tube 6, has been represented preferably coincident with the top end of flow divider 14, as already in EP 0925132. The area of said cross-section 10 is narrower than the one relating to the passage section of upper tube 6 denoted by reference number 11.

[0027] According to the present invention, the ratio between these areas is in the range from 0,6 to 0,8. Such a condition is better visible in Fig. 2. As a matter of fact, it is to be noted that even though the side walls of connection 18 in Fig. 1 do appear divergent downwards, namely in a cross-sectional view parallel to the wide faces of the mould, in all other sectional planes they are convergent, thus causing a reduction of cross-section area downwards. Still according to the present invention, the reduction of the passage area between section 11 and section 10 is accomplished over a short piece with a length comprised between 4 and 6 times the hydraulic radius of pipe 6, the latter being equal to the ratio between the sectional area and the relevant wet periphery (for the circular sections, the hydraulic radius is equal to 1/4 of the diameter). Basically, from the hydrodynamic point of view, the SEN according to the invention provides a length of firm acceleration of the flow of molten material between section 11 and upper section 10 of the diffuser as well as a further acceleration between section 10 and a narrow lower section 10bis in which takes place the maximum flow speed that afterwards gradually becomes slower along both channels 16 and 16' while maintaining the contact with the walls. Section 10bis is at a level below the upper vertex of flow divider 14 to avoid, thanks to the high flow rate and turbulence, a deposition of oxides just in the flow dividing zone, a deposition that would already occur in this zone in the presence of a premature slowing down of the stream. To this end it is preferable that the passage section area of both flows 16 and 16' becomes even narrower between upper section 10 of the diffuser and 10bis of largest width of the flow divider. This can be achieved for instance by forming the above named upper zone of flow divider 14 with a suitable shape. The flow is slowed down in the twin diffusion channels 16 and 16' until having, at output holes 9, 9' a speed not exceeding 1,2 m/sec for any working condition.

[0028] Due to various reasons, among which those of achieving an optimal dissipation of kinetic energy of both flows in the mould, of fitting to often thin moulds, and not running the risk of incurring occlusions owing to the oxides, the output section of each channel 9, 9' in the mould is almost rectangular in shape with a so-called "aspect" ratio between the long side and short side at that cross-section comprised between 3 and 10. The said diffuser 8, towards the narrow sides of the mould 5, has inner

side walls 12, 12' which symmetrically diverge and depart downwards from a vertical axis 13, with a curvature that is increasing in this embodiment from the top to the bottom and is a function of the maximum possible flow diffusion without vein detachment at the operation rates, with a shape resembling "a bell". Through an analytical definition, when the curve pertains to plane (x, y) then the curvature is expressed by the formula:

$$c=([y''(x)]/(1+y'^2(x))^{3/2}).$$

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[0029] As already disclosed in EP 0925132, the flow divider 14 narrows in its lower portion 15, 15', on the sides turned towards the narrow faces of the thin mould 5, thus forming two angles β with vertical axis 13, which in this case are ≤8°. In addition, with a view not to provoke detachment phenomena of the fluid vein contacting the vertex of flow divider (that unavoidably give rise to vortexes which, being then dragged by the stream, interfere with and take away firmness from the flow within the mould), the function describing the upper contour of the flow divider has to be continuous and derivable without the presence of angular points according to the analytical definition (non-derivable points of the function as the first right and left derivatives do exist and are distinct).

[0030] Fig. 4 shows the preferred embodiment of flow divider in which the geometry is of the ogival type, with an angle θ at the apex of 45°, wherein the segment of line symmetrical with respect to the vertical plane II-II forming the intersection between the upper part of the flow divider with a vertical half-plane perpendicular to the plane comprising the axis of the continuous casting machine is a well connected sequence of circle arcs and straight segments, without discontinuities or angular points. Furthermore the radii of said circle arcs are increasing from the top downwards and the lowest arc is well connected towards the bottom without any discontinuity or angular points with the segment of one of the two converging straight lines 15, 15' according to said angle β.

[0031] In order to increase the pressure in the region of the flow regulating valve, there has been introduced within tube 6, under regulating valve 7 and at a distance from the latter comprised between 4 and 8 times the hydraulic radius of the tube, a throttle X formed as a disk provided with a circular gauged hole whose hydraulic radius with respect to the hydraulic radius of the tube corresponds to a ratio between 0,4 and 0,6, and whose thickness with respect to the diameter of the gauged hole corresponds to a ratio between 0,3 and 0,7.

[0032] Possible additions and/or changes may be introduced by those skilled in the art into the above described and explained embodiment of the SEN according to the present invention without departing from the scope of the invention. In particular, the submerged entry nozzle

1 instead of being provided with a flow controlling surface 7, as shown in Figs. 1 and 2, could be directly connected through a flange in a known manner with the bottom of container 3, whereas the flow controlling surface could be formed on a different element placed within the same container. In an alternative embodiment, the SEN 1 could also be secured through a flange, still in a known manner, below a flow regulating sliding gate and placed on the bottom of vessel 3, to operate in a known manner by selectively shutting the passage port formed between two perforated and opposed plates sliding over each other.

Claims

1. A submerged entry nozzle adapted to feed by gravity with a molten metal or alloy (2), from a vessel or tundish (3) with nearly constant head, a slab (4) being formed from a fluid body (17) with free surface in a mould (5) with cooling walls, formed by four walls developing substantially vertically with a horizontal section formed by two sides longer than the other two, the nozzle (1) comprising a length of vertical tube (6) connected to the upper vessel (3) and to a lower flat dispensing part or diffuser (8) having outlet ports (9, 9') that correspond to two separate passages (16, 16') with vertical axes, provided by a flow separating baffle (14), and outflowing under the free surface (17) of the slab being formed (4) in a position spaced apart from the walls of the mould (5), **characterized in that**:

    - the ratio between the area of diffuser (8) in its higher transversal passage section area (10) and the passage area at a cross-section area (11) of upper tube (6) is in the value range between 0,6 and 0,8;
    - the reduction of the passage area between sections (11) and (10) is carried out in a total length with respect to the hydraulic radius of the tube (6) between 4 and 6;
    - the working output speed of the flow from both output sections is smaller than 1,2 m/sec;
    - the horizontal outflow sections (9, 9') of each diffusion channel (16, 16') are nearly rectangular in shape with an "aspect" ratio between the long side and the short side comprised between 3 and 10:
    - said diffuser (8) has towards the narrow sides of the mould (5) lateral inner walls (12, 12') that symmetrically diverge from a median vertical axis (13) and with respect to the latter are diverging from the top downwards;
    - the flow separating baffle has a geometry of the ogival type with a contour symmetrical with respect to a plane (II-II) and continuous without the presence of angular points;
    - the flow separating baffle (14) in its upper part,

in an underlying section (10bis) wherein the flow speed is at its maximum, forms two passage areas for the stream whose addition is narrower than the passage area of section 10;
- the angle at the vertex θ (theta) of the flow divider is comprised between 30° and 60°; and
- the flow divider baffle (14) in its lower portion narrows symmetrically with its sides (15, 15') towards the median vertical axis (13).

2. A nozzle according to claim 1, wherein said inner side walls (12, 12') of the diffuser (8) are straight and make each an angle $\alpha \leq 8°$ with said median vertical axis (13).

3. A nozzle according to claim 1, wherein said sides (15, 15') of the flow divider baffle (14) have in their lower portion straight contours that form with said median vertical axis (13) two angles $\beta \leq 8°$.

4. A nozzle according to claim 3, wherein:

   - the line segment symmetrical with respect to a vertical plane (II-II) that forms the intersection between the upper vertex of the flow divider (14) with a vertical half-plane perpendicular to the plane comprising the axis of the continuous casting machine, forms a well connected sequence of circle arcs and straight segments, without any discontinuity or angular points;
   - the radii of said circle arcs are increasing from the top downwards; and
   - the lowest arc is connected downwards, without any discontinuity or angular points, to the segment of one of said two convergent straight lines (15, 15').

5. A nozzle according to claim 1, wherein:

   - said diffuser (8) has inner side walls (12, 12') towards the narrow side of the mould with curved contours whose curvature is increasing from the top to the bottom and is a local function of the maximum possible flow diffusion at the working speeds without vein detachment; and
   - said flow divider baffle (14) in its lower part narrows symmetrically towards the vertical axis (13) with contours (15, 15') whose curvature is increasing from the top to the bottom and is a local function of the maximum possible flow diffusion at the working velocities without vein detachment.

6. A nozzle according to any one of the previous claims, wherein said straight or curved lines (12, 15) and (12', 15') are respectively symmetrical with respect to the median vertical axes of the corresponding diffusion channels (16, 16').

7. A nozzle according to any one of the previous claims, wherein the upper portion of the flow divider (14) has a geometry that causes a controlled whirling of the contours facing towards the median axis (II-II) of both streams formed in both diffusion channels (16, 16') at the output of the nozzle in order to obtain two bifurcated streams and a quadruple flow recirculation in the liquid body of the slab.

8. A nozzle according to any one of the previous claims, wherein:

   - the total length of the nozzle (1) is comprised between 1400 and 1000 mm with an average dipping of 100 mm in the mould;
   - the region of the tube (6) underlying a flow regulation valve (7) placed in the upper portion of the tube has a further throttle (X) adapted to increase the absolute pressure level in the valve zone;
   - the hydraulic radius of the passage of said throttle with respect to the hydraulic radius of the tube (6) corresponds to a ratio comprised between 0,4 and 0,6; and
   - said throttle is spaced apart from the flow regulation zone at a distance comprised between 4 and 8 times the hydraulic radius of the pipe (6).

9. A nozzle according to claim 8 wherein:

   - said throttle (X) under the flow regulating valve (7) is formed as a disk provided with a gauged circular hole; and
   - the thickness of said disk having a gauged hole, with respect to its diameter corresponds to a ratio comprised between 0,3 and 0,7.
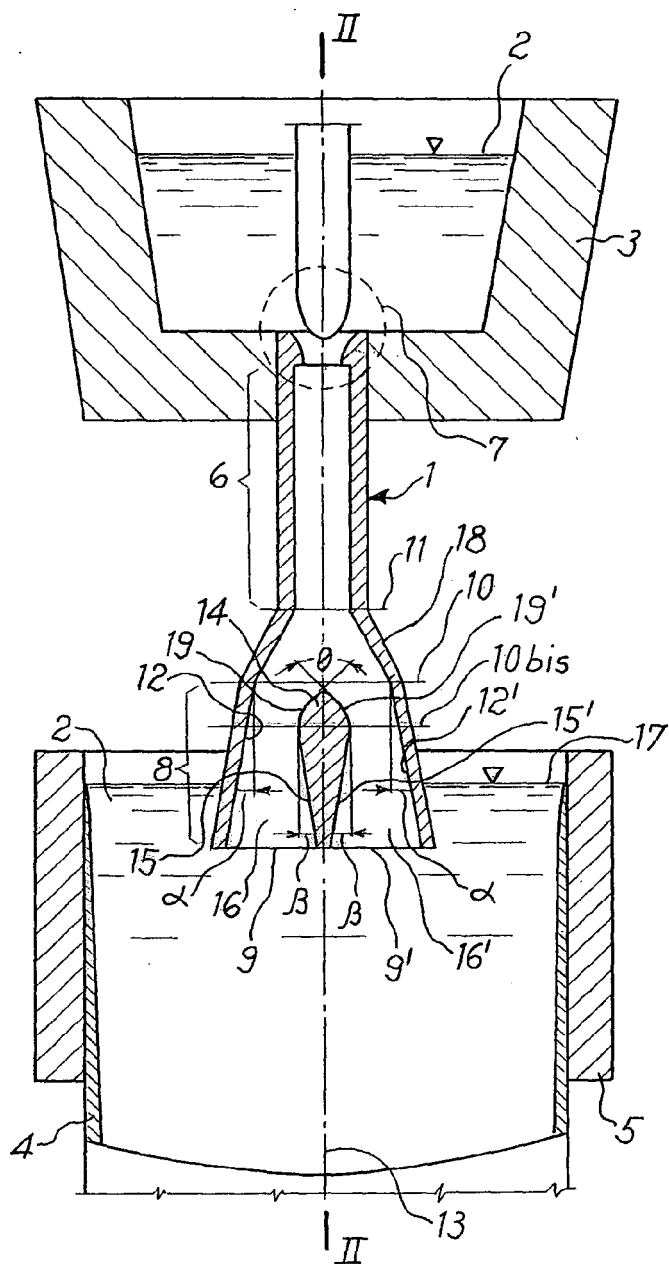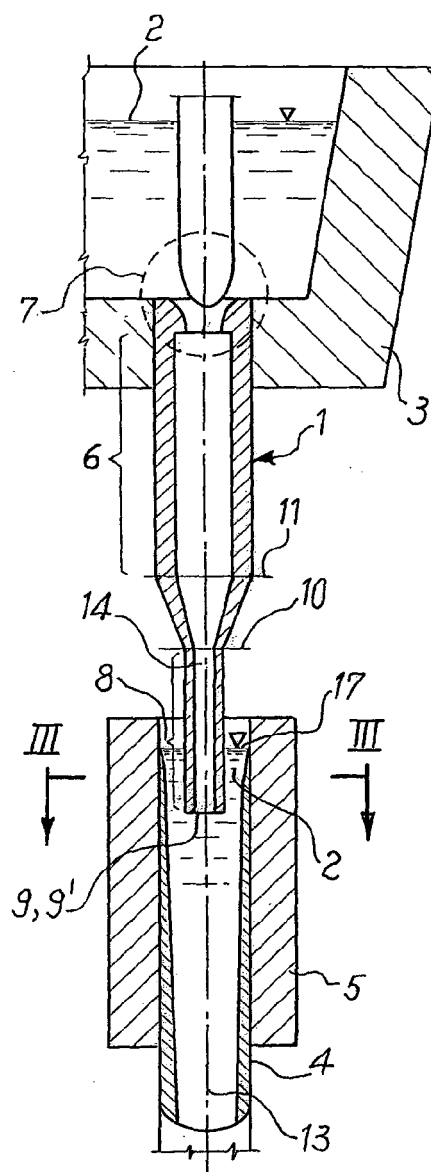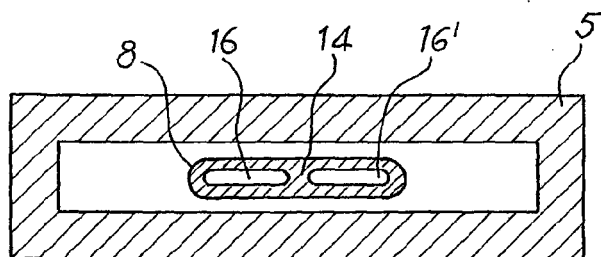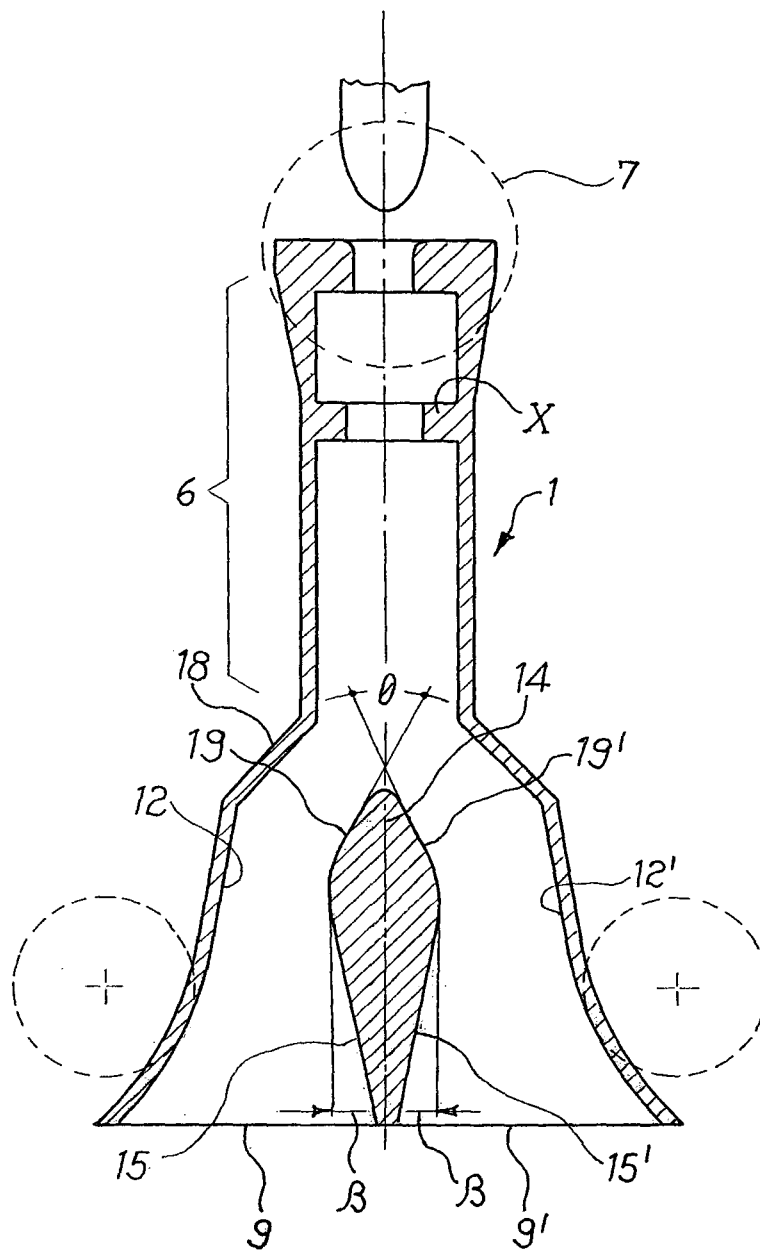
Fig.1

Fig.2

Fig.3

Fig.4

European Patent Office

EUROPEAN SEARCH REPORT

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Y	* figures 1-3 * * column 3, line 56 - column 4, line 6 *	4,5,8,9	
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TECHNICAL FIELDS SEARCHED (Int.Cl.7)

B22D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	30 September 2005	Scheid, M

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ANNEX TO THE EUROPEAN SEARCH REPORT
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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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