



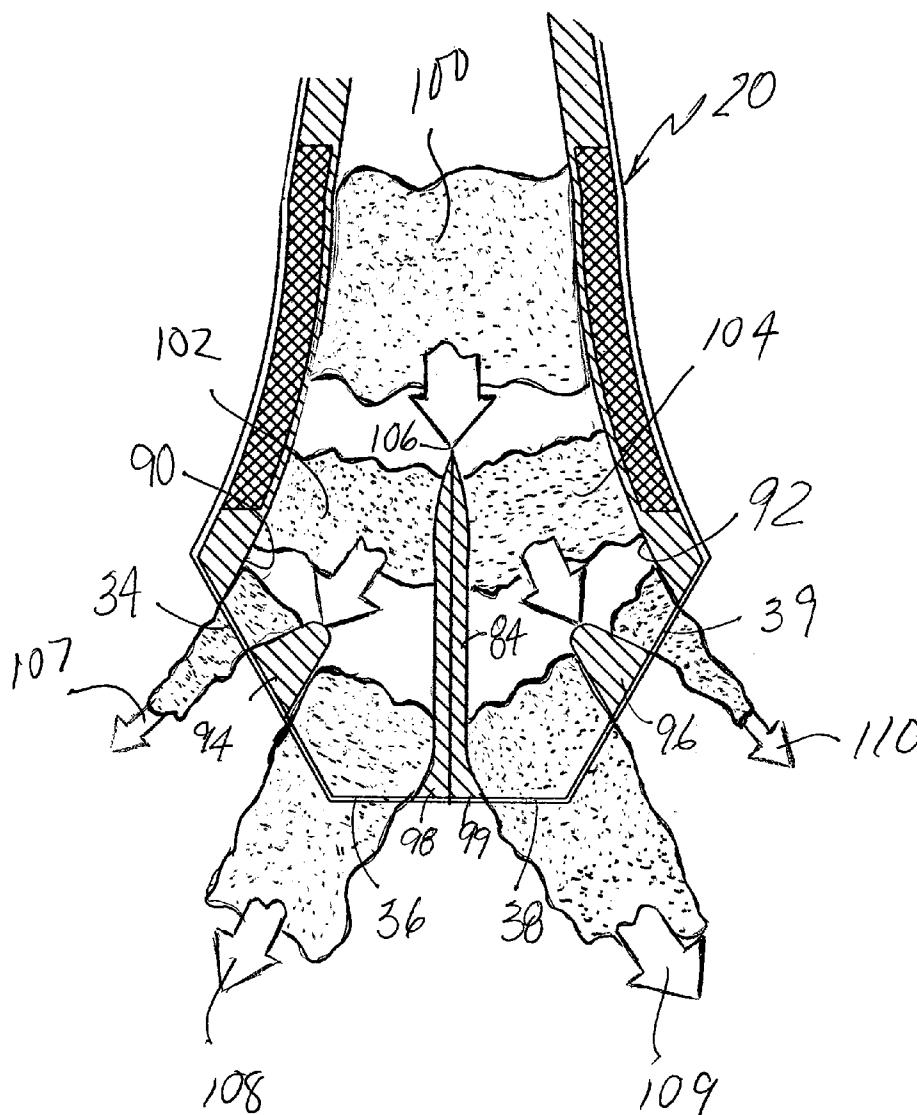
US 20060243760A1

(19) **United States**(12) **Patent Application Publication**
McIntosh et al.(10) **Pub. No.: US 2006/0243760 A1**(43) **Pub. Date: Nov. 2, 2006**(54) **SUBMERGED ENTRY NOZZLE****Publication Classification**(76) Inventors: **James L. McIntosh**, Loveland, OH
(US); **Mark C. Pole**, Summerville, SC
(US)(51) **Int. Cl.**
B22D 37/00 (2006.01)(52) **U.S. Cl.** **222/606**

Correspondence Address:

MOORE & VAN ALLEN PLLC**P.O. BOX 13706****Research Triangle Park, NC 27709 (US)**(57) **ABSTRACT**(21) Appl. No.: **11/380,546**(22) Filed: **Apr. 27, 2006****Related U.S. Application Data**(60) Provisional application No. 60/594,665, filed on Apr.
27, 2005.

A nozzle for transferring molten steel in a thin slab continuous casting machine from the tundish to the mold which provides at least two areas of stream compression below the major changes in section required to transition from the entry diameter to the rectangular submerged portion of the nozzle.



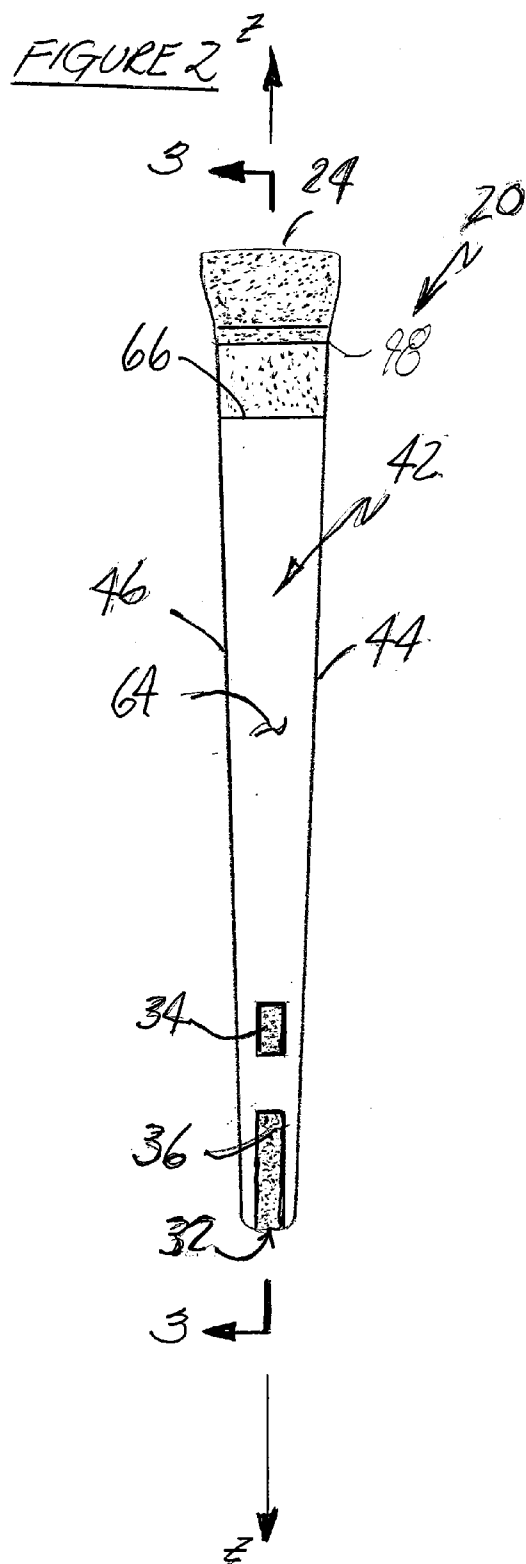
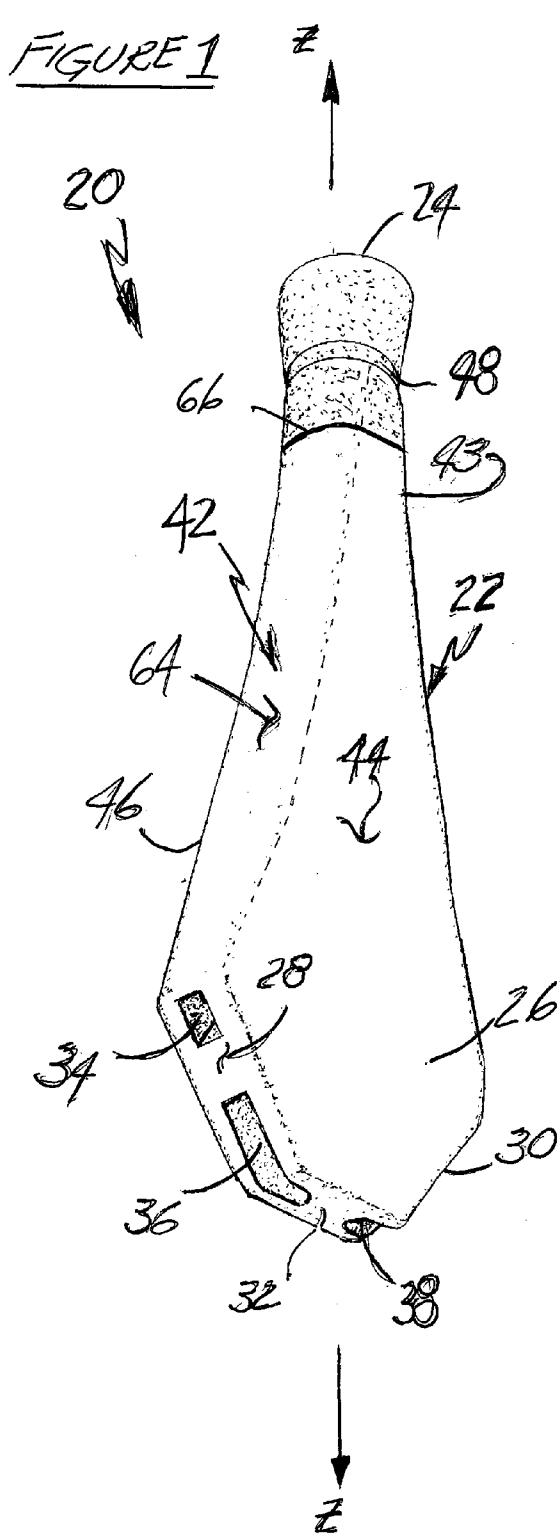
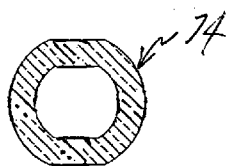
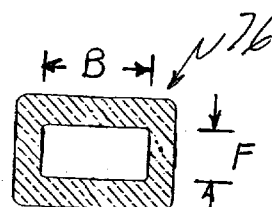


FIGURE 5



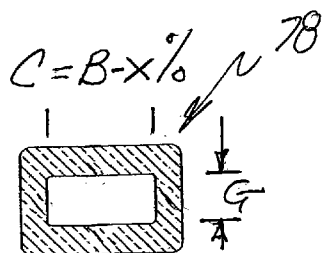
Section A-A

FIGURE 6



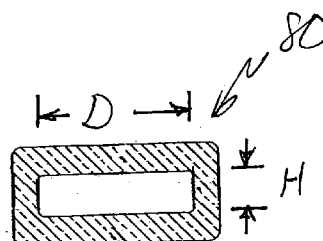
Section B-B

FIGURE 7



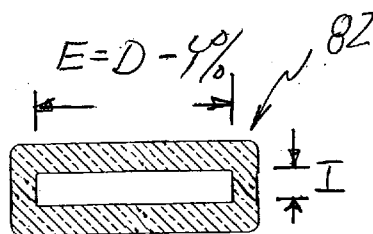
Section C-C

FIGURE 8



Section D-D

FIGURE 9



Section E-E

FIGURE 10

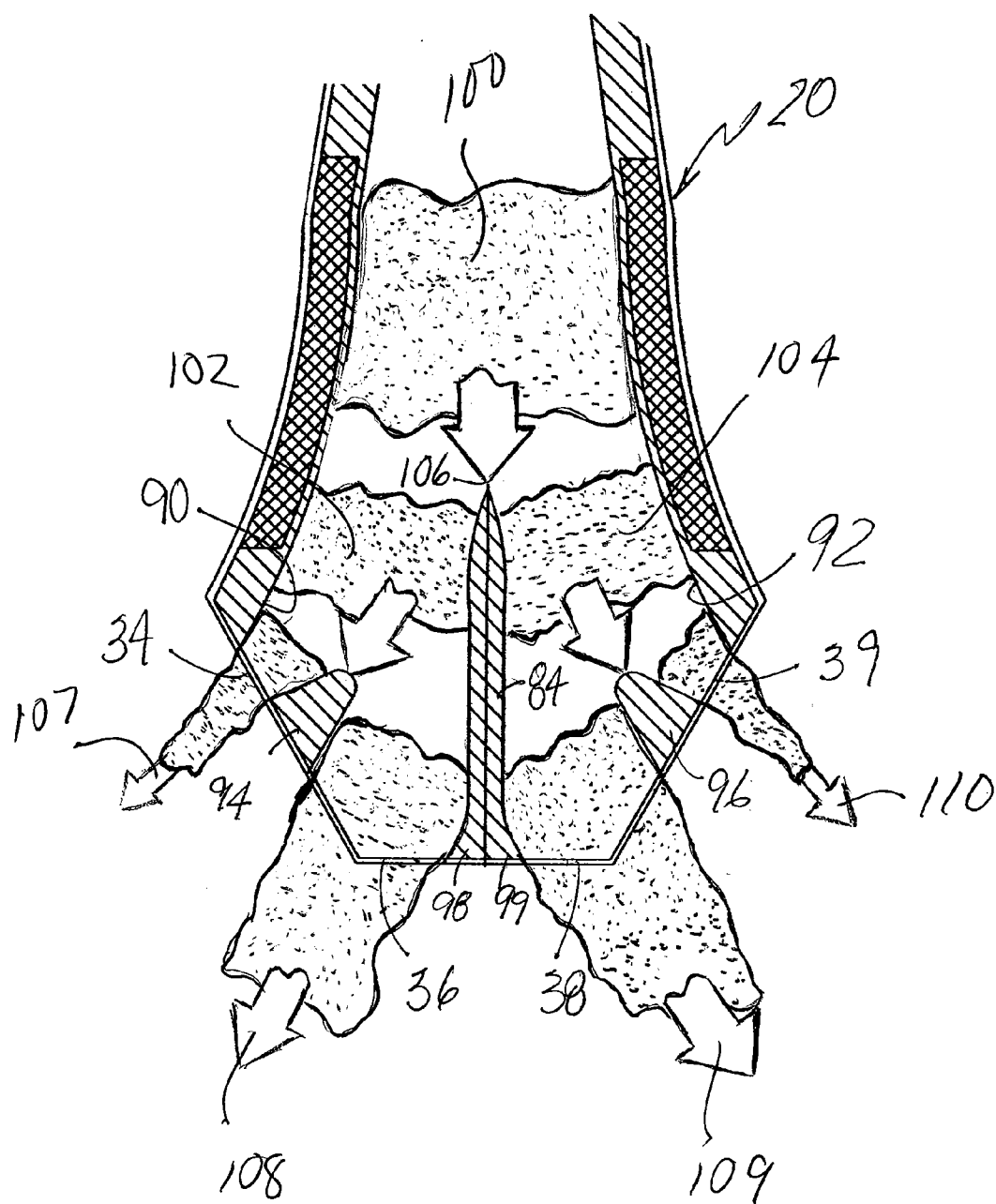


FIGURE 11

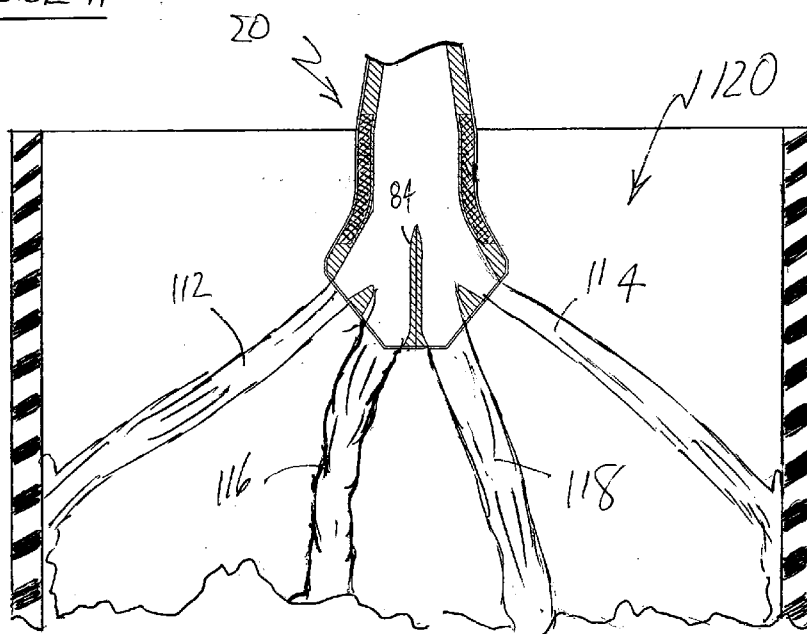


FIGURE 12

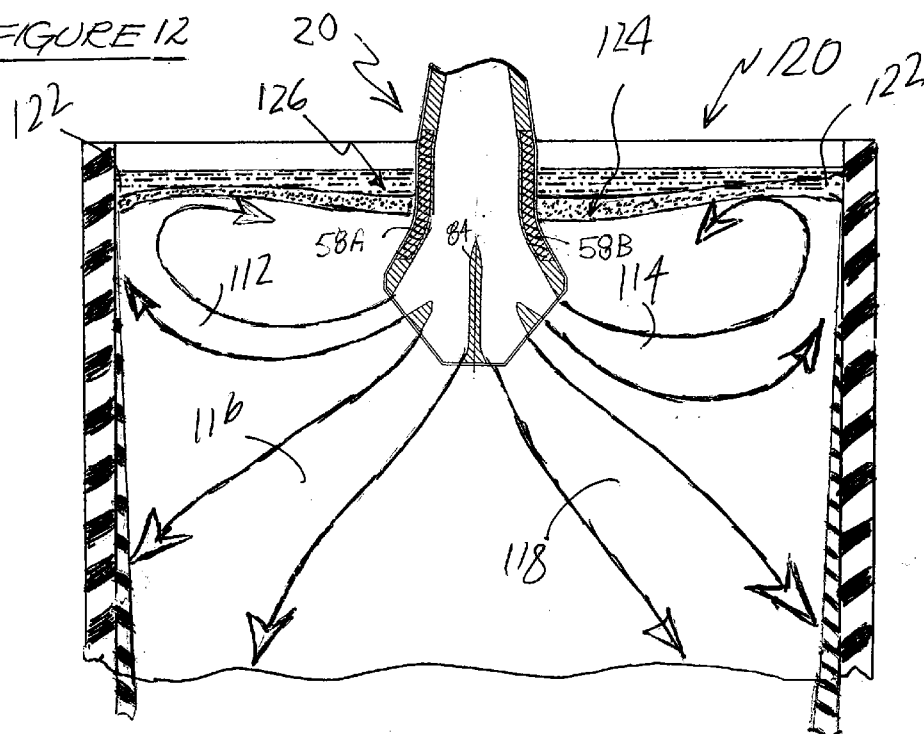


FIGURE 13

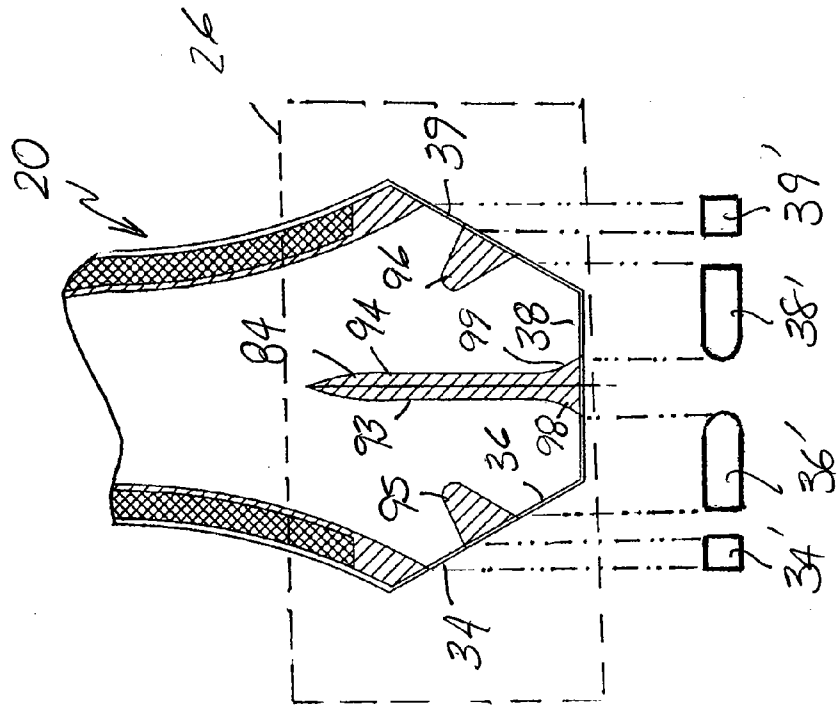
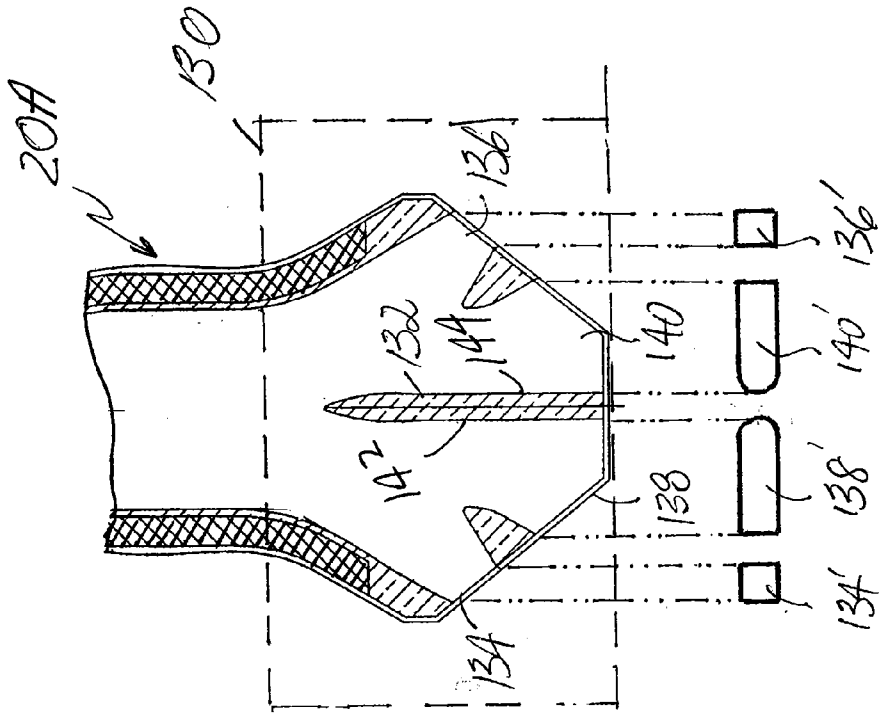


FIGURE 14



SUBMERGED ENTRY NOZZLE

RELATED APPLICATIONS

[0001] This application claims priority from Provisional Patent Application Ser. No. 60/594,665, filed Apr. 27, 2005, the entire disclosure of which is incorporated herein by reference.

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TECHNICAL FIELD

[0003] This invention relates to the continuous casting of steel, and more particularly to submerged entry nozzles for use in flowing molten steel between the tundish and mold of a continuous casting machine.

BACKGROUND ART

[0004] Continuous casting is a steel making process that transforms large volumes of liquid steel into semi-finished slabs, blooms, and billets that can be further processed into finished products. In its operation, liquid steel is supplied by ladle to a casting machine tundish and fed through a submerged entry nozzle, or "SEN", to a casting machine mold. The mold is an open ended box-like structure which provides the cast section with its desired shape. It has four copper surfaced steel plates that function as the mold walls. The walls can be position adjusted inward and outward to change the width and thickness of the cast section, such as slabs that are from 50 to 230 millimeters (mm) thick and 610 mm to 1520 mm wide. Water jackets in the copper lining provide primary cooling to the liquid steel that comes in contact with the mold walls, causing it to solidify and form a shell. An oscillating vertical displacement of the mold prevents the solidifying shell from sticking to the walls.

[0005] The shell and its liquid core form a strand that is withdrawn from the mold by casting machine drive rollers at a rate that is substantially equal to the rate of flow of the liquid steel into the mold. This provides the continuous casting process with its operational steady state condition. As the strand exits the mold it is subjected to water spray or water mist secondary cooling which prevents reheating of its surface by the core until it has traveled its "metallurgical length," at which point the core has solidified and the strand can be cut to desired length on exit from the casting machine.

[0006] In the casting machine the liquid metal is gravity fed from the tundish to the mold at a maximum flow rate established by the bore size of the SEN. Different nozzle bore shapes and sizes may be selected depending on the section size to be cast and the required casting speed. The steel flow can be changed (slowed or stopped) as necessary for the control of the casting operation. This is done either with a stopper rod that is fitted to the SEN inlet to restrict the whole or any part of the flow, or by a slide-gate that is drawn across the SEN inlet. The operation of the stopper rod and

slide-gate may be performed manually by an operator, or automatically in response to a feedback signal from a level sensor in the mold.

[0007] The flow dynamics of the molten steel moving from the tundish to the mold can affect the quality of the continuous cast steel. The most critical part of the casting process is the initial solidification of the liquid steel at the meniscus, which is the point at which the top of the solidifying steel shell meets the mold wall and the liquid steel of the mold bath. This is where the surface of the final cast product is created, and defects such as surface cracks can form if problems, such as too severe level fluctuations, occur in the liquid surface. To minimize this probability, oil or mold powder is added to the surface of the liquid steel in the mold. The mold powder produces a mold slag layer on the liquid surface which protects the liquid steel from the open air, provides it with thermal insulation, and also absorbs inclusions that are present in the liquid steel. It also flows into the gap between the mold wall and the shell to provide lubrication to the shell-to-copper interface.

[0008] Another factor which is critical to the surface quality of the cast steel is the presence of turbulence and other transient phenomena in the flow of the molten steel from the SEN into the mold. The SEN delivers the molten steel through outlet ports in its distribution zone, which is submerged in the mold bath, below the mold slag line. Among the prior art nozzles that are commonly used are those in which the distribution zone has outlet ports positioned in opposite-side lateral passages at the bottom of the nozzle. This discharges liquid steel in opposite lateral directions, into the longer, width dimension of the mold. Two outlet ports in each lateral passage provide the "double roll pattern" known in the art, in which each lateral passage discharge provides two flows. One moves upward through the mold bath and curls along the under surface of the meniscus and back toward the nozzle, and the other curls downward and also returns toward the nozzle.

[0009] The opposite side upward flows heat the meniscus to maintain its temperature at a level sufficient to melt the mold powder and provide proper lubrication to the casting. They also produce a standing wave profile at the liquid steel surface, which causes the mold powder slag layer to be thinner at the meniscus than around the nozzle body. Preferably the standing wave has a minimum amplitude, or is at least a constant amplitude. Too high an amplitude standing wave, as may result from too high of a velocity of the upward flow, or a varying amplitude, as may result from disrupted or intermittent flow velocities of the opposite side flows, can shear off droplets of mold slag or foreign particles trapped at the meniscus into the flow and entrain them in the liquid steel. These inclusions can also generate surface defects and surface cracks in the finished steel.

[0010] These problems have a greater effect in Compact Strip Production (CSP), which is the casting of thin slabs which are only 50 mm to 100 mm (2 to 4 inches) thick. The narrower dimensions of the CSP mold require an SEN with a narrow rectangular distribution zone. Even then a funnel must be fitted to the top of the mold to receive the SEN. With the CSP required narrower dimensions, inclusion entrapment resulting from nozzle-to-mold flow patterns can occur with higher frequency than in thick slab casting. This is due primarily to the required higher flow velocity from smaller

geometry SEN outlet ports which is necessary to cast the thin slab at the same throughput rate as thick slab. It is important, therefore, to provide an SEN for use in CSP casting that is capable of maintaining steady steel flow velocities which are high enough to satisfy the CSP throughput requirements, while low enough to prevent it from entraining particles from the mold slag layer. It must also provide flows which have a uniform steel consistency, and which are substantially balanced at its lateral outlet ports.

DISCLOSURE OF INVENTION

[0011] The present invention is to a submerged entry nozzle for use in a casting machine to conduct molten steel from the tundish to the mold in a manner that improves the flow dynamics of the molten steel entering the mold, thereby minimizing steel flow turbulence, improving the cast steel quality, and increasing the product yield.

[0012] According to the present invention, a submerged entry nozzle (SEN) includes, within a common housing, an inlet for receiving an incoming flow of molten steel from the tundish, a distribution zone for delivering the molten steel to the mold, and a main body having a central bore which is intermediate to and in fluid communication with the inlet and the distribution zone, the central bore conducting the incoming flow of molten steel along a flow path having sequential section geometries that alternately compresses and decompresses the molten steel flow, to alternately increase and decrease the steel flow velocity to present a substantially laminar primary flow of molten steel at a flow path exit to the distribution zone, thereby minimizing the occurrence of flow turbulence introduced into the mold liquid steel bath by the molten steel delivered thereto. In further accord with the present invention, the flow path includes at least two section geometries that compress the steel flow.

[0013] In still further accord with the present invention the distribution zone includes oppositely directed lateral passages, each in fluid communication at a passage inlet end thereof with the flow path exit from the main body and each in fluid communication at an outlet end thereof with one or more outlet ports, the distribution zone further including a flow divider disposed adjacent to the flow path exit and intermediate of the lateral passages, and having a leading edge with a minimum radius of curvature for dividing the molten steel primary flow into substantially equal secondary level flows and directing each secondary flow to an associated one of the lateral passages with minimum flow turbulence.

[0014] In yet still further accord with the present invention, each lateral passage includes one or more baffles disposed in the outlet end thereof for dividing the received secondary flow into two or more discharge flows that are directed through outlet ports established on opposite sides of the baffle, into the mold.

[0015] In yet still further accord with the present invention, the common housing of the SEN transitions along the length of the main body, from a circular inlet adapted for connection to the tundish, to a rectangular distribution zone having first and second pairs of opposing walls that are dimensionally adapted in their span for insertion into the mold, the first pair of opposing walls each housing the outlet ports of an associated one of the lateral passages and each

having a wall span which is dimensioned in relation to the range of thickness of a cast slab, the second pair of opposing walls each having a wall span which is dimensioned in relation to the range of width of the cast slab, the SEN transition characterized by having the second pair of opposing walls converge in a continuous linear taper from the inlet to the distribution zone. In yet still further accord with the present invention, the first pair of opposing walls transitions from the inlet circular geometry to the distribution zone rectangular geometry incrementally along their length. In yet still further accord with the present invention, the interval spacing between opposite ones of the first pair of opposing walls changes along the bore flow path, as necessary to provide the sequential section geometries in consideration of the linear taper convergence of the second pair of opposing walls.

[0016] These and other objects, features, and advantages of the present invention will become more apparent in light of the following detailed description of a best mode embodiment thereof, as illustrated in the accompanying Drawing.

BRIEF DESCRIPTION OF DRAWING

[0017] FIG. 1, is a perspective illustration of a submerged entry nozzle embodiment according to the present invention, shown vertically positioned along its longitudinal axis (Z) as in its operational placement between a casting machine tundish and mold;

[0018] FIG. 2, is side elevation illustration of the submerged entry nozzle embodiment of FIG. 1;

[0019] FIG. 3, is an axial section of the submerged entry nozzle of FIG. 1, taken along the section line 3-3 of FIG. 2;

[0020] FIG. 4, is an axial section of the submerged entry nozzle of FIG. 1, taken along the section line 4-4 of FIG. 3;

[0021] FIG. 5, is a cross section of the submerged entry nozzle of FIG. 1, taken along the section line A-A of FIG. 3;

[0022] FIG. 6, is a cross section of the submerged entry nozzle of FIG. 1, taken along the section line taken along the line B-B of FIG. 3;

[0023] FIG. 7, is a cross section of the submerged entry nozzle of FIG. 1, taken along the section line taken along the line C-C of FIG. 3;

[0024] FIG. 8, is a cross section of the submerged entry nozzle of FIG. 1, taken along the section line taken along the line D-D of FIG. 3;

[0025] FIG. 9, is a cross section of the submerged entry nozzle of FIG. 1, taken along the section line taken along the line E-E of FIG. 3;

[0026] FIG. 10, is an illustration of an operating characteristic of the submerged entry nozzle embodied in FIGS. 1-9;

[0027] FIG. 11, is an illustration of another operating characteristic of the submerged entry nozzle embodied in FIGS. 1-9;

[0028] FIG. 12, is an illustration of still another operating characteristic of the submerged entry nozzle embodied in FIGS. 1-9;

[0029] FIG. 12, is an illustration of yet still another operating characteristic of the submerged entry nozzle embodied in FIGS. 1-9;

[0030] FIG. 13, is a figurative illustration, partially in section, of a further physical detail of the submerged entry nozzle embodied in FIGS. 1-9; and

[0031] FIG. 14, is a figurative illustration, partially in section, of a physical detail of an alternative embodiment of a submerged entry nozzle embodiment to that shown in FIG. 3 and FIG. 13.

BEST MODE FOR CARRYING OUT THE INVENTION

[0032] FIG. 1 is a perspective illustration of the submerged entry nozzle, or "SEN" 20 of the present invention, which is shown vertically positioned along its longitudinal axis (Z) as in its operational placement between the casting machine tundish and mold. The SEN 20 has a main body 22, with an inlet 24 at one end for receiving liquid steel from a tundish (not shown), and a distribution zone 26 at the opposite end for delivering the liquid steel to the casting machine mold. The inlet 24 is adapted to mate with the output coupling of the tundish, which is generally a circular coupling at a stated diameter. The liquid steel received at the inlet flows through a central bore in the main body 22 (described hereinafter with respect to FIGS. 3 through 10) to the distribution zone 26. The distribution zone 26 channels the flow through interior lateral passages (also described hereinafter with respect to FIGS. 3 through 10) to outlet ports disposed in opposite side segments, or facets 28, 30 of the SEN, and along a bottom portion 32 of the SEN. These include outlet ports 34, 36 in facet 28, with the port 36 extending into the bottom portion 32, and outlet port 38 partially shown in the bottom 32 and extending to opposite side facet 30. Outlet port 39, also on facet 30 is not shown in this Figure.

[0033] FIG. 2 is a sidewall elevation of the SEN 20. This is the narrower dimension of the SEN 20 and in this description is referred to as the SEN side wall 42, and opposite side wall 43 (FIG. 1). The widest dimensions of the SEN 20 are associated with that portion of the SEN which is here referred to as the front wall 44 (FIG. 1, 2) and back wall 46 (FIG. 1). As shown in FIG. 2 the front and back walls 44, 46 of the SEN converge in a substantially continuous and substantially linear tapered manner, beginning at a point 48 tangent to the circumference of the circular inlet 24, and continuing to the bottom portion 32 of the SEN. The taper is necessary to provide the SEN with the narrowed depth dimensions necessary for use in CSP operations.

[0034] FIG. 3, is an axial section of the SEN 20 taken along the line 3-3 of FIG. 2 which, in terms of reference to FIGS. 1, 2, is a section that includes the back wall 46 of the SEN 20. FIG. 4 is an axial section of the SEN 20 taken along the line 4-4 of FIG. 3 which, in terms of reference to FIG. 3, is a section that includes the side wall 43 of the SEN 20. The following description of the SEN structural and functional features simultaneously refers to FIGS. 3 and 4.

[0035] The SEN main body 22, inlet 24, and distribution zone areas 26 are shown as proximate to the areas that are bounded by the dashed lines associated with their reference numbers. The main body 22 has a central bore 50 formed

collectively by the front and back walls 44, 46 and side walls 42, 43. The bore 50 provides a fluid pathway from the aperture, or opening 52 of the SEN inlet 24, to the entrance 54 of the distribution zone 26, which is located at the section line E-E.

[0036] The overall length (L) of the SEN, from the inlet 24 to its bottom 32, is determined by the tundish-to-mold operational distance for casting machine in which the SEN is to be used. In an exemplary embodiment of an SEN for use in a CSP application, the overall length is substantially 1180 millimeter (mm) (or 46.5 inches). Of this, the main body 26 accounts for approximately 772 mm (30.4 inches), or 65%, the inlet 24 is approximately 130 mm (5.12 inches) or 11%, and the distribution zone (from its entrance 54 to the bottom 32 of the SEN) approximately 278 mm (11 inches) or 24%.

[0037] With the exception of the top throat area 56A, 56B, and 58A, 58B of the inlet 24, and the segments 60A, 60B and 62A, 62B which bridge the main body and distribution zones, the SEN body structural material comprises Alumina graphite, which typically contains greater than 60% Al₂O₃, approximately 3% silica, and approximately 20% carbon and other anti-oxidants and fluxes. The throat areas 56, 58 of the inlet 24 are enhanced for wear purposes by adding Magnesite graphite, which typically contains greater than 75% MgO, approximately 3% silica, and approximately 15% carbon and other anti oxidants and fluxes. The area of the SEN associated with the segment 60, 62 is that which is positioned at or along the slag line when installed in the mold, and the Alumina graphite is replaced with Zirconia graphite to enhance the wear ability of the SEN to the effects of surface erosion caused by the standing wave undulation of the slag surrounding the SEN.

[0038] The SEN is manufactured in an iso-static press in which the Alumina graphite, Magnesite graphite, and Zirconia graphite mixed materials are all exactly placed in their designated SEN positions inside a mold and pressed together at the same time. The mold comprises: (i) a press tool normally made of steel whose exterior surface establishes the finished wall dimensions and geometry of the central bore 50, (ii) an outer elastomeric mold covering which encloses the press tool and defines the SEN exterior geometry; (iii) filling tools which permit exact placement of the Alumina graphite, Magnesite graphite, and Zirconia graphite mixed materials in their relative SEN body positions inside the cavity created between the press tool and the outer elastomeric mold; and (iv) upper and lower closures which seal the press tool, mixed materials and the elastomeric outer mold.

[0039] The filled and sealed mold is then pressed inside the iso-static press which provides omni directional forces to the elastomeric outside mold to compact the materials at a greater than 4000 pounds per inch force on all plains of the elastomeric mold to provide a homogeneous structure. The tooling is then disassembled by removing the top and bottom closures, the outer elastomeric mold, and the inner steel press tool leaving a completely pressed SEN product consisting of the three pressed materials. The product is then cured in an oven, after which it is fired in a kiln to produce the carbo ceramic bond in the product. The outside surface is then machined to provide the required, final outside geometry of the SEN.

[0040] Following the outside surface machining the SEN body is coated with various materials which protect the alumina graphite, zirconia graphite and magnesia graphite from oxidation when the SEN is subjected to the preheat process performed by the steel mill end user prior to SEN installation in the casting machine. The preheat step is normally for a 90 minute period at 1100 degrees Celsius, and which is intended to prevent thermal shock of the SEN by the liquid steel when placed in use. These coatings are known glazes that maintain the material integrity of the SEN through the preheating process.

[0041] The final step is to add a known type, commercially available ceramic fiber wrap **64** (FIGS. **1** and **2**) to the SEN. The wrap **64** covers the distribution zone and main body and extends the length of the SEN to a point **66** short of the inlet **24**. The purpose of the wrap is to allow the SEN to retain much of the preheat process temperature during the time it takes to install it in the castor. This can be up to 4 minutes. The SEN has to retain enough heat to withstand the thermal stresses induced by the 1560 degrees Celsius liquid steel that flows through it when the stopper rod or slide-gate is opened. In the best mode embodiment the ceramic fiber wrap is at least four (4) millimeters thick.

[0042] Referring again to FIGS. **3**, **4**, in the exemplary embodiment of SEN **20** the length of the central bore **50** from the inlet **24** to the entrance **54** of the distribution zone is approximately 942 mm, and along this length the bore geometry transitions from the circular geometry of the inlet **24** to a rectangular geometry at the entrance **54** to the distribution zone **26**. Within its length the bore is provided with a variable geometry for the purpose of varying the flow velocity of the liquid steel in sections along the flow path to change the steel flow rate within the SEN in a manner which accommodates flow changes from tundish and provides the distribution zone with a uniform and concentrated column of liquid steel. This in turn allows for a more laminar flow of steel from the outlet ports **34**, **36**, **38**, **39** and minimizes turbulence within the mold.

[0043] These changes in flow velocity are accomplished through changes in the cross sectional area along sections of the bore. Since the front wall and back wall converge over the length L of the SEN at a substantially constant rate, they provide a steady convergence or compression of the steel flow, which in turn provides a steady increase in flow velocity. To counter the velocity increase, the side walls are made to diverge sufficiently in certain sections of the bore flow path to overcome the flow compression effects of the taper to allow the steel flow to diverge and to decrease in velocity. This axial arrangement of alternating convergent and divergent zone sections in the bore flow path provides for an averaging of the flow which evens out flow disruptions from the tundish which, at a minimum, occurs at each initiation of flow with removal of the stopper rod or slide-gate.

[0044] In FIG. **4** the inner surfaces **68**, **70** of the front wall **44** and back wall **46** begin their taper at the surface tangent **72** to the inlet aperture **52**. The flow section from the tangent **72** to the cross section A-A begins with the diameter of the aperture **52** and due to the taper of the front and back wall inner surfaces **68**, **70** continually decreases in cross sectional area (CSA) until at Section A-A the area appears as shown in FIG. **5** with CSA **74**. The section provides compression

of the flow and an increased flow velocity. In the exemplary SEN embodiment the length of this flow section is approximately 407 mm, or 43% of the bore length. The aperture **52** has an 81 mm diameter and a 5152 mm² area while Section A-A (**74**, FIG. **5**), due to convergence of the front and back wall inner surfaces **68**, **70** has a bore cross sectional area of 4796 mm²; a 7% reduction in CSA with a consequent increase in flow velocity.

[0045] The bore flow path interval between Section A-A and B-B, approximately 193 mm in length (20% of total), provides a flow divergence. This is the first point of transition from the circular inlet section diameter to the rectangular distribution zone, which is the submerged portion of the SEN. At Section B-B the SEN side walls **42**, **43** have completed their circular-to-rectangular transition and the Section B-B profile **76**, FIG. **6**, is shown as a rectangle. The radiused corners are required to ensure that there are no undue stresses between the corners of the section of the nozzle and to aid smooth transition of the steel stream inside the nozzle at the extremities of the inside bore. The front and back wall inner surface spacing is F and the side wall spacing is B, and for the exemplary SEN embodiment the Section B-B area is 5292 mm², a 10% increase in CSA over Section A-A with a consequent decrease in flow velocity.

[0046] The flow path interval from Section B-B to C-C is approximately 50 mm long, or 5% of the total bore flow path. It provides a second compression zone. Section C-C is shown at **78**, FIG. **7** with a front to back wall inner surface spacing as G (where G<F) and the side wall spacing as C=B-X%, where X is greater than or equal to 5% and less than or equal to 10% (5%<X<10%). In the exemplary embodiment the area of Section C-C is 4977 mm², or 6% less than Section B-B and yields an increased flow velocity.

[0047] In the SEN exemplary embodiment the flow path interval from Section C-C to D-D is 156 mm long, 16% of total bore length. It provides a second diverging flow interval. Section D-D is shown at **80**, FIG. **8** with the front and back wall inner surface spacing as H (where H<G) and the side wall spacing as D. The exemplary embodiment area of Section D-D is 5934 mm², a 19% increase over that of Section C-C with a consequent decrease in flow velocity.

[0048] The final interval of the bore flow path is from Section D-D to E-E. It is 136 mm long and 14% of the total path. Section E-E is shown at **82**, FIG. **9** with the front and back wall inner surface spacing as I (where I<H) and the side wall spacing as E=D-Y%, where Y is greater than or equal to 12% and less than or equal to 18% (12%≤Y≤18%). The exemplary embodiment area of Section E-E is 5224 mm², a 12% decrease over that of Section D-D with a consequent increase in flow velocity. This creates the concentrated steel stream inside the compression zone immediately above the distribution zone **26**, to ensure that the supply is uniform prior to entering the flow-dividing portion of the nozzle. The acceleration of the liquid stream at the Section E-E exit ensures that the desired angular trajectory of the steel stream discharged from the outlet ports to the mold will be achieved. Also, the steel flow above the compression zone is uniformly oriented to fill the bore completely as the steel attempts entry into the compression zone, thereby improving the stream conditions by eliminating dead zones and encouraging laminar flow.

[0049] Of the three compression zones along the bore flow path, the one from the inlet aperture **52** to Section A-A

(referred to here as the “initial compression zone”) is essentially fixed in its geometry due to its proximity to the inlet **24** and well within the circular to rectangular transition area of the SEN. While it may be possible to alter the geometry to affect its compression characteristics, it would be difficult and provide little effect so as to make it impractical. Therefore, only Section B-B to C-C (“Upper Compression Zone”) and Section D-D to E-E (Lower Compression Zone”) have practical application in programming the flow characteristics, since they are more easily altered and have higher gain characteristics since they are deeper within the narrowed taper profile where relatively small changes in sidewall to sidewall divergence provide a large velocity change.

[0050] The cross sectional area at the beginning of each of the two or more compression zones is larger at the upper most point, the entry point of the compression zone, than the lower exit point of the compression zone. This creates the concentration of the steel stream inside the compression zone and also accelerates the stream velocity at the exit point into the next phase of transition within the internal geometry of the submerged entry nozzle. Due to the restriction caused by the smaller cross sectional area at the outlet of the compression zones the volume of steel able to pass through is restricted and causes a positive steel pressure at the inlet position which uniformly fills the complete cavity as the supply of steel enters the compression zone. This stabilizes the stream conditions by eliminating dead zones and encouraging laminar flow through the compression zone and its resultant exit conditions are more consistent.

[0051] The alternating diffusion and compression zones deliver a uniform and concentrated column of steel to the distribution zone **26** which in turn provides a compressed and uniform lateral stream distribution into the caster mold, including thin slab molds. This is in major part attributable to the compression zones that may be provided in at least one, and preferably two or more, locations along the length of the bore flow path. These compression zones provide delivery of a uniform and concentrated column of steel to the distribution zone **26**.

[0052] Within the distribution zone, the primary column of steel flowing from the bore is divided by flow divider **84** into two lateral flows. The distribution zone directs the lateral flows to associated lateral passages **86, 88** which house the SEN outlet ports. The flow divider is provided with a leading edge **89** that has a maximum 5 mm radius. This leading edge radius together with an approximate 150 mm radius of the outside walls **90, 92** of the lateral passages **86, 88** allows the individual lateral flows to maintain intimate contact with the vertical surfaces **93, 94** of the divider **84** and the outside walls while flowing through the passages.

[0053] The passage **86** channels the received flow between the flow divider vertical surfaces **93** and outside passage wall **90** to outlet ports **34, 36**, and passage **88** directs its flow between the flow divider surface **94** and outside passage wall **92** to outlet ports **38, 39**. The divider vertical sections **93, 94** and the diverging passage walls **90, 92** increase the cross sectional area of their associated passages as they approach the outlet ports. This enables the outlet ports to perform two functions: (i) the deceleration of the steel flow in each of the lateral passages ensuring that the steel columns within the passages are uniform and concentrated and completely fill the cross sectional area of the passages leading to the outlet ports, and (ii) the further division of the secondary streams into concentrated upper lateral and lower lateral streams by the baffles **95, 96**.

[0054] The surface contours of the baffles **95, 96** are customized as necessary to provide the required flow discharge angles for a given mold configuration or cast section shape. In the exemplary embodiment of the SEN the baffles provide the upper lateral streams with a discharge angle from outlet ports **34, 39** which is greater than 30 degrees. As shown in **FIG. 3** the flow divider **84** is provided with an increasing width base section **98, 99** which provides angular displacement of the secondary steel flows as necessary to suit the mold flow requirements. The 5 mm commencing radius of the leading edge **89** of the divider **84** permits the division of the primary flow from the bore flow path with minimal turbulence, which ensures that the secondary lateral flows remains in contact with the divider vertical surfaces **93, 94**.

[0055] The principal of dividing the stream into two secondary lateral columns provides greater control of the steel exiting the ports when combined by the stream concentration, which has occurred in the compression zones. Each of these columns will have a totally uniform and completely laminar flow characteristic which will aid in effectively producing a consistent stream at both lateral streams inside the mold.

[0056] **FIG. 10** is a figurative illustration of the flow division performed by the distribution zone. The primary laminar flow of liquid steel **100** from the bore enters the distribution zone and is first divided into two secondary flows **102, 104** by the divider **84**. The divider has a fine tip **106** and relatively narrow width so as to divide the primary flow into the secondary flows with minimum turbulence allowing the distribution zone to maintain laminar flow in the secondary flows **102, 104**. This in turn allows the secondary flows to be divided by the baffles **94, 96** into four outlet port flows **107-110**; each of which are substantially laminar, thereby minimizing the chance that they may produce excess turbulence within the mold.

[0057] **FIG. 11** illustrates the trajectory of the discharged upper lateral steel streams **112, 114** and lower lateral streams **116, 118** from SEN **20** into an empty mold **120**, as occurs upon the initiation of the casting process. The upper lateral streams are shown to have a greater than 30 angular displacement. **FIG. 12** shows the double roll flow pattern of the upper and lower lateral steel streams **112-118** from SEN **20** in a mold liquid steel bath as occurs in the casting process steady state operation. The upper lateral flows **112, 114** move upward and curl along the under surface of the meniscus **122** and back toward the nozzle. The upper lateral flows heat the meniscus **122** to maintain its temperature at a level sufficient to melt the mold powder **124** and provide proper lubrication to the casting. They also produce a minimal amplitude standing wave profile with the mold powder slag layer **126** that is only slightly thinner at the meniscus **122** than at the slag line **128** along the SEN **20**.

[0058] As known in the art, the slag layer erodes the surface of the SEN that it surrounds. This erosion is one of the useful-life determinants of the SEN. Adding the Zirconia graphite layers in the circumferential band (**58A, 58B, FIGS. 3, 4, 12**) of the SEN helps in extending the SEN wear life. In the present invention, however, the continuous taper provided to the SEN, which begins at a point tangent to the circular inlet, allows the bore flow path to achieve its terminal sectional geometry at an earlier position of the overall length **L** of the SEN. This means that the internal geometry of the present SEN is narrower in the area of the Zirconia graphite bands than prior art SENs. This allows the

present SEN to have a greater wall thickness in this area, thereby extending the useful life of the SEN.

[0059] Referring to **FIG. 13**, which is a partial section of the SEN for the purpose of illustrating the configuration that has been described hereinabove for the distribution zone **26**. **FIG. 14**, is a partial section of an alternative embodiment SEN **20A** in which the only difference is in the distribution zone **130** whose only difference over that of the zone **26** is a flow divider **132** which has no flow divider base equivalent to that shown as **98, 99** in **FIGS. 3 and 13**. While all other elements of the two distribution zones are the same, the outlet ports of the zone **130** are numbered differently to distinguish them for comparative purposes.

[0060] The zone **130** has the same lateral passage geometries and baffle configurations, and provides upper lateral outlet ports **134, 136** which are identical to the upper lateral outlet ports **34, 39** of the zone **26**. However, elimination of the divider base increases the area of the lower lateral outlet ports **138, 140** by more than 15% over that of the lower lateral outlet ports **36, 38** of the zone **26**, and the straight vertical surfaces **142, 144** of the flow divider **132** provide for a greater volume of flow from the lower lateral ports **138, 140** being discharged directly downward. This is the optimum discharge flow characteristic for ultra narrow cast products which are those in the 50 mm to 100 mm band of thin cast slabs.

[0061] Although the invention has been shown and described with respect to a best mode embodiment thereof, it should be understood by those skilled in the art that various changes, omissions, and additions may be made to the form and detail of the disclosed embodiment without departing from the spirit and scope of the invention, as recited in the following claims.

We claim:

1. A submerged entry nozzle (SEN) for use in a casting machine to conduct molten steel from the tundish to the mold, comprising:

a housing having

an inlet, for receiving an incoming flow of molten steel from the tundish;

a distribution zone, for delivering the molten steel to the mold; and

a main body, having a bore disposed at opposite ends thereof in fluid communication with said inlet and said distribution zone, said bore conducting the incoming flow of molten steel received from said inlet along a bore flow path having sequential, sectional flow path geometries that sequentially and alternately compress and decompress the molten steel flow in one or more compression and decompression zones to alternately increase and decrease the steel flow velocity to present the molten steel, at a flow path exit thereof, to said distribution zone as a substantially laminar molten steel primary flow, thereby minimizing the occurrence of flow turbulence introduced into the mold by the molten steel delivered thereto.

2. The SEN of claim 1, wherein said bore flow path has at least two said compression zones along its length.

3. The SEN of claim 1, wherein said distribution zone comprises:

first and second oppositely directed lateral passages, each in fluid communication with said flow path exit at a passage inlet end thereof, and each having a distal end passage outlet;

a flow divider, comprising a vertical section disposed adjacent to the flow path exit and intermediate to said lateral passages, said flow divider vertical section having a leading edge for dividing the molten steel primary flow into two molten steel secondary flows, and directing each said secondary flow to an associated one of said lateral passages; and

baffles, at least one disposed in the passage outlet end of each of said lateral passages to provide each said passage outlet end with an upper lateral outlet port and a lower lateral outlet port.

4. The SEN of claim 3, wherein said flow divider leading edge has a minimum radius of curvature for dividing the molten steel primary flow into said molten steel secondary flows with minimum flow turbulence.

5. The SEN of claim 4, wherein the radius of curvature of said flow divider leading edge is a maximum 5 mm radius.

6. The SEN of claim 4, wherein said flow divider vertical section further includes a base extending on opposite sides thereof into each of said lateral passages, said base having a surface contour adapted to maintain said molten steel secondary flow through said passage to said lower lateral outlet port, thereby providing the metal flow discharge from said lower lateral outlet port with a lateral angle trajectory.

7. The SEN of claim 3, wherein said housing transitions along the length of said main body from a circular geometry at said inlet, to a rectangular geometry having opposing side walls and opposing front and back walls at said distribution zone, said opposing side walls each having disposed therein said upper lateral outlet port and said lower lateral outlet port of said lateral passage associated therewith, and each having a wall span dimension which is sized in relation to an elected range of values for the thickness of the cast section to be produced, the opposing front and back walls each having a wall span dimension which is sized in relation to an elected range of values for the width of the cast section to be produced, the housing transition characterized by having said opposing front and back walls converge in a continuous linear taper from said inlet to said distribution zone.

8. The SEN of claim 7, wherein said opposing side walls transition from a circular geometry at said inlet to said rectangular geometry at said distribution zone in an incremental manner.

9. The SEN of claim 7, wherein, in consideration of said continuous linear taper convergence of said opposing front and back walls, the spacing between said opposing side walls is altered incrementally along the bore flow path, as necessary to provide said sectional flow path geometries.

10. The SEN of claim 7, wherein said sequential sectional flow path geometries include an upper compression zone and a following, lower compression zone, said upper compression zone providing from five percent to ten percent compression of the molten steel flowing therethrough and said lower compression zone providing from twelve percent to eighteen percent compression of the molten steel flowing therethrough.