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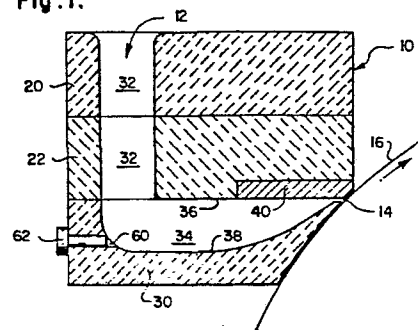
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(54) Method and apparatus for strip casting.

(57) Apparatus for continuously casting strip material is disclosed comprising a tundish (10) having an internal cavity (12) for receiving and holding molten metal and an orifice passage (14) defined between two spaced lips in the tundish through which the molten metal is delivered from the cavity to a casting surface (16) located within 3.048mm (0.120 inch) of the orifice passage and movable past the orifice passage at a speed of from 61 to 3048 metres (200 to 10,000 linear surface feet) per minute. In the present invention at least one aperture (60) is provided through the tundish (10) to a portion of the internal cavity (12) of the tundish (10) and a removable plug (62) is disposed in the aperture (60). The aperture (60) must be large enough to divert molten metal in the internal cavity (12) therethrough, and thereby reduce the metallostatic head pressure at the orifice passage (14) below that pressure necessary to cast strip material. A method of substantially instantaneously stopping a casting operation is also disclosed comprising the step of selectively removing a plug (62) from an appropriately sized aperture (60) in communication with a tundish cavity (12).

Fig. 1.



METHOD AND APPARATUS FOR STRIP CASTING

The present invention relates to a method and apparatus for the rapid casting of metallic strip material.

Rapid casting of metallic strip material involves delivering a controlled stream of molten metal onto a chilled casting surface. Typically, molten metal is poured into a tundish or other receptacle, having a specifically constructed nozzle, or orifice passage, to control the molten metal stream which is delivered onto the casting surface. Such metal may be poured into the tundish from a ladle, directly from a furnace, or the like. Strip casting is a continuous operation; however, it is often necessary or desirable to stop the casting operation quickly.

A present method of discontinuing a continuous casting operation is to stop delivering molten metal to the tundish. However, even though additional molten metal is no longer poured into the tundish the metal which is already present in the tundish continues to flow to and through the nozzle and onto the casting surface. It is understandable that the discontinuance of the supply of molten metal to the tundish significantly interrupts an operation which relies

upon strict maintenance of steady-state conditions.

Therefore, as the molten metal supply is stopped the molten metal stream pressure, and flow patterns to the casting surface are affected resulting in the production of poor quality strip material, scrap material, or perhaps spurts of molten metal until the tundish is nearly empty or until the orifice passage becomes frozen shut.

Poor quality strip or scrap material which is formed at the end of a casting operation may damage the high quality strip previously produced, or the strip casting equipment. Also, spurts of molten metal from the tundish may land on the high quality strip material previously produced which could burn, tear or otherwise mar the good strip material.

Accordingly, a new and improved method and apparatus for casting metallic strip material is desired which is able to substantially instantaneously stop a strip casting operation when required or desired.

Among the objects of the present invention is the provision of an apparatus which is able to substantially instantaneously stop a casting operation. Such advantage may be critical in instances where unforeseen or unanticipated problems arise during casting which makes discontinuance of metal flow imperative.

Another object of this invention is to provide a strip casting apparatus, which is able to stop molten metal flow to a casting surface as desired and thereby minimize the possibilities and occurrences of damage to strip material previously cast. It follows that quickly stopping the

metal flow may also reduce possible damage to cast strip material and related equipment.

Another object of this invention is to provide a method and apparatus for diverting molten metal from a strip casting tundish after a casting operation is completed to allow such tundish to be reused in subsequent casting operations.

The present invention provides strip casting apparatus comprising a tundish having an internal cavity for receiving and holding molten metal, and an orifice passage defined between two spaced lips in the tundish through which molten metal is delivered to a casting surface located within 3.048mm (0.120 inch) of the orifice passage, and movable past the orifice passage at a speed of from 61 to 3048 metres (200 to 10,000 linear surface feet) per minute, characterized in that:-

at least one aperture is provided through the tundish in communication with a portion of the internal cavity of the tundish, said aperture being large enough to divert molten metal in the internal cavity therethrough and to thereby reduce the metallostatic head pressure at the orifice passage below that pressure necessary to cast strip material,

at least one plug is disposed in said aperture to restrict molten metal flow therethrough, and,

means is provided for removing said plug from said aperture.

The present invention also provides a method for substantially instantaneously stopping a strip casting operation comprising the step of:

removing a plug from an aperture in communication with a molten metal holding cavity of a tundish having an orifice passage for delivering a stream of molten metal onto a casting surface located within 3.048mm (0.120 inch) of the orifice passage and moving past said orifice passage at a speed of 61 to 3048 metres (200 to 10,000 linear surface feet) per minute, said aperture being large enough to divert molten metal in the molten metal holding cavity of the tundish therethrough, and thereby reduce the metallostatic head pressure at the orifice passage below that pressure necessary to cast strip material.

The invention will be more particularly described with reference to the accompanying drawings in which :-

Figure 1 is a cross-sectional view illustrating a strip casting apparatus of the present invention.

Figures 2 and 3 are cross-sectional views illustrating alternative strip casting apparatus of the present invention.

Figure 4 is a cross-sectional view of the apparatus of Figure 3 showing a plug removed from an aperture thereof.

Referring particularly to the drawings, Figures 1-4 illustrate various preferred strip casting apparatus of the present invention. As shown in the drawings, the apparatus includes a tundish generally designated by reference numeral 10. The tundish 10 necessarily has an internal cavity 12 designed to receive and hold molten metal. The tundish 10 further includes an orifice passage or nozzle 14, through which the molten metal in the cavity is delivered to a casting surface 16.

In a preferred embodiment, molten metal is delivered from the nozzle 14 onto the outer peripheral surface 16 of a

water cooled precipitation hardened copper alloy wheel containing about 99% copper. Copper and copper alloys are chosen for their high thermal conductivity and wear resistance although other materials may be utilized for the casting surface 16. In the operation of the apparatus of the present invention, the casting surface 16, whether round, flat or ovular, is movable past the nozzle 14 at a speed of from 61 to 3048 metres (200 to about 10,000 linear surface feet) per minute.

As shown in Figure 1, the tundish 10 may be comprised of at least one upper block 20, at least one lower block 30, and, perhaps, intermediate blocks 22. As used in the present invention, the terms upper and lower, as well as the terms front and rear are used with general respect and reference to the casting surface 16 with the terms upper and rear referring to locations away from the casting surface 16. Also, the term vertical is used herein with general respect and reference to the force of gravity. The upper and lower blocks 20 and 30 of the tundish 10 illustrated in Figure 1 are preferably vertically aligned and secured together. Such vertical alignment is explained in our co-filed patent application entitled Strip Casting Apparatus. In such preferred embodiment the secured blocks should allow molten metal in the cavity 12 to pass through any interface of the assembly. It should be understood that in instances where the orifice passage 14 is located at an interface, as shown in Figure 1, molten metal is intended to pass therethrough. Therefore, the interface discussed above is not intended to include an orifice passage 14 of the tundish 10. In addition

to the vertically stacked block construction shown in Figure 1, a tundish of the apparatus of the present invention may consist of horizontally aligned blocks, or may be a monolithic structure.

The cavity 12 defined inside the tundish assembly should provide an unrestricted path for molten metal to flow from the cavity opening through the cavity 12 to the orifice passage 14 and onto the casting surface 16. It should also be noted that the tundish 10 need not have a generally rectangular configuration as is illustrated in the drawings.

The tundish materials utilized in the apparatus of the present invention must be resistant to molten metal attack. In this regard, it has been found that refractory boards, such as insulating boards made from fiberized kaolin are suitable. Additional materials including graphite, alumina graphite, fire clay, clay graphite, quartz, boron nitride, silicon nitride, silicon carbide, boron carbide, alumina, silica, zirconia, stabilized zirconium silicate, magnesia, chrome magnesite, and combinations of such materials may also be used to construct such blocks.

In a preferred embodiment, such tundish 10 is constructed of vertically aligned or horizontally stacked sections of 38mm (1.5 inch) thick Kaowool fiberboard. It should be noted that thicker or thinner blocks may be employed depending upon the desirable strip casting conditions. The 38mm (1.5 inch) thick blocks are utilized in this preferred embodiment because of their commercial availability.

Furthermore, such fiberized kaolin blocks are preferred because of their relatively low cost and because of the relative ease with which they can be drilled and carved into the desired cavity 12 and orifice passage 14 configurations. However, it should be understood that other materials, such as those enumerated above, may perform equally well and may well be worked into any desired configuration.

The tundish 10 includes a cavity 12 consisting of at least one introductory cavity portion 32. The introductory cavity portion 32 preferably extends from an upper surface of the tundish 10 through an upper portion of the tundish 10 and is in communication with a base cavity portion 34 formed in a hollow section at a lower portion of the tundish 10. The opening for the introductory cavity portion 32 is preferably located in the upper surface of the tundish 10 as shown in the drawings. However, such opening may be disposed elsewhere such as in a sidewall of the tundish 10. Also, as shown in the drawings, it is preferred that the opening be slightly radiused into a funnel shaped structure to facilitate metal transfer therethrough.

The formation of the base cavity portion 34 and the orifice passage 14 are critical in the apparatus of the present invention. The base cavity portion 34 is typically carved or cast in a bottom portion of the tundish and may be formed between a bottom surface 36 of an intermediate block 22 and the carved surface 38 of a bottom block 30 of a vertically stacked tundish 10, as shown in Figure 1.

Preferably, though not required, at least a portion, and perhaps the majority of the bottom surface 38 of the base cavity 34 is disposed below the height of the orifice passage 14. In such preferred embodiment at least a portion of the bottom surface 38 of the base cavity 34 is disposed at least 6.35mm (0.25 inch) below the height of the orifice passage 14. Furthermore, it is desirable in such preferred embodiment that the bottom surface 38 of the base cavity 34 extend upwardly toward the orifice passage 14 at an angle of at least 30° from horizontal.

The orifice passage 14 through which molten metal is fed onto the casting surface 16 preferably has a substantially uniform width dimension throughout the longitudinal extent thereof. Such width dimension is at least 0.254mm (0.010 inch) and preferably less than 3.048mm (.120 inch). More preferably, such width dimension for the orifice passage 14 is within the range of from 0.508 to 1.524mm (0.020 to 0.060 inch), and even more preferably from 0.762 to 1.27mm (0.030 to 0.050 inch).

The orifice passage 14 may be constructed in a number of ways in the apparatus of the present invention. In one embodiment, as illustrated in Figure 1, the orifice passage 14 is formed between the bottom surface 36 of an intermediate block 22, and a cut-out portion extending across a front wall of the bottom block 30. As also shown in the Figures, it is preferred that a molten metal resistant plate 40 be disposed in such intermediate block 22. Regardless of which method is used to provide the orifice passage, the strict dimensional tolerances mentioned above should be maintained.

In a preferred embodiment at least one surface forming the orifice passage 14 comprises the surface of the plate 40. As shown, it is preferable that the upper surface of the orifice passage 14 comprise a surface of the plate 40 of molten metal resistant material. It should be understood that it is more critical to maintain the upper surface of the orifice passage during casting and, therefore, it is preferable to use a plate 40 at such location. However, the bottom surface or alternatively both surfaces of the orifice passage 14 may consist of a surface of a plate 40. The plate 40 should be at least as resistant to the molten metal as are the blocks, and preferably, the plate is significantly more molten metal resistant than the blocks forming the remainder of the tundish 10. As shown in Figure 1 the plate 40 may be fitted into an appropriate slot cut in the bottom surface 36 of an intermediate block 22. The plate 40 should have a length greater than the longitudinal extent of the orifice passage 14. Thus, the peripheral end portions of the plate 40 are sandwiched between adjacent blocks 22 and 30 in the assembly illustrated in Figure 1. Such structure is further illustrated in our said cofiled patent application mentioned above.

In a preferred embodiment the plate 40 is formed of boron nitride. However, other materials including silicon nitride, silicon carbide, boron carbide, silica, alumina, zirconia, stabilized zirconium silicate, graphite, alumina graphite, fire clay, clay graphite, quartz, magnesite, chrome magnesite and combinations of such materials may be used for constructing the plate 40.

As mentioned above, the introductory cavity portion 32 is in communication with the base cavity portion 34. In a preferred embodiment the introductory cavity portion 32 comprises a tubular passageway through the tundish 10. The total height of the tubular passageway should be that which is necessary to provide the cavity height required to control and contain the desired metallostatic head pressure at the orifice passage 14 of the tundish 10. It has been found that maintaining a substantially constant molten metal level about 50.8mm (two inches) above any orifice passage provides a metallostatic head pressure of about 35 grams per square centimetre (0.5 psi) which is typically adequate for casting strip material.

Means may also be provided to heat the plates 40 forming one or both lips of the orifice passage 14. In a preferred embodiment, at least one lance is disposed in the tundish with the tip thereof directed toward the plate 40. A corresponding aperture may be provided in such tundish through which the combustion products which are delivered against the plate 40 from such lance may escape the tundish. By this embodiment the temperature of the plates 40 can be raised to the desired level prior to the initiation of a strip casting operation. It has been found that heating such plates near the melting temperature of the alloy to be cast prevents metal from freezing in such cavity which may otherwise occur especially at the initiation of a casting operation. In a preferred embodiment high temperature flames from reactive gases are directed through a

plurality of lances towards the plate 40. To reduce the possibility of undesired flame effects on such plate 40 a more flame resistant heat conductive layer may be provided on at least a portion of the upper surface of the plate 40 at least at the location where such flames impinge against the plate 40. Such layer serves to absorb flame abuse and still to transfer the heat to the plate 40 therebelow. In a preferred embodiment, such layer is graphite, although other materials may be employed. Such heating lance structure is described in our co-filed patent application entitled Strip Casting Apparatus With Heated Orifice.

As shown in the drawings at least one aperture 60 is provided through a lower portion of the tundish 10. In particular, such aperture is in communication with a portion of the base cavity 34 which is preferably located vertically below the height of the orifice passage 14. A plug 62 disposed in the aperture 60. It should be understood that the term plug is meant to encompass gates, flaps, stopper rods or any other molten metal restricting apparatus which can be opened as desired. The purpose of the aperture 60 and the corresponding plug 62 is to provide a drain through which molten metal in the tundish can be directed to substantially instantaneously stop molten metal from being delivered through the orifice passage 14 when it is desired or required to stop a casting operation.

It has been found that the casting operation should be stopped within one second, and preferably within about one-half second, in order to minimize adverse affects that could result if the orifice 14 continued to deliver molten

metal to a casting surface 16 in an uncontrolled fashion. Thus, for the purpose of this application the term substantially instantaneously means at least within one second. In order to ensure that the supply of metal to the orifice passage 14 stops substantially instantaneously, the size of the aperture 60 must be at least large enough to divert sufficient molten metal in the internal cavity through the aperture when the plug is removed. Such diverted molten metal flow must further have the effect of reducing the metallostatic head pressure at the orifice passage below that pressure necessary to cast strip material.

In a preferred embodiment, as illustrated in the drawings the orifice passage 14 is located vertically above, with respect to the direction of pressure in the tundish 10, at least a portion of the base cavity 34. Preferably, the internal cavity is disposed at least 6.35mm (0.25 inch) below the orifice passage 14. It should be noted that the direction of pressure is usually the direction of gravitational force. However, the tundish 10 may be disposed at any location about the casting surface 16 and casting pressure may be obtained by auxiliary devices. With the preferred tundish arrangement set forth above it is further preferred that at least one aperture for diverting metal flow be disposed in communication with that portion of the tundish cavity which is located vertically below the orifice passage.

As is understandable, the size of the aperture, or apertures, for diverting molten metal flow from the tundish

should depend upon the various strip casting parameters that are being employed. Functionally, the size of the aperture should be that which is sufficient to effect a reduction in the metallostatic head pressure at the nozzle 14 below that pressure necessary to cast strip material. In this specific, exemplary case wherein the lips of the orifice passage 14 are spaced from each other at a distance of 0.508 to 1.524mm (0.020 to 0.060 inch), and the orifice passage 14 is disposed within 0.254 to 0.508mm (0.010 to 0.020 inch) of the casting surface 16, the aperture should be large enough to cause the metallostatic head pressure at the orifice passage 14 to drop below 35g/cm^2 (0.5 psi.). With a wider dimension between the lips of the orifice passage 14, such as 1.524 to 2.54mm (0.060 to 0.100 inch), and with the same standoff distance of 0.254 to 0.508mm (0.010 to 0.020 inch), the aperture should be large enough to cause the metallostatic head pressure at the orifice passage to drop below 17.58g/cm^2 (0.25 psi). Such pressure drop should be effected within less than about one second after the plug is pulled.

In a preferred embodiment the plug 62 is a molten metal resistant, and heat resistant material, such as fiberized kaolin. Necessary precautions should be taken to facilitate plug sealing. For example, thin, flat or small diameter refractory seals could be applied to all plug-to-tundish mating surfaces to ensure the sealing of all passages. Cementing is also possible provided that the plug pulling device can overcome the cement seal when desired.

It has been found that a pressure of about 140 to 351g/cm² (2 to 5 pounds per square inch) is typically required to remove the plug 62 from the aperture 60 of a refractory tundish of the present invention. Thus, a pneumatic cylinder could be employed for automatic activation to remove the plug 62 when required. Other devices which could be employed to move the plug 62, or to slide a gate or stopper rod, whichever is employed, could also include hydraulics, screw-jacks, and other similar devices. However, it should be understood that manual removal of the plug 62 may also be readily accomplished when desired.

Upon removal of the plug 62, as illustrated in Figure 4, the molten metal is diverted through the aperture. The aperture, or apertures, should be large enough to accomodate flow of molten metal delivered to the tundish cavity at least at the rate that the metal is delivered to the cavity. In a preferred embodiment, as illustrated in Figures 3 and 4, a runner 70 may be provided through which the diverted metal may flow to another receptacle 72, or the like.

It will be appreciated by those skilled in this art that it is important to stop a casting operation as quickly as possible. Otherwise, uneven and often intermittent streams of molten metal flow through the nozzle at the end of a casting operation and such intermittent streams impinge onto the rapidly moving casting surface 16 without the control necessary to produce high quality strip material. Thus, such uncontrolled drippings of molten metal through the orifice passage 14, particularly at the end of a casting operation, tend to splash onto the successfully cast product

and can damage the previously cast strip and, perhaps, damage some of the strip casting equipment.

Also, in order to effect the reusability of the tundish 10 it is important that the molten metal in the cavity 12 be drained from the tundish 10 at the end of a casting operation. By removing such plug 62 substantially all of the molten metal in the tundish passes through the plug aperture 60 and therefore the tundish is readily reusable in subsequent casting operations with little or no cleaning or machining.

It has been found that the internal geometry of the casting cavity may be of importance with respect to the final quality of the metallic strip material produced thereby. Such geometry factors seem to be significantly more important as the width of the cast strip material increases. It has been found that for a given set of conditions of melting temperature, metallostatic head height, orifice opening, plate 40 temperature, casting surface speed and orifice to casting surface distance, minor changes in the casting cavity design may produce significant variations in across width quality of wider metallic strip material if certain geometric preferred design features are not employed. These preferred features include two specific areas; cavity slope, and cross cavity profile. In a preferred embodiment the bottom surface 38 of the base cavity 34 extends upwardly toward the orifice passage 14 at an angle of at least 30° from horizontal. Also, the cross profile of the bottom surface 38 of the base cavity 34 should have a dish type configuration. In particular the height of the

base cavity at a central portion is preferably at least 2.54mm (0.10 inch) greater than the height of the base cavity 34 as measured at both lateral edges of the base cavity 34. The introductory cavity 32 in a tundish of the present invention may be provided by drilling one or more appropriately sized holes through the tundish material. The bottom portion of the tundish may be appropriately shaped into an outwardly extending fan shaped structure diverging outwardly from the bottom of the tubular introductory cavity 32, in the direction of the orifice passage 14 approximately to the width of the strip to be cast. It should also be appreciated that the alternative of drilling a plurality of holes into the tundish to provide the introductory cavity 32, usually depends upon the width of the strip material to be cast, and thus the width of the orifice passage 14.

As mentioned above, the orifice passage 14 should have a substantially uniform width dimension throughout the longitudinal extent thereof. Such width dimension may be slightly altered at the lateral edges of the orifice passage. In particular, the edge quality of the metallic strip material produced by the apparatus of the present invention may be improved by fanning out the lateral edge portions of the orifice passage. The height to which such lateral edge portions may be fanned should not exceed 1.5 times the uniform width of the orifice passage 14. Additionally, the length at the lateral end portions of the orifice passage 14 which can be fanned should not exceed twice the uniform width of the orifice passage 14. What is critical about such fanning

structure is that slightly more molten metal be made available at the lateral edge portions than is available along the internal portions of the orifice passage. Such fanning must continuously increase the orifice passage 14 height dimension in the direction of the lateral edge of the orifice passage 14 and such height dimension must not decrease in such lateral direction.

CLAIMS:-

1. Strip casting apparatus comprising a tundish having an internal cavity for receiving and holding molten metal, and an orifice passage defined between two spaced lips in the tundish through which molten metal is delivered to a casting surface located within 3.048mm (0.120 inch) of the orifice passage, and movable past the orifice passage at a speed of from 61 to 3048 metres (200 to 10,000 linear surface feet) per minute, characterized in that:-

at least one aperture is provided through the tundish in communication with a portion of the internal cavity of the tundish, said aperture being large enough to divert molten metal in the internal cavity therethrough and to thereby reduce the metallostatic head pressure at the orifice passage below that pressure necessary to cast strip material,

at least one plug is disposed in said aperture to restrict molten metal flow therethrough, and

means is provided for removing said plug from said aperture.

2. Apparatus according to claim 1, wherein the orifice passage is located vertically above, with respect to the direction of pressure in the tundish, at least a portion of the cavity.

3. Apparatus according to claim 1 or 2, wherein said at least one aperture is disposed vertically below at least a portion of the orifice passage.

4. Apparatus according to claim 1, 2 or 3, wherein the aperture is large enough to accomodate flow of the amount of molten metal delivered to the tundish cavity at least at the

rate such molten metal is delivered to the tundish cavity.

5. Apparatus according to any one of the preceding claims, wherein the lips of the orifice passage are substantially uniformly spaced from each other at a distance of 0.508 to 1.524mm (0.020 to 0.060 inch), the orifice passage is spaced within 0.508mm (.120 inch) of the casting surface, and the aperture is large enough to divert molten metal sufficient to cause the metallostatic head pressure at the orifice passage to drop below 35 grams per square centimetre (0.5 pounds per square inch).

6. Apparatus according to any one of the preceding claims, 1 to 4, wherein the lips of the orifice passage are substantially uniformly spaced from each other at a distance of 1.524 to 2.54mm (0.060 to 0.100 inch), the orifice passage is spaced within 0.254 to 0.508mm (.010 to .02) inch) of the casting surface, and the aperture is large enough to divert molten metal sufficient to cause the metallostatic head pressure at the orifice passage to drop below 17.58 grams per square centimetre (0.25 pounds per square inch).

7. Apparatus according to any one of the preceding claims, wherein the tundish is constructed of a molten metal resistant material selected from boron nitride, silicon nitride, silicon carbide, boron carbide, silica, alumina, zirconia, stabilized zirconium silicate, graphite, alumina graphite, fire clay, clay graphite, fiberized kaolin, quartz, magnesia, chrome magnesite and combinations of such materials.

8. A method for substantially instantaneously stopping a strip casting operation comprising the step of:

removing a plug from an aperture in communication with

a molten metal holding cavity of a tundish having an orifice passage for delivering a stream of molten metal onto a casting surface located within 3.048mm (0.120 inch) of the orifice passage and moving past said orifice passage at a speed of 61 to 3048 metres (200 to 10,000 linear surface feet) per minute, said aperture being large enough to divert molten metal in the molten metal holding cavity of the tundish therethrough, and thereby reduce the metallostatic head pressure at the orifice passage below that pressure necessary to cast strip material.

Fig. 1.

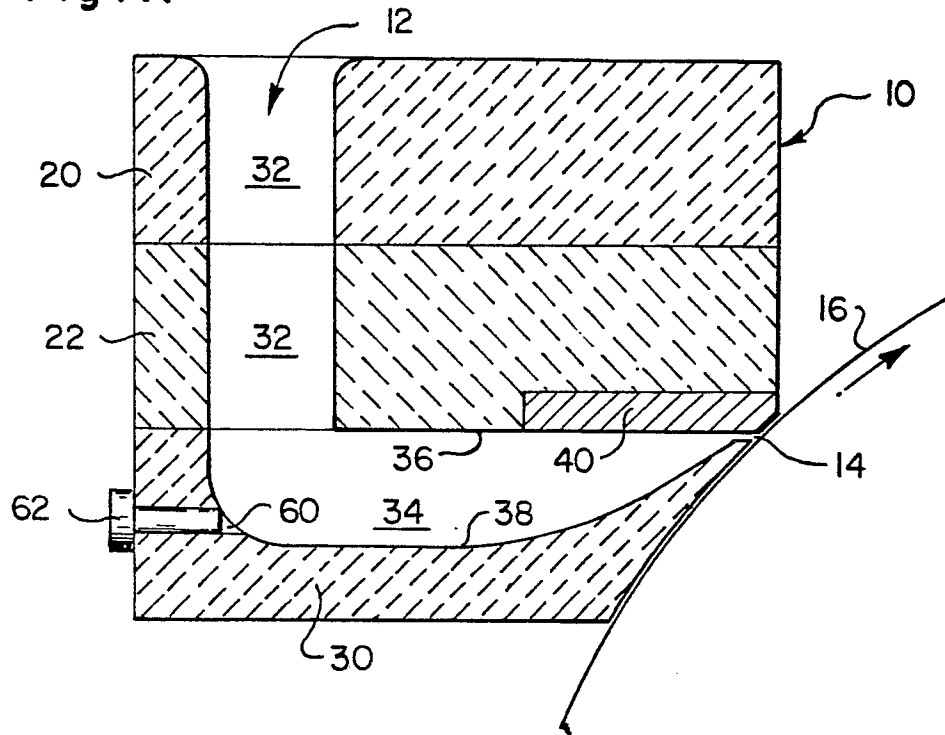


Fig. 2.

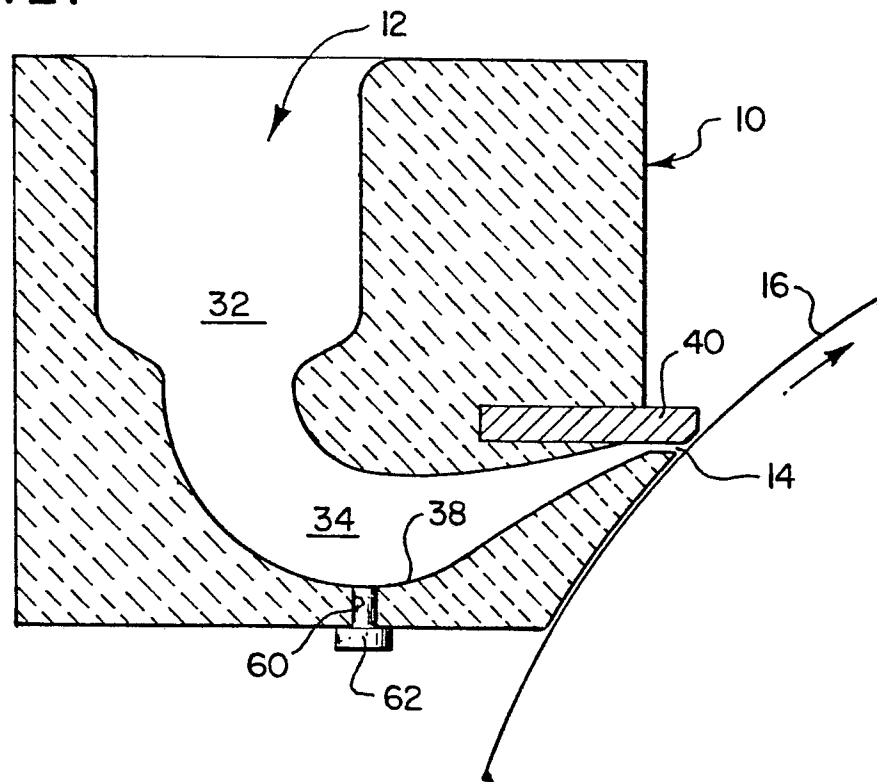


Fig. 3.

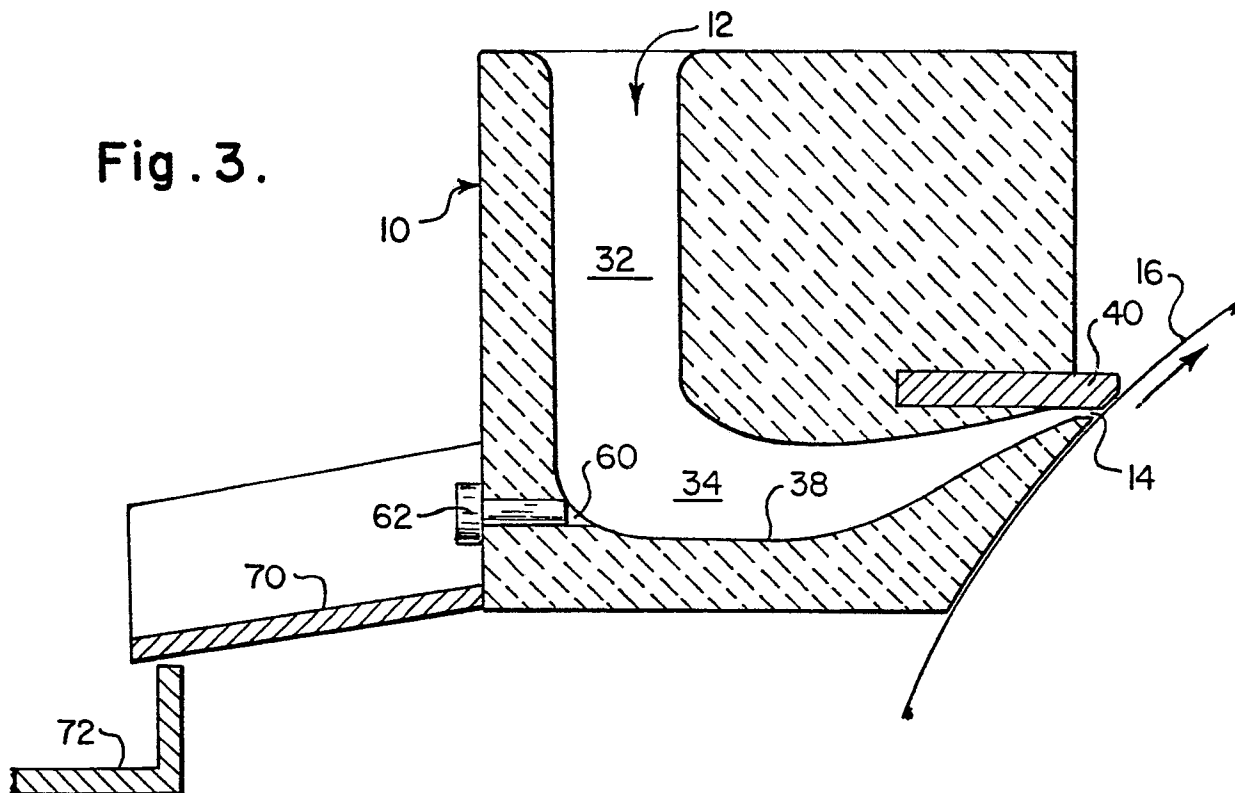


Fig. 4.

