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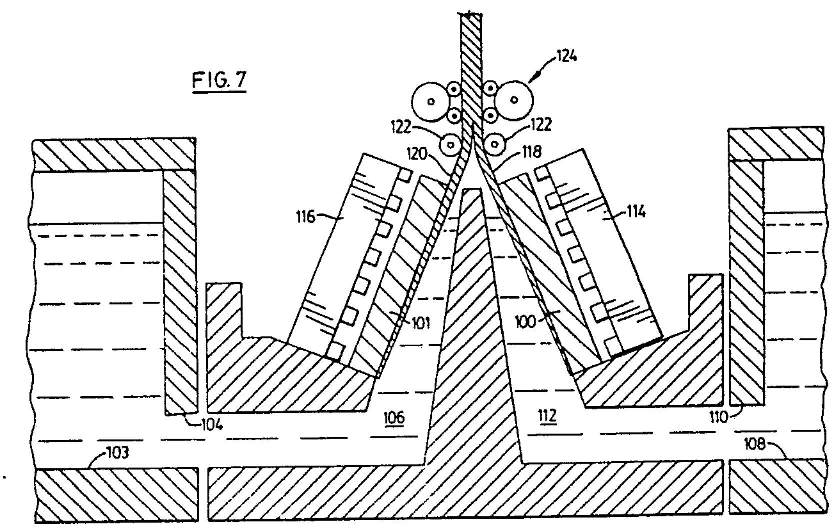
(54) Dual plate strip caster.

(57) Thin metal strip is continuously cast by providing a first plate and a second plate, each having a mold surface, and each having cooling means for controllably withdrawing heat from the respective plate. The mold surfaces contact molten metal which continuously solidifies against the surfaces, forming strips. The strips are withdrawn continuously and merged together to form a single, composite strip. High frequency vibration can be applied to the plates in order to reduce sliding friction between each strip and its respective plate.

FIG. 7



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DUAL PLATE STRIP CASTER

This invention relates generally to the production of thin steel slabs and strip, and has to do particularly with a process and an apparatus by which such materials can be directly cast.

One conventional method of making steel strip is to use the well known continuous casting process to make slabs which may typically be 180 mm to 250 mm thick. These slabs are then put through a hot strip mill where they are rolled down to a thickness of typically 1.8 to 4.8 mm, whereupon they are passed through a cold finishing mill to achieve the final thickness.

In contrast to the procedure just described, there are also thin-strip casting methods currently used which employ some form of double or twin roll caster. Typical of this process is French patent 2547518, issued December 21, 1984. Another typical patent is U.S. 4,546,814, issued October 15, 1985.

A significant departure from the twin roll casting concept is represented by Japanese patent application 2230458, assigned to Nippon Steel Corp. In this development, a container with an open top is defined by a sloping bottom wall and a weir extending around three sides. The bottom wall is water cooled and receives the input of high-frequency vibratory energy to reduce friction. Hot melt is poured into the basin so defined, and solidifies as a layer against the cooled bottom wall. This layer is then withdrawn through the missing fourth wall, coming off as a strip which passes between one or more pairs of nip rollers. Another patent directed to this approach is U.S. 4,709,745, issued December 1, 1987 to Rossi.

A major disadvantage of the above-mentioned Japanese development is the fact that the melt has its top surface exposed to the air. Moreover, in the region where the strip is exiting from the continuous casting mold, the upper surface of the molten steel literally "becomes" the top surface of the final cast product. This is very disadvantageous due to the fact that the upper surface of the melt tends to become covered with slag, flux or oxides which are undesirable as inclusions in the top surface of the finished strip. Additionally there are certain fluid flow problems associated with trying to cast from a liquid surface, problems that can contribute to a rough (wavy) solidified surface. The U.S. Rossi patent suffers from the same disadvantage.

In an earlier development by the present applicant, now filed as a British informal patent application, there is proposed a strip caster concept utilizing a thermally insulated chamber for containing molten metal, the chamber being in part defined by a flat mold wall from which heat can be withdrawn (for example by water jets). A slot-like outlet is provided from the chamber at one extremity of the wall, and means are provided for pulling formed strip out through the slot-like outlet. Optionally, the plate can be vibrated at high frequency to eliminate or reduce the sticking of the solidifying steel strip to the water-cooled plate. It will be appreciated that the quality of the strip surface facing the water-cooled plate will be of better quality than the surface of the strip facing the melt. In the earlier proposal, an improvement of the surface of the melt side of the strip is sought by providing a short water-cooled second mold wall of much smaller size than the main plate. The second mold wall is provided adjacent the slot-like outlet of the apparatus, and has the function of solidifying the surface facing the melt, in order to improve its quality.

One potential application of this prior proposal will be described subsequently in connection with the drawings.

The prior proposal for a one-sided molding apparatus presents a number of technological problems which have to be overcome in order to make it technically and economically feasible:
- sealing of the oscillating plate to the stationary insulating part of the mold;
- lubricating of the two-face exit of the mold;
- percent solidification control;
- plugging prevention (slush and surface tension resistance to liquid feeding of the exit two-face mold);
- edge build-up and strip jamming; and
- mold powder or lubricating control.

In the foregoing proposal, it will be appreciated that the resistance to motion by the combination of sliding and viscous friction will dictate how much pulling force is required to obtain the necessary strip speeds exiting from the one-face mold.

The introduction of the second, smaller mold plate adjacent the slot-like outlet from the chamber introduces additional resistance, providing opportunities for stress-related cracking. To overcome the problem of stress-related cracking, casting speed could be reduced. If it were reduced to about 1/5 of that needed to compete with the productivity of conventional slab casters, this would require five strip casting machines in place of one, in order to meet the targeted productivity.

The use of mold powders in the prior proposal represents additional expense. To be economic, mold powder consumption should be about 1/10 of that found with conventional slab casting. Additionally, mold powder could be a potential source of mold powder related strip surface defects (unmelted powder) which would be extremely difficult to remove. A one-millimeter-deep defect on a ten-millimeter-thick strip represents ten percent of the thickness, whereas the same defect on a 250 mm thick slab represents 0.4 percent of the slab thickness.

In view of the above, it is clearly desirable to design a strip caster that does not have the aforementioned built-in deficiencies. The caster should produce 125 tons an hour with an excellent surface quality free of mold powder entrapment and stress-induced surface cracks.

In broad terms, the present invention eliminates the short, water-cooled mold plate adjacent the exit from the chamber (thus reducing friction significantly), and proposes to utilize two single-plate molds, immersed in the same or different chambers containing molten metal. Both plates are vibrated in the preferred embodiment, and the two strips being withdrawn along the surface of the two plates are then combined to form one single strip.

More particularly, this invention provides an apparatus for continuously casting thin metal strip, having vessel means for containing molten metal, and a plate defining a mold surface adapted to be disposed in contact with molten metal in said vessel means, means for withdrawing heat from the plate to induce solidification of metal in the form of a strip against the mold surface, and means for continuously withdrawing the strip from the apparatus,

characterized in that,

the apparatus includes a first plate defining a first mold surface, a second plate defining a second mold surface, each said plate being disposed such that its mold surface contacts molten metal contained in said vessel means, first cooling means controllably withdrawing heat from said first plate, second cooling means for controllably withdrawing heat from said second plate, and withdrawing means for a) continuously withdrawing a first formed strip solidifying at the mold surface of the first plate, b) continuously withdrawing a second formed strip solidifying at the mold surface of the second plate and c) merging the two formed strips together to form a single composite strip.

Additionally, this invention provides a method for the continuous casting of thin metal strip utilizing an apparatus that includes vessel means for containing molten metal, and a plate defining a mold surface disposed in contact with molten metal in said vessel means, the method including withdrawing heat from the plate to induce solidification of metal in the form of a strip against the mold surface, and continuously withdrawing the strip from the apparatus;

characterized in that

there are provided a first plate and a second plate defining a first mold surface and a second mold surface, both mold surfaces being in contact with molten metal in said vessel means, in that heat is withdrawn from both plates, thus inducing the formation of two strips, and in that both strips are continuously withdrawn and merged together to form a single composite strip.

For a better understanding of the invention, and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1 is a schematic view showing the essential components of a preliminary development leading to the present invention;

Figures 2 and 3 are further schematic views showing possible structures for a one-sided mold plate application, this again being preliminary to the present invention;

Figure 4 is a vertical sectional view through a first embodiment of this invention, in which a feeder tundish is only partly seen;

Figure 5 is a sectional view taken at the line 5-5 in Figure 4;

Figure 6 is a somewhat schematic vertical sectional view through a second embodiment of this invention; and

Figure 7 is another schematic view, showing the third embodiment of this invention.

Attention is first directed to Figure 1, in which the prior proposal apparatus is seen to incorporate a tundish 10, a mold apparatus 12 defining a chamber 14 which is defined in part by a primary mold plate 16 extending vertically within the apparatus 12. A nozzle bank 18 is adapted to spray cooling water against the side of the mold plate 16 which is remote from the chamber 14. A secondary mold plate is seen at 20, adjacent but spaced apart from the lower region of the primary mold plate 16. Due to the cooling of the plate 16, the molten metal in chamber 14 solidifies in the form of a strip against the inside surface of the plate 16, from where it can be withdrawn downwardly as a cast strip 22. The secondary mold plate 20 serves to finish the inside surface of the strip.

Attention is now directed to Figures 2 and 3, which show two possible arrangements for producing cast strip without the use of a secondary mold plate similar to the plate 20 of Figure 1.

In Figure 2 a tundish is partially shown at 30, and feeds molten metal under reverse weir 32 into a chamber 34 which is defined in part by a mold plate 36, the reverse side of which can be cooled by a water cooling nozzle bank 38. The strip forms against the inside surface of the plate 36 (that exposed to the melt in the chamber 34), and is withdrawn from the apparatus over a roller 39.

Figure 3 shows a similar arrangement of components identified by numerals with the subscript a functioning identically except for the fact that strip is withdrawn in a different direction. The Figure 3 components do not need to be explained in detail, as they are analogous to the equivalent components in Figure 2.

Attention is now directed to Figure 4 and 5, which illustrate the first embodiment of this invention.

As seen in these figures, the essence of this embodiment of the invention is to provide two single-plate mold surfaces immersed in a single chamber containing liquid steel or other metal. Each mold surface generates a strip as the molten metal solidifies, and the two strips are withdrawn from the melt and merged or combined together to form one single strip.

In Figures 4 and 5, a tundish 40 is again only partly shown, the tundish being provided with a weir 42 and an outlet 43, the latter communicating with a chamber 45 seen in both Figures 4 and 5. The chamber 45 is defined by a lower wall 46, two end walls 48 and 50, and two similar mold plates 52 and 54, each with a respective cooling water nozzle bank 56, 58.

In the preferred embodiment, the plates 52 and 54 are oscillated or vibrated at a high frequency, in order to reduce frictional drag between the forming strips and their respective plates. The oscillation may be applied by mechanical means or electronically (e.g. piezoelectric elements). The formed strips are withdrawn by withdrawing rollers 60 and 62, and downstream of these rollers is located a set of reducing rollers 64 which have the effect of slightly reducing the thickness of the composite strip after the two initial strips have been merged together. This reduces minor imperfections and welds any centre porosity.

As shown in Figure 5, the liquid steel level (67) in the chamber 45 is below the location where the two single strips join into a combined strip. By maintaining the liquid steel level at this location, i.e. below the point where the strips join together, it is possible to eliminate the need for side seals to prevent liquid steel leaking from the chamber. The variation of the level of the liquid metal in the chamber 45 influences the strip thickness. Withdrawal speed also influences strip thickness, and thus there are two variables available to control the casting process.

The cavity formed above the molten metal meniscus and between the two strips may be flooded with a substantially inert gas, e.g. nitrogen or argon, in order to prevent reoxidation.

Attention is now directed to Figure 6, in which a tundish partly shown at 70 delivers molten metal through a passageway 72 to a chamber 74 defined within an apparatus 76. The chamber 74 is defined in part by a first mold plate 78 which slopes leftwardly and downwardly, and a second mold plate 80 which slopes leftwardly and upwardly. It is thus seen that the plates 78 and 80 converge in the leftward horizontal direction. The strips 82 and 84 forming on the respective plates also converge in the leftward horizontal direction. A withdrawing means is provided including withdrawing rollers 86 and 88, and these are followed by a compressing roller assembly 90.

As in the previous embodiment, each plate 78, 80 has a respective cooling water nozzle bank 92 and 94.

Attention is directed now to Figure 7, which shows an arrangement very similar to that in Figure 5, with the exception that each of the mold plates 100, 101 is in contact with metal in a different cavity. Thus, a first tundish 103 provides liquid metal through an opening 104 to a chamber 106 to which the mold plate 101 is exposed. Similarly, a second tundish 108 provides molten metal through an opening 110 to a second chamber 112 to which is exposed the mold plate 100. Each of the mold plates 100, 101 is provided with a respective cooling water nozzle bank 114, 116. The two forming strips 118 and 120 are withdrawn by withdrawing rollers 122, and these are followed by a set of compression rollers 124.

It will be appreciated that the arrangement shown in Figure 7 can allow the production of a final strip 127 consisting of two dissimilar metals.

In all three of the embodiments illustrated and described above, the respective mold assembly and melt chamber can be attached directly to a tundish, thus preventing the steel or other metal from coming into contact with air when transferring it from the tundish to the mold assembly. This structure avoids the formation of inclusions which have a much more detrimental effect on material properties with strip casting than with regular cast slabs. The tundishes may be provided with the usual flow control devices, e.g. dams, weirs, stirring elements, etc., in order to cleanse the steel before it enters the mold cavity. It will be evident that the tundish should be sealed by either mechanical means or a gas blanket.

Optionally, the various mold plates for the described embodiments may be coated with a layer of a low-friction material such as Boron Nitride.

Claims

1. An apparatus for continuously casting thin metal strip, having vessel means for containing molten metal, and a plate defining a mold surface adapted to be disposed in contact with molten metal in said vessel means, means for withdrawing heat from the plate to induce solidification of metal

in the form of a strip against the mold surface, and means for continuously withdrawing the strip from the apparatus,
characterized in that,
the apparatus includes a first plate (52, 78, 100) defining a first mold surface, a second plate (54, 80, 101) defining a second mold surface, each said plate being disposed such that its mold surface contacts molten metal contained in said vessel means, first cooling means (56, 114) for controllably withdrawing heat from said first plate (52, 78, 100), second cooling means (58, 116) for controllably withdrawing heat from said second plate (54, 80, 101), and withdrawing means (60, 62, 64, 90, 122, 124) for a) continuously withdrawing a first formed strip (118) solidifying at the mold surface of the first plate (52, 78, 100), b) continuously withdrawing a second formed strip (120) solidifying at the mold surface of the second plate (54, 80, 101) and c) merging the two formed strips together to form a single composite strip.

2. The invention claimed in claim 1, in which both plates (52, 54, 78, 80, 100, 101) are vibrated to reduce frictional drag between each plate and the respective forming strip.

3. The invention claimed in claim 2, in which said vessel means defines a single chamber containing molten metal, and in which the two plates (52, 54, 78, 80) contact the molten metal in said single chamber.

4. The invention claimed in claim 3, in which the plates (52, 54) slope upwardly toward each other such that the forming strips converge upwardly, and in which the withdrawing means includes roller means (60, 62, 64) for pulling the strips upwardly through the molten metal surface (67) and for compressing the two formed strips together such that they contact at their surfaces remote from the respective plates (52, 54).

5. The invention claimed in claim 4, in which the molten metal surface (67) is below the location at which the two strips merge together, and in which the invention further includes protection means for providing a substantially inert gas adjacent the strip surface remote from the plates and above said surface, thereby to suppress oxidation.

6. The invention claimed in claim 2, 3, 4 or 5 in which the withdrawing means includes roller means (64) for slightly reducing the thickness of the composite strip after the two initial strips have been merged together, thereby to reduce minor imperfections and to weld any centre porosity.

7. The invention claimed in claim 2, in which the said vessel means defines two separate chambers (106, 112), each containing a different molten metal, the first plate (100) contacting the molten metal in one of the chambers (112), the second plate (101) contacting the molten metal in the other of the chambers (106).

8. The invention claimed in claim 7, in which the plates (100, 101) slope upwardly toward each other such that the forming strips (118, 120) converge upwardly, and in which the withdrawing means includes roller means (122, 124) for pulling the strips upwardly through their respective molten metal meniscus and for compressing the two formed strips together such that they contact at their surfaces remote from the respective plates (100, 101).

9. The invention claimed in claim 8, in which each molten metal meniscus is below the location at which the two strips (118, 120) merge together, and in which the invention further includes protection means for providing a substantially inert gas adjacent the strip surfaces remote from the plates (100, 101) and above the respective meniscus, thereby to suppress oxidation.

10. The invention claimed in claim 8 or 9, in which the roller means (122, 124) has the effect of slightly reducing the thickness of the composite strip after the two initial strips (118, 120) have been merged together, thereby to reduce minor imperfections and to weld any centre porosity.

11. The invention claimed in claim 3, in which the first plate (78) slopes laterally downwardly and the second plate (80) slopes laterally upwardly, whereby the two plates converge in a horizontal direction, the forming strips (82, 84) also converging in the same horizontal direction, and in which the withdrawing means includes roller means (86, 88, 90) for pulling the strips (82, 84) horizontally out of the said single chamber (74) and for compressing the two formed strips (82, 84) together such that they have contact at their surfaces remote from the respective plates (78, 80).

12. The invention claimed in claim 11, in which the roller means (90) has the effect of slightly reducing the thickness of the composite strip after the two initial strips (82, 84) have been merged together, thereby to reduce minor imperfections and to weld any centre porosity.

13. A method for the continuous casting of thin metal strip utilizing an apparatus that includes vessel means for containing molten metal, and a plate defining a mold surface disposed in contact with molten metal in said vessel means, the method including withdrawing heat from the plate to induce solidification of metal in the form of a strip against the mold surface, and continuously withdrawing the strip from the apparatus,
characterized in that,
there are provided a first plate (52, 78, 100) and a second plate (54, 80, 101) defining a first mold surface and a second mold surface, both mold surfaces being in contact with molten metal in said vessel means, in that heat is withdrawn from both

plates (56, 114, 58, 116), thus inducing the formation of two strips (118, 120), and in that both strips (118, 120) are continuously withdrawn and merged together to form a single composite strip.

14. The invention claimed in claim 13, in which both plates (52, 54, 78, 80, 100, 101) are vibrated to reduce frictional drag between each plate and its respective forming strip.

15. The invention claimed in claim 14, in which both said surfaces contact a single melt in a single chamber (74, 50), and in which the forming strips emerge upwardly through the metal meniscus prior to being merged together, the strips being merged together such that they contact each other at the surfaces remote from the respective plates (52, 54, 78, 80).

16. The invention claimed in claim 15, further including the action of providing a substantially inert gas above the meniscus and adjacent the strip surfaces which are remote from the plates (52, 54, 78, 80), thereby to suppress oxidation.

17. The invention claimed in claim 15, further including the action of utilizing rollers (86, 88, 90, 60, 62, 64) to reduce the thickness of the composite strip adjacently downstream of the merging location, thereby to reduce minor imperfections and to weld any centre porosity.

18. The invention claimed in claim 14, in which the two said surfaces contact two different melts in two separate chambers (106, 112), and in which the forming strips (118, 120) emerge upwardly through the respective metal menisci prior to being merged together, the strips (118, 120) being merged together such that they contact each other at the surfaces remote from the respective plates (100, 101).

19. The invention claimed in claim 18, further including the action of providing a substantially inert gas above the meniscus and adjacent the strip surfaces which are remote from the plates (100, 101), thereby to suppress oxidation.

20. The invention claimed in claim 18, further including the action of utilizing rollers (124) to reduce the thickness of the composite strip adjacently downstream of the merging location, thereby to reduce minor imperfections and to weld any centre porosity.

21. The invention claimed in claim 14, in which the forming strips (82, 84) are withdrawn horizontally from the apparatus, and are merged together such that they contact each other at the surfaces remote from the respective plates (78, 80).

22. The invention claimed in claim 21, further including the action of utilizing rollers to reduce the thickness of the composite strip adjacently downstream of the merging location, thereby to reduce minor imperfections and to weld any centre porosity.

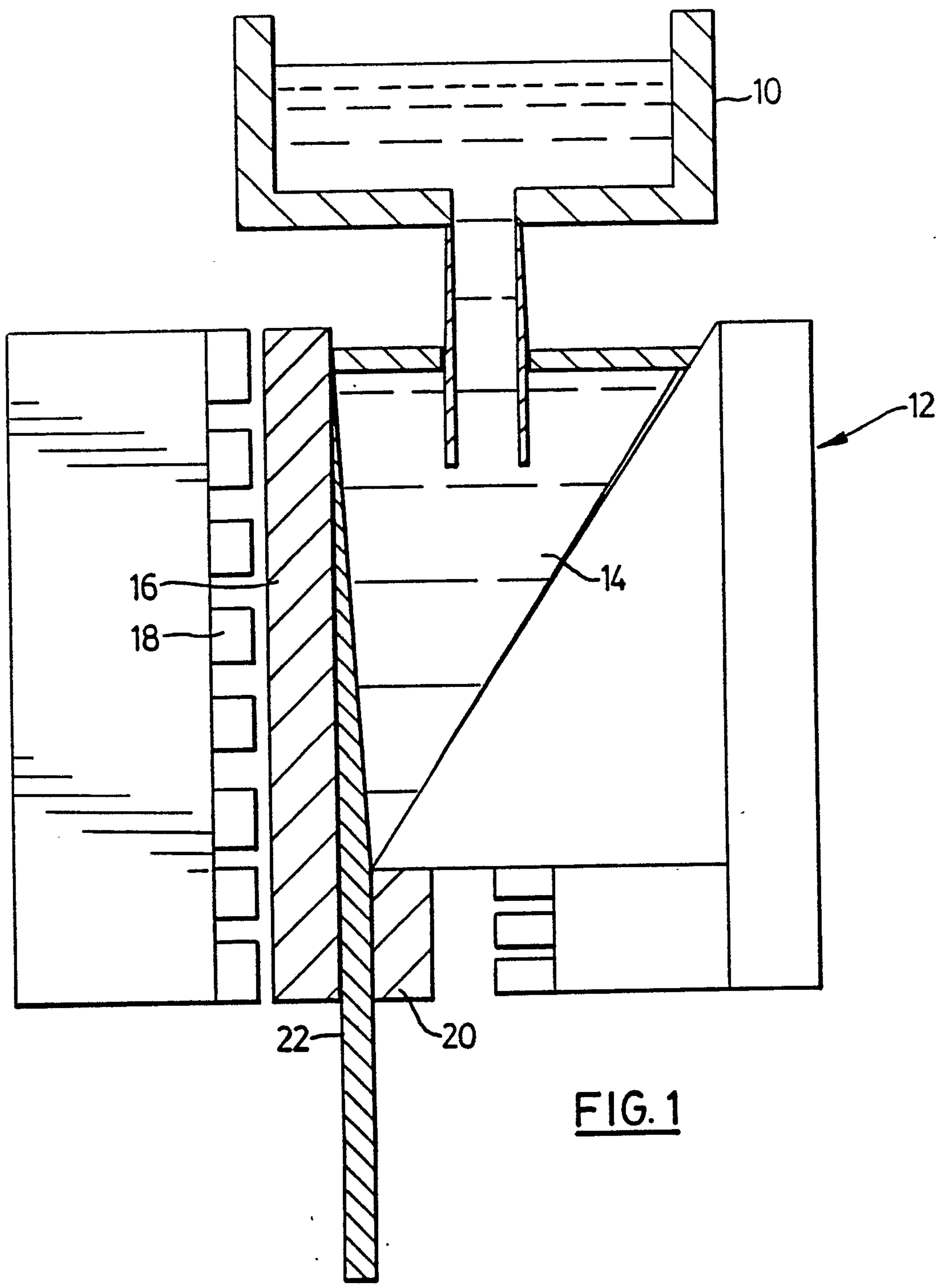


FIG. 1

FIG.2

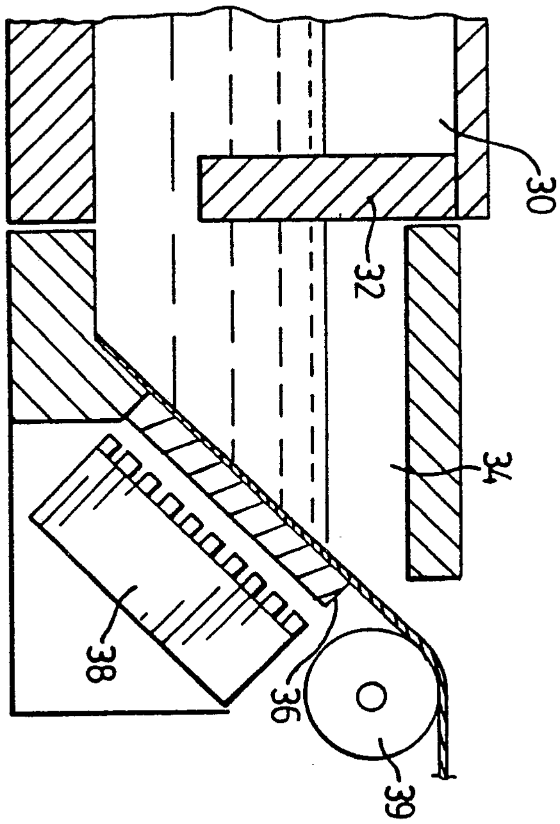
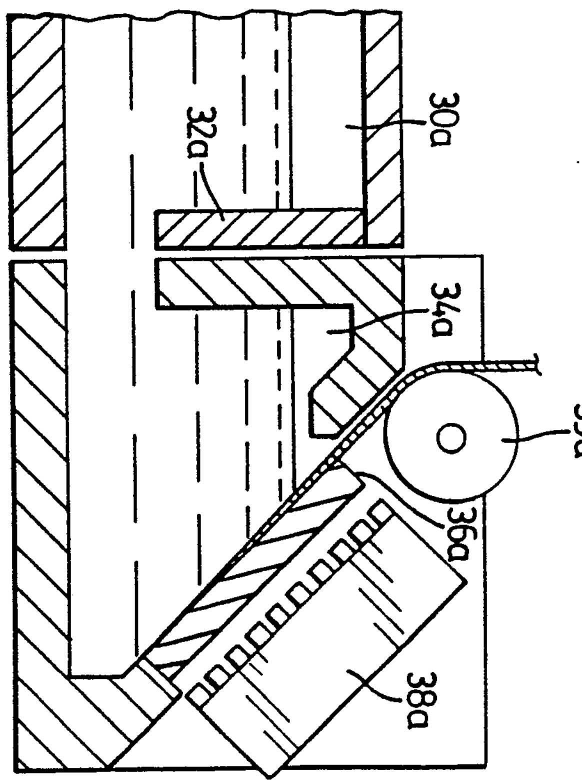


FIG. 3



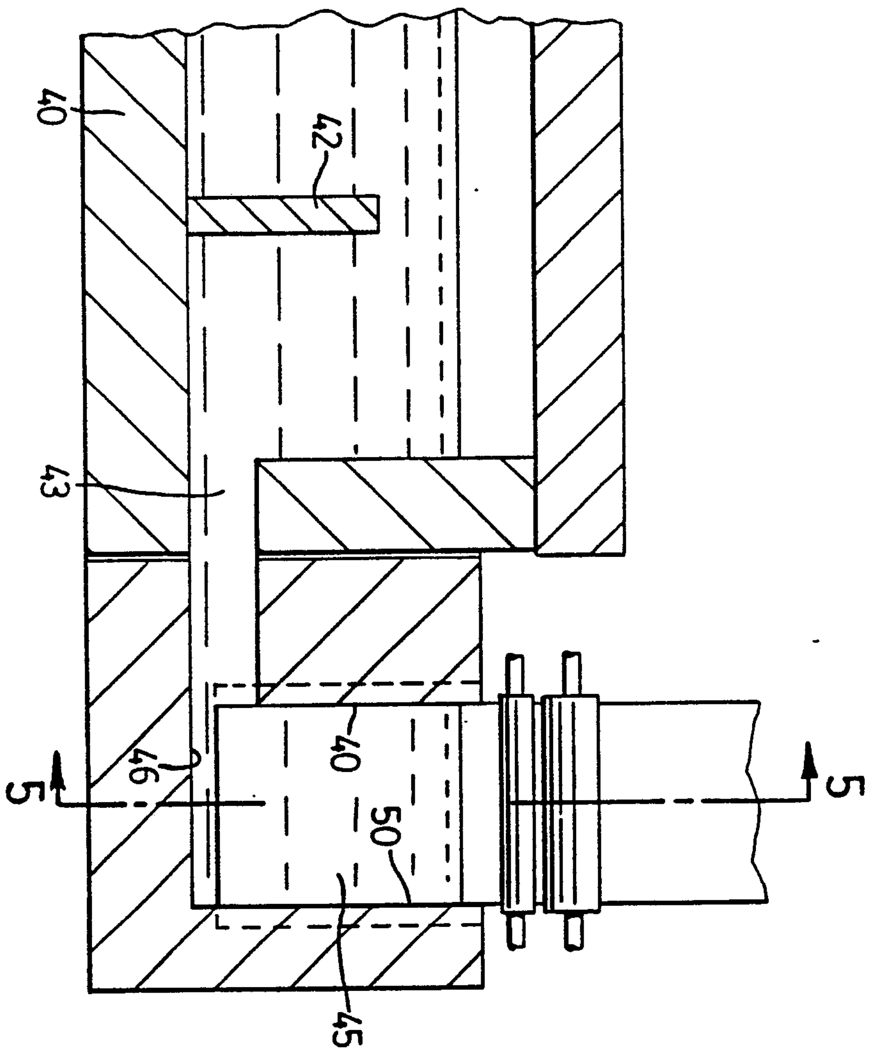


FIG. 4

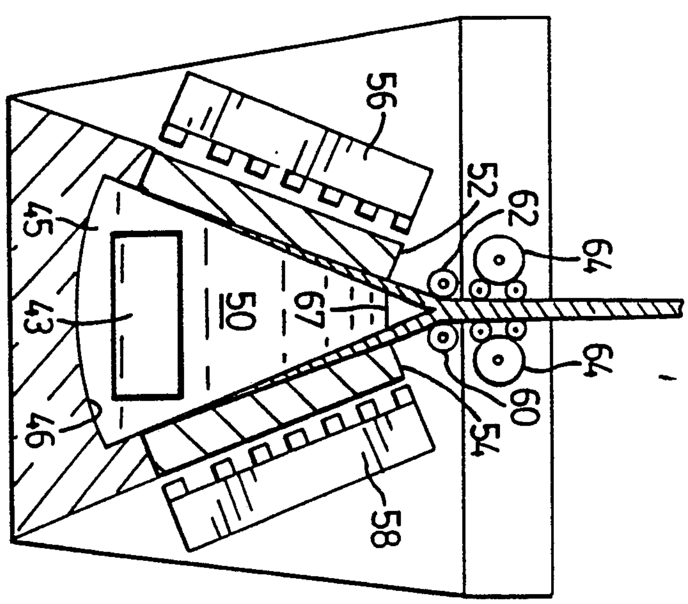


FIG. 5

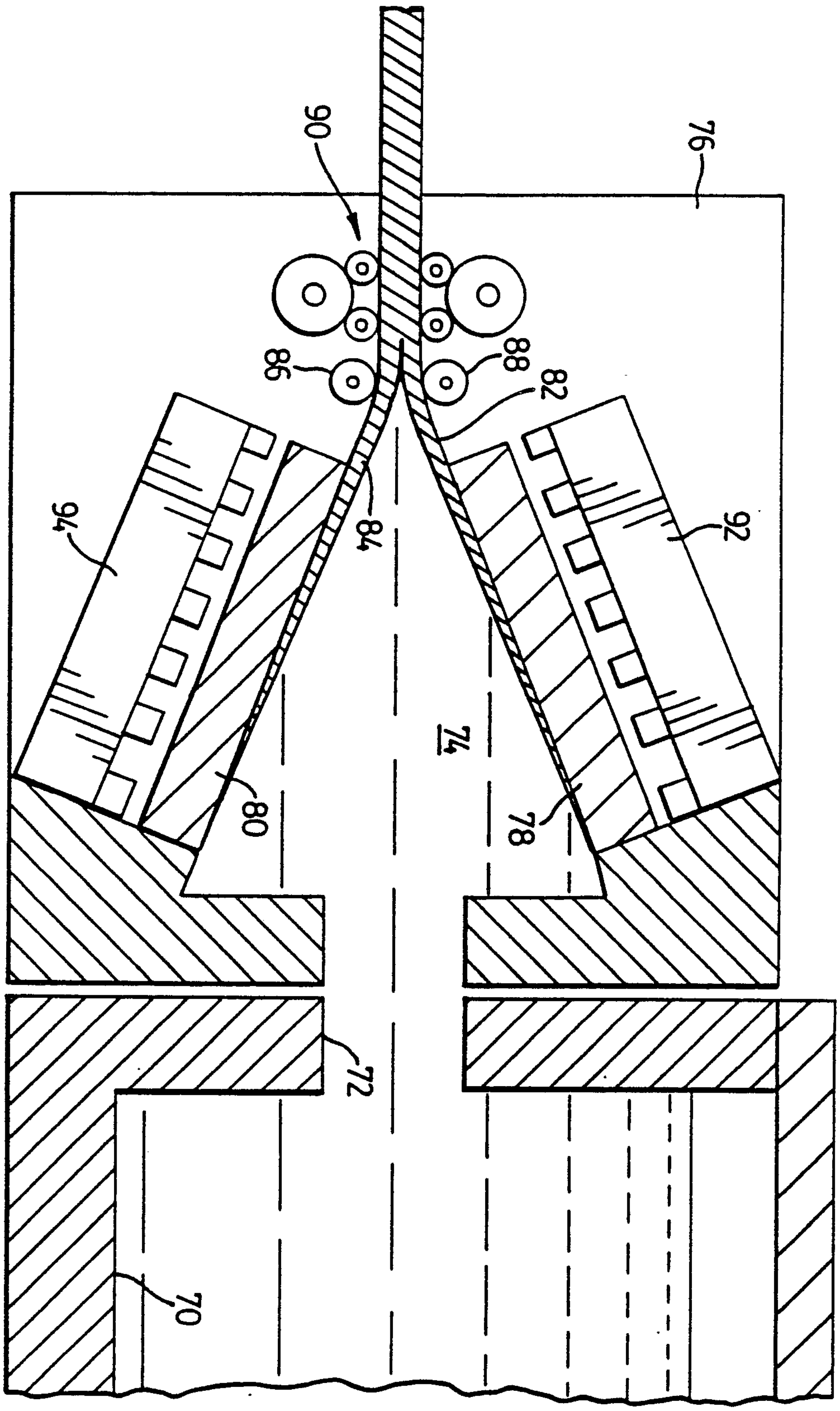


FIG. 6

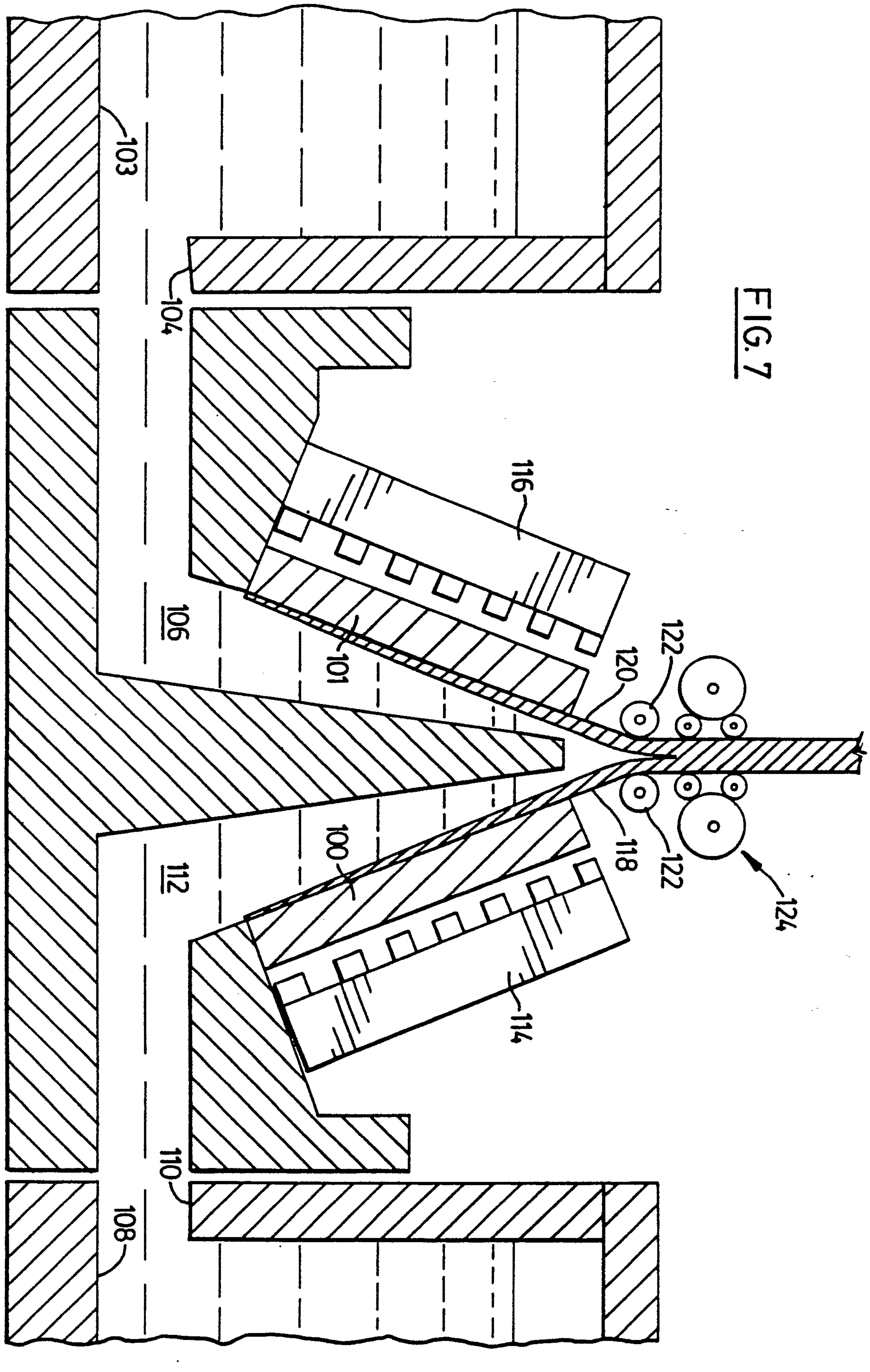


FIG. 7