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54 **Method and apparatus for forming a continuous strip.**

57 Apparatus for continuously casting a strip of metallic bearing material comprising a stationary nozzle 11 and a rotating drum 16. Molten bearing material is fed under pressure to a convergent space 22 between the nozzle 11 and the drum 16 via a slot 25. The material solidifies within the space 22 after coming into contact with the drum surface and leaves as a solid strip by means of an outlet opening 23.

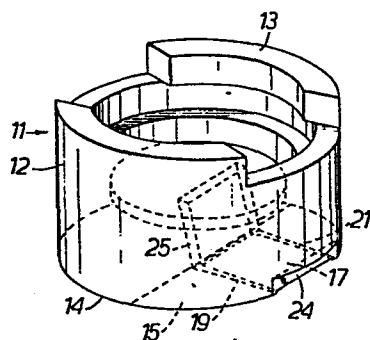


Fig. 4.

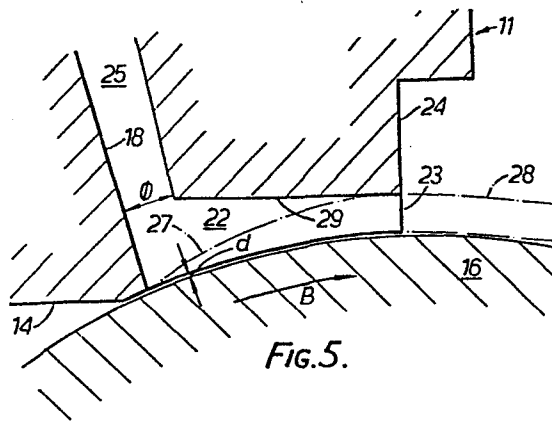


Fig. 5.

1.

METHOD AND APPARATUS FOR FORMING
A CONTINUOUS STRIP

5. The present invention relates to the continuous formation of a strip material, in particular a metal alloy strip for use as a bearing material, however, the invention may be applicable to other materials for other uses.

10. Various methods exist for what is effectively the continuous casting of metal alloy strips by rapid cooling. One of these is known as "Melt Spinning". In this process a stream of molten metal is directed against a rapidly moving chill surface, such as a wheel or belt, where it is cooled instantaneously. This is
15. generally used for the manufacture of thin films, for example of about 10^{-5} m in thickness, and frequently suffers from the disadvantage that it can be very difficult to obtain an even stream distribution.

In order to obtain a thicker strip, a process
20. known as "Melt Drag" has been devised. In this process, the molten metal is made to form a meniscus of molten metal between the outlet of a nozzle and the surface of a cooled drum or belt. As the drum surface is
25. rotated with an upward component past the meniscus, molten metal is dragged up and away from the meniscus and cools on the drum surface to form a strip.

Although relatively thicker strips can be manufactured by the melt drag technique, it does tend to suffer from a number of disadvantages. Firstly, it is
30. almost impossible to predetermine the strip thickness

with any great accuracy since it is dependent on a number of variables such as temperature, drum speed and metal viscosity. Secondly, it is very difficult to avoid variations in thickness across the strip due
5 to edge effects. Thirdly, the moving drum frequently entrains air (or some other gas) bubbles as it encounters the molten metal which are then entrapped within the cooling strip to leave voids in the strip.

It is an object of the present invention to provide
10 a process for continuously casting a strip of material with an accurate uniform thickness. It is a further object to provide a strip with a high surface finish and without voids.

According to one aspect of the present invention,
15 there is provided a method of continuously casting a strip of material in which a shaping die is brought into contact with a relatively moving chill surface to define a space and an outlet opening between the die and the chill surface, the material in molten
20 form is applied to the die under pressure and is brought into contact with the chill surface within the space, the said pressure, the temperature of the chill surface and the speed of relative movement between the chill surface and the die are arranged so that as
25 the strip issues from the outlet opening its surface has solidified, and in which the strip is then removed from the chill surface.

Thus, the outlet opening effectively acts as a continuous casting die and its contours precisely define
30 the cross-section of the strip. It is important that the various parameters, particularly the pressure, are

- arranged as defined above so that freezing occurs just prior to or at the outlet opening since, for example, if the pressure is too low, the molten material may freeze in the die, while if the pressure is too high, the material may leave the outlet opening while still molten, thus losing the die effect of the outlet opening.
- 5.

- The combination of the pressure and the die effect of the outlet opening helps to ensure that no gas is entrained in the strip material, with the consequent absence of voids, and also tends to improve the surface correspondence between the formed strip and the chill surface. The pressure also tends to improve heat transfer to the chill surface, thus increasing the cooling rate of the strip.
- 10.

- According to another aspect of the invention, there is provided apparatus for continuously casting a strip of material comprising a shaping die and a relatively movable chill surface, the die being arranged to direct the material in molten form on to the chill surface within space defined between the die and the chill surface, the die and the chill surface together defining an outlet opening through which the strip issues.
- 15.
- 20.

- The outlet opening is preferably a uniform slot though it may be non-uniform, for example to compensate for edge effects or centre effects. Thus, the slot may be deeper at the edges than it is in the centre, either by having a centre depression or by having "bulbous" edges.
- 25.

- The pressure may be brought about by the head of molten material above the die or may be exerted by external means, such as gas pressure above the molten material. The molten material may be held in a
- 30.

crucible or an equivalent vessel above the die and may be maintained in the molten state by external heating means with optional stirring, for example radio frequency stirring.

5. In order to prevent the pressure forcing the molten material out of the apparatus other than through the outlet opening, the space is preferably defined by a rear wall and two side walls formed on the die which closely contact the chill surface to leave the outlet opening opposite the rear wall. The space preferably:
10. converges towards the outlet opening from the rear wall.

- Then is then a hydrodynamic effect as the molten metal is forced into the narrowing gap, which in turn forces the solidifying strip on to the chill surface, thus
15. expelling any entrained gas and helping to cause the chill surface to draw out the solidified strip. The pressure should be arranged so that it does not exceed the value of $4\gamma/d$, where γ is the surface tension of the molten material and d is the contact clearance between
20. the die and the chill surface.

- Preferably, the molten material is delivered to the space via an inclined slot so that the change in direction of the molten material in the die is optimised. Too steep a slot may result in turbulence in
25. the molten material while too shallow a slot may affect the transmission of the pressure. Thus, an inclination of between 45° and 80° , e.g. 70° to the direction of strip formation is preferred. The bore of the slot may be about 1.5mm.

- The chill surface may comprise a belt or, more
30. preferably, a cylindrical drum and the relative movement

between the chill surface and the die is preferably effected by moving the chill surface, for example by rotating the drum or by driving the belt. The speed of relative movement may be between 0.1 and 10.0 m/s, preferably between 0.75 and 2.0 m/s e.g. 1.5 m/s.

5. The chill surface preferably has a high surface finish, for example $\pm 10^{-6}$ or thereabouts and is preferably highly conductive. The surface composition may be a copper alloy or stainless steel. The die
10. is preferably made from a non-metallic refractory material, for example zirconia or silicon nitride which is both heat and wear resistant.

- The apparatus may be surrounded by an inert atmosphere e.g. nitrogen. This may be achieved by
15. enclosing at least a part of the apparatus in an inert atmosphere, or by blowing an inert gas over the die region. In addition, or alternatively, means is preferably provided to remove any layer of air adhering to the drum surface. Such means might take the form of
20. a suction device or a wiper or scraper for the drum surface.

- The present invention is particularly applicable to the manufacture of metal bearing alloys, for example alloys of aluminium with tin, copper and optionally
25. silicon or nickel, particularly, Al with 20% Sn and 1% Cu and Al with 11% Si and 1% Cu. Previous methods of obtaining these alloys in strip form have generally necessitated casting billets of the alloys and then rolling these down. It is common to cast the material
30. at a thickness of over 15mm and then to roll this down

- to about 1mm in three passes in order to obtain the desired microstructure. This is, of course, very wasteful in terms of manpower, equipment and energy, particularly since it is necessary with many alloys to head/anneal the material between the roll passes.
- 5.

- However, with the method and apparatus according to the invention, this can be avoided; in fact, it may be possible to form the strip to the required thickness directly. This thickness may be between 0.5 and 2.5mm, or perhaps 0.75 to 1.5mm for example about 1.0mm.
- 10.
- Furthermore, since the cooling is so rapid, the microstructure of the alloy tends to be extremely fine (particularly at the face contacting the chill surface) so that the material may exhibit an improved ductility.
- 15.
- As a result, the alloys tend to be more workable and in fact, alloys which have hitherto been considered too brittle may now be used in bearing applications where roll bonding to a backing is called for. Certain alloys of aluminium and silicon may fall into this category,
- 20.
- particularly Al with 10.6% Si and 1% Cu. For aluminium/tin, it has been found that 80% of the alloy solidifies by the time the temperature has reached 500°C, though a temperature of about 200°C is required to allow convenient handling. With aluminium/silicon/tin, or
- 25.
- alloys sold under the Trade Mark Lo-eX, these are handleable at about 575°C, while copper/lead can only be handled at about 300°C. Since the strip tends to come off a drum at perhaps about 480°C in the case of a 0.5m diameter drum, the strip may be supported on an air
- 30.
- cushioning system since this involves no physical handling and also cools the strip.

When the invention is applied to an aluminium/tin alloy, further advantages are observed. One of the problems with Al/Sn as a bearing material is the difficulty in forming a direct bond with a steel backing.

5. This is due to the presence of regions of pure tin at the surface. However, the rapid cooling employed in the method of the present invention results in a microcrystalline surface layer of the bearing material where it contacts the chill surface.
10. The cooling is so rapid that a non-equilibrium or metastable microstructure is formed in which the tin is present as an atomic dispersion or solid solution, i.e. it is frozen in the form in which it was when in liquid solution before the tin atoms have had time to
15. agglomerate. When the alloy is in this form there is no tendency for the tin to affect the bond to a steel backing.

- However, from the point of view of its bearing properties, it is highly desirable to have agglomerated
20. tin particles in the alloy. In the process of the present invention, as the cooling rate decreases through the thickness of the strip, so the proportion of agglomerated tin increases, though of _____

course the actual proportion of tin itself is generally constant throughout the strip. Thus, a strip may be produced which has one surface whose properties enable it to be bonded directly to a steel backing and
5 another surface which has the desired bearing properties.

This is probably also true for many other alloys which include a relatively hard and relatively soft phase, for example Al/Pb.

In some instances where a relatively thick and
10 wide strip is to be produced, it may prove to be difficult to start the casting process cleanly since there is a tendency for the molten metal to dribble out of the die before the drum has begun to rotate at the correct speed. This may affect the control
15 of the entire run. It is therefore a further object of the invention to ensure a clean start to the casting process.

According to another aspect of the present invention, there is provided a method of continuously casting a
20 strip of material in which a shaping die is brought into contact with a relatively movable chill surface to define a space and an outlet opening between the die and the chill surface, the material in molten form is applied to the die and is brought
25 into contact with the chill surface within the space, a negative pressure is applied to the molten material, and in which, when the relative movement between the die and the chill surface is at the desired speed, a positive pressure is applied to the molten metal
30 at the chill surface.

Thus, there is preferably also provided in the

apparatus according to the invention some means to apply a negative pressure to the molten material within the space.

5. Preferably, the negative pressure is achieved effectively by "sucking" at the molten material while the positive pressure is achieved by applying an inert gas, e.g. nitrogen, to the molten material. In this way, a clean start to the casting operation may be achieved when the drum is rotating at the correct speed.

10. It is believed that if hpg is greater than $\frac{4\gamma}{\phi}$; where h is the head of molten material; p is the density of the molten material; g is the force exerted by gravity; γ is the surface tension of the molten material, and ϕ is the bore of the slot leading to the space, then dribbling will occur. In order to ensure that no dribbling occurs, a negative pressure is applied thereby effectively reducing the effect of the term hpg .
- 15.

- However, it is important that the negative pressure applied is not sufficiently great to suck gas bubbles back through the molten material. Thus the negative pressure should not exceed $hpg + \frac{4\gamma}{\phi}$.
- 20.

- To ensure the desired characteristics, the positive pressure P applied to the molten material should be greater than $\frac{4\gamma}{\phi}$. In practice it has been found that an applied pressure of 2 to 15 psi (70 to 1050 kg/m²), preferably 3 to 8 psi (210 to 560 kg/m²), for example 5 psi (350 kg/m²), is generally sufficient. In practice, the negative pressure is a function of $\gamma\phi p$ and the positive pressure is controlled in _____
- 25.

dependance upon the drum speed, the die dimensions and the density and surface tension of the molten material. This control is preferably achieved by an automatic control system which may also make pressure adjustments during a casting run.

5.

In an alternative system for starting up the casting process, a stopper rod may be used. This stopper rod would be movable from a closed position in which the molten metal is prevented from contacting the chill surface and an open position in which the molten metal is allowed to flow through the die when the required parameters have been achieved.

10.

The invention may also be applied to the formation of multi-layer strips. The strips may be formed sequentially from the molten state by methods in accordance with the invention.

15.

After the strip has been produced and removed from the chill surface, it can either be directed to a coiling or take up device or may be fed directly to roll bonding apparatus for bonding to a backing.

20.

The invention may be carried into practice in various ways and some embodiments will now be described by way of example with reference to the accompanying drawings in which:-

25.

Figure 1 is a side view of a shaping die for use in the present invention;

Figure 2 is an end view in the direction of arrow A in Figure 1;

Figure 3 is a plan view of the die;

30.

Figure 4 is an isometric sketch of the die with

much of the hidden detail omitted for clarity;

Figure 5 is a vertical section to an enlarged scale thorough a portion of the die;

5. Figures 6 to 8 are simplified isometric sketches showing the underside uppermost of alternative forms to die; and

Figure 9 is a schematic side view of another embodiment of the invention; and

10. Figure 10 is a view similar to Figure 9 showing a further embodiment of the invention.

Referring firstly to Figures 1 to 4, the shaping die is in the form of a nozzle 11 which has a generally cylindrical body 12 composed of silicon nitride. The upper part of the body 12 is generally hollow and has a bayonet fitting 13 for attaching the nozzle 11 to a suitable crucible (not shown) for a molten bearing alloy. The underside of the nozzle 11 has a flat portion 14 and an upwardly curved concave portion 15 whose curvature follows that of a cylindrical stainless steel drum 16 as shown in Figure 5.

A channel 17 is formed in the curved portion 15 having a rear wall 18 and two side walls 19, 21. Thus, when the nozzle 11 is in position on the drum 16 as shown in Figure 5, the channel defines with the drum a space 22 which gradually converges towards an outlet opening 23 between the nozzle 11 and the drum 16.

The outlet opening 23 is in the form of a rectangular slot, the cylindrical surface of the drum 16 having been cut away as shown at 24.

The space 22 is connected to the hollow interior of the nozzle 11 by an inclined slot 25. The slot 25 may be of constant cross-section or may converge downwards as shown in Figure 5 or as shown by the chain line 26 in Figure 1. The gauge of the slot 25 is 1.5mm.

In use, the nozzle 11 is located on the surface of the drum 16, as shown in Figure 5, with the bases of the rear wall 18 and two side walls 19, 21 in close contact with the drum surface leaving a contact clearance d. Molten material is then fed under pressure to the

nozzle 11 and travels down the slot 25 to the space 22, thus coming into contact with the surface of the drum 16, which is rotated with a peripheral speed of about 1.5m/s in the direction of arrow B. The molten material

5. solidifies by transferring heat to the drum 16, the solidification front being totally within the space 22 and being indicated generally by the chain line 27 in Figure 5. The pressure on the molten material and the rotation of the drum draws the solidified strip out of
10. the outlet opening 23 as shown in broken lines 28. The solidified strip remains in contact with the drum for a short distance after leaving the nozzle and is then removed. Since the strip has solidified before leaving the space 22, the contour of the outlet opening 23
15. defines precisely the cross-sectional shape of the strip.

- The convergent shape of the space 22 enhances the hydrodynamic effect of the molten material which exerts pressure on the forming strip which in turn tends to
20. expel any bubbles from the material of the strip while also improving the surface finish. Although the top surface 29 of the space 22 is shown as being horizontal and planar, it could be inclined and or somewhat curved to follow to an extent the curvature of the drum 16.

25. As will be seen from the solidification front 27, the maximum cooling rate is at the drum surface and decreases through the thickness of the strip. Thus, in the case of an aluminium/tin alloy, the material at the lower surface tends to be a solid solution, with the tin
30. present as an atomic dispersion, while the material at the upper surface includes agglomerated tin atoms giving

- rise to tin particles. In order to maintain the conditions to ensure that the solidification front 27 is entirely within the space 22 (so that the outlet opening 23 defines the strip cross-section) the drum 16 may be
5. cooled and the nozzle 11 may be heated or cooled near the outlet opening 23. In this regard, the pressure on the molten material must also be taken into consideration to ensure that it is sufficient to prevent the molten material solidifying so rapidly that a blockage occurs,
10. but that its value is below $4\gamma/d$, where γ is the surface tension of the molten material and d is the contact clearance, so that the molten material is not squeezed out past the rear and side walls 18, 19 and 21.

- Thus, in order to achieve the desired conditions,
15. it will be necessary to adjust various parameters including drum rotation rate, molten material temperature, drum surface temperature and pressure, depending on the nature of the molten material and the thickness of the strip. Means may be incorporated to vary the thickness
20. of the strip, the angle of the channel 22 leading to the outlet opening etc..

- Figures 6 to 8 show alternative forms for the slot connecting the channel 17 to the interior of the nozzle 11. The nozzles are shown upside down and have been
25. simplified for clarity by omitting the interior detail of the nozzles and the cutaway portion 24. However, the slots are shown as being vertical as opposed to inclined and this is indeed a possible alternative. In fact, the slots could also be vertical and generally convergent
30. towards the channel 17.

In Figure 6, the slot 25 and therefore the rear wall 18, are angled. This may help to increase the flow of material for a given strip thickness.

5. In Figure 7, the slot 25, and therefore the rear wall 18 are curved, so as to be concave from the direction of the channel 17. This may help to compensate for uneven cooling due to edge effects.

10. In Figure 8, the slot 25 and the rear wall 18 are set at an oblique angle to the side walls 19, 21. This may help to increase the flow rate of molten material, which may be required in the case of a thicker strip.

15. Figure 9 shows a second embodiment in which the solidified strip 31 is maintained in contact with the drum 16 rather than removing it almost immediately as shown in Figure 5. In this instance the strip is in contact with the drum through about 180° and is then run out on rollers 32, though a belt or a run-out table may be used in place of the rollers 32. This arrangement
20. has the advantage that the strip 31 is in contact with the drum 16 for a considerably greater length of time, thus enabling more heat to be transferred to the drum 16 with the result that the strip 31 is much cooler and probably easier to handle as it runs out.

25. In order to help to keep the strip 31 on the drum 16 prior to run-out, a shroud 33 surrounds that portion of the drum 16 which the strip 16 contacts. The shroud 33 has a compressed air inlet 34 supplying air at about 80 psi and a series of outlets of slits 35 directed
30. towards the strip 31 on the drum 16. The air pressure on the strip 31 also helps to improve the heat transfer to the drum 16.

In the embodiment shown in Figure 10, the rollers 32 are replaced by an air cushioning system 41 on which the strip 31 is supported. This arrangement is particularly suitable in the case of high melting point alloys, such as Cu/Pb which comes off the drum at about 480°C. Under these conditions, the strip 31 is rather difficult to handle directly, and the air cushion additionally helps to cool the strip further.

While the shroud 33 is shown as being spaced from the strip surface, it can equally well be arranged to provide an effectively sealed channel for the air along the lines of the "hovercraft principle" in order to minimise the amount of air used. Furthermore, although high pressure air is used in this embodiment, it might be preferable to use helium, which although more costly, has a better cooling effect.

In order to aid the separation of the strip 31 from the drum 16 a high pressure air knife 36 is located at the take-off point. This delivers air at about 80 psi.

The rollers 32 may be replaced by an air cushioning support system. This has the advantage of cooling the strip without physical contact.

Although in all the embodiments described, the nozzle 11 is shown as being generally circular, it could of course be any appropriate shape e.g. square or rectangular when viewed from above.

Furthermore, although the invention has been described as being suitable for aluminium based bearing alloys, it is also suitable for tin and lead based white metals, for example Sn/Cu/Sb optionally with additional chromium and cadmium and Pb/Sb/Sn and also for copper based alloys such as Cu with lead and/or tin, optionally with zinc.

CLAIMS

1. A method of continuously casting a strip of material in which the material in molten form is brought
5. into contact with a relatively moving chill surface, is solidified on the chill surface and is then removed from the chill surface characterised in that a shaping die is place in contact with the chill surface to define a space and an outlet opening between the die and the
10. chill surface, the material in molten form is applied to the die under pressure and is brought into contact with the chill surface within the space, and the said pressure, the temperature of the chill su-rface and the speed of relative movement between the chill surface
15. and the die are arranged so that as the strip issues from the outlet opening its surface has solidified.

2. A method as claimed in Claim 1 characterised in that the said pressure is as a result of the head of
20. molten material above the die.

3. A method as claimed in Claim 1 characterised in that the said pressure is exerted on the molten material by external means.

25.

4. A method as claimed in any preceding Claim characterised in that the space converges towards the outlet causing a hydrodynamic pressure as the molten material passes through the space and solidifies.

5. A method as claimed in any preceding claim characterised in that the relative movement between the die and the chill surface is achieved by moving the chill surface.

5.

6. A method as claimed in any preceding claim characterised in that the relative speed between the chill surface and the die is between 0.1 and 2.0 metres per second.

10.

7. A method as claimed in any preceding claim characterised in that, prior to casting, a negative pressure is applied to the molten material, and when the relative movement between the die and the chill surface is at the desired speed, a positive pressure is applied to the molten material at the chill surface.

15.

8. A method as claimed in any of Claims 1 to 6 characterised in that the molten material is initially prevented from contacting the chill surface by a stopper and when the relative movement between the die and the chill surface is at the desired speed, the stopper is moved, thus allowing the molten material to contact the chill surface.

20.

25.

9. Apparatus for continuously casting a strip of material comprising means for supplying the material in molten form and a relatively movable chill surface, characterised by a shaping die arranged to direct the material in molten form on to the chill surface within a space defined between the die and the chill surface, the die and the chill surface together defining an outlet opening through which the strip issues.

30.

10. Apparatus as claimed in Claim 9 characterised in that the space is defined by a rear wall and two side walls form on the die, and converges from the rear wall towards the outlet opening.

5.

11. Apparatus as claimed in Claim 9 or Claim 10 characterised in that the die includes an inclined slot to direct the molten material to the space.

10. 12. Apparatus as claimed in any of Claims 9 to 11 characterised in that the chill surface comprises a cylindrical drum with a highly conductive and highly polished surface of a copper alloy or stainless steel.

15. 13. Apparatus as claimed in any of Claims 9 to 12 characterised in that the die is made from a non-metallic refractory material.

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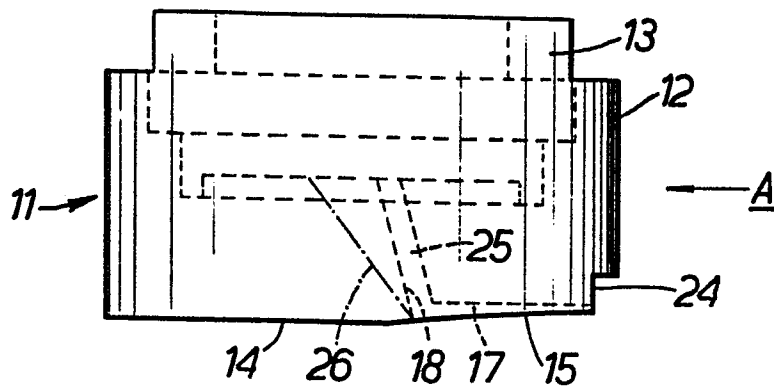


FIG. 1.

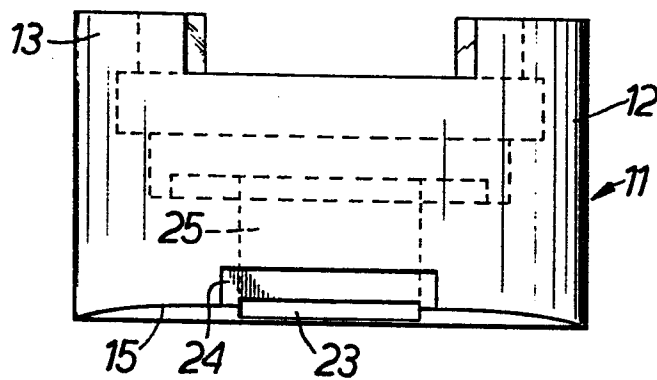


FIG. 2.

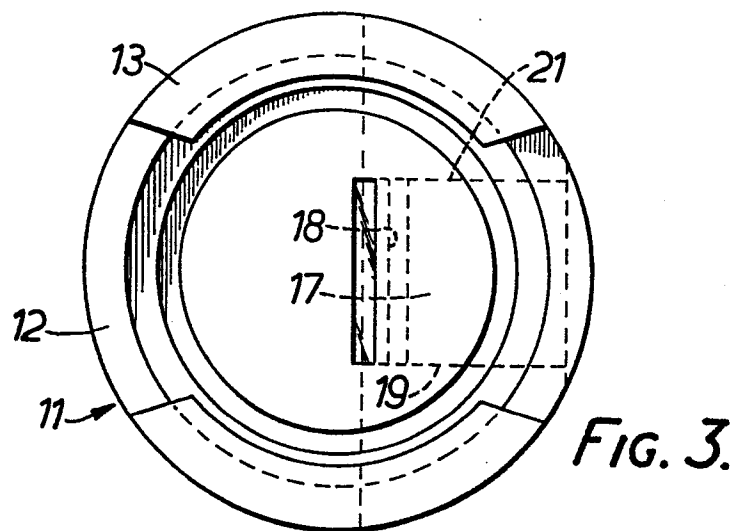
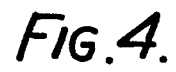


FIG. 3.



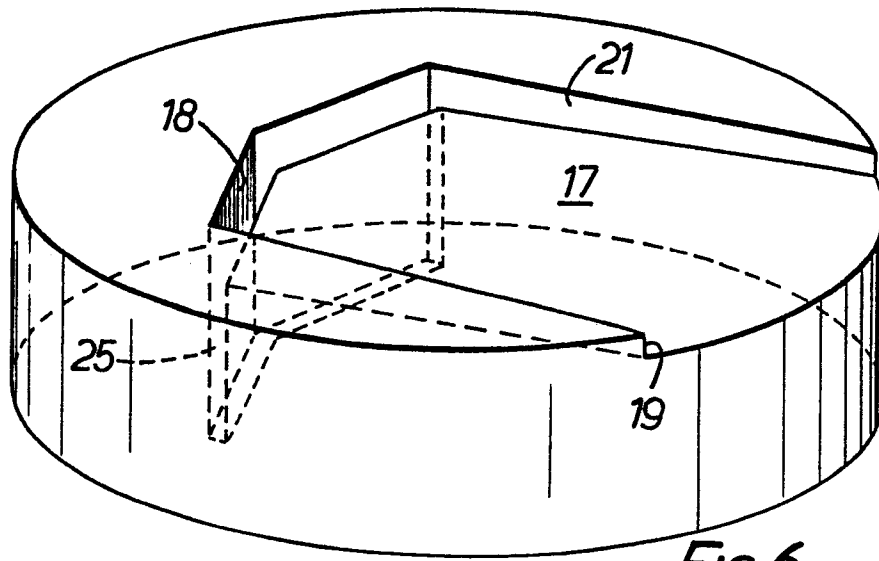
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FIG. 6.

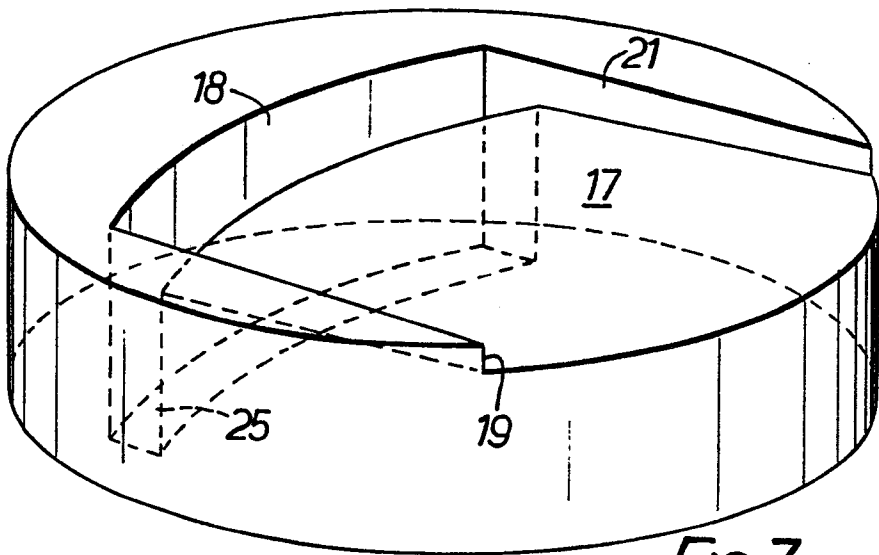


FIG. 7.

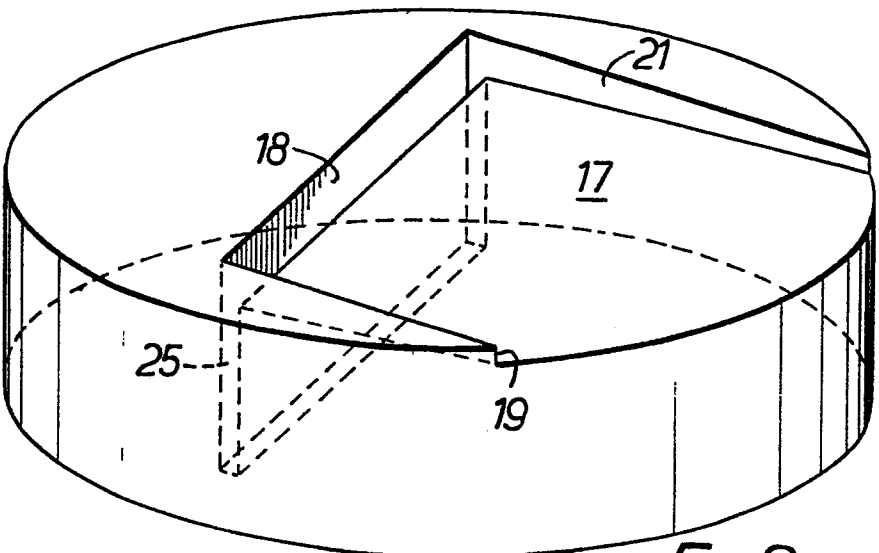


FIG. 8.

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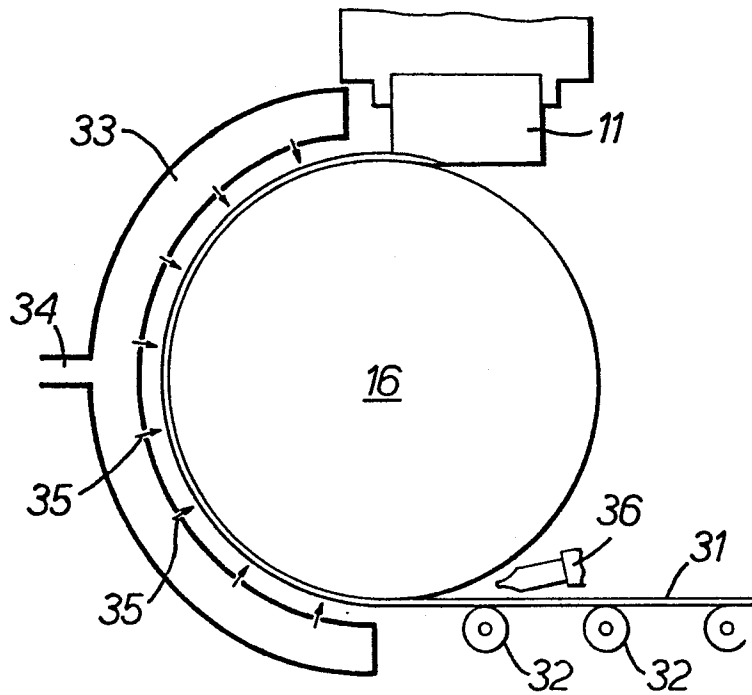


FIG. 9.

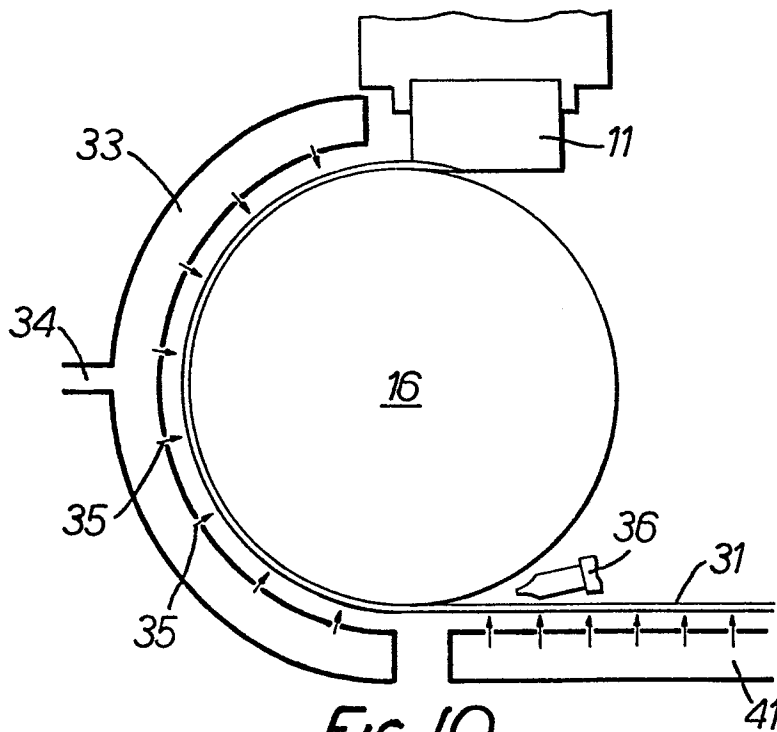


FIG. 10.