ABSTRACT: A method and apparatus for manufacturing wire and the like by maintaining static equilibrium in molten material at the outlet of a nozzle to form a convex meniscus from which the material is continuously drawn off and solidified by means of a moving surface at constant temperature.
The present invention relates to a method of manufacturing a continuous product such as a metallic wire or strip from a molten material, comprising bringing forward said molten material continuously to the outlet orifice of a nozzle and moving a surface past said orifice so as to form the desired product thereon.

The methods of manufacturing by drawing or rolling out, which are normally used for producing metallic wires and strips, require a great number of operations and relatively complicated installations adapted to each product.

Certain conventional continuous casting methods for metals consist in creating a flow of molten material which is directed towards a moving surface serving to solidify and remove said material continuously. Manufacturing a product in this manner from the molten material obviously presents considerable advantages, in particular an appreciable reduction of the number of operations required. To obtain a uniform product having given quality and dimensions, one must, however, be able to pour said metal at a controlled rate so as to control the metal feed speed in a precise manner so as to keep it always equal to the speed of removal of the metal by means of said moving surface. When, however, the desired product has a small cross-section, such as is the case for a thin metallic wire or strip, none of the known continuous casting methods allow the metal feed speed to be controlled in a sufficiently precise manner to produce a uniform continuous product.

In order to avoid this disadvantage, a method of continuous casting has been proposed which does not entail the usual pouring operation. This method consists in moving a mold which is open at the side downwards through a bath of molten material kept at constant level, whereby said material continuously fills the cavity of said mold. The material in the mold is subsequently cooled to form the desired product. The speed at which the molten material is capable of flowing into the mold is, however, rather limited, especially in the case of a product having a small cross-section. Furthermore, extraction of the product from the mold is difficult. Thus, this method is not suitable for continuous, high-speed production of such a product.

The object of the present invention is to provide a method allowing any uniform continuous product, and in particular a metallic wire or strip having a small cross-section, to be continuously manufactured in a simple manner from a molten material. With this object in view, the method according to the invention, comprising bringing forward said molten material continuously to the outlet orifice of a nozzle and moving a surface past said orifice so as to form the desired product thereon, further comprises the steps of: maintaining said material at said orifice at a constant temperature and pressure, said pressure being chosen to provide static equilibrium to allow said material to form a convex meniscus projecting at said orifice, bringing said moving surface into contact with said meniscus to draw off said molten material continuously therefrom; and maintaining said surface at a constant temperature such that said material solidifies progressively thereon to form the desired product.

Thus it may be seen that the method according to the invention consists essentially in maintaining the molten material, at a constant temperature and at an appropriate static pressure, at the outlet of a nozzle such that the said material forms, at said outlet, a convex meniscus due to the equilibrium between the pressure and the surface tension thereof, and in carrying away from said meniscus the material serving to form the desired product. Thus, in the present method, the disadvantage of the conventional operation which consists in pouring the material are completely eliminated by keeping the various parameters at constant values such as to effect the material feed solely by dragging off said material by means of a moving surface kept at constant temperature. The principle on which the present invention is based thus consists in using a moving surface to effect a continuous "wiping" action on a meniscus formed by the molten material while maintaining the pressure in the latter within the limits corresponding to static equilibrium in order to allow replacement of the material removed by said surface. It is thus the speed of said moving surface which mainly determines the flow speed of the molten material. As will be seen below, the range of pressures extending between said limits is relatively large so that the conditions necessary for static equilibrium may be easily established, thus allowing stable flow and consequently a uniform product to be obtained in all cases.

The present invention also relates to an apparatus for manufacturing a continuous product by said method. This apparatus comprises: a reservoir having at least one outlet pipe provided with a nozzle; means for maintaining said reservoir at atmospheric pressure; an adjustable heating device for maintaining said material, in said reservoir and in said pipe, at a constant temperature lying above the melting point thereof; a regulator for keeping the free surface of said material in the reservoir at a desired constant level lying above said pipe; a drum adapted to rotate about a horizontal axis such that the peripheral surface thereof moves continuously past the outlet orifice of said nozzle, at a given adjustable distance therefrom; first adjustable drive means for rotating said drum at a given speed; and means for delivering a stream of fluid at an adjustable temperature for circulation within said drum to keep said drum surface at a desired constant temperature.

The accompanying drawing represents, by way of example, an embodiment of an apparatus according to the invention as well as a variant of said embodiment, said apparatus being intended, in particular for manufacturing a metallic wire.

FIGURE 1 is a vertical cross-section of said embodiment.

FIGURE 2 shows a variant of the apparatus represented in FIGURE 1.

FIGURE 3 shows schematically, on a larger scale, a detail of FIGURES 1 and 2.

The device represented in FIGURE 1 comprises a reservoir 1 of refractory material such as alumina, which is open at the top and arranged within a chamber 2 formed by insulating walls 3, 4. This chamber 2 is equipped with an electrical heating element 5 and forms a furnace resting on an adjustable support 6. A horizontal outlet pipe 7, likewise of refractory material e.g. alumina, is mounted on the reservoir 1 and passes through the side wall of the chamber 2. This pipe 7 is surrounded by an insulating jacket 8 and by an electrical heating element 9. A nozzle 10 having a free-cross-section adapted to the profile of the desired product is mounted at the outlet of the pipe 7. As may be seen in FIGURE 1, the reservoir 1 contains molten metal M having a free surface situated at a given small height above the pipe 7.

The heating elements 5 and 9 are connected to an A.C. source 11 by means of control devices 12 and 13 which regulate respectively the heating currents passing through said elements. Two thermo-couples 14, 15 serve to measure the temperature of the molten metal in the reservoir 1 and at the outlet of the pipe 7 respectively and to control operation of the control devices 12, 13 so as to maintain the material surrounding said thermo-couples at predetermined temperatures.

This apparatus further comprises a hollow steel drum 16 mounted on a horizontal shaft and rotatably driven by means of an adjustable-speed motor 17, the means for controlling the speed of said motor being omitted from the drawing. This drum 16 has a smooth peripheral surface and is arranged so that this surface moves upwards, at a given constant speed, past the outlet orifice of the nozzle 10. So as to allow the exact position of the outlet of the nozzle 10 with respect to the peripheral surface of the drum 16 to be determined, according to the product to be manufactured, the support 6 on which the furnace rests further comprises two mechanisms (not shown) serving respectively for horizontal and vertical displacement of the furnace. Furthermore, said drum surface is kept at an appropriate constant temperature by means of a stream of water circulating within the drum 16, said flow being supplied.
by a constant-temperature water-bath 18. This bath comprises a coil 19 in which cold water circulates continuously, an electrical heating element 20 and a pump 21 adapted to continuously circulate water, by the supply and return conduits 22 and 23 respectively, between the bath 18 and the drum 16. A control device 24 further serves to regulate the heating current delivered to the heating element 20 from an A.C. source 25, as a function of the water temperature measured by means of the thermo-couple 26, such that a constant desired temperature is maintained in the bath 18. The wall 4 forming the core of another resistor 2 is provided with a pipe 27 which serves for the introduction of a charge of molten metal into the reservoir 1. This pipe further serves to maintain the chamber 2, and consequently the reservoir 1 at atmospheric pressure during operation of the apparatus.

The level of the free surface of the molten metal in the reservoir 1 is controlled by means of a regulator comprising a piston 29 driven by an electrical motor 30. As may be seen in FIGURE 1, this motor 30 is connected to the piston 29 by means of a conventional transmission and reduction mechanism formed by a pulley 31 fixed to the shaft of motor 30, and endless belt 32 and a second pulley 33 co-operating with a vertical shaft 34 to which the piston 29 is fixed. Well known means (not shown in FIGURE 1) comprising, in particular, internal and external screw threads arranged respectively on the pulley 33 and at the upper end of the shaft 34, allow the rotational movement of the pulley 33 to be transformed into a linear vertical movement of the piston 29.

The operation of motor 30 is controlled by a switch 35 arranged in the supply circuit thereof which is connected to the A.C. source 25, said switch 35 being actuated by excitation of a relay 37. Two electrodes 38, 39, of which one (38) is adapted to be immersed in the molten metal and the other (39) is arranged so that the lower end thereof is situated at the desired level of said metal, are connected in series with the energizing coil of the relay 37 and a D.C. current source 40. Two switches 41 and 42 further serve to manually break the supply circuits of the motor 30 and the relay 37 respectively.

Thus when the surface of the molten metal is at the desired level, a galvanic contact is established, across the said metal, between the electrodes 38 and 39, whereby the energizing circuit of the relay 37 is closed and the motor 30 is stopped by means of the switch 35. When however, the surface of the metal is situated below the desired level, said galvanic contact is interrupted, the relay 37 becomes deenergized and the switch 35 closes. The motor 30 now being supplied with current, it drives the piston 29 so that the latter moves downwards progressively and as a result the metal surface rises until it attains the desired level once more and causes the motor 30 to be stopped.

The apparatus further comprises a wiping member 36 for cleaning that part of the drum surface which is about to come into contact with the molten metal.

As may be seen in FIGURE 2, the variant differs from the embodiment according to FIGURE 1 in that regard to the means for regulating the level of the molten metal. Thus identical components already described with reference to the first embodiment have the same reference numerals in FIGURES 1 and 2.

The regulation of the level of the molten metal is obtained, in this variant, by means of a bar 43 of the metal intended for manufacturing the desired product, said bar being connected by means of a flexible supply and return conduits 44 passing around two pulleys 45,46 to an electric motor 30. The latter is controlled in the same manner as described above with reference to the motor 30 of the embodiment shown in FIGURE 1 and thus serves to move the bar downwards progressively when the surface of the metal lies below the desired level. As a result, the lower part of the bar 43 is immersed progressively in the molten metal and thus the molten state so that the surface of the molten metal rises up to the desired level. Once this level is reached, the galvanic contact is established between the electrodes 38 and 39, the motor 30 stops and the downward movement of the bar 43 is interrupted.

The pipe 28 may also be used for the introduction of an inert gas such as argon substantially at atmospheric pressure so as to prevent oxidation at the metal surface.

FIGURE 3 shows schematically the manner in which the metal is drawn off, from the meniscus formed at the outlet orifice of the nozzle 10, by means of the drum 16. As may be seen in this figure, the meniscus (represented by dotted lines) may be more or less curved according to the height H of the metal level 33 and said level 7, i.e. above the axis of the outlet orifice of the nozzle 10. The height H which is maintained while manufacturing the product is chosen between the extreme positions I and II corresponding respectively to the minimum pressure for forming a convex meniscus and the maximum pressure constituting the limit of static equilibrium, beyond which the meniscus breaks and, consequently, the metal pours out of the nozzle 10.

The maximum height H2 (in cms) may be estimated in most cases, for nozzles with outlet orifices having small vertical dimensions of the order of a few millimeters, by means of the following formulae:

a. For circular outlet orifices:

\[ H_2 = \frac{2T}{R \cdot \rho \cdot g} \]

where \( T \) is the surface tension (dyne/cm) of the molten material at the orifice
\( R \) is the radius (in cms.) of the orifice
\( \rho \) is the density (g/cm³) of the molten material in the reservoir
\( g \) is the gravitational constant in cm/sec².

b. For rectangular outlet orifices having dimensions \( a \) x \( b \) (cms.), a being the vertical and \( b \) the horizontal dimension and a being much smaller than \( b \):

\[ H_2 = \frac{2T}{a \cdot \rho \cdot g} \]

where \( T, \rho \) and \( g \) are the same as indicated above.

To manufacture a given product by means of the apparatus described above, one proceeds as follows:

After having mounted at the outlet of pipe 7 a nozzle 10 having an orifice selected according to the section of the desired product, the heating elements 5, 9 are switched on so as to preheat the reservoir 1 and the pipe 7. The metal is next introduced slowly into the reservoir 1 so as to form therein a bath of molten metal at constant temperature, the surface of which rises progressively. When the level of the molten metal has attained a sufficient height above pipe 7 for the metal to form an appropriate convex meniscus at the outlet orifice of said nozzle 10, introduction of the metal into the reservoir 1 is stopped. The level which is chosen will obviously be situated between the limits I, II mentioned above, at a height giving a meniscus which is sufficiently curved to allow it to be brought into contact with the drum 16. The metal temperature at the orifice is preferably at least 20°C above the melting point of the particular metal.

The height of the electrode 39 is then adjusted so that the lower end thereof comes into contact with the metal surface which is situated at the desired level and the switches 41 and 42 are closed to allow the motor 30 and the relay 37 to operate.

The drum 16 is then heated to a temperature of at least 40°C by means of the bath 18 and made to rotate with a peripheral velocity which corresponds to the desired feed velocity of the metal. The meniscus formed at the orifice of the nozzle 10 is next brought into contact with the peripheral surface of the drum by adjusting the horizontal and vertical position of the support 6. So as to obtain the desired product, the various parameters, such as drum temperature and speed, metal temperature at the orifice and the minimum distance between orifice and drum may then be adjusted so that the molten metal is drawn off uniformly and the product solidifies.
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progressively on a portion of the periphery of the drum 16. Finally, appropriate take-off means (not shown) such as e.g.
roll systems may be used to separate the solidified product from the drum 16.

The product thus obtained may obviously be subjected to a
drawing out or rolling operation so as to modify the shape or
surface quality thereof.

The optimal operating conditions of the apparatus according
to the invention may thus be easily determined in each
case by varying, in turn, the temperature of the molten materi-
al at the said meniscus, the temperature of the moving surface
adapted to carry off the material and the speed of said surface
until the desired product is obtained.

It should be noted that the ratio H_a/H_b of the limiting heights
between which the liquid level may vary while manu-
facturing may easily be of the order of 5.1. It is thus obvious
that the height H is not critical for manufacturing the product,
provided it be kept between said limiting heights so as to keep
the drum surface in contact with the meniscus.

It may also be mentioned that the method according to the
present invention allows the rate of solidification of the
material on the moving surface to be controlled in a precise
manner especially by regulating the speed as well as the tem-
perature of this surface. This allows the crystal-line structure
of the product to be determined so as to confer desired
mechanical properties to said product.

The apparatus described above has allowed various con-
tinuous products, in particular wires and strips of aluminium,
the alloy known as anti-corroded, copper and steel to be manu-
factured; these products had uniform dimensions and were of
satisfactory quality.

Example 1

For manufacturing uniform wires made of aluminium,
copper and mild steel (1 % Cu) and having a diameter of 2 mm,
the apparatus is provided with a nozzle having a circular or-
ifice with a diameter of 2 mm and with a drum having a diame-
ter of 200 mm. One then manufactures in the manner described
above, while choosing the following values for the
various parameters: 003000

<table>
<thead>
<tr>
<th>Al</th>
<th>Cu</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>720</td>
<td>1,100</td>
<td>1,600</td>
</tr>
<tr>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

The manufacturing speed, which is equal to the peripheral
velocity of the drum, is about 38 meters per minute.

Example 2

For manufacturing strips of anti-corroded alloy (Al: 96.5 to
97.8%; Si: 0.5 to 1.5%; Mn: 0.2 to 1%; Mg: 0.5 to 1%)
the same drum is used as in Example 1. So as to obtain two types
(A, B) of strip having the dimensions 6 x 0.8 and 4.5 x 1 mm
respectively, the apparatus is provided with a nozzle having the
following dimensions: 004000

<table>
<thead>
<tr>
<th>Width in mm</th>
<th>Height in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>1.5</td>
</tr>
</tbody>
</table>

One then manufactures in the manner described above,
while choosing the following values for the various para-

ters: 005000

<table>
<thead>
<tr>
<th>Type A</th>
<th>Type B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature of alloy at orifice in °C</td>
<td>985</td>
</tr>
<tr>
<td>Temperature of peripheral surface of drum in °C</td>
<td>60</td>
</tr>
<tr>
<td>Rotational speed of drum, r.p.m.</td>
<td>60</td>
</tr>
<tr>
<td>Minimum distance between orifice and drum in mm</td>
<td>0.3</td>
</tr>
<tr>
<td>Height (H) of alloy above nozzle axis in mm</td>
<td>15</td>
</tr>
</tbody>
</table>

The manufacturing speeds were 6 and 4.4 meters per
minute, respectively. It may be mentioned that these strips had a
convex surface on the side opposite to that adhering to the
drum. A single rolling operation, carried out on the drum itself
by means of a roller exerting a pressure on the partially
solidified strip, allowed, however, a product having a rectangu-
lar cross-section to be obtained, the faces of said product
being perfectly smooth and the thickness thereof being easily
adjustable by varying said pressure exerted by the roller.

It may be mentioned that the peripheral speed of the drum
may be increased so as to obtain a product of smaller cross-
section than that of the orifice.

The apparatus described above has also been used for manu-
facturing aluminium fibres of a relatively short length by
rotating the drum (16) at much higher speeds than those indi-
cated above.

It should be mentioned that the method according to the in-
vention is also suitable for manufacturing a continuous
product from other materials than those mentioned above by
way of example. Thus materials may be considered particu-
larly suitable which do not allow manufacturing by drawing or
rolling, such as brittle intermetallic compounds having body-
centered cubic crystal ("BCC") structures or metallic oxides.

It is obvious that numerous other variants exist of the ap-
paratus for carrying out the method of the invention. Thus,
for example, instead of using a level-regulator to keep the surface
of the material at the pressure necessary for forming a
meniscus, it is possible to provide the apparatus with a device
allowing the pressure of a gas which is in chamber 2 and is in
contact with the surface of the material in the reservoir to be
controlled. Such a device is shown generally by reference nu-
meral 47. This device serves to increase the pressure of the gas
as the height of the metal level falls during operation of the ap-
paratus, such that the pressure of the material be kept at the
desired value at the orifice. This would allow a relatively high
column, i.e. a larger reserve of metal in the reservoir by choos-
ing a gas pressure below atmospheric pressure.

Furthermore, it is obvious that the nozzle serving to form
the meniscus may be oriented in any other direction than the
horizontal direction.

I claim:

1. A method of manufacturing a continuous product such as
a metallic wire or strip from a molten material comprising:
(a) providing molten material continuously available to a
nozzle;
(b) maintaining a convex meniscus of molten material
projecting from said nozzle;
(c) maintaining said material at a substantially constant
temperature until it exits from said nozzle;
(d) moving a heat extracting surface at a constant
predetermined speed in a path substantially parallel to
the outlet orifice of said nozzle and into contact with
said meniscus to continuously draw off material and
form a uniform continuous product, the speed of said
moving surface determining the rate at which material
passes through said nozzle;
(e) maintaining said surface at a constant predetermined
temperature below the solidification temperature of
said material whereby said material progressively
solidifies;
(f) directing said moving surface after contact with said
meniscus in a path which allows the deposited material
to gravitationally maintain continuous contact with
said surface until said material is solidified through sub-
stantially its entire cross section; and
(g) removing the product from said surface.

2. A method according to Claim 1, wherein the molten
material is brought forward from a reservoir to said nozzle
and is kept at the constant pressure necessary for forming said
meniscus by controlling the level of the molten material in said
reservoir.

3. A method according to Claim 1, wherein the material at
said nozzle is kept at the pressure necessary for forming said
meniscus by controlling the pressure of a gas in contact with the surface of the material in said reservoir.

4. A method according to Claim 2, wherein the surface of said material in said reservoir is kept at atmospheric pressure and the height of said surface above said nozzle is kept at a constant value allowing equilibrium to be established, at the nozzle orifice, between the static pressure and the surface tension of said material.

5. A method according to Claim 2, wherein an inert medium is maintained in contact with said surface of the molten material in said reservoir.

6. A method according to Claim 5, wherein said inert medium is argon.

7. A method according to Claim 1, wherein said material is heated in said reservoir and in any pipe connecting said reservoir and said nozzle such that the temperature thereof is kept constant at the nozzle and lies at least 20°C above the melting point of said material.

8. A method according to Claim 1, in which said moving surface is moved in an upward direction.

9. A method according to Claim 1, wherein said moving surface is kept at constant temperature by means of a circulating fluid at constant temperature.