United States Patent

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[54] **METHOD OF MANUFACTURING WIRE AND THE LIKE**
9 Claims, 3 Drawing Figs.

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[51] **Int. Cl.** **B22d 11/06**
[50] **Field of Search** .... 164/65, 66, 87, 133, 259, 281, 337; 264/212, 40 consulted Silbaugh; 117/34, 105.3; 118/7, 401, Bead Digest

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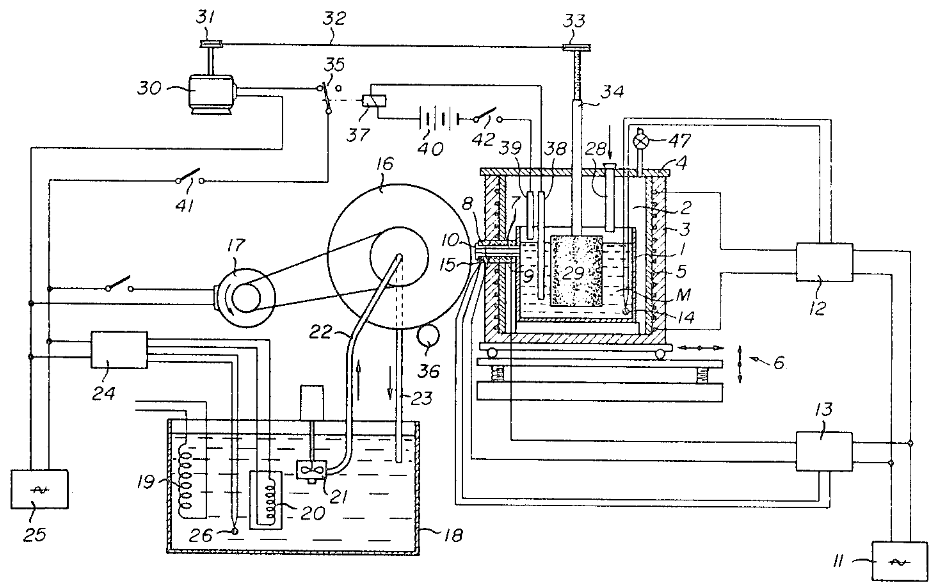
ABSTRACT: A method and apparatus for manufacturing wire and the like by maintaining static equilibrium in molten material at the outlet of a nozzle to form a convex meniscus from which the material is continuously drawn off and solidified by means of a moving surface at constant temperature.



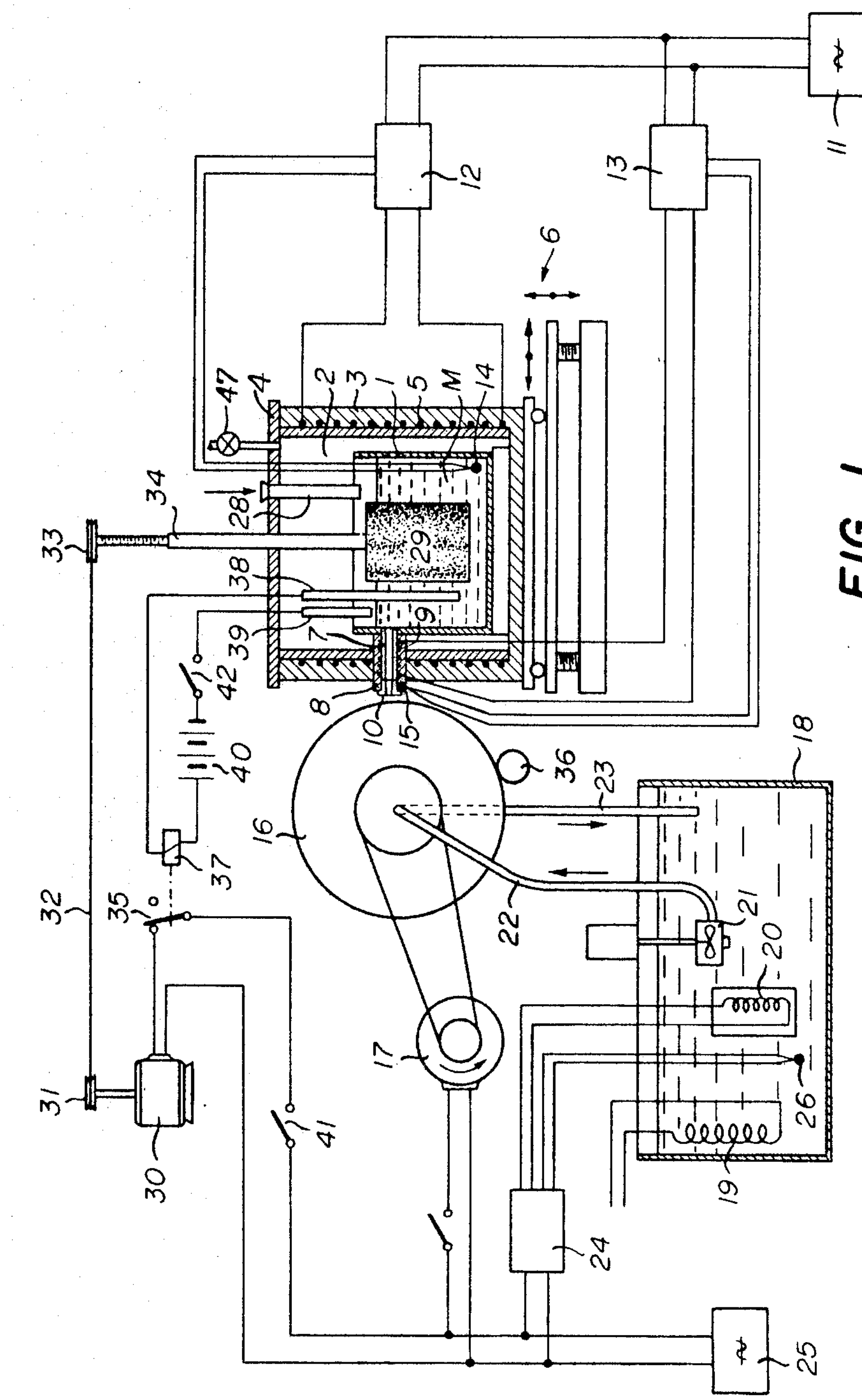


FIG. 1

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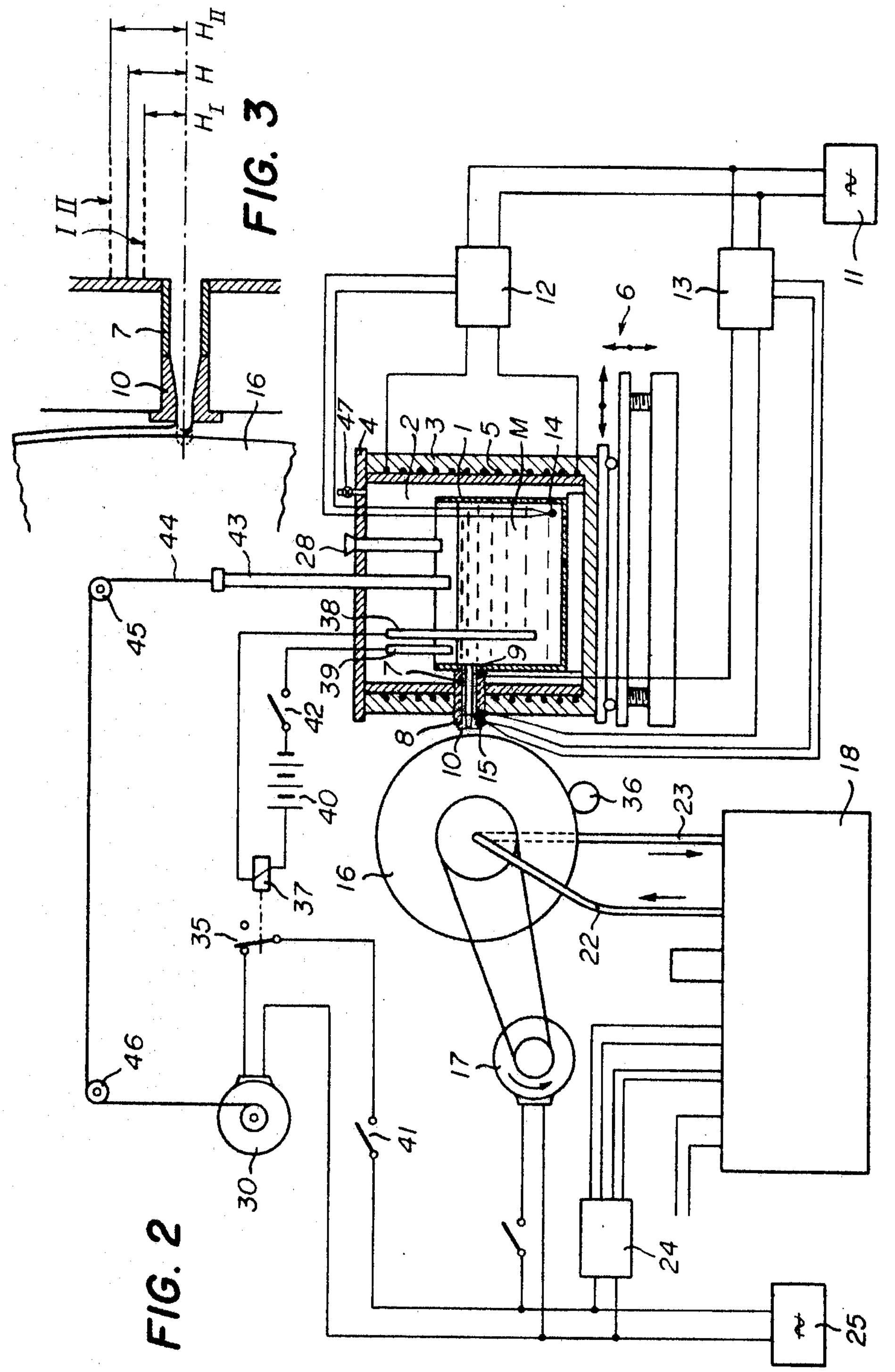

FIG. 3

FIG. 2

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METHOD OF MANUFACTURING WIRE AND THE LIKE

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 i.e. 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 subsquently 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 disadvantages 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 cover of the chamber **2** is provided with an inlet pipe **28** 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 is moved 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 only with 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 cable **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 brought into 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 above the pipe **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 H_{II} (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:

$$H_{II}=\frac{2T}{R.\rho.g.}$$

where T is the surface tension (dyne/cm.) of the molten material at the orifice

R is the radius (in cms.) of the orifice

ρ is the density (gr/cm.^{3}) of the molten material in the reservoir

g is the gravitational constant in cm/sec^2.

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:

$$H_{II}=\frac{2T}{a.\rho.g.}$$

where T, p 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 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 material 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_{II}:H_I of the limiting heights between which the liquid level may vary while manufacturing 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 temperature 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 continuous products, in particular wires and strips of aluminium, the alloy known as anti-corrodal, copper and steel to be manufactured; these products had uniform dimensions and were of satisfactory quality.

Example 1

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

	Al	Cu	Steel
Metal temperature at orifice in ° C	720	1, 150	1, 600
Temperature of peripheral surface of drum in ° C	80	95	95
Rotational speed of drum r.p.m	60	60	60
Minimum distance between orifice and drum in mm	0. 3	0. 3	0. 3
Height (H) of metal level above nozzle axis in mm	10	10	10

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-corrodal 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**

	Type A	Type B
Width in mm	8	6
Height in mm	1	1. 5

One then manufactures in the manner described above, while choosing the following values for the various parameters: **005000**

	Type A	Type B
Temperature of alloy at orifice in ° C	685	700
Temperature of peripheral surface of drum in ° C	50	60
Rotational speed of drum, r.p.m	10	7
Minimum distance between orifice and drum in mm	0. 8	1
Height (H) of alloy above nozzle axis in mm	15	10

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 rectangular 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 manufacturing aluminium fibres of relatively short length by rotating the drum (**16**) at much higher speeds than those indicated above.

It should be mentioned that the method according to the invention is also suitable for manufacturing a continuous product from other materials than those mentioned above by way of example. Thus materials may be considered particularly 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 apparatus 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 numeral **47**. This device serves to increase the pressure of the gas as the height of the metal level falls during operation of the apparatus, 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 choosing 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 substantially 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.