APPARATUS FOR BLOWING HOLLOW METAL ARTICLES

Fig. 1

Fig. 2

Fig. 3

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FIG. 4
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ABSTRACT OF THE DISCLOSURE

Apparatus is disclosed for making hollow articles from a container holding a bath of liquid material. The apparatus includes a hollow mold which is movably supported above the bath. In one position the open end of the mold is either immersed in or touching the bath surface. A blowpipe is provided whose outlet is positioned below the bath surface and a source of gas under pressure is intermittently connected, through a valve to the other end of the blowpipe. The operation of the valve causes a bubble to be formed in the bath which rises into the mold and there is solidified to form a hollow article in the shape of the mold. The mold is then moved to a second position remote from the first position where the article is removed from it. A two piece mold is also disclosed, one part of the mold remaining in or touching the bath and the other part being moved after the bubble is blown into the mold. The complete specification should be consulted for a full description of the apparatus.

This invention relates to a novel apparatus for forming hollow articles and containers from molten metals, and in particular to an apparatus for the automatic fabrication of relatively thin walled containers from molten aluminum and its alloys. This application is a continuation-in-part of Ser. No. 250,902, filed Jan. 11, 1963, which is in turn a continuation-in-part of Ser. No. 185-473, filed Apr. 15, 1962, both now abandoned.

It is the primary object of this invention to provide an improved apparatus for fabricating thin walled hollow metal articles.

It is also an object of this invention to provide an apparatus for the automatic and continuous blowing of hollow metal containers from molten metals.

It is a further object to provide an apparatus for automatically blowing, and trimming the mouths of, opened end metal containers.

It is still a further object to provide an improved blowpipe and blowpipe head for blowing hollow articles from molten metals.

The objects of this invention are achieved by improved apparatus for performing a process in which a metal or metal alloy in a molten liquid state, and having the characteristic of a reduced surface tension compared with the base metal in its pure state, is blown by a gas to provide the desired structure or article. Reduced surface tension can be secured by alloying agents. The process is also operative under conditions of constitutional supercooling. An example is 2024 aluminum alloy, which has a reduced surface tension relative to pure aluminum, and which forms an adherent, continuous oxide film of the primary component metal. In its liquid state, this alloy is blown by an oxygen-containing gas to provide the desired structure or article. The term "blowing" is used in much the same manner as in glass blowing, in that a single, hollow, walled structure is formed above the molten metal surface. However, completely different problems and concepts are involved in the blowing of metals and metal alloys, which when solidified are crystalline materials, than in blowing amorphous glass or plastic materials.

In accordance with one aspect of the invention, a quantity of aluminum alloy is melted in a vessel in which is disposed a blowpipe for blowing one or more orifices or openings of predetermined size, shape, and number. These are directed upwardly toward, and spaced at a predetermined distance beneath, the surface level of the molten aluminum alloy. Gas under pressure is introduced into the blowpipe, and aluminum is blown above the surface of the bath and into the open end of a mold suspended in registry over the blowpipe orifice. The open end of the mold is immersed at a predetermined distance into the molten aluminum alloy. The gas utilized is preferably a mixture of nitrogen and oxygen, in a volumetric ratio selected to obtain sufficient surface oxidation of the inside surface of the bubble to effect retention of shape and provide a coherent, thin, strong, continuous film-like layer of aluminum oxide. After the bubble has filled the mold and solidifies the article is ejected by gas pressure, or recovered by other methods. Where a thin walled aluminum lining is desired in a container such as a glass, plastic, or metal container, the container may serve as the mold into which the bubble is blown.

According to the invention, the mold forms a cavity in the configuration of the article which is to be fabricated, and has an open end for receiving the bubble. It is necessary to provide a relative movement of the mold so that the open end is immersed in, or at least brought into contact with, the surface of the bath while the bubble is being blown, but is then withdrawn from the bath so that the blown article may be removed. Several different mold arrangements may be used; in an elementary form, the mold is moved as a unit between a first position in which its open end is immersed in the bath of material, and a second position in which the entire mold is withdrawn from the bath. In another embodiment, the mold is formed of two parts, comprising a die and a mating skirt of congruent cross-sections. The mold cavity formed by these parts is generally cylindrical, but is preferably tapered slightly to facilitate the removal of the work. The die and skirt are independently positioned, being brought into mating engagement for the blowing of an article, but being separated for removal of the formed articles. The die itself does not enter the bath of molten material, but engages the skirt slightly above the bath; while the skirt is almost fully immersed at all times. Consequently, the skirt is maintained at substantially the same temperature as a molten metal bath, while the die remains relatively cool and at a temperature well below the solidification temperature range of the metal. One important advantage is that the material freezes only within the die, while that portion of the bubble which contacts the skirt remains liquid. As the skirt and die are separated after the article is blown, the mouth of the article is roughly trimmed to final form, since freezing terminates rather abruptly at the parting surface. This avoids the formation of a rough flash at the open end of lips of the blown article, which is a characteristic of the elementary version of the mold. Subsequent automatic finishing of the blown articles is therefore considerably simplified, and little or no trimming is required.

A further advantage of the two-part mold arrangement is that it permits the temperature of each part to remain nearly stable. This avoids the thermal stresses which might distort a mold which is recurrently dipped and raised from a molten bath. The resulting upper mold equilibrium temperature also leads to better surface finish and structure in the blown article.

The use of a two-part mold lends itself to incorporation in a high-production molding apparatus, in which a series
3 of dies are mounted on a rotatable turret for successive cooperation with a skirt immersed in the bath. As each successive die is brought into molding relation to the skirt, the preceding die is rotated to a position for convenient ejection of its contained article.

While the specification concludes with claims particularly pointing out the subject matter which we regard as our invention, it is believed that a clearer understanding may be gained from the following detailed description of preferred embodiments thereof, referring to the accompanying drawings, in which:

FIGURE 1 is a diagrammatic representation of a first form of apparatus for the continuous fabrication of thin-walled metal articles;

FIGURE 2 is a top plan view of an improved blowpipe and blowpipe head;

FIGURE 3 is a cross-sectional view along line 3-3 in FIGURE 2, showing the improved blowpipe and blowpipe head;

FIGURE 4 is a fragmentary view in side elevation, and partially in section, of another form of the improved apparatus, incorporating a two-part mold;

FIGURE 5 is a plan view of the apparatus of FIGURE 4;

FIGURE 6 is a fragmentary sectional view in end elevation, showing details of a mold and blowpipe;

FIGURE 7 is a schematic wiring diagram of control apparatus forming a portion of the molding apparatus of FIGURES 4-6; and

FIGURE 8 is a graph illustrating the operation of the apparatus of FIGURES 4-6 during a typical operating cycle.

In FIGURE 1 there is shown a first form of apparatus for fabricating thin-walled cylindrical aluminum alloy containers. Pressurized sources of oxygen 152 and nitrogen 154 are individually controlled by constant pressure regulators 156 and 158. These are adjusted and provide for the flow of a correctly-proportioned gaseous mixture into a common gas conduit 160, which leads into a volume jar 162 containing a desiccant, such as calcium chloride, magnesium sulfate, or calcium oxide, to remove water from the gaseous mixture and to provide a reservoir. The pressure in the conduit is measured by a gauge 164. A solenoid-operated flow control valve 166 is controlled by an electrical timer 168 to deliver a pre-determined volume of the gas to the inlet of a blowpipe 170. A volume jar 172 provides a reservoir to cushion the periodic injection of the gas mixture into the blowpipe head. The outlet end of the blowpipe 170 terminates in an improved blowpipe cap 180. An aluminum alloy bubble 178 is shown in the process of being blown. The cap is disposed a predetermined distance beneath the upper surface level of a bath of molten aluminum alloy 180, contained in a heated refractory container 182.

Mold support apparatus 192 movably positions a mold 200, which is shown in position for receiving the bubble 178. An open lower end 203 of the mold is immersed to a predetermined depth in the metal bath. The mold forms a cylindrical cavity 202, whose upper end is partially closed by a horizontal cover 204. The cover is adjustably supported by screws 206 and 208 to form a relatively narrow peripheral air vent opening 210, for the expulsion of air from the mold cavity as the bubble expands. A pair of pins 212 and 214 support the mold on telescopic tubular members 216 and 218. These are slidably mounted within tubes 220 and 222 supported on a cross-piece 224. The entire mold support apparatus 192 is mounted for vertical movement on a rack 226. The rack 226 is moved vertically by an electric motor 230 having a pinion engaged with the rack 226. A horizontal block 234 limits the downward travel of the cross-bar 224. Adjustment of the extended length of the telescopic members 216 and 218 is provided by nuts 235 and 236, and threaded rods 237 and 238 extending through the cross-bar and fastened at their lower ends to the members 216 and 218. In this manner, the downward movement of the mold, and hence the depth of its immersion into the molten alloy bath, is adjustable limited. Alternatively, upper and lower electrical limit switches on the rack, the mold, or the mold support may control the limits of vertical movement of the mold.

The motor 230 and the timing means 168 can be electrically interconnected to provide for sequential timed operation of the mold and the blowpipe. The mold must first be lowered to the proper immersed position; the solenoid 166 is then energized to admit into the blowpipe a proper volume of pressurized gas to ejection blow the bubble 178 into the mold. After a predetermined interval, deenergization of the solenoid discontinues the gas flow, and the mold is retracted from the metal bath 180 for removal of the article which has solidified in conforming relation to the cavity 202.

FIGURES 2 and 3 show an improved blowpipe cap 100 in detail, mounted over the outlet end 102 of the blowpipe. The cap body 106 is provided on its upper surface 108 with a recessed annular ring 110, whose diameter determines the initial size of the bubble 178. Disposed within the annular ring 110 are a series of relatively small-diameter capillary openings 112a, 112b, c, d, e, etc., and a series of longitudinal passages 114 communicating with the discharge opening 104 of the blowpipe. The capillary openings commonly range in diameter from 0.001 to 0.2 inch; for example, a diameter of 0.0040 inch has been used successfully. The optimum number and size of the openings is dependent upon the pressure and volume of the gas mixture, the surface tension and the viscosity of the alloy employed, and the ventilation of the mold.

The material of the cap, especially within the annular ring 110 on the surface 108, should not be wettably by the molten metal alloy to be blown; that is, there should exist little or no surface adhesion between the molten alloy and the material of the cap. Non-wettably solid materials are defined as those which, when placed in contact with the liquid phase in the presence of a gas, result in the formation of a convex meniscus at the interface of the solid and liquid and gas phases. A suitable non-wettably cap material for use with aluminum is a commercial product called Marinite, manufactured by Johns-Manville Co., Inc; this is a cemenitious solid non-wettably material comprising an alkaline earth silicate of about 85 percent by weight calcium silicate, and about 15 percent by weight of asbestos fibers to impart added mechanical strength. Another suitable non-wettably material for use with molten metal alloys is silicon dioxide, or silicon nitride. The employment of any material of this nature permits the uninterrupted flow of the pressurized gas mixture through the blowpipe 102 and the capillary openings, while molten metals such as aluminum alloy 2024 are inhibited from flowing into these non-wettably capillaries between blowing periods. Other materials having inherent porosity sufficient to permit the proper volume of gas flow, such as zirconia, are also suitable. The diameter of the surface openings should be sufficiently small to prevent the molten metal alloy from entering the non-wettably capillaries. Conversely, the peripheral ring 110 should be formed of a material that is wetted by the particular metal alloy to be blown, but is preferably not rapidly attacked thereby. For blowing aluminum alloy 2024 a suitable ring material is glass. The selection of the particular peripheral form, size or diameter of the annular ring is a means of limiting and controlling the bubble size to be formed.

In the mold support apparatus of FIGURE 1, the valves 156 and 158 are adjusted to provide a flow of a proper gaseous mixture, such as 100 parts of nitrogen to 3 parts of oxygen, at a predetermined pressure. The proper pressure depends upon the size and ventilation of the mold; for example, a pressure of 20 to 40 millimeters of mercury may be suitable for a mold volume of about 2 to 6 fluid ounces if ventilation is adequate. Sufficient
pressure should be employed to cause the alloy bubble to fill the mold completely. Larger molds require increased blowing pressures. The timing means 168 may typically be actuated for a period ranging from 0.1 to 0.5 second, as required to blow a bubble 178 containing the desired amount of alloy.

Prior to the introduction of the gas mixture into the blowpipe, the motor 230 is energized to move the support 192 and the mold 200 downwardly against the stop 234, and thus immerse the lower open end 203 to the point where the molten alloy bath 150, in relation with the blowpipe cap 100. The alloy bubble 178 is then blown, enters the mold, and assumes the configuration of the internal cavity 202. As the bubble swells and enters the mold, air within the cavity is expelled through the vent opening 210. The motor 236 is then energized to retract the mold upwardly from the blow bath, while the solenoid valve 166 remains deenergized. The thin-walled cylindrical article formed in the mold by the process is recovered by removing the die cover 204 and ejecting the article.

This apparatus permits the continuous production of metal objects from one or more molds. In a continuous process, it is often advantageous to provide means for removing surface oxide from the bath 180, such as an automatic surface skimmer which continually sweeps the surface of the melt free of any oxide accumulated as the hot metal alloy contacts the atmosphere. The operation may alternatively be carried on in an inert gaseous atmosphere.

It is often advantageous to place the air vent 210 in contact with a vacuum-creating source such as a vacuum pump, in order to aid in the rapid expulsion of air from the mold, in order to enhance the deposition of the thin-walled metal film.

In practice, aluminum alloy is a preferred material because of its high strength-to-weight ratio, its low melting point, and its readily-formed thin surface oxide. It is within the contemplation of this invention that other metal alloys, such as those of nickel and titanium and the like, can be employed. The selected metal or alloy should exhibit decreased surface tension relative to the pure chemical form of the metal during the blowing process. Alloying agents or additives like phosphorus, sulfur, silicon or other metallic or non-metallic contaminants may be used for this purpose. Additionally, the metal or metal alloy can possess constitutional supercooling associated with the absence of a single sharp melting point, or can be capable of rapid surface oxidation to form an electron-bonding coherent metal oxide layer, or both. It might be noted that while an alloy having too great a range of constitutional supercooling is not satisfactory for use in our process, it is preferred that the metal have this property in at least a limited range.

As noted above, an aluminum alloy is favored. Testing has shown that while aluminum alloys such as ASTM 5051 and 5056 may be blown by our process, the finish on the product may be grainy. When ASTM 6061 aluminum alloy was used the finish on the product was uneven. Very satisfactory results have been achieved with ASTM 2024 aluminum alloy. Therefore, this is the preferred aluminum alloy when it is desired to obtain a production finish, such as for packaging food or liquid. Also, this is a relatively low grade commercial alloy the use of which will result in economy as compared with specially compounded alloys. But it will be understood that it is within the scope of our invention to use any suitable metal or metal alloy which is oxidizable to provide a protective coating, strong, continuous, film-like layer of oxide over the surfaces of the blown article.

It has been found in practice that there should be a reasonably linear gradient of equilibrium temperature along the length of the mold. The temperature gradient affects the grain structure and surface finish of the molded article. Heaters and/or cooling fins can be applied to the mold to secure a desirable linear gradient.

There are at least two independent means of varying and controlling the wall thickness of the metal alloy bubble, and hence the article to be formed therefrom. The first of these is the temperature and viscosity of the molten alloy; and the second is the distance between the blowpipe openings and the surface of the alloy bath. These parameters may be varied separately or jointly to attain minimum wall thickness varying from about 0.005" to 0.010". There is no discernible maximum, although the optimum wall thickness is believed to range from 0.005" to 0.25".

Generally, when the surface of the molten alloy is at atmospheric pressure, the blowing pressure of the gas may range from about 20 to 40 millimeters of mercury, with the depth of immersion of the blowpipe ranging from 20 to 50 millimeters, for a 6-ounce container. The mold should be immersed to such a depth, relative to the blowpipe, that the bubble does not escape outside the open end of the mold. Air expulsion from the mold, of course, influences the proper blowing pressure.

Although other gases such as argon and the like can be employed for reasons of economy, it is preferred to utilize a mixture of nitrogen and oxygen as the blowing gas. It has been found that the optimum ratio of oxygen to nitrogen is not substantially less than about one part of oxygen to 100 parts of nitrogen by volume, although higher proportions of oxygen and even pure oxygen may be used. When the oxygen content is very substantial oxidation occurs at the surface of the molten alloy bath. This oxide must be removed prior to each blowing cycle or it will be forced into the die as the bubble is blown. Further, the formation of this oxide waste detracts from the yield of the process, and is undesirable from an economic standpoint. The use of a mixture of nitrogen and oxygen is preferred to maintain the oxygen content of the blowing gas at a level sufficient to achieve the oxidation of the bubble surface, but not substantially in excess of that content. The gas used in blowing the bubble has been described as a mixture of an inert gas and oxygen. The term "mixture" is used merely to denote that free oxygen is available for the desired oxidizing step, and therefore includes 100% free oxygen gas. This term also includes gases such as carbon dioxide which, upon heating by contact with or in the presence of a molten metal alloy like aluminum, will liberate oxygen, so that the gas in contact with the metal alloy during the formation or growth of the bubble includes free oxygen or promotes the surface oxidation of the internal bubble layer. The oxidation of the inside surfaces of the article takes place because of the presence of oxygen in the gas utilized to blow the bubble. The desired oxidation of the outside of the bubble will occur as the bubble contacts the air in the mold.

It is beneficial, if not necessary, to maintain the mold dry when a smooth external finish is desired. If excessive amounts of water or water vapor should be present on the inside of the mold as the bubble is blown, the hot alloy vaporizes the water. The resulting vapor pressure will tend to deform the bubble wall so that the external finish on the product will be uneven.

A modified apparatus is shown in FIGURES 4-7, in which a two-part mold is used, including a skirt 300 and a series of dies 302, which are mounted on a rotatable turret 304, to bring each of the dies successively into mold-forming cooperation with the skirt. In the mated position shown in FIGURE 4, the mating die and the skirt meet at a parting line 306, at an inflex end of the die and an inflex end of the skirt. The two parts then form a cylindrical, preferably tapered, cylindrical cavity 308, which projects outwardly toward the parting line 306, to facilitate subsequent removal of blown articles from the die.

The apparatus includes means for independently moving each successive die and the skirt into the mating positions shown in FIGURES 4 and 6 in solid lines, and
for subsequently retracting them to positions shown at 300° and 302° in FIGURE 6. It will be observed that the parting line 306 is positioned only slightly above the level of the molten alloy bath 310, so that the skirt is largely or completely immersed in the bath at all times, whereas the dies do not contact the bath directly. Articles are formed by passing suitable charges of a gaseous mixture through a blowpipe 312 having a cap 314, as in the preceding embodiment. However, as the skirt maintains substantially the same temperature as the molten bath, the bubble does not freeze on the walls of the skirt, but only on the interior surfaces of the dies. After a bubble is blown, the wiper may be adjusted, and the solid phase of the blown material terminates abruptly at the parting line, or influx end of the die. Articles are thus produced which have an open mouth roughly finished or trimmed to shape in the blowing process; automatic handling and finishing operations performed subsequently on the articles are therefore greatly simplified.

The molten alloy bath 310 is contained in a heated crucible 316, mounted on a stable supporting structure generally designated at 318. The crucible is formed with a dividing partition 320, in which a passage 322 is formed to connect the alloy bath 310 with a reservoir 324; the passage is positioned below the surface to allow liquid metal to pass from the reservoir into the bath. Fresh supplies of molten metal are added to the reservoir from time to time. In order to maintain a uniform level in the bath as articles are formed, a displacement block 326 of refractory material is gradually depressed into the reservoir by a supporting arm 328 and a suitable positioning mechanism 330. The mechanism 330 is controlled by a float 331, also formed of refractory material, which is mounted on an arm 332 pivoted at 334 on a supporting plate 336. The free end of the arm 332 is arranged to operate a control switch 335 for actuating the mechanism 330 as required to maintain a uniform level in the bath 310. Inasmuch as this levelling means forms no part of the present invention, it will not be described in further detail. Both the positioning mechanism 330 and the plate 336 are supported on a table 340, as are other elements of the molding apparatus.

The skirt 300 has an integrally cast curved supporting arm 344 mounted on an elongated tube 346, and this is in turn secured to an L-shaped bracket 348. This skirt assembly is mounted on a slide 350 (FIGURE 4), which is vertically movable on ways 352 supported on the table 340. The bracket 348 is mounted on the slide by a screw 354 so that the depth of immersion of the skirt 300 relative to the slide block 366, at the limits of the stroke of the wiper, will hereinafter be described, are mounted on a support bar 372 for engagement by a finger 374, affixed to the slide block 366, at the limits of the stroke of the wiper.

In the construction shown, the turret 304 mounts 4 dies 302 at 90° intervals on mounting plates 380. The turret is mounted on a shaft 382, which is rotatably supported in a horizontal position by means (not shown) in a head 384. To permit freedom of the dies and turret for indexing rotation into successive molding engagement with the skirt 300, as well as to clear the wiper 360 for operation after each molding cycle, it is necessary to raise the turret 304 before indexing. At the same time, a positive indexing drive for the turret must be provided to accurately index the turret and dies in 90° steps. To these ends, the head 384 carries a vertical slide 386, which is received on ways 388 mounted on the table 340 by a webbed bracket 390. The terminal positions of vertical motion of the head and turret are detected by means of limit switches 1LS and 2LS mounted on the bracket 390 for actuation by a finger 392 affixed to the head. The indexing drive is formed by a pair of bevel gears 394 affixed to the turret shaft 382 and to a jack shaft 396, respectively. The jack shaft is mounted in thrust and radial bearings (not shown) in a bearing housing 398 on top of the head. The jack shaft is driven by an adjustable bevel gear 400 and a conventional spline 402; this permits vertical movement of the jack shaft and the head without interrupting the indexing drive connection.

Both the indexing and the vertical reciprocating drives are delivered by a gear box D, which provides for one-quarter revolution of the shaft 404 at the conclusion of each full revolution of a face cam 406. The shaft 404 may be connected to a suitable Geneva drive or quarter-revolution clutch suitable for this purpose. The gear box is driven through a pulley arrangement 408 by means of an electric motor M, having a reduced speed output appropriate to the desired time cycle of the molding process. The cam 406 is mounted on an output shaft 410 of the gear box D, and has an eccentric recessed cam track 412 in which a follower 414 is received. The follower is carried by an adjustable-length turnbuckle 416, which is pinned at 418 to an ear 420 affixed to the slide 386 of the turret head. Each revolution of the cam 406, the head 384, turret 304, and dies 302 are reciprocated vertically between their limiting positions, which are determined by the form of the cam track 412. These correspond to the limits of die motion indicated in FIGURE 6 by the parting line 306 and the withdrawn position of the influx end of the die at 302°. The drive shaft 404 is driven by the gear box D to index the turret 304 and the attached dies 90° at the conclusion of an upward movement of the head and turret. The cam 406 is formed to cause the head to dwell in this position during the indexing movement, and then return the turret to the lowered position, in which it dwells during an ensuing molding operation. The drive shaft 404 also remains stationary during the molding operation. Subsequently, the cam 406 again raises the head and turret, and the gear box indexes the turret. A complete molding operation thus occurs on each revolution of the cam 406. Control of the skirt-positioning servo-motor SM1 and the wiper servo-motor SK2 are synchronized with the indexing and reciprocating movements of the turret by means of a control system hereinafter described.

As previously explained, the depth of the blowpipe cap 314 below the surface of the bath is one of the factors controlling the thickness of the moldings. As shown in FIGURES 5 and 6 are therefore provided for adjusting this depth. The blowpipe 312 is mounted in a bracket 416, and is adjustable transversely of the crucible 316 by means of a screw 418 threaded into the bracket and adjustably secured by lock nuts 420 engaging an upstanding ear 422 in a vertical slide member 424. The slide member includes a threaded block portion 426, which is engaged with a jack screw 428 to adjust the blowpipe
vertically. The blowpipe and slide member are guided vertically on a post 430, which is supported by a base 432 on the table 340. Twisting movement about the post 430 is restrained by a pair of headed studs 434, which are slidably received through a flange 435 extending transversely from the slide member 424. By these means, the blowpipe cap 314 may be accurately aligned with an open end 438 of the skirt, and adjusted to a desired depth within the bath 310 to control the thickness of the blown inlets. It should be understood that the open end 438 must be slotted at a slight depth, relative to the cap 314, to prevent the bubble from escaping around the side walls of the skirt and outside the mold.

In FIGURE 7, we have adopted certain conventions to facilitate the illustration of a control system for use with the apparatus of FIGURES 4-6. Specifically, relays are shown by blocks representing their windings, and contacts of the relays are shown in some instances disassociated from their windings and identified by the reference characters denoting the relay, suffixed by a lower-case identifying letter. Solenoid windings have been symbolized as inductors to distinguish them from relays. Relay contacts are shown in the position assumed when the circuit is in the state shown in the drawing. Finally, while any suitable power supply may be employed, I have shown the apparatus provided with a power supply comprising a source of alternating voltage connected between a first terminal 350 and a second terminal 351. The circuit of FIGURE 7 comprises a first relay 1CR having an energizing circuit extending over the contacts of the upper mold switch 1LS. The switch 1LS is closed as illustrated, when the turret 304 is in its raised position, and opened when the turret leaves its raised position. A relay 1M is provided when the apparatus is in automatic operation and operating properly. For this purpose, the relay 1M is provided with an energizing circuit extending from the source terminal L1 over a two-position manually operated switch S in an "automatic" position, over the contacts of a start pushbutton PB, and of the spring-return variety, over front contacts a of the relay 1CR paralleled by a normally-closed, cam-operated test switch 1TS, and thence through the winding of the relay 1M to ground. A holding circuit is provided for the relay 1M that is the same as its energizing circuit except that it includes a front contact 1Me of the relay 1M, in parallel with the contacts of the start pushbutton PB.

The test switch 1TS is opened, once during each revolution of the shaft 410 of the cam 406 (FIGURE 4), by a cam C1 which is affixed to this shaft. A second switch 2TS is closed once during each revolution of the shaft 410 by another cam C2 on this shaft, and 90 degrees behind the cam C1 in sequence of operation, for purposes to be described.

The position of the skirt 300 is controlled by the servo-motor SM1, which in accordance with one embodiment of my invention is a double-acting pneumatic servo-motor controlled by a conventional four-way valve SV1. The valve is positioned to cause the motor to raise the skirt when a solenoid 3S is energized, and is positioned to lower the skirt when a solenoid 4S is energized.

The solenoid 3S has an energizing circuit extending from the line terminal L1 over front contact 1Mb of the relay 1M, a contact a of the two-position skirt switch 4LS that is engaged when the skirt is not in its raised position, and a front contact 1Cr of the relay 1CR, thence in parallel paths over front contacts 3Cr and 4Cr of two relays 3CR and 4CR, to be described, over the cam operated switch 2TS in its closed position, and finally through the winding of the solenoid 3S to ground. An energizing circuit for the skirt-lowering solenoid 4S extends from the line terminal L1 over front contact 1Mb of the relay 1M, over a contact b of the skirt limit switch 4LS which is engaged when the skirt is up, over contact a of the two-position mold limit switch 2LS which is closed when the mold is not down, over front contact 1Cr of the relay 1CR, over front contact 2Cr of a relay 2CR, to be described, and thence through the winding of the solenoid 4S to ground.

A bubble of metal is blown from the melt into the mold by a pressurized gas supply, similar to that shown in FIGURE 1, under the control of a blow valve BV, arranged to be opened at times when a solenoid 7S is energized. An energizing circuit for the solenoid 7S extends from the line terminal L1 over front contact 1Mb of the relay 1M, over the contact b of the blow switch 4LS engaged when the skirt is up, and in parallel over the contact b of the switch 2LS, engaged when the mold is down, and a front contact 2CRb of the relay 2CR, and thence over front contact 2Cr of the relay 2CR, to be described, and a contact 1TRa of an electronic timer 1TR, closed under conditions to be described.

The electronic timer 1TR may be of any conventional type arranged to close contact 1TRa for a relatively precisely determined period of time following the closure of a control contact, here indicated as a front contact a of a relay 5CR, to be described. For example, a contact 5Cr of the line limit switch 5LS of the mold, and a contact 5Cr which might be arranged to produce a pulse to trigger a monostable multivibrator, causing the latter to produce a pulse of predetermined duration, such as for example, two-tenths of a second, for energizing a relay briefly to close contact 1TRa for a corresponding period.

The contact 1TRa would thus close and then open a predetermined time later to cause the solenoid 7S to open and then close the blow valve BV for a time appropriate to blow a metal bubble into the mold.

The relay 5CR has an energizing circuit extending from the line terminal L1 over front contact 1Mb of the relay 1M, over the contact b of the skirt switch 4LS engaged when the skirt is up, in parallel over the contact b of the mold limit switch 2LS, engaged when the mold is down, and front contact 2CRb of the relay 2CR, and thence over front contact 2Cr of the relay 2CR and through the winding of the relay 5CR to ground.

The relay 2CR is provided with an energizing circuit extending from terminal L1 of the line over front contact 1Mb of the relay 1M, over the skirt switch 4LS in the position assumed when the skirt is up, over the mold limit switch 2LS in the position assumed when the mold is down, and thence in parallel through the winding of the relay 2CR to ground. A holding circuit is provided for the relay 2CR comprising a circuit that is the same as the energizing circuit except that it includes front contact 2Cr of the relay 2CR in parallel with the mold limit switch 2LS.

A pair of wiper-position repeater relays 3CR and 4CR are provided. An energizing circuit for the relay 3CR extends from the line terminal L1 over front contact 1Mb of the relay 1M, the limit switch 6LS closed when the wiper is in the back position shown in FIGURE 5, and thence through the winding of the relay 3CR to ground.

The energizing circuit for the relay 4CR extends from the terminal L1 of the line, over front contact 1Mb of the relay 1M, and thence over the limit switch 6LS, closed when the wiper is in the forward position, and thence through the winding of the relay 4CR to ground.

The wiper is driven by the servomotor SM2, which may be of the same variety as the servomotor SM1 described above, and is controlled by a conventional four-way valve SV2. The position of the valve SV2 is determined by a pair of solenoids 5S and 6S. When the solenoid 5S is energized, the valve SV2 is positioned to drive the wiper to its forward position. When the solenoid 6S is energized, the valve is positioned to drive the wiper to its back position.

The wiper control solenoids 5S and 6S have energizing circuits that both include a path from the line terminal L1 over front contact 1Mb of the relay 1M, and the limit switch 3LS, which is closed briefly when the skirt goes to its lowered position, to produce an energizing pulse. The circuit for the solenoid 5S extends from the switch 3LS...
over front contact 3CRb of the relay 3CR, and the energizing circuit for the solenoid 6S extends from the switch 3LS over front contact 4CRb of the relay 4CR.

The operation of the control circuit of FIGURE 7 will next be described, with reference both to FIGURE 7 and of the timing diagram of FIGURE 8. It is assumed that the apparatus is initially in an indexed position with the turret 304 and dies 302 up and the skirt down. Assume that the switch S has been in the manual position and has just been moved to the automatic position. The apparatus will then be in the condition shown in FIGURE 7, with the switch 1TS closed, the relay 1CR energized, and all other apparatus deenergized. Assume that the motor M is energized and that the shaft 410 carrying the cams C1 and C2 begins to rotate at, for example, 15 r.p.m. The switch 1TS will be opened once during each rotation of this shaft, and the switch 2TS will be closed once during each rotation of the shaft, ninety degrees behind the opening of the switch 1TS. Assume that at a time when the cams C1 and C2 are in the relative positions shown, the start pushbutton PB is momentarily depressed. The relay 1M will then be energized, closing its front contact 1Ma to keep the relay energized when PB is released. While the apparatus can be operated with the wiper initially in either position, it is assumed that the wiper is in the back position, and that the limit switch 6LS is closed.

With the relay 1M energized, and its front contact 1Ma closed, the relay 3CR will pick up over the closed contacts of the wiper limit switch 6LS. With that relay picked up, a circuit is prepared for the skirt-raising solenoid 5S that is completed when the cam switch 2TS is closed. When the solenoid 5S is energized, the servo-control valve SV1 will be moved to cause the servo-motor SM1 to move the skirt to its raised position. The skirt limit switch 4LS will then be actuated to engage its contact b. Thereafter, the gear box D of FIGURE 4 will cause the turret to be moved to its lowered position, opening the upper mold limit switch 1LS and causing the lower mold limit switch 2LS to engage its contact b.

The skirt 300 and one of the dies 302 have engaged as shown in FIGURE 4, and are prepared for the blowing of an article. When the limit switch 1LS is open, the relay 1CR will release. The relay 1M will remain energized over the closed contact of the test switch 1TS. The relay 2CR will remain in front contact 1M of the 1Ma, the contact b of the skirt limit switch 4LS, and the contact b of the mold limit switch 2LS.

When the relay 2CR picks up, its front contact 2CRb will be closed, bypassing the mold limit switch 2LS; and its front contact 2CRc will be closed, energizing the relay 3CR.

The relay 5CR will pick up, actuating the timer 1TR to begin its cycle of operation and close its contacts 1TRa for a predetermined period, to blow a bubble of liquid metal into the mold to form the desired article.

After the bubble of molten metal is blown into the mold the dies and turret are moved to the raised position by the gear box D, disengaging the contact b of the mold limit switch 2LS and engaging the contact a. The mold limit switch 1LS is also closed when the turret reaches its raised position, causing the relay 1CR to be reenergized. The relay 2CR will remain energized over its front contact 2CRc. With the turret in its raised position, relay 2CR energized, and contact a of the switch 2LS now closed, the solenoid 4S will be energized to reposition the servo-valve SV1 to cause the servo-motor SM1 to move the skirt to its lower position.

As the skirt reaches its lower position, the shaft 410 of the gear box D will drive the cam C4 into its position to momentarily open the test switch 1TS. This action will have no effect if the turret is in its proper raised position, with the relay 1CR still energized. However, if the turret has not reached the proper position, the cycle will be stopped at this point to permit maintenance. At the same time, the switch 3LS will close momentarily, causing the solenoid 5S to be energized and move the control valve SV2 to a position causing the servo-motor SM2 to move the wiper forward across the surface of the bath 310. At the same time, the turret will be angularly indexed by the gear box D and shaft 404, to move the next die into position for the start of another molding cycle.

The indexing operation, during which a new die 302 is moved into position and the surface of the bath is wiped off, occupies about ninety degrees of rotation of the cam 406, or about one second of time in the particular embodiment of my invention described above. The die which contains the article just blown is moved from a vertical to a horizontal position, in which the article may then be ejected by compressed air, or by other means forming no part of the present invention.

When the wiping operation is completed, the wiper will remain in its forward position, closing the contacts of the switch 5LS, and energizing the relay 4CR. Its front contact 4CRb will be closed to prepare a path for the energization of the solenoid 3S when the cam-operated switch 2TS is closed, after the end of the ninety-degree indexing cycle. The operation just described is repeated, except that the relay 4CR is energized instead of the relay 3CR, and at the end of the operation when the skirt is again moved down, the servo-motor SM2 will be actuated to bring the wiper across the melt to the back position of FIGURE 5. The wiper accordingly moves alternately in opposite directions in successive operating cycles.

The apparatus of this invention produces relatively thin-walled, hollow articles in a manner which achieves economy and simplicity of operation. The blown articles offer distinct advantages over normally-cast articles of similar types; they have the characteristic of forged or rolled articles that the grain structure is oriented and is not random as in castings.

It should be noted that the apparatus is adaptable to the production of sealed hollow articles, closed at both ends. The bubble is blown in the apparatus of FIGURE 1, in the same manner as described above; however, after the gas pressure has been removed and prior to lifting the mold 200 completely out of the molten alloy, in imperforate plate, or the like, is placed under the open end of the mold, covering the entire open end. The mold and plate are then raised together, whereby the plate traps a layer of alloy in the lower open end. The thickness of this layer corresponds to the distance the mold is immersed in the molten metal when the plate is contacted with the open end thereof. It will be understood that when desired, the mold may be lifted partially out of the molten metal before the plate is placed under the open end in order to provide a thinner wall. Upon cooling, this layer of metal forms an imperforate closure or wall for the otherwise open end of the product.

Glass-lined metal containers may also be blown. In accordance with this aspect of the invention a quantity of glass or other blowable material having a softening point about that of the temperature of the molten alloy is placed on the discharge end of the blowpipe and is blown in the usual manner of blowing glass employing a pressurized gas such as air. As the glass bubble is blown, a thin or thick layer of molten aluminum will adhere to the bubble, so that as a final product, there will be produced a glass vessel externally clad with a layer of aluminum.

It is intended that all modifications that fall within the scope of the above description or shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense. Having thus described our invention, we claim:

1. Apparatus for the fabrication of hollow articles from a bath of liquid material comprising in combination:

a. a container adapted to hold the molten liquid material from which the article is to be formed,

b. mold means forming an internal cavity, said cavity having an open end and being closed at another end, and having the configuration of the article to be fabricated, said mold means being formed with vent means to permit the escape of gases from said mold.
cavity, the area of the open end of said mold cavity being substantially less than the surface area of said bath,
a blowpipe having an outlet opening positioned below the surface of said bath, in said full container,
means for delivering gas from a source at a pressure greater than the pressure on the surface of said bath of liquid material to said blowpipe over an interval to form a bubble in said bath of liquid material,
positioning means for moving said mold means relative to said container between a first position in which said open end is in registry with said blowpipe and at least in contact with the surface of said bath whereby said bubble of material may enter said mold means, and a second position in which an article formed in said mold means by said bubble is withdrawn from the surface of said bath for removal from said mold means.

2. Apparatus as recited in claim 1, in which said positioning means is constructed and arranged to move said mold means between a said first position in which said open end is immersed in said bath and a said second position in which said open end is withdrawn from said bath.

3. Apparatus as recited in claim 1, in which said mold means comprises a die having an influx end and said closed end, and a skirt having said open end and an efflux end mating with said influx end of said die, said cavity communicating with all of said ends and said die and said skirt combining to form said mold means when engaged with said efflux and influx ends mated.

4. Apparatus as recited in claim 3, in which said positioning means are constructed and arranged to move said die and said skirt between a said first position in which said efflux and influx ends are mated, and said open end of said skirt extends at least into contact with said bath, and a said second position in which said efflux and influx ends are separated for removal of an article from said die.

5. Apparatus as recited in claim 3, in which said positioning means are constructed and arranged to continuously immerse said skirt into said bath in both of said positions to a depth such that said skirt remains substantially at the temperature of said bath, and to continuously hold said die from contact with said bath, together with means for heating said bath to a temperature in excess of the melting point of the bath material; whereby a bubble of material received in said mold freezes in contact with said die, but remains liquid in contact with said skirt, and the solidified article terminates at said influx end of the die means.

6. Apparatus as recited in claim 1, in which said positioning means are constructed and arranged to immerse said open end at a predetermined depth in the bath in said first position.

7. Apparatus as recited in claim 6, in which said positioning means is adjustable to vary the depth of immersion of said open end in the bath.

8. Apparatus as recited in claim 1, together with means supporting said blowpipe and being adjustable to vary the depth of said outlet opening below the surface of said bath.

9. The apparatus of claim 1 wherein said blowpipe includes a cap on the outlet opening, the cap having an upper surface which is non-wettable by the liquid to be blown and having a plurality of capillaries first ends of which open onto the upper surface of the cap and the other ends of which are in gas flow communication with the blowpipe, the capillaries openings being of sufficiently small size to prevent flow therein by capillary action of the liquid material to be blown.

10. The apparatus of claim 9 wherein the cap is fabricated from a non-gas-permeable refractory material which comprises a mixture of an alkaline earth silicate and asbestos.

11. The apparatus of claim 9 wherein the capillary openings are from 0.001 to 0.02 inch in width.

12. The apparatus of claim 9 wherein the upper surface of the cap includes an annular ring of material that is wetted by the liquid to be blown with the capillaries located within the ring.

13. Apparatus for the fabrication of hollow articles from a bath of liquid material comprising in combination: a container adapted to hold a bath of liquid material from which the article is to be formed, hollow skirt means formed with an open end and with a connected efflux end, a plurality of die means each having an influx end and a closed end, gas vent means adjacent said closed end, and forming a cavity having the configuration of the article to be fabricated, said skirt means being formed to mate with said die means, with said efflux end substantially abutting said influx end of the mating die means, said skirt means and a mated die means forming a hollow mold, a blowpipe having an outlet opening positioned below the surface of said bath, means for delivering gas, at a pressure greater than the pressure on the surface of said bath of liquid material, to said blowpipe over an interval to form a bubble in said bath of liquid material, and first positioning means constructed and arranged to successively present each of said die means in a first position in which the influx end of the presented die means is mated with the efflux end of said skirt means and in a second position in which said presented die means is withdrawn from said skirt means to a second position remote from said first position for removal of the article therefrom; and second positioning means constructed and arranged to move said skirt means from a first position at which the efflux end of said skirt means is mated with the influx end of a presented die means and the open end of said skirt is in contact with said bath to a second position in which said skirt is immersed in said bath.

14. Apparatus as recited in claim 13, in which said first positioning means comprises: a turret, head means rotatably mounting said turret for rotation about an axis, said die means being mounted on said turret in circumferentially-spaced relation about said axis for angular indexing movement into successive mated relationship with said skirt means, means for angularly indexing said turret about said axis.

15. Apparatus as recited in claim 13, in which said die means are continuously held out of contact with said bath; means for heating said bath to a temperature in excess of the melting point of the bath material; whereby a bubble of material received in said mold freezes in contact with said mated die means, but remains liquid in contact with said skirt means, and the solidified fabricated article terminates at said influx end of said mated die means.

16. Apparatus for the fabrication of hollow articles from a bath of liquid material comprising in combination: a container adapted to hold a bath of liquid material from which the article is to be formed, a mold having an internal cavity, said cavity being open at one end and closed at the other, the cavity of said mold having the configuration of the article to be fabricated, vent openings in said mold to permit the escape of gases from said mold cavity to the outside surface of said mold, a blowpipe having an inlet opening, an outlet opening fixed below the surface of said bath and a passage for the flow of gas between said openings, a source of gas at a pressure greater than the pressure on the surface of said bath of liquid material.
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means including a normally closed valve connecting said source of pressure to the inlet of said blowpipe, means operating said valve for short predetermined periods, to thereby form a gas bubble in said bath of liquid material,

means for positioning said mold in a first position in which its open end is in registry with and above said blowpipe, the edges of said open end being at least in contact with the surface of said bath whereby said bubble of material may enter said mold, and in a second position remote from said first position for removal of the article formed therein.

17. The apparatus of claim 16 which includes means for placing an imperforate plate member across the open end of the mold after the formation of the article and while the mold is immersed in the liquid bath.

18. The apparatus of claim 16 which includes a vacuum source and means to place the vacuum source in communication with the vent means of the mold.

19. As an article of manufacture a blowpipe for blowing bubbles of a molten metal which blowpipe includes: a conduit characterized by an inlet and an outlet and adapted to permit the flow of gas from the inlet to the outlet; and a cap in the outlet of the conduit, the cap fabricated from a non-gas-permeable refractory material and having an upper surface which is non-wettable by the molten metal to be blown, and which surface includes an annular metal ring which is wettable by the molten metal to be blown, the cap having located inwardly of the ring a plurality of capillary tubes having openings of from 0.001 to 0.01 inch, one end of which tubes are in gas flow communication with the outlet and the other end of which open on the upper surface.

20. As an article of manufacture, a blowpipe for blowing bubbles of liquid material which blowpipe includes: a conduit characterized by an inlet and an outlet and adapted to permit the flow of gas from the inlet to the outlet; and a cap of non-gas-permeable refractory material on the outlet of the conduit, the cap having an upper surface which is non-wettable by the liquid to be blown and which includes an annular metal ring wettable by the liquid to be blown on the upper surface thereof, the cap having located inwardly of the metal ring a plurality of passages in gas flow communication with the outlet of the conduit, the passages being of sufficiently small size to prevent the flow thereinto by capillary action of the liquid to be blown.

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