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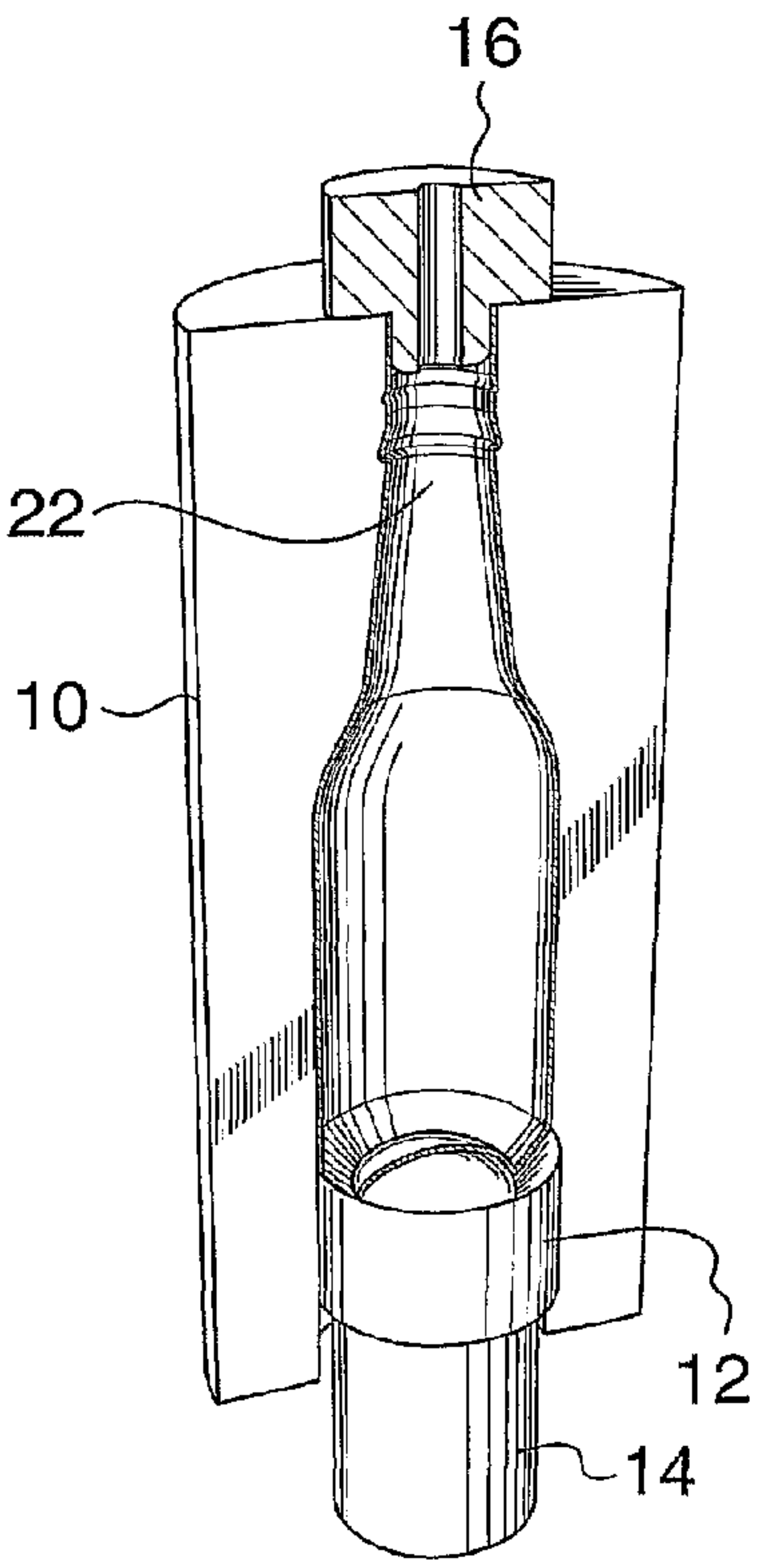
(54) Title: METHOD OF PRESSURE-RAM-FORMING METAL CONTAINERS AND THE LIKE



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A method of forming a bottle-shaped or other contoured metal container by subjecting a hollow metal preform having a closed end to internal fluid pressure to cause the preform to expand against the wall of a die cavity (10) defining the desired shape, and advancing a punch (12) into the die cavity (10) to displace and deform the closed end of the preform either before or after expansion begins but before it is complete. The pressure-subjecting step is performed by simultaneously subjecting the preform in the die cavity to independently controllable internal and external positive fluid pressures and varying the difference between them to control strain rate.

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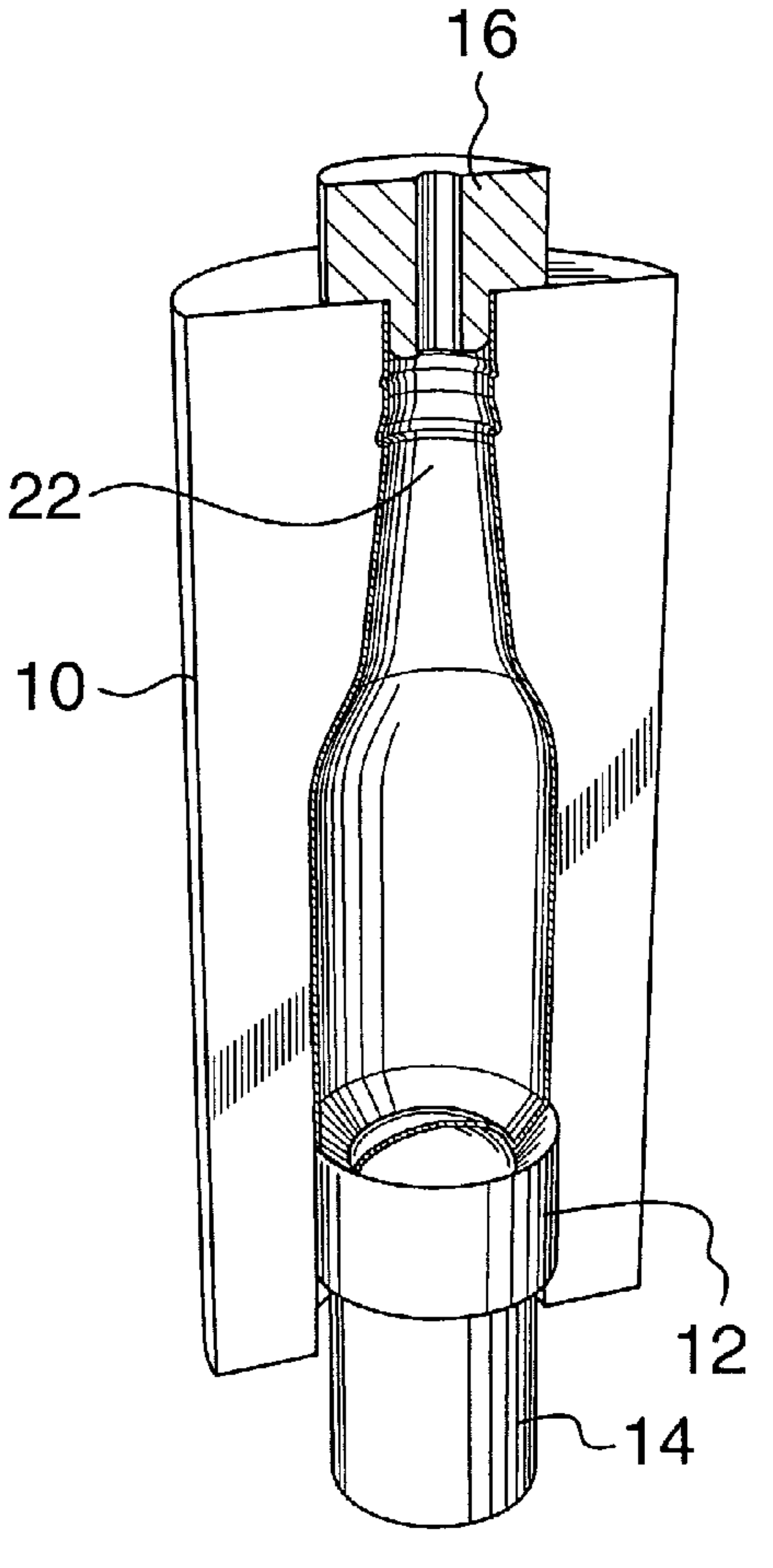

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METHOD OF PRESSURE-RAM-FORMING METAL CONTAINERS AND THE LIKE

Technical Field

This invention relates to methods of forming metal containers or the like, utilizing internal fluid pressure to expand a hollow metal preform or workpiece against a die cavity. In an important specific aspect, the invention is directed to methods of forming aluminum or other metal containers having a contoured shape, e.g. such as a bottle shape with asymmetrical features.

Background Art

Metal cans are well known and widely used for beverages. Present day beverage can bodies, whether one-piece "drawn and ironed" bodies, or bodies open at both ends (with a separate closure member at the bottom as well as at the top), generally have simple upright cylindrical side walls. It is sometimes desired, for reasons of aesthetics, consumer appeal and/or product identification, to impart a different and more complex shape to the side wall of a metal beverage container, and in particular, to provide a metal container with the shape of a bottle rather than an ordinary cylindrical can shape. Conventional can-producing operations, however, do not achieve such configurations.

For these and other purposes, it would be advantageous to provide convenient and effective methods of forming workpieces into bottle shapes or other complex shapes. Moreover, it would be useful to provide such procedures capable of forming contoured container shapes that are not radially symmetrical, to enhance the variety of designs obtainable.

In U.S. Patent 3,040,684 an apparatus is described for forming door knobs from a preform using a die cavity and hydraulic pressure. The preform is placed in a die cavity, filled with hydraulic fluid and sealed. The die is then closed and a bottom ram moves upwardly forcing the wall of the preform into conformity with the shape of the die cavity. In this procedure the volume of fluid does not change and the expansion of the preform is caused by the movement of the ram.

Another device for forming a door knob is described in U.S. Patent 4,362,037 in which a split die is used. The preform comprises a partially formed door knob and the outer circular face of the knob is placed on a lower die. An upper die has a cavity with side wall portions defining the final shape of the knob. This upper die is pressed downwardly over the preform resting on the lower die. Then a fluid is forced internally into the preform whereby the preform is forced into the shape of the die cavity.

U.S. Patent 6,182,487 describes a method for fabricating a metal vessel which uses a split die including a fixed die and a moveable die. A cylinder is first formed having a bottom welded to a shell and is placed with the bottom end mounted in the moveable die while the open end of the cylinder is attached to the fixed die. The cylinder is pressurized through the fixed die and the moveable die closes on the fixed die to form the vessel.

Disclosure of the Invention

The present invention broadly contemplates the provision of a method of forming a metal container of defined shape and lateral dimensions, comprising disposing a hollow metal preform having a closed end in a die cavity laterally enclosed by a die wall defining the shape and lateral dimensions, with a punch located at one end of the cavity and translatable into the cavity, the preform closed end being positioned in proximate facing relation to the punch and at least a portion of the preform being initially spaced inwardly from the die wall; subjecting the preform to internal fluid pressure to expand the preform outwardly into substantially full contact with the die wall, thereby to impart the defined shape and lateral dimensions to the preform, the fluid pressure exerting force, on the preform closed end, directed toward the aforesaid one end of the cavity; and, either before or after the preform begins to expand but before expansion of the preform is complete, translating the punch into the cavity to engage and displace the closed end of the preform in a direction opposite to the direction of force exerted by fluid pressure thereon, deforming the closed end of the preform. Translation of the punch is effected by a ram which is capable of applying sufficient force to the punch to displace and deform the preform. This method will sometimes be referred to herein as a pressure-ram-forming (PRF) procedure, because the container is formed both by applied internal fluid pressure and by the translation of the punch by the ram.

As a further feature of the invention, the punch has a contoured surface, and the closed end of the preform is deformed so as to conform to the contoured surface. For instance, the punch may have a domed contour, the closed end of the preform being deformed into the domed contour.

The defined shape, in which the container is formed, may be a bottle shape including a neck portion and a body portion larger in lateral dimensions than the neck portion, the die cavity having a long axis, the preform having a long axis and being disposed substantially coaxially within the cavity, and the punch being translatable along the long axis of the cavity.

Advantageously and preferably, the die wall comprises a split die separable for removal of the formed container. With a split die, the defined shape may be asymmetric about the long axis of the cavity.

The punch is preferably initially positioned close to or in contact with the preform closed end, before the application of fluid pressure, in order to limit axial lengthening of the preform by the fluid pressure. Translation of the punch may be initiated after the expanding lower portion of the preform has come into contact with the die wall.

The preform for forming a bottle shaped container or the like is preferably an elongated and initially generally cylindrical workpiece having an open end opposite its closed end. In particular embodiments of the invention, it may be substantially equal in diameter to the neck portion of the bottle shape, and may have sufficient formability to be expandable to the defined shape in a single pressure forming operation. If it lacks such formability, preliminary steps of placing the workpiece in a die cavity smaller than the first-mentioned die cavity, and subjecting the workpiece therein to internal fluid pressure to expand the workpiece to an intermediate size and shape smaller than the defined shape and lateral dimensions, are performed prior to the PRF method described above.

Alternatively, if the elongated and initially generally cylindrical workpiece is larger in initial diameter than the neck portion of the bottle shape, the method of forming a bottle shaped container may include a further step of subjecting the workpiece, adjacent its open end, to a spin forming operation to form a neck portion of reduced diameter, after performance of the PRF procedure.

Alternatively, the diameter of the neck area of the preform is reduced using a die necking procedure. This die necking procedure could be applied before the expansion stage.

The preform may be an aluminum preform (the term "aluminum" herein being used to refer to aluminum-based alloys as well as pure aluminum metal) and may be made from aluminum sheet having a recrystallized or recovered microstructure with a gauge in a range of about 0.25 to about 1.5 mm. It may be produced as a closed end cylinder by subjecting the sheet to a draw-redraw operation or back extrusion.

During the step of subjecting the preform to internal fluid pressure, the fluid pressure within the preform occurs in successive stages of (i) rising to a first peak before expansion of the preform begins,

(ii) dropping to a minimum value as expansion commences, (iii) rising gradually to an intermediate value as expansion proceeds until the preform is extended though not complete contact with the die wall, and (iv) rising from the intermediate pressure during completion of preform expansion. Stated with reference to this sequence of pressure stages, the initiation of translation of the punch to displace and deform the closed end of the preform in a preferred embodiment of the invention occurs substantially at the end of stage (iii).

Typically, when the internal fluid pressure is applied, the closed end of the preform assumes an enlarged and generally hemispherical configuration as the preform comes into contact with the die wall; and initiation of translation of the punch occurs substantially at the time that the preform closed end assumes this configuration.

Also in accordance with the invention, the step of subjecting the preform to internal fluid pressure comprises simultaneously applying internal positive fluid pressure and external positive fluid pressure to the preform in the cavity, the internal positive fluid pressure being higher than the external positive fluid pressure. The internal and external pressure are respectively provided by two independently controllable pressure systems. Strain rate in the preform is controlled by independently controlling the internal and external positive fluid pressures to which the preform is simultaneously subjected for varying the differential between the internal positive fluid pressure and the external positive fluid pressure. In this way, problems associated with excessive strain rates are avoided and additional beneficial results, such as reduction in the hydrostatic stress that may cause microstructural damage to the container wall, are achieved.

According to a still further feature of the invention, it has been found to be advantageous to apply heat during expansion of the preform, such as to induce a temperature gradient in the preform. By adding heaters to the punch, a temperature gradient is induced in the preform from the bottom up. Separate heaters may be added at the top of the die which induce a temperature gradient in the preform from the top down. Further heaters may be included in the side walls of the die cavity. The addition of the temperature gradient during expansion of the preform serves to define the point of initiation of the expansion and provides improved formability.

It has also been found to be advantageous to have the punch in contact with the bottom of the preform before the start of the expansion phase and to apply some axial load by the punch throughout the expansion phase. With this procedure where the punch applies some axial load to the closed end of the preform throughout the expansion phase, the displacement and deformation of the preform closed end is preferably not carried out until completion of the expansion phase.

Further features and advantages of the invention will be apparent from the detailed description hereinafter set forth, together with the accompanying drawings.

Brief Description of the Drawings

FIG. 1 is a simplified and somewhat schematic perspective view of tooling for performing the method of the present invention, in illustrative embodiments;

FIGS. 2A and 2B are views similar to FIG. 1 of sequential stages in the performance of a first embodiment of the method of the invention;

FIG. 3 is a graph of internal pressure and ram displacement as functions of time, using air as the fluid medium, illustrating the time relationship between the steps of subjecting the preform to internal fluid pressure and translating the punch in the method of the invention;

FIGS. 4A, 4B, 4C and 4D are views similar to FIG. 1 of sequential stages in the performance of a second embodiment of the method of the invention;

FIGS. 5A and 5B are, respectively, a view similar to FIG. 1 and a simplified, schematic perspective view of a spin-forming step, illustrating sequential stages in the performance of a third embodiment of the invention;

FIGS. 6A, 6B, 6C and 6D are computer-generated schematic elevational views of successive stages in the method of the invention;

FIG. 7 is a graph of pressure variation over time (using arbitrary time units) illustrating the feature of simultaneously applying independently controllable internal and external positive fluid pressures to the preform in the die cavity and comparing therewith internal pressure variation (as in FIG. 3) in the absence of external positive pressure;

FIG. 8 is a graph of strain variation over time, derived from finite element analysis, showing strain for one particular position (element) under the two different pressure conditions compared in FIG. 7; and

FIG. 9 is a graph similar to FIG. 7 illustrating a particular control mechanism that can be used in the forming process when internal and external positive fluid pressures are simultaneously applied to the preform in the die cavity.

FIG. 10 is a schematic illustration of an expanding preform using a heated punch;

Fig. 11 is a graph showing loadings on the punch, internal pressures and displacements of the punch during expansion of a preform; and

FIG. 12 is a perspective view showing stages in the production of a preform from a flat disc.

Best Modes For Carrying Out The Invention

The invention will be described as embodied in methods of forming aluminum containers having a contoured shape that need not be axisymmetric (radially symmetrical about a geometric axis of the container) using a combination of hydro (internal fluid pressure) and punch forming, i.e., a PRF procedure.

The PRF manufacturing process has two distinct stages, the making of a preform and the subsequent forming of the preform into the final container. There are several options for the complete forming path and the appropriate choice is determined by the formability of the aluminum sheet being used.

The preform is made from aluminum sheet having a recrystallized or recovered microstructure and with a gauge in the range of 0.25 mm to 1.5 mm. The preform is a closed end cylinder that can be made by, for example, a draw-redraw (-redraw) process or by back-extrusion. The diameter of the preform lies somewhere between the minimum and maximum diameters of the desired container product. Threads may be formed on the preform prior to the subsequent forming operations. The profile of the closed end of the preform may be designed to assist with the forming of the bottom profile of the final product.

As illustrated in FIG. 1, the tooling assembly for the method of the invention includes a split die 10 with a profiled cavity 11 defining an axially vertical bottle shape, a punch 12 that has the contour desired for the bottom of the container (for example, in the illustrated embodiments, a convexly domed contour for imparting a domed shape to the bottom of the formed container) and a ram 14 that is attached to the punch. In FIG. 1, only one of the two halves of the split die is shown, the other being a mirror image of the illustrated die half; as will be apparent, the two halves meet in a plane containing the geometric axis of the bottle shape defined by the wall of the die cavity 11.

The minimum diameter of the die cavity 11, at the upper open end 11a thereof (which corresponds to the neck of the bottle shape of the cavity) is equal to the outside diameter of the preform (see FIG. 2A) to be placed in the cavity, with allowance for clearance. The preform is initially positioned slightly above the punch 12 and has a schematically represented pressure fitting 16 at the open end 11a to allow for internal pressurization. Pressurization can be achieved, for example, by a coupling to threads formed in the upper open end of the preform, or by inserting a tube into the open end of the preform and making a seal by means of the split die or by some other pressure fitting.

The pressurizing step involves introducing, to the interior of the hollow preform, a fluid such as water or air under pressure sufficient to cause the preform to expand within the cavity until the wall of the preform is pressed substantially fully against the cavity-defining die wall, thereby imparting the shape and lateral dimensions of the cavity to the expanded preform. Stated generally, the fluid employed may be compressible or noncompressible, with any of mass, flux, volume or pressure controlled to control the pressure to which the preform walls are thereby subjected. In selecting the fluid, it is necessary to take into account the temperature conditions to be employed in the forming operation; if water is the fluid, for example, the temperature must be less than 100°C, and if a higher temperature is required, the fluid should be a gas such as air, or a liquid that does not boil at the temperature of the forming operation.

As a result of the pressurizing step, detailed relief features formed in the die wall are reproduced in inverse mirror image form on the surface of the resultant container. Even if such features, or the overall shape, of the produced container are not axisymmetric, the container is removed from the tooling without difficulty owing to the use of a split die.

In the specific embodiment of the invention illustrated in FIGS. 2A and 2B, the preform 18 is a hollow cylindrical aluminum workpiece with a closed lower end 20 and an open upper end 22, having an outside diameter equal to the outside diameter of the neck of the bottle shape to be formed, and the forming strains of the PRF operation are within the bounds set by the formability of the preform (which depends on temperature and deformation rate). With a preform having this property of formability, the shape of the die cavity 11 is made exactly as required for the final product and the product can be made in a single PRF operation. The motion of the ram 14 and the rate of internal pressurization are such as to minimize the strains of the forming operation and to produce the desired shape of the container. Neck and side wall features result primarily from the expansion of the preform due to internal pressure, while the shape of the bottom is defined primarily by the motion of the ram and punch 12, and the contour of the punch surface facing the preform closed end 20.

Proper synchronization of the application of internal fluid pressure and operation (translation into the die cavity) of the ram and punch are important in the practice of the invention. FIG. 3 shows a plot of computer-generated simulated data (sequence of finite element analysis outputs) representing the forming operation of FIGS. 2A and 2B with air pressure, controlled by flux. Specifically, the graph illustrates the pressure and ram time histories involved. As will be apparent from FIG. 3, the fluid pressure within the preform occurs in successive stages of (i) rising to a first peak 24 before expansion of the preform begins, (ii) dropping to a minimum value 26 as expansion commences, (iii) rising gradually to an intermediate value 28 as expansion proceeds until the preform is in extended though not complete contact with the die wall, and (iv) rising more rapidly (at 30) from the intermediate value during completion of preform expansion. Stated with reference to this sequence of pressure stages, the initiation of translation of the punch to displace and deform the closed end of the preform in preferred embodiments of the invention occurs (at 32) substantially at the end of stage (iii). Time, pressure and ram displacement units are indicated on the graph. The effect of the operations represented in FIG. 3 on the preform (in a computer generated simulation) is shown in FIGS. 6A, 6B, 6C and 6D for times 0.0, 0.096, 0.134 and 0.21 seconds as represented on the x-axis of FIG. 3.

At the outset of introduction of internal fluid pressure to the hollow preform, the punch 12 is disposed beneath the closed end of the preform (assuming an axially vertical orientation of the tooling, as shown) in closely proximate (e.g. touching) relation thereto, so as to limit axial stretching of the preform under the influence of the supplied internal pressure. When expansion of the preform attains a substantial though not fully complete degree, the ram 14 is actuated to forcibly translate the punch upwardly, displacing the metal of the closed end of the preform upwardly and deforming the closed end into the contour of the punch surface, as the lateral expansion of the preform by the internal pressure is completed. The upward displacement of the closed preform end cannot move the preform upwardly relative to the die or cause the side wall of the preform to buckle (as might occur by premature upward operation of the ram) owing to the extent of preform expansion that has already occurred when the ram begins to drive the punch upward.

A second embodiment of the method of the invention is illustrated in FIGS. 4A-4D. In this embodiment, as in that of FIGS. 2A and 2B, the cylindrical preform 38 has an initial outside diameter equal to the minimum diameter (neck) of the final product. However, in this embodiment it is assumed that the forming strains of the PRF operation exceed the formability limits of the preform. In this case, two sequential pressure forming operations are required. The first (FIGS. 4A and 4B) does not require a ram and simply expands the preform within a simple split die 40 to a larger diameter workpiece 38a by internal pressurization. The second is a PRF procedure (FIGS. 4C and 4D), starts with the workpiece as initially expanded in the die 40 and, employing a split die 42 with a bottle shaped cavity 44 and a punch 46 driven by a ram 48, i.e., using both internal pressure and the motion of the ram, produces the final desired bottle shape, including all features of the side wall profile and the contours of the bottom, which are produced primarily by the action of the punch 46.

A third embodiment is shown in FIGS. 5A and 5B. In this embodiment, the preform 50 is made with an initial outside diameter that is greater than the desired minimum outside diameter (usually the neck diameter) of the final bottle shaped container. This choice of preform may result from considerations of the forming limits of the preforming operation or may be chosen to reduce the strains in the PRF operation. In consequence, manufacture of the final product must include both diametrical expansion and compression of the preform and thus can not be accomplished with the PRF apparatus alone. A single PRF operation (FIG. 5A, employing split die 52 and ram-driven punch 54) is used to form the wall and bottom profiles (as in the embodiment of FIGS. 2A and 2B) and a spin forming or other necking operation is required to shape the neck of the container. As illustrated in FIG. 5B, it is possible to employ a spin forming procedure of the type set forth in co-pending U.S. patent application Serial No. 09/846,169, filed May 1, 2001, utilizing plural tandem sets of spin forming discs 56 and a tapered mandrel 58 to shape the bottle neck 60.

In the practice of the PRF procedure described above, PRF strains may be large. Alloy composition is accordingly selected or adjusted to provide a combination of desired product properties and enhanced formability. If still better formability is required, the forming temperature may be adjusted as described hereinafter, since an increase in temperature affords better formability; hence, the PRF operation(s) may need to be conducted at elevated temperatures and/or the preform may require a recovery anneal, in order to increase its formability.

The present invention differs from known pressure-forming operations such as blow-forming of PET containers, in particular, in adding an external punch-forming component. An internal punch, as sometimes used for PET bottle-forming, is not required. At present, there is no way known to applicants to produce an aluminum container with a shaped profile with the range of diameters that can be achieved with the present invention. Furthermore, there is no way currently known to applicants to produce an asymmetric profile (for example, feet on the bottom or spiral ribs on the side of the container).

The method of the invention could also be used to shape containers from other materials, such as steel.

The importance of moving the ram-driven punch 12 into the die cavity 11 to displace and deform the closed end 20 of the preform 18 (as in FIGS. 2A and 2B) may be further explained by reference to FIG. 3 (mentioned above) as considered together with FIGS. 6A-6D, in which the dotted line represents the vertical profile of the die cavity 11, and the displacement (in millimeters) of the dome-contoured punch 12 at various times after the initiation of internal pressure is represented by the scale on the right-hand side of that dotted line.

The ram serves two essential functions in the forming of the aluminum bottle. It limits the axial tensile strains and forms the shape of the bottom of the container. Initially the ram-driven punch 12 is held in close proximity to, or just touching, the bottom of the preform 18 (FIG. 6A). This serves to minimize the axial stretching of the preform side wall that would otherwise occur as a result of internal pressurization. Thus, as the internal pressure is increased, the side wall of the preform will expand to contact the inside of the die without significant lengthening. Typically, the central region of the preform will expand first, and this region of expansion will grow along the length of the preform, both upward and downward. At some point in time the bottom of the preform becomes nearly hemispherical in shape, with the radius of the hemisphere approximately equal to that of the die cavity (FIG. 6B). It is at or just before this point in time that the ram must be actuated to drive the punch 12 upwards (FIG. 6C). The profile of the nose of the ram (i.e. the punch surface contour) defines completely the profile of the bottom of the container. As the internal fluid pressure completes the molding of the preform against the die cavity wall (compare the bottle shoulder and neck in FIGS. 6B, 6C and 6D), the motion of the ram, combined with the internal pressure, forces the bottom of the preform into the contours of the punch surface in a manner that produces the desired contour (FIG. 6D) without excessive tensile strains that could, conceivably, lead to failure. The upward motion of the ram applies compressive forces to the hemispherical region of the preform, reduces general strain caused by the pressurizing operation, and assists in feeding material radially outwards to fill the contours of the punch nose.

If the ram motion is applied too early, relative to the rate of internal pressurization, the preform is likely to buckle and fold due to the compressive axial forces. If applied too late, the material will undergo excessive strain in the axial direction causing it to fail. Thus, coordination of the rate of internal pressurization and motion of the ram and punch nose is required for a successful forming operation. The necessary timing is best accomplished by finite element analysis (FEA) of the process. FIG. 3 is based on results of FEA.

The invention has been thus far described, and exemplified in FIG. 3, as if no positive (i.e., superatmospheric) fluid pressure were applied to the outside of the preform within the die cavity. In such a case, the external pressure on the preform in the cavity would be substantially ambient atmospheric pressure. As the preform expands, air in the cavity would be driven out (by the progressive diminution of volume between the outside of the preform and the die wall) through a suitable exhaust opening or passage provided for that purpose and communicating between the die cavity and the exterior of the die.

Stated with specific reference to aluminum containers, by way of illustration, it has been shown by FEA that in the absence of any applied positive external pressure, once the preform starts to deform (flow) plastically, the strain rate in the preform becomes very high and is essentially uncontrollable, owing to the low or zero work hardening rate of aluminum alloys at the process temperature (e.g. about 300°C) of the pressure-ram-forming operation.

That is to say, at such temperatures the work hardening rate of aluminum alloys is essentially zero and ductility (i.e., forming limit) decreases with increasing strain rate. Thus, the ability to make the desired final shaped container product is lessened as the strain rate of the forming operation increases and the ductility of aluminum decreases.

In accordance with a further important feature of the invention, positive fluid pressure is applied to the outside of the preform in the die cavity, simultaneously with the application of positive fluid pressure to the inside of the preform. These external and internal positive fluid pressures are respectively provided by two independently controlled pressure systems. The external positive fluid pressure can be conveniently supplied by connecting an independently controllable source of positive fluid pressure to the aforementioned exhaust opening or passage, so as to maintain a positive pressure in the volume between the die and the expanding preform.

FIGS. 7 and 8 compare the pressure vs. time and strain vs. time histories for pressure-ram-forming a container with and without positive external pressure control (the term “strain” herein refers to elongation per unit length produced in a body by an outside force). Line 101 of FIG. 7 corresponds to the line designated "Pressure" in FIG. 3, for the case where there is no external positive fluid pressure acting on the preform; line 103 of FIG. 8 represents the resulting strain for one particular position (element) as determined by FEA. Clearly the strain is almost instantaneous in this case, implying very high strain rates and very short times to expand the preform into contact with the die wall. In contrast, lines 105, 107 and 109 of FIG. 7 respectively represent internal positive fluid pressure, external positive fluid pressure, and the differential between the two, when both internal and external pressures are controlled, i.e., when external and internal positive fluid pressures, independently controlled, are simultaneously applied to the preform in the die cavity; the internal pressure is higher than the external pressure so that there is a net positive internal-external pressure differential as needed to effect expansion of the preform. Line 111 in FIG. 8 represents the hoop strain (strain produced in the horizontal plane around the circumference of the preform as it is expanding) for the independently controlled internal-external pressure condition represented by lines 105, 107 and 109; it will be seen that the hoop strain shown by line 111 reaches the same final value as that of line 103 but over a much longer time and thus at a much lower strain rate. Line 115 in FIG. 8 represents axial strain (strain produced in the vertical direction as the preform lengthens).

By simultaneously providing independently controllable internal and external positive fluid pressures acting on the preform in the die cavity, and varying the difference between these internal and external pressures, the forming operation remains completely in control, avoiding very high and uncontrollable strain rates. The ductility of the preform, and thus the forming limit of the operation, is increased for two reasons. First, decreasing the strain rate of the forming operation increases the inherent ductility of the aluminum alloy. Second, the addition of external positive pressure decreases (and potentially could make negative) the hydrostatic stress in the wall of the expanding preform. This could reduce the detrimental effect of damage associated with microvoids and intermetallic particles in the metal. The term "hydrostatic stress" herein refers to the arithmetic average of three normal stresses in the x, y and z directions.

The feature of the invention thus described enhances the ability of the pressure-ram-forming operation to successfully make aluminum containers in bottle shapes and the like, by enabling control of the strain rate of the forming operation and by decreasing the hydrostatic stress in the metal during forming.

The selection of pressure differential is based on the material properties of the metal from which the preform is made. Specifically, the yield stress and the work-hardening rate of the metal must be considered. In order for the preform to flow plastically (i.e., inelastically), the pressure differential must be such that the effective (Mises) stress in the preform exceeds the yield stress. If there is a positive work-hardening rate, a fixed applied effective stress (from the pressure) in excess of the yield stress would cause the metal to deform to a stress level equal to that applied effective stress. At that point the deformation rate would approach zero. In the case of a very low or zero work-hardening rate, the metal would deform at a high strain rate until it either came into contact with the wall of the mold (die) or fracture occurred. At the elevated temperatures anticipated for the PRF process, the work-hardening rate of aluminum alloys is low to zero.

Examples of gases suitable for use to supply both the internal and external pressures include, without limitation, nitrogen, air and argon, and any combinations of these gases.

The plastic strain rate at any point in the wall of the preform, at any point in time, depends only on the instantaneous effective stress, which in turn depends only on the pressure differential. The choice of external pressure is dependent on the internal pressure, with the overall principle to achieve and control the effective stress, and thus the strain rate, in the wall of the preform.

FIG. 9 shows a different control mechanism that can be used in the forming process. Finite element simulations have been used to optimize the process. In FIG. 9, line 120 represents internal pressure (Pin) acting on the preform, line 122 represents external pressure (Pout) acting on the preform, and line 124 represents the pressure differential (Pdiff = Pin - Pout). This figure shows the pressure history from one control method. In this case, the fluid mass in the internal cavity is kept constant and the pressure in the external cavity (outside the preform) is decreasing linearly. Strain rate-dependent material properties are also included in the simulation. This latter control mechanism is currently preferred because it results in a simpler process.

FIG. 10 relate to a further embodiment of the invention where heating is applied to the preform which induces a temperature gradient to the preform. As shown in FIG. 10, the punch 12 is in contact with the bottom of the preform 18 and the punch 12 contains a heating element 19. This heats the preform from the bottom up causing the expansion of the preform to grow from the bottom up when internal pressure is increased.

FIG. 11 shows graphs illustrating the expansion process. One line of the graph shows the displacements of the ram/punch while the other shows the variations in the load on the ram/punch, both as a function of time. A third line shows the internal pressure in the preform.

At point A the ram is pre-loaded to a compressive load of about 22.7 kg and at point B the preform is internally pressurized and held at a level of 1.14 MPa. In the procedure illustrated, the position of the ram was stepped between points B and C to maintain a compressive ram load of 68 kg. When the ram load no longer decreased rapidly after an increment in ram position (point C to D), the ramping of the ram was continued to a displacement of about 25 mm and a load of about 454 kg (point E). During the ramping of the ram from point D to point E, the bottom profile of the container was formed simultaneously with the expansion of the preform so that point E represents the completion of the forming of the container.

While the graph of FIG. 11 shows a stepwise procedure, it is also possible to expand and form the preform into a container in one smooth operation, e.g. by utilizing a computerized control of the procedure. The advantage of this procedure is that due to the induced temperature gradient, the expansion proceeds gradually from the bottom to the top as the ram and punch move up. It has been shown that this technique leads to reduced improved formability when compared to the previously described methods in which expansion occurs essentially simultaneously over the entire length of the preform.

While FIG. 10 shows a heating element only within the punch 12, it is possible to provide different heating zones to aid in the forming. For instance, there can be a further separate heater around the top of the preform as well as further separate heating elements within the side walls of the die cavity. By independently manipulating the temperatures in each of these areas, optimal expansion histories are developed for various container designs.

FIG. 12 shows a typical sequence in the making of a preform from a flat disc. A standard draw/redraw technique is used with the aluminum sheet 70 being first drawn into a shallow closed end cylinder 71, which is then redrawn into a second cylinder 72 of smaller diameter and longer side wall. Cylinder 72 is then redrawn to form cylinder 73, which is redrawn to form cylinder 74. It will be noted that the cylinder 74 has a long thin configuration.

It is to be understood that the invention is not limited to the procedures and embodiments hereinabove specifically set forth but may be carried out in other ways without departure from its spirit.

Claims:

1. A method of forming a hollow metal article of defined shape and dimensions, comprising (a) disposing a hollow metal preform having a closed end in a die cavity having a die wall defining said shape and dimensions, with at least a portion of the preform being initially spaced inwardly from the die wall, and (b) subjecting the preform to internal fluid pressure to expand the preform outwardly into substantially full contact with the die wall, thereby to impart said defined shape and dimensions to the preform,

characterized in that the die cavity is dimensioned to laterally enclose a hollow metal preform having a closed end with a punch located at one end of the cavity and translatable into the cavity, the preform being located within the cavity with the preform closed end positioned in proximate facing relation to the punch, an internal fluid pressure is applied to the preform to expand the preform outwardly and exert fluid pressure force on the closed end and, (c) either before or after the preform begins to expand but before expansion of the preform is complete, the punch is translated into the one end of the cavity to engage and displace the closed end of the preform in a direction opposite to the direction of force exerted by fluid pressure thereon, deforming the closed end of the preform while the preform expands outwardly into substantially full contact with the die wall.

2. A method according to claim 1, characterized in that the internal fluid pressure is applied by applying both internal positive fluid pressure and

external positive fluid pressure to the preform within the die cavity, with the internal positive fluid pressure being higher than the external positive fluid pressure.

3. A method according to claim 1, characterized in that prior to subjecting the preform to internal fluid pressure, heat is applied to the preform within the die cavity to induce a temperature gradient therein.

4. A method according to claim 1, 2 or 3, characterized in that the fluid used for applying fluid pressure is a gas.

5. A method according to claim 4, characterized in that the gas is nitrogen, air or argon.

6. A method according to claim 4 or 5, characterized in that the forming is carried out at a temperature greater than 100°C.

7. A method according to claim 6, characterized in that the forming is carried out at a temperature of about 300°C.

8. A method according to claim 1, characterized in that the preform is an elongated and initially generally cylindrical workpiece having an expandable closed end and an open end opposite its closed end.

9. A method according to any one of claims 1-8, characterized in that the punch is moved into the cavity after the preform begins to expand but before expansion of the preform is complete in step (b).

10. A method according to any one of claims 1-8, characterized in that the punch is moved into contact with the closed end of the preform before commencing expansion of the preform and the contact is maintained throughout the expansion of the preform.

11. A method according to any one of claims 1-10, characterized in that said punch has a contoured surface, the closed end of the preform being deformed so as to conform to said contoured surface.

12. A method according to any one of claims 1-11, characterized in that said defined shape is a bottle shape including a neck portion and a body portion larger in lateral dimensions than the neck portion, said die cavity having a long axis, said preform having a long axis and being disposed substantially coaxially with said cavity in step (a), and said punch being translatable along the long axis of the cavity.

13. A method according to claim 12, characterized in that said punch has a domed contour, and wherein step (c) deforms said closed end of said preform into said domed contour.

14. A method according to any one of claims 1-13, characterized in that said die wall comprises a split die separable for removal of the formed container following step (c).

15. A method according to claim 12, 13 or 14, characterized in that said defined shape is asymmetric about said long axis of said cavity.

16. A method according to any one of claims 1-15, characterized in that said punch is initially positioned, before subjecting the preform to internal fluid pressure, to limit axial lengthening of the preform by said fluid pressure.

17. A method according to any one of claims 12-16, characterized in that said preform is an elongated and initially generally cylindrical workpiece having an open end opposite said closed end and is substantially equal in diameter to said neck portion of said bottle shape.

18. A method according to any one of claims 12-17, characterized in that said workpiece has sufficient formability to be expandable to said defined shape in a single pressure forming operation.

19. A method according to claim 17, characterized by a preliminary step of placing the workpiece in a die cavity smaller than the first-mentioned die cavity and subjecting the workpiece therein to internal fluid pressure to expand the workpiece to an intermediate size and shape smaller than said defined shape and lateral dimensions, before performing steps (a), (b) and (c).

20. A method according to claim 1, characterized in that said preform is an elongated and initially generally cylindrical workpiece having an open end opposite said closed end and is larger in diameter than said neck portion of said bottle shape; and including a further step of subjecting the workpiece, adjacent said open end, to a spin forming operation to form a neck portion of reduced diameter, after performance of steps (a), (b) and (c).

21. A method according to any one of claims 1-20, characterized in that said preform is an aluminum preform.

22. A method according to claim 21, characterized by the step of making the preform from aluminum sheet having a recrystallized or recovered microstructure with a gauge in a range of about 0.25 to about 1.5 mm, prior to performance of step (a).

23. A method according to claim 22, characterized in that said preform is produced as a closed end cylinder by subjecting said sheet to a draw-redraw operation or back extrusion.

24. A method according to any one of claims 1-23, characterized in that, during step (b), fluid pressure within the preform occurs in successive stages of (i) rising to a first peak before expansion of the preform begins, (ii) dropping to a minimum value as expansion commences, (iii) rising gradually to an intermediate value as expression proceeds until the preform is in extended though not complete contact with the die wall, and (iv) rising from the intermediate value during completion of preform expansion; and wherein initiation of translation of the punch in step (c) to displace and deform the closed end of the preform occurs substantially at the end of stage (iii).

25. A method according to any one of claims 1-23, characterized in that, during step (b), the closed end of the preform assumes an enlarged and generally hemispherical configuration as said portion of the preform comes into initial contact with the die wall in

step (b); and wherein initiation of translation of the punch in step (c) to displace and deform the closed end of the preform occurs substantially at the time that the preform closed end assumes said configuration.

26. A method according to claim 2, characterized by independently controlling the internal and external positive fluid pressures to which the preform is simultaneously subjected for varying the differential between said internal positive fluid pressure and said external positive fluid pressure, thereby controlling strain rate in the preform.

27. A method according to claim 3, characterized in that the heat is applied to the preform by way of heating means in the punch to thereby induce a temperature gradient to the preform commencing at the closed bottom and extending upwardly.

28. A method according to claim 3, characterized in that the preform is held vertically with said closed end at the bottom of the preform, and in that heat is applied to the preform by way of heating means around the top of the preform in the die to thereby induce a temperature gradient to the preform commencing at the top and extending downwardly.

29. A method according to claim 27 or 28, characterized in that heat is applied to the preform by way of heating means in the side walls of the die.

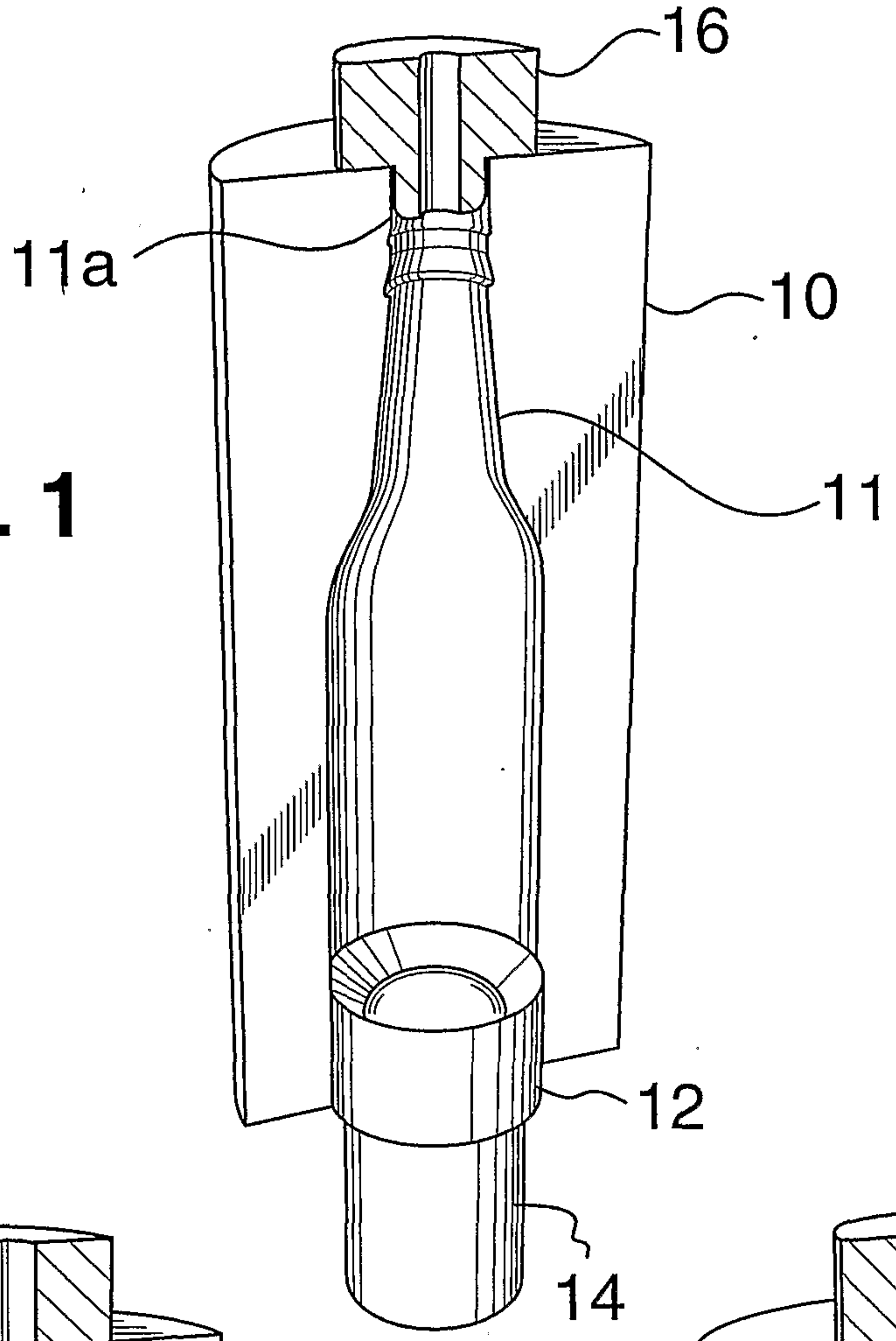


FIG. 1

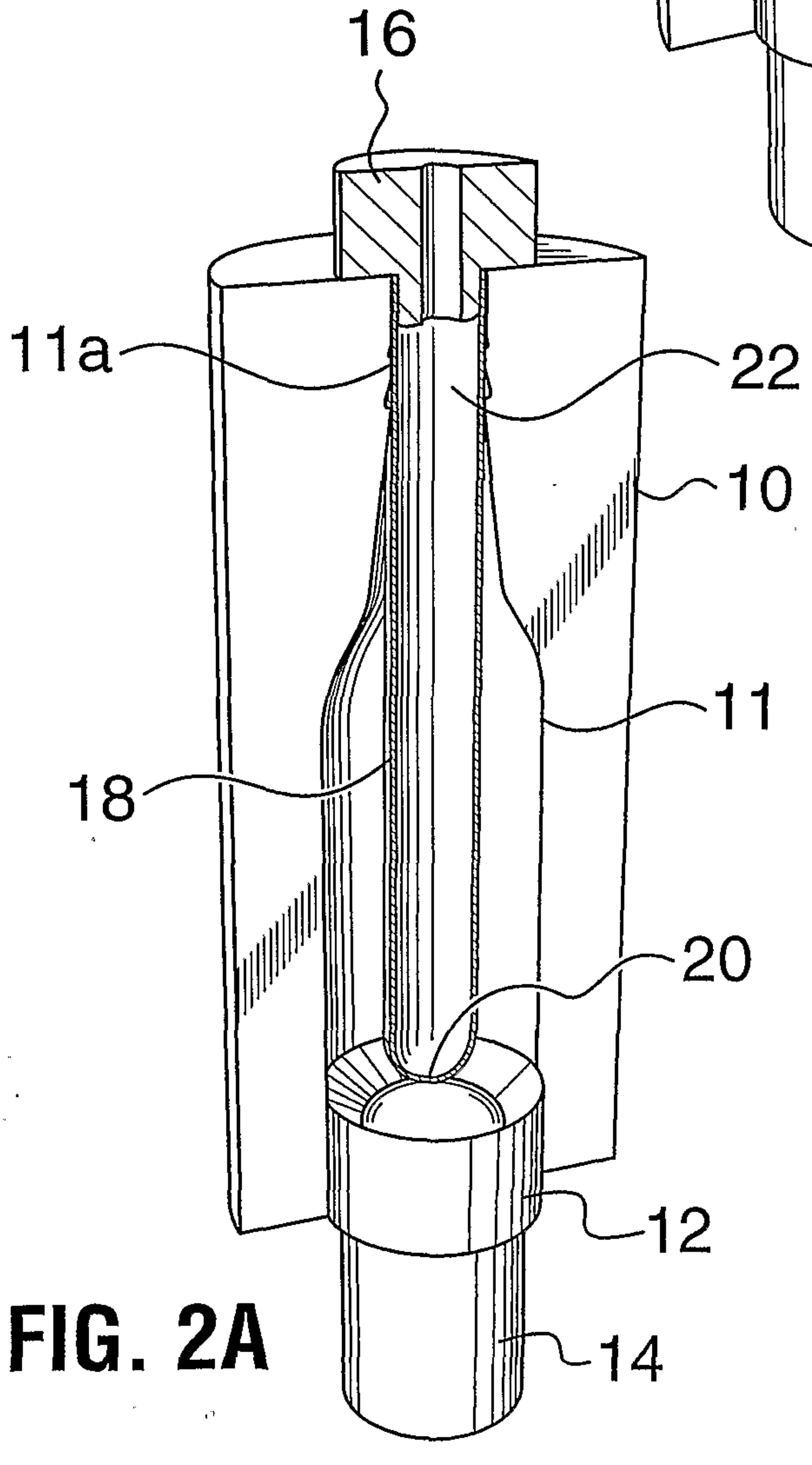


FIG. 2A

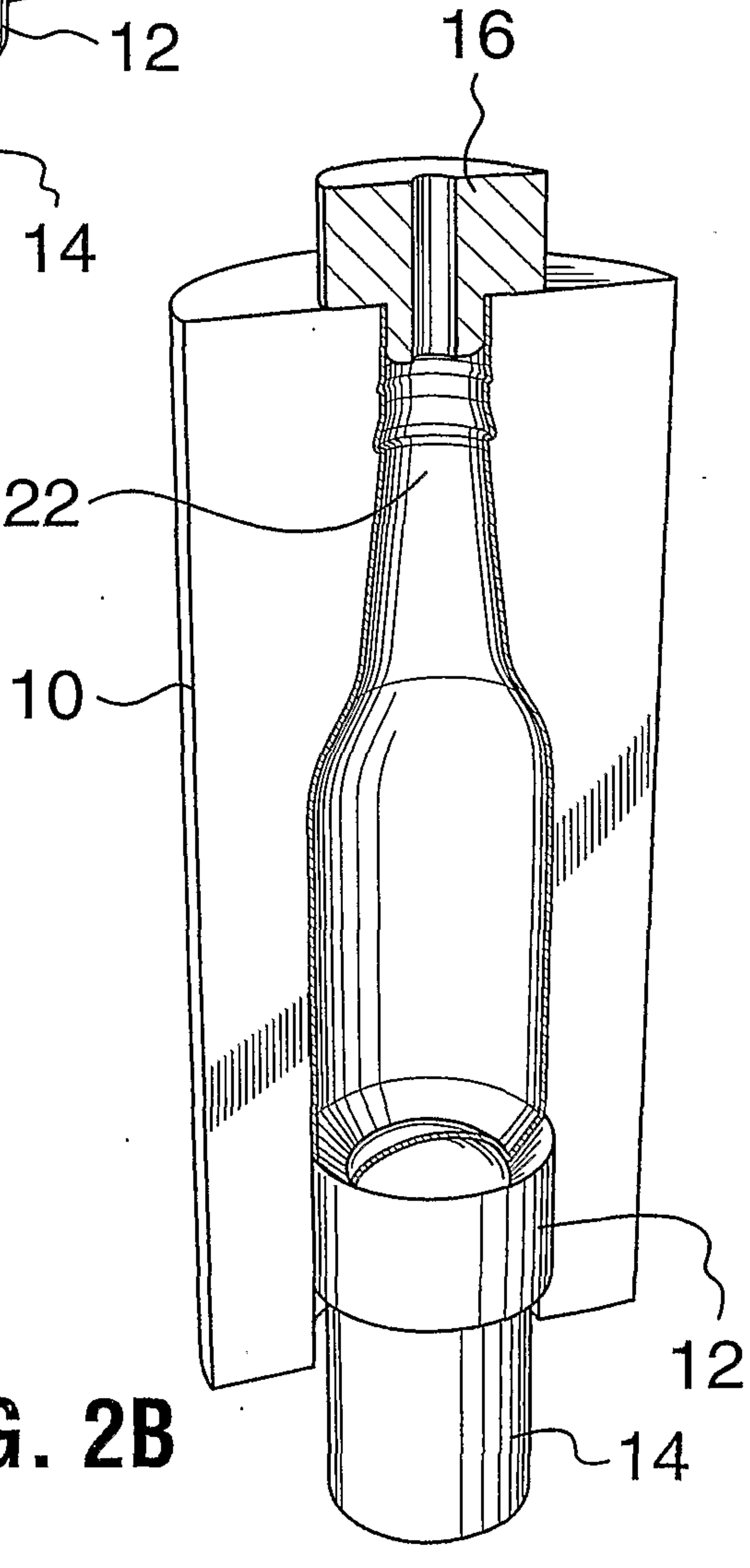


FIG. 2B

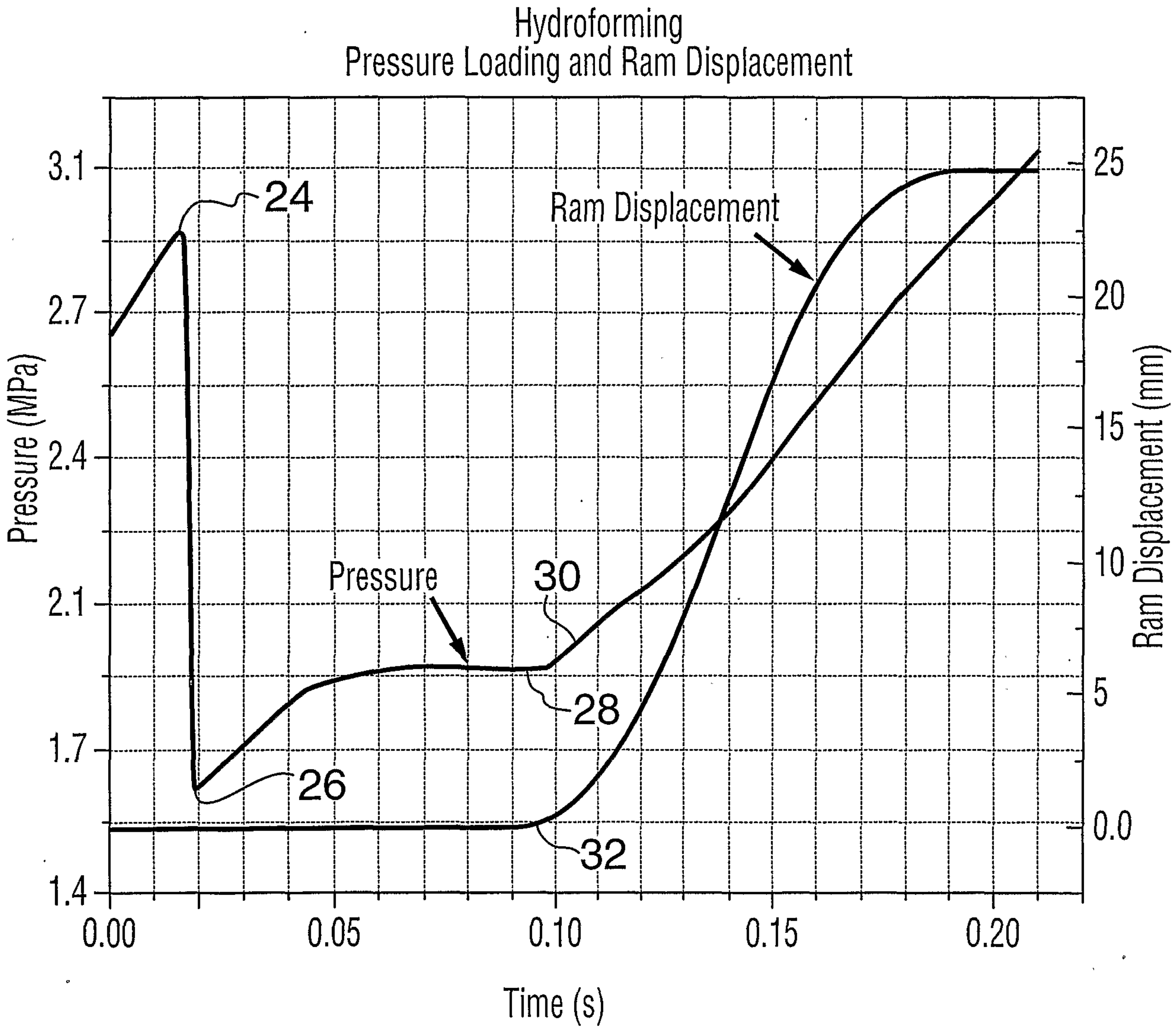

Hydroforming
Pressure Loading and Ram Displacement
Pressure (MPa)
3.1
2.7
2.4
2.1
1.7
1.4
Ram Displacement (mm)
25
20
15
10
5
0.0
Time (s)
0.00
0.05
0.10
0.15
0.20
Ram Displacement
Pressure
24
26
28
30
32

FIG. 3

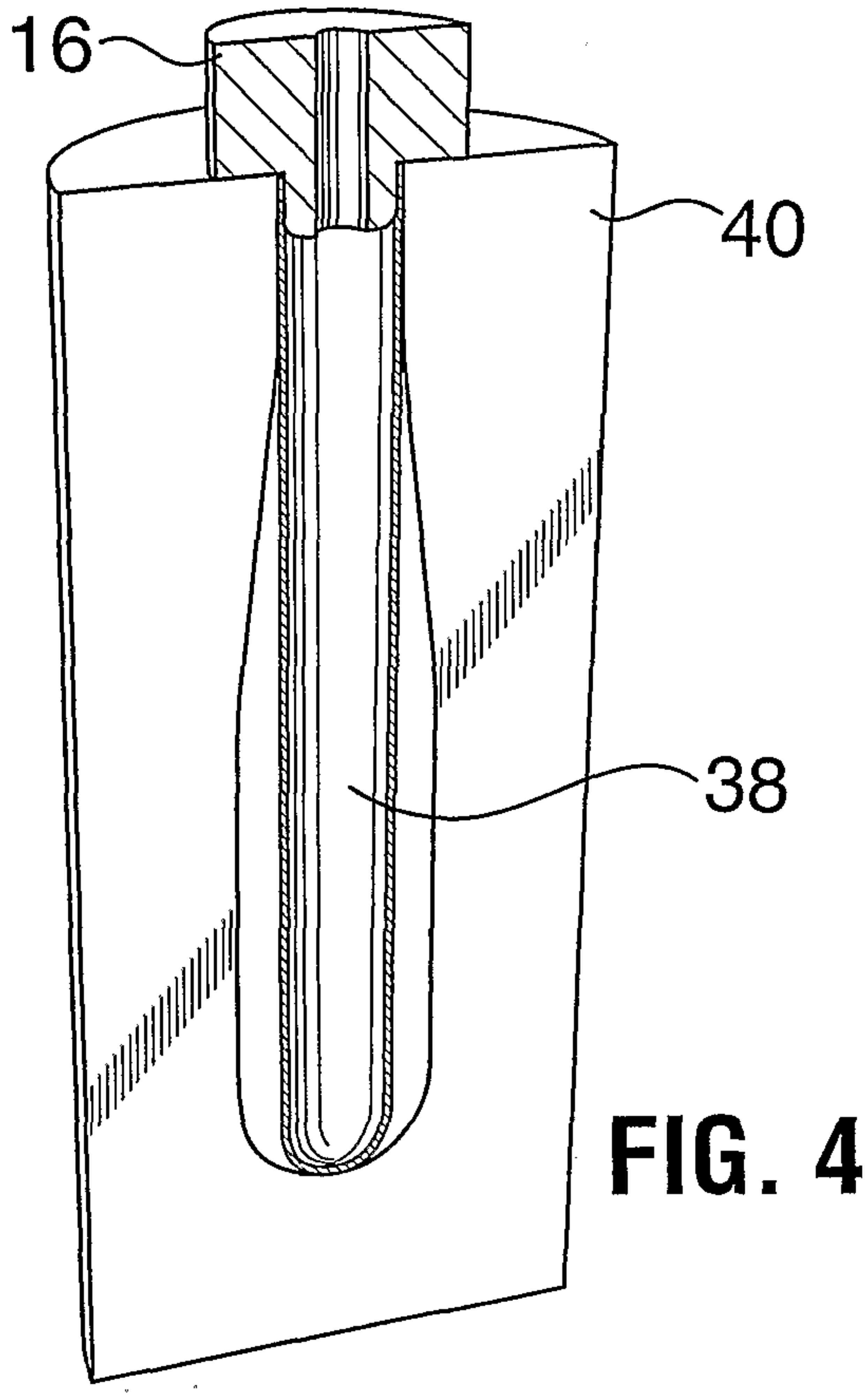


FIG. 4A

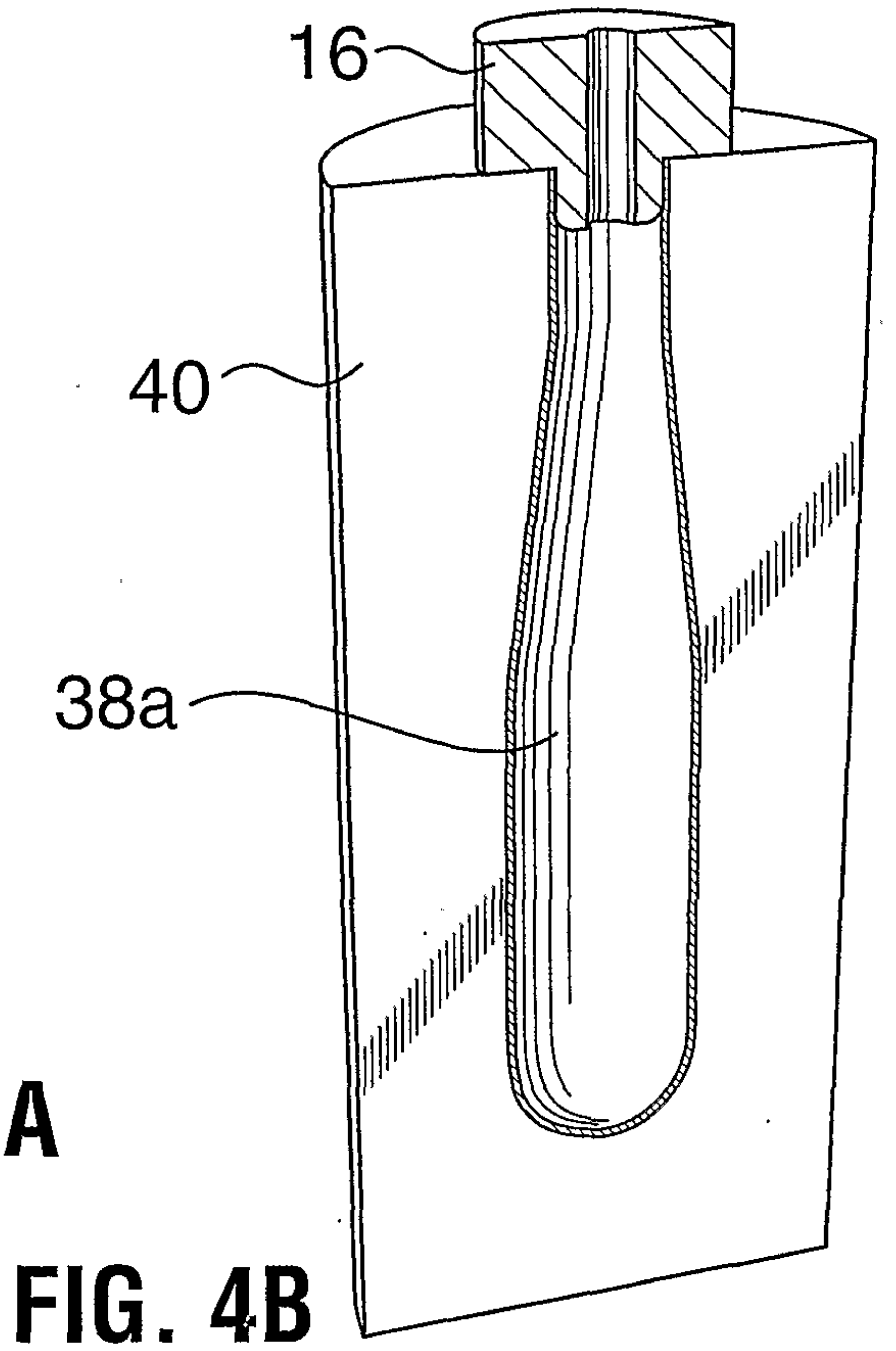


FIG. 4B

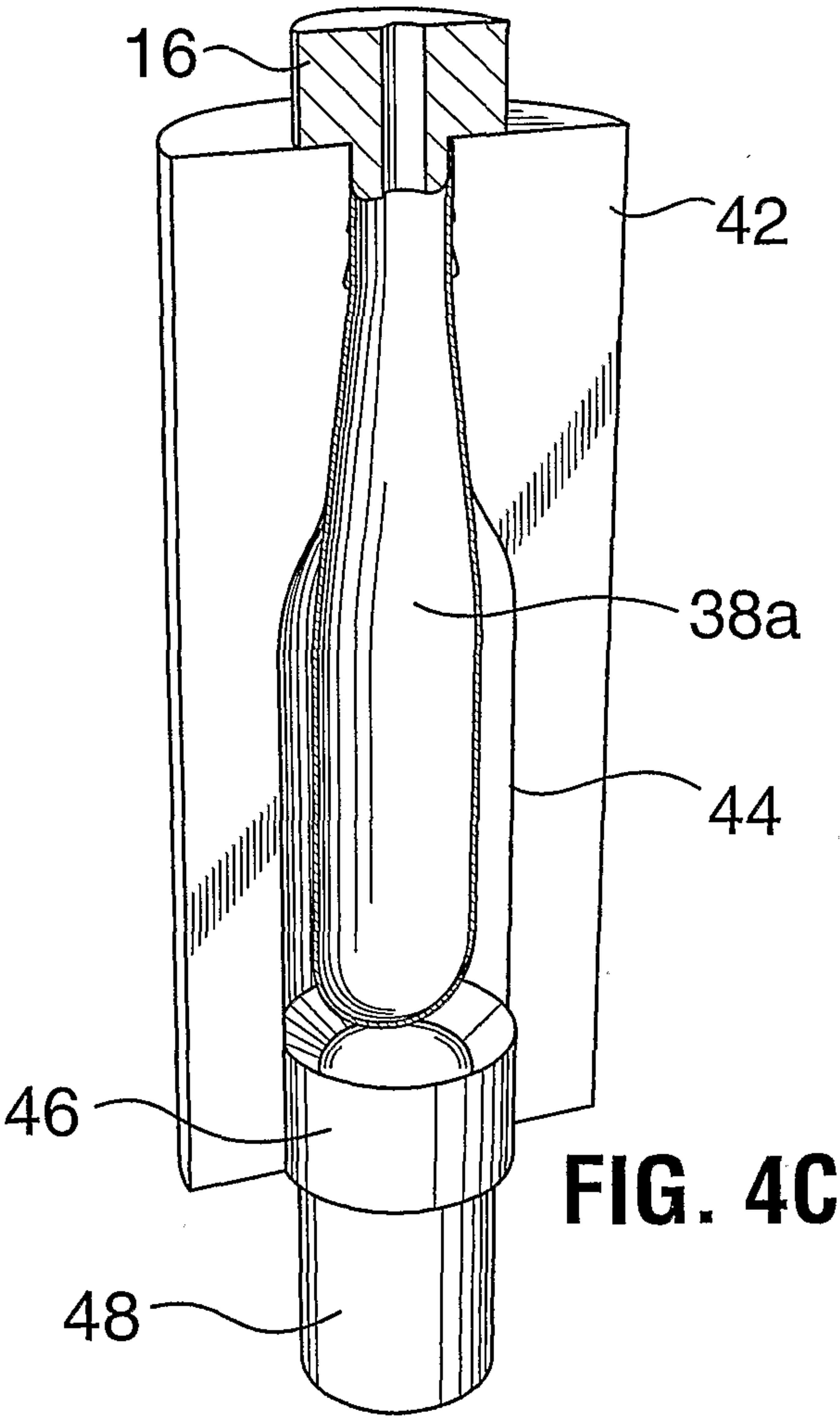


FIG. 4C

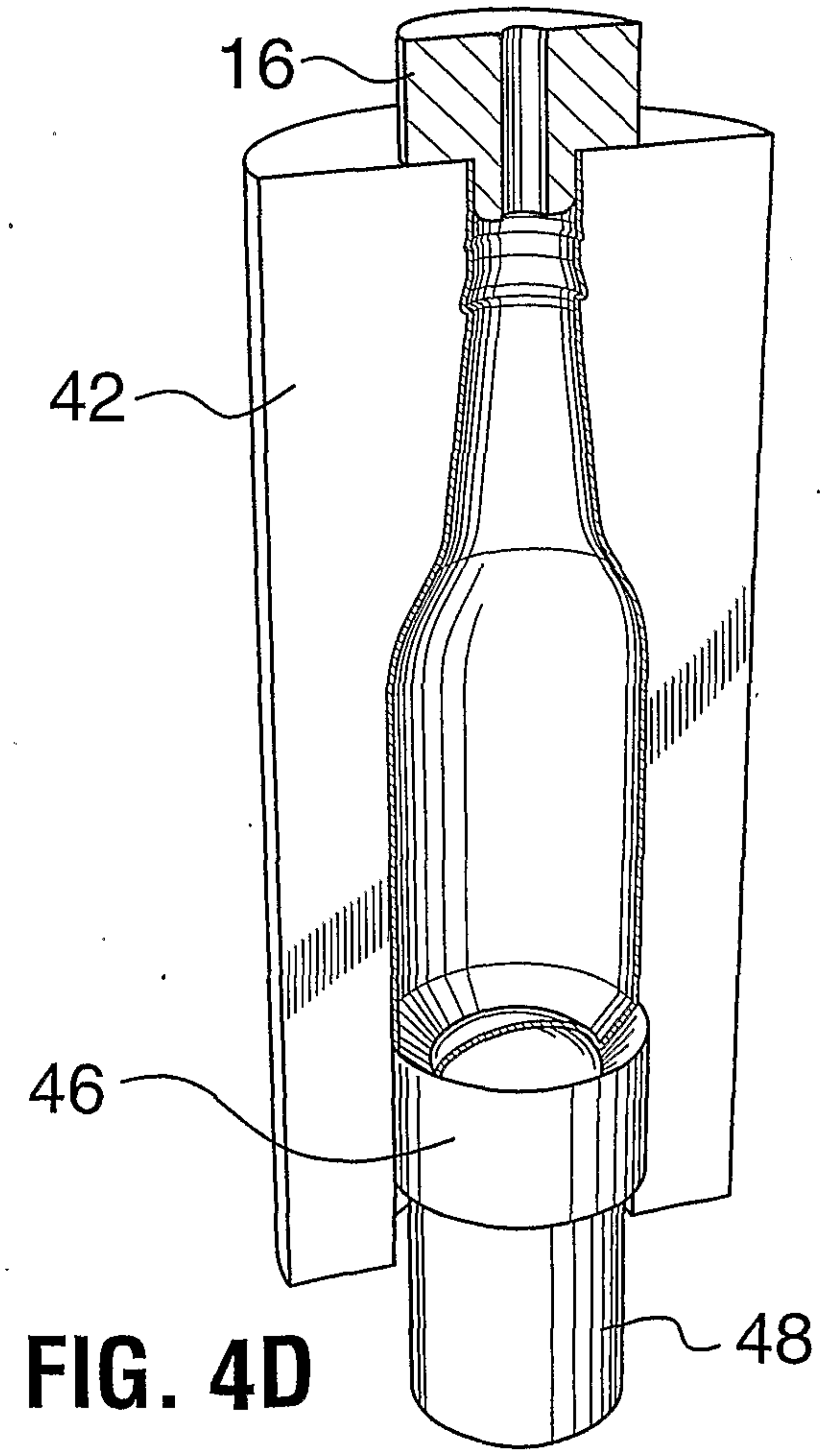


FIG. 4D

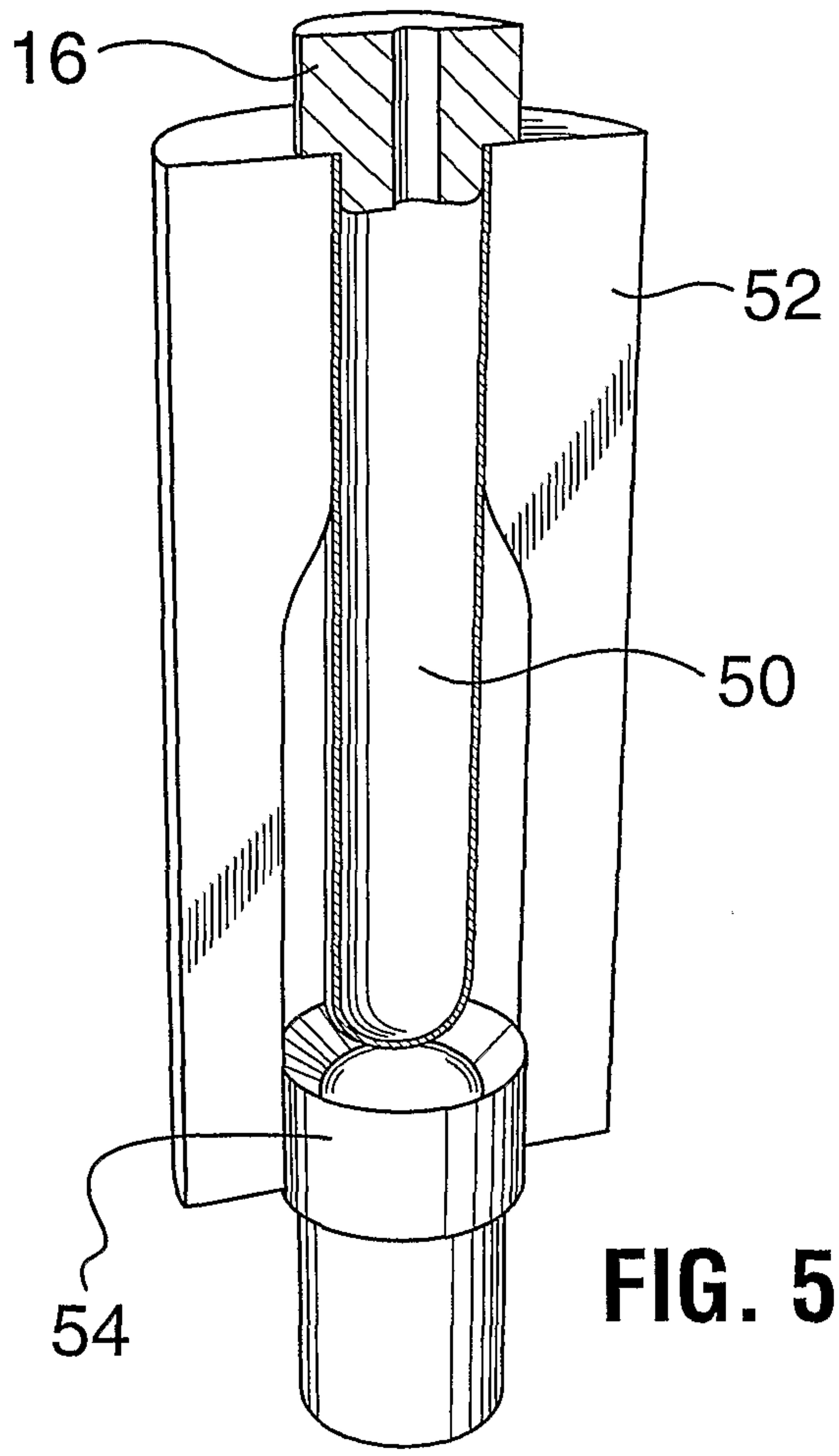


FIG. 5a

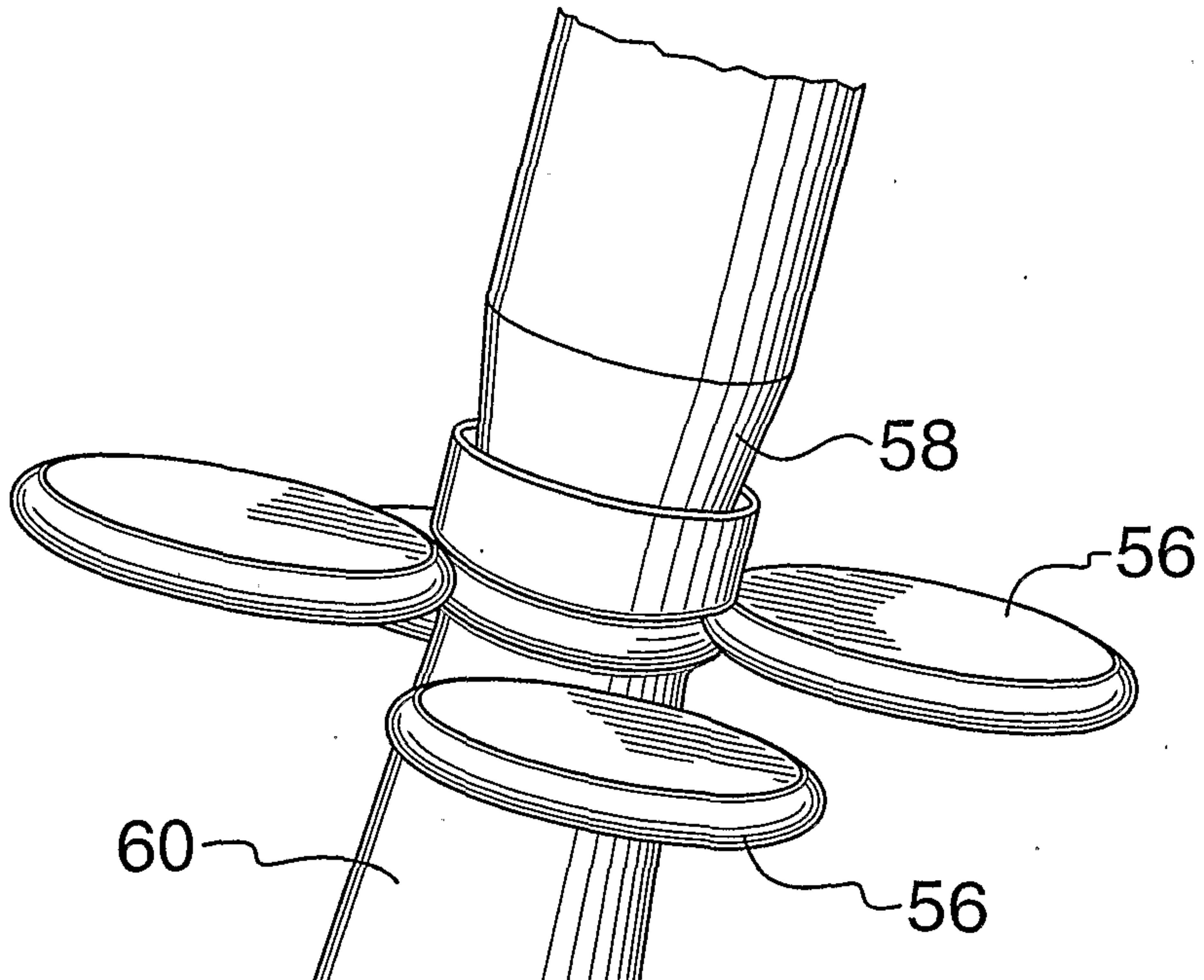


FIG. 5B

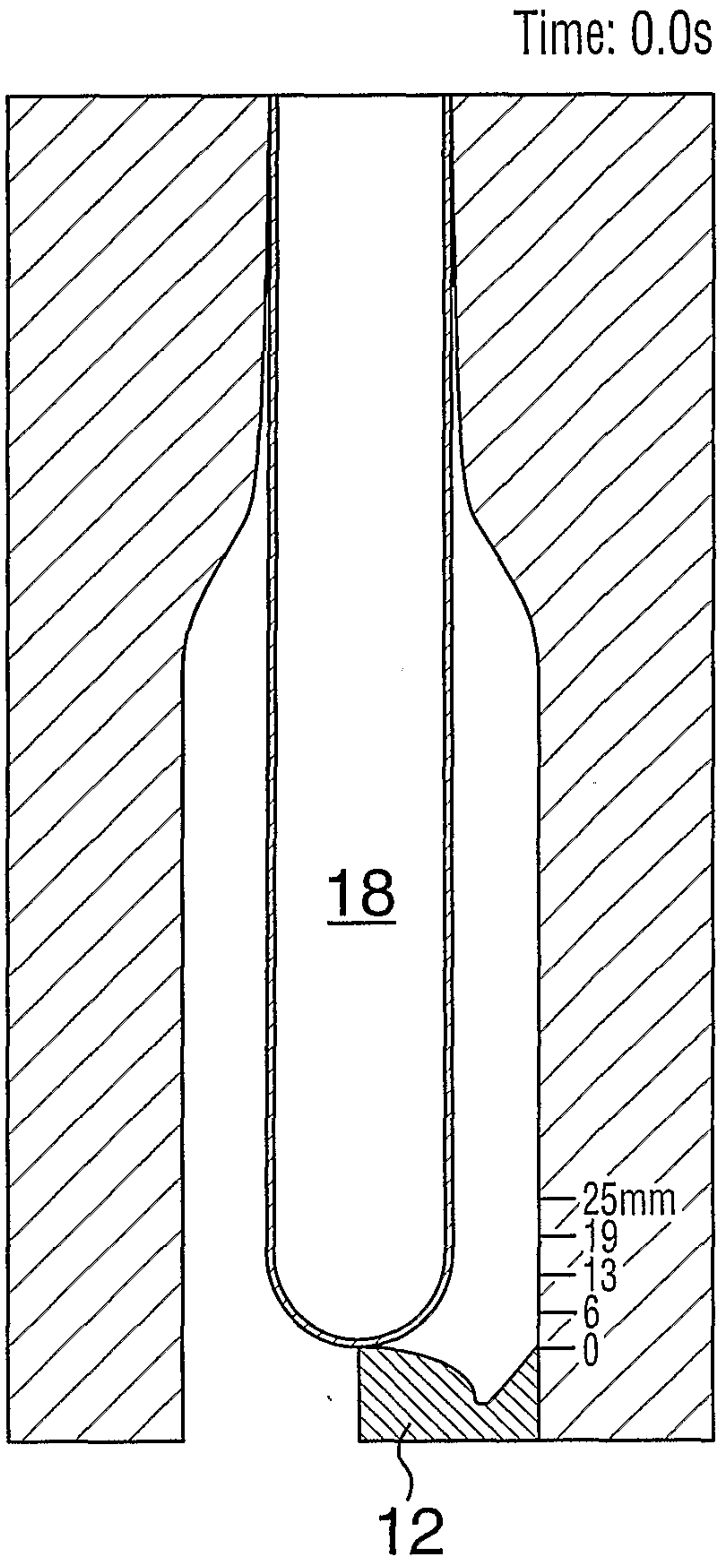


FIG. 6A

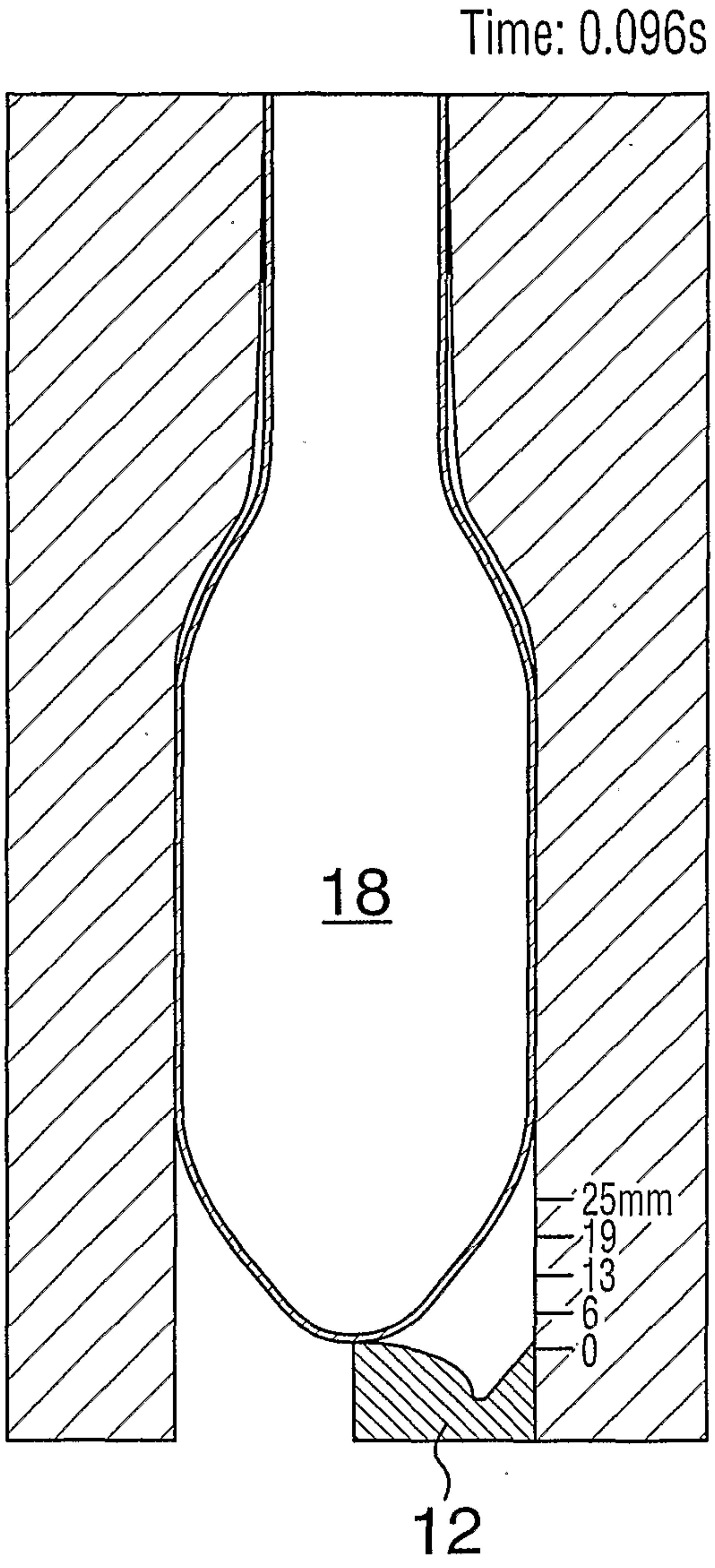


FIG. 6B

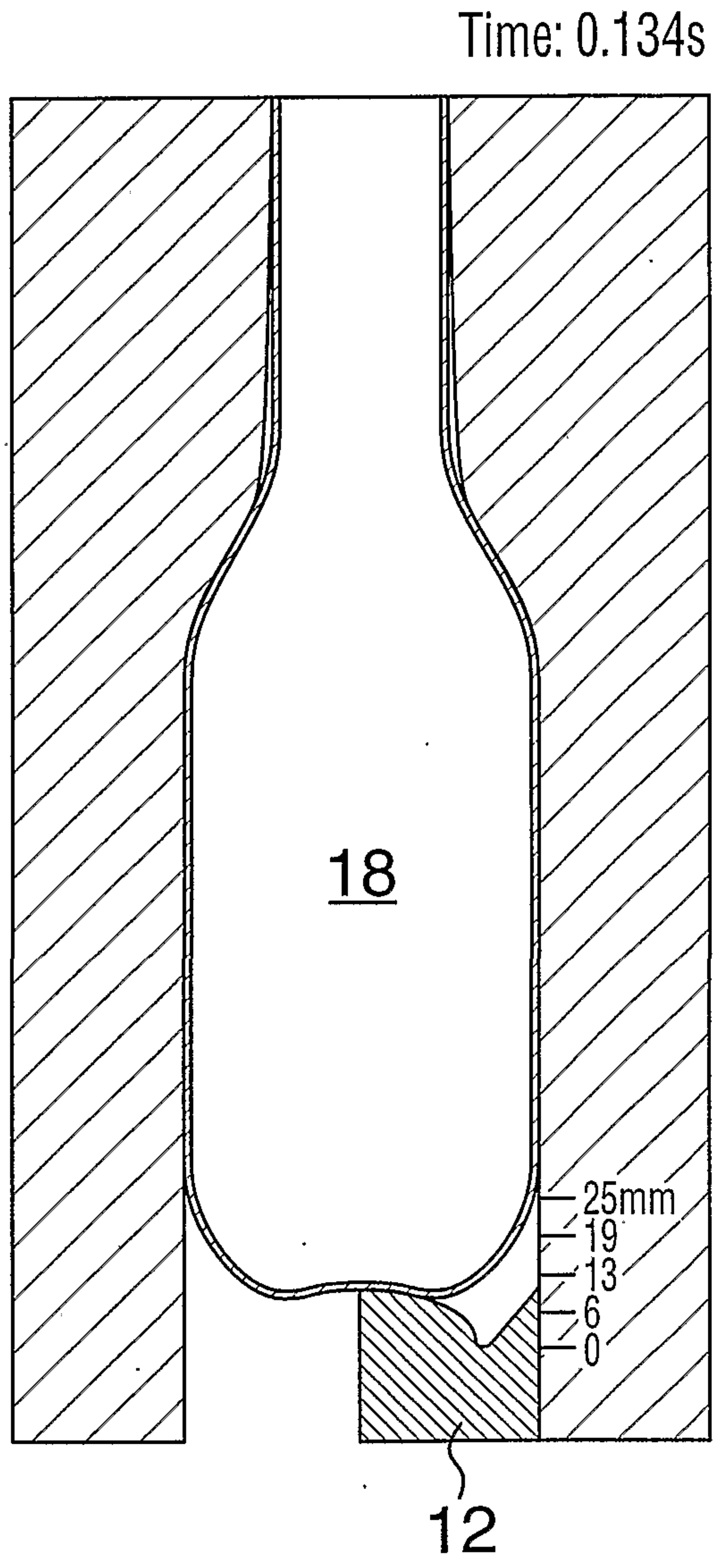


FIG. 6C

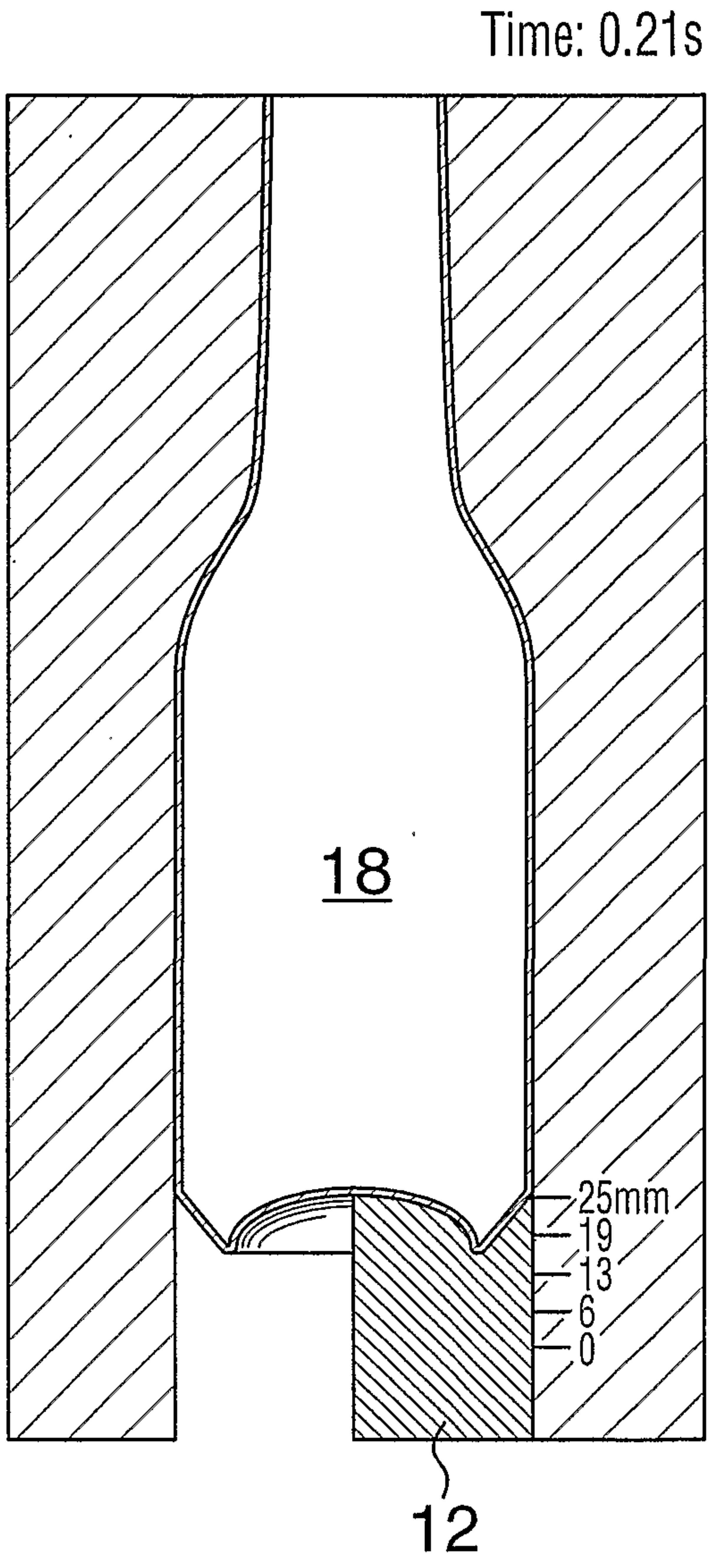


FIG. 6D

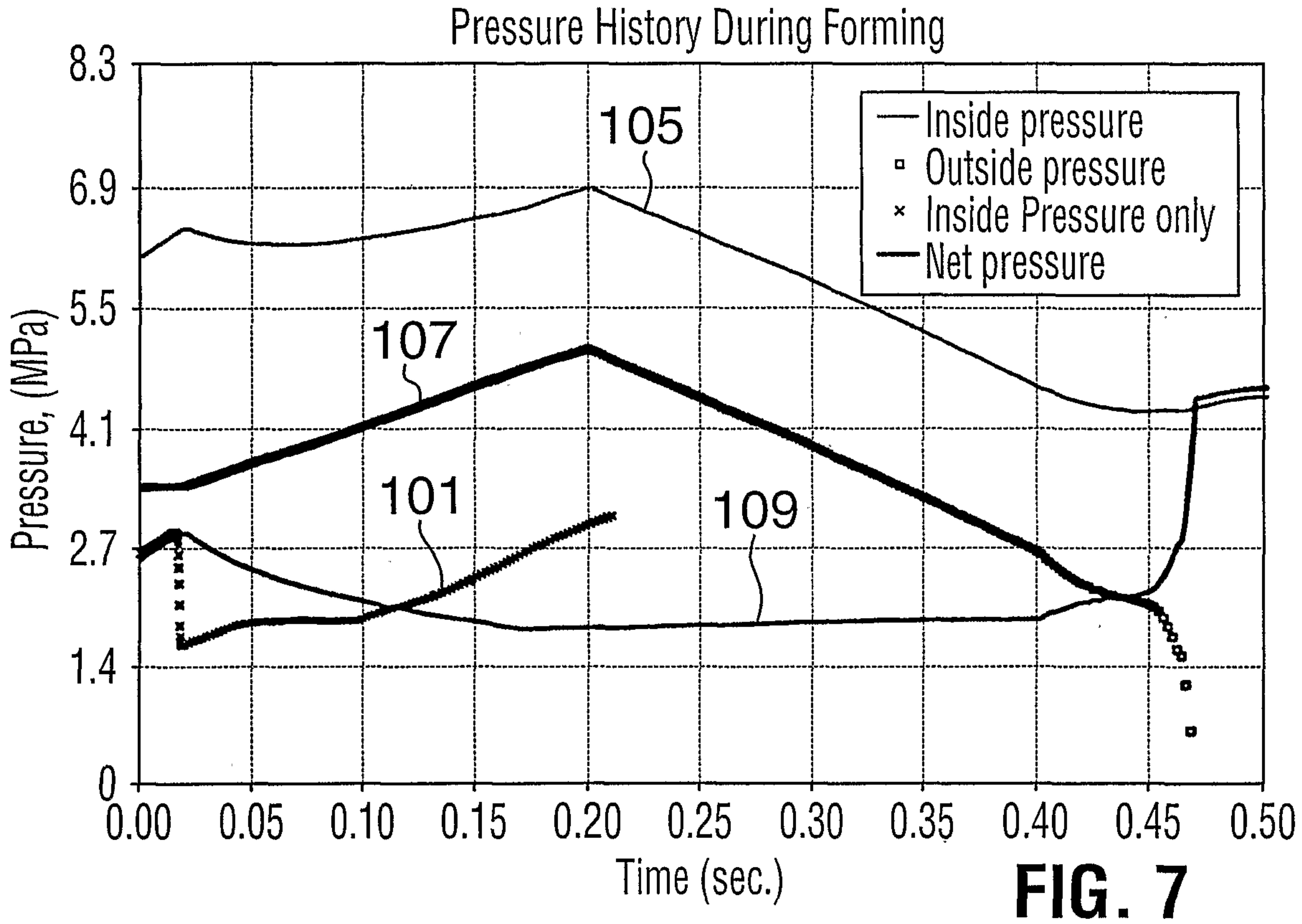

Pressure History During Forming
Pressure, (MPa)
8.3
6.9
5.5
4.1
2.7
1.4
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Time (sec.)
Inside pressure
Outside pressure
Inside Pressure only
Net pressure
105
107
101
109

FIG. 7

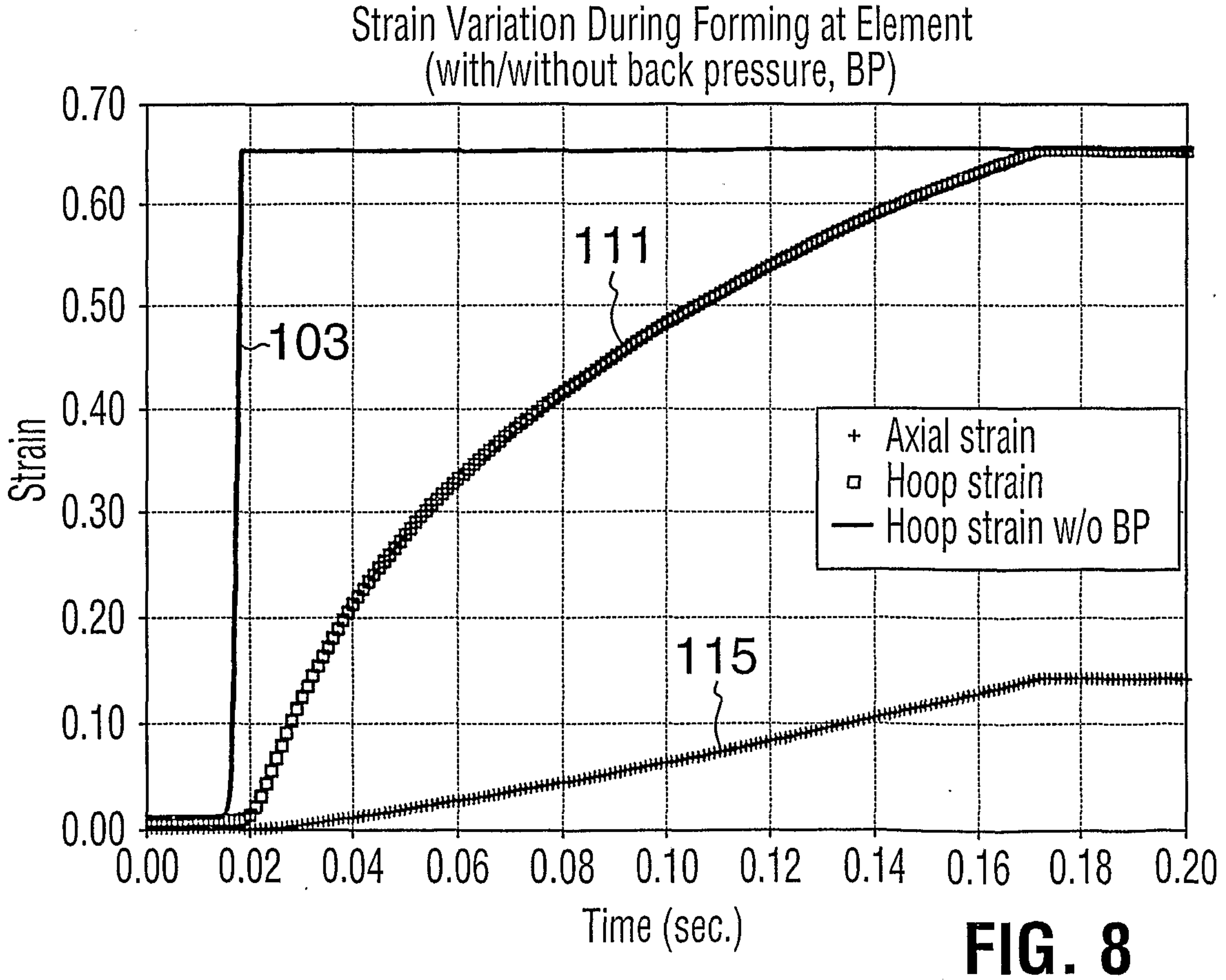

Strain Variation During Forming at Element
(with/without back pressure, BP)
Strain
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
Time (sec.)
Axial strain
Hoop strain
Hoop strain w/o BP
103
111
115

FIG. 8

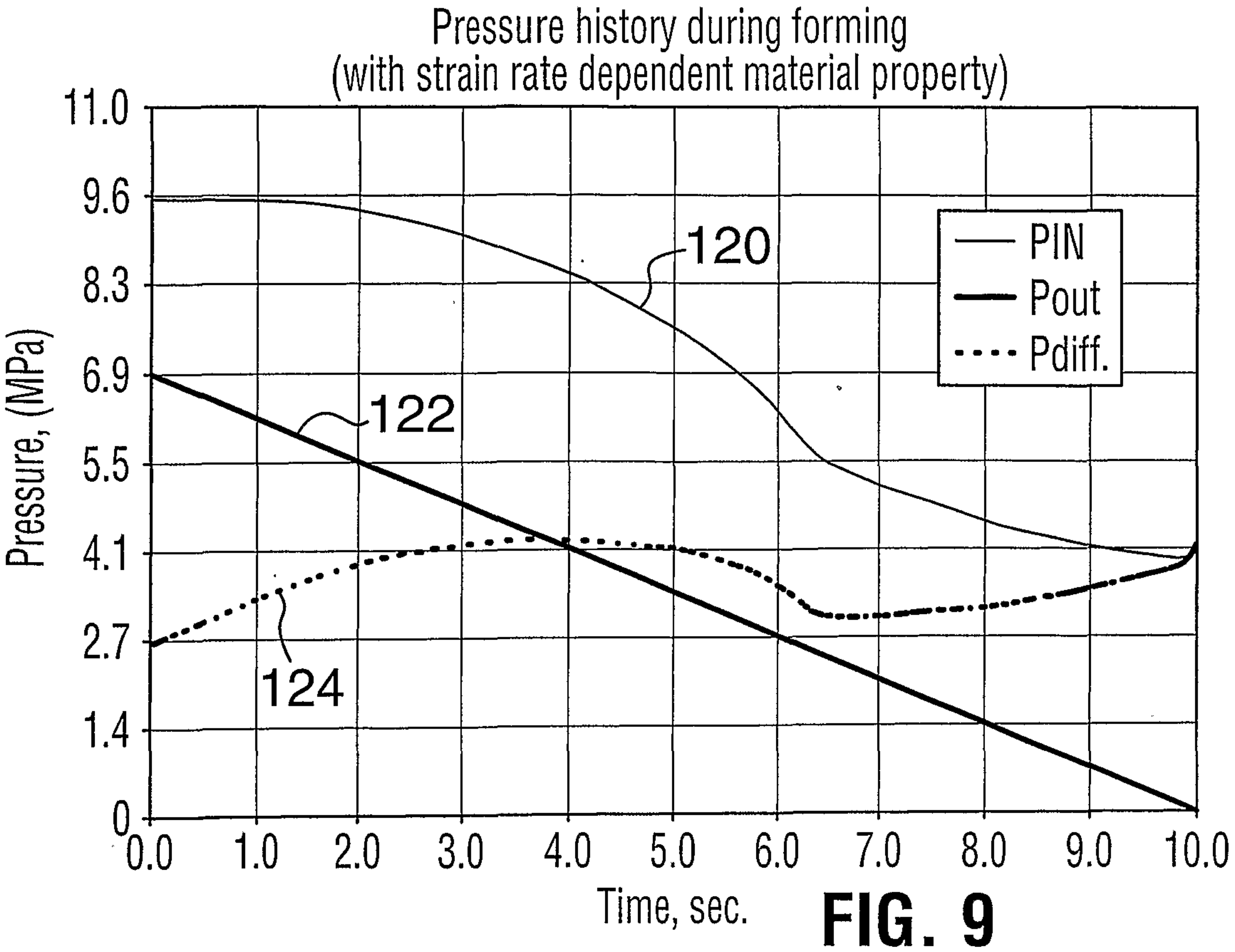

Pressure history during forming
(with strain rate dependent material property)
Pressure, (MPa)
11.0
9.6
8.3
6.9
5.5
4.1
2.7
1.4
0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Time, sec.
PIN
Pout
Pdiff.
120
122
124

FIG. 9

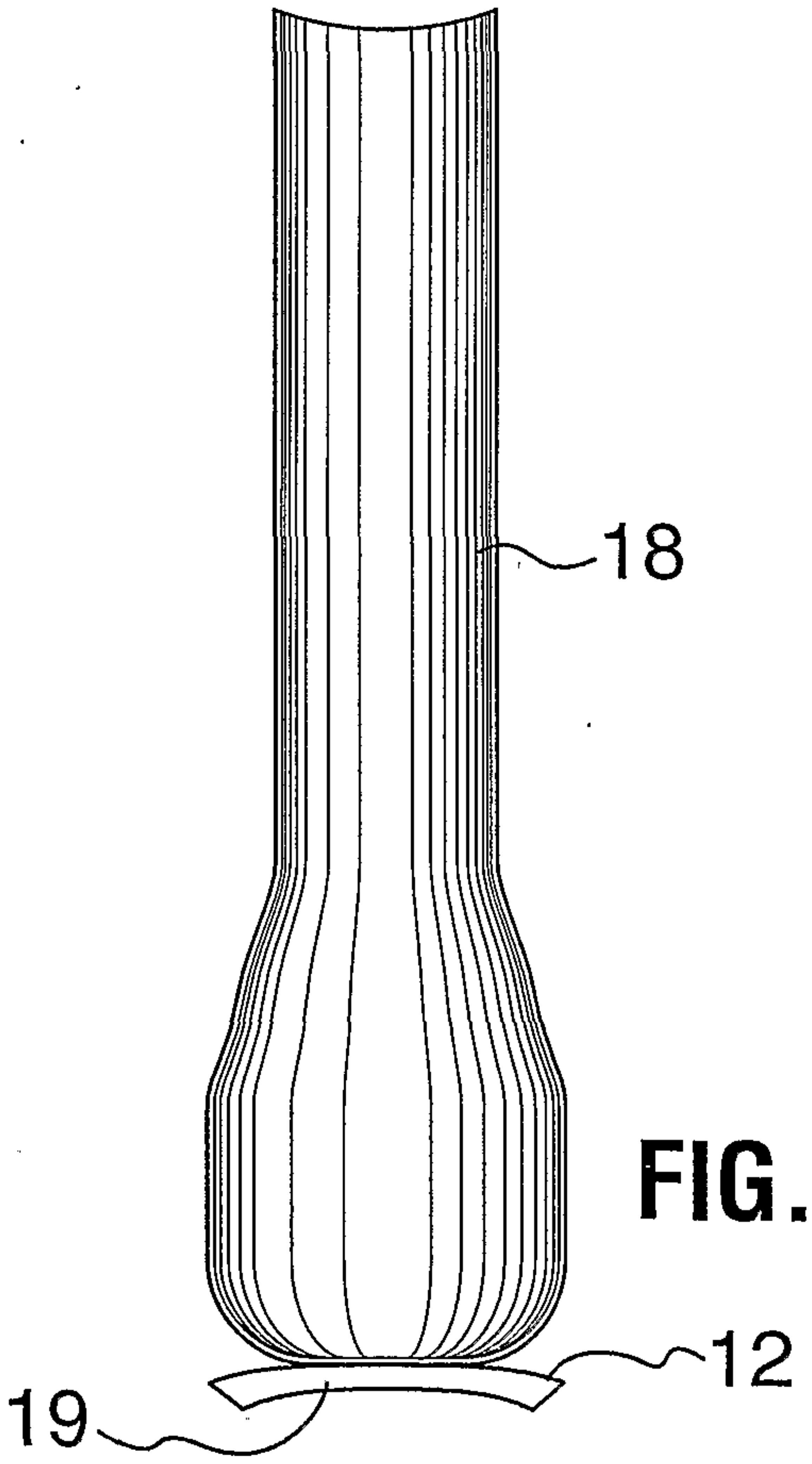

18
12
19

FIG. 10

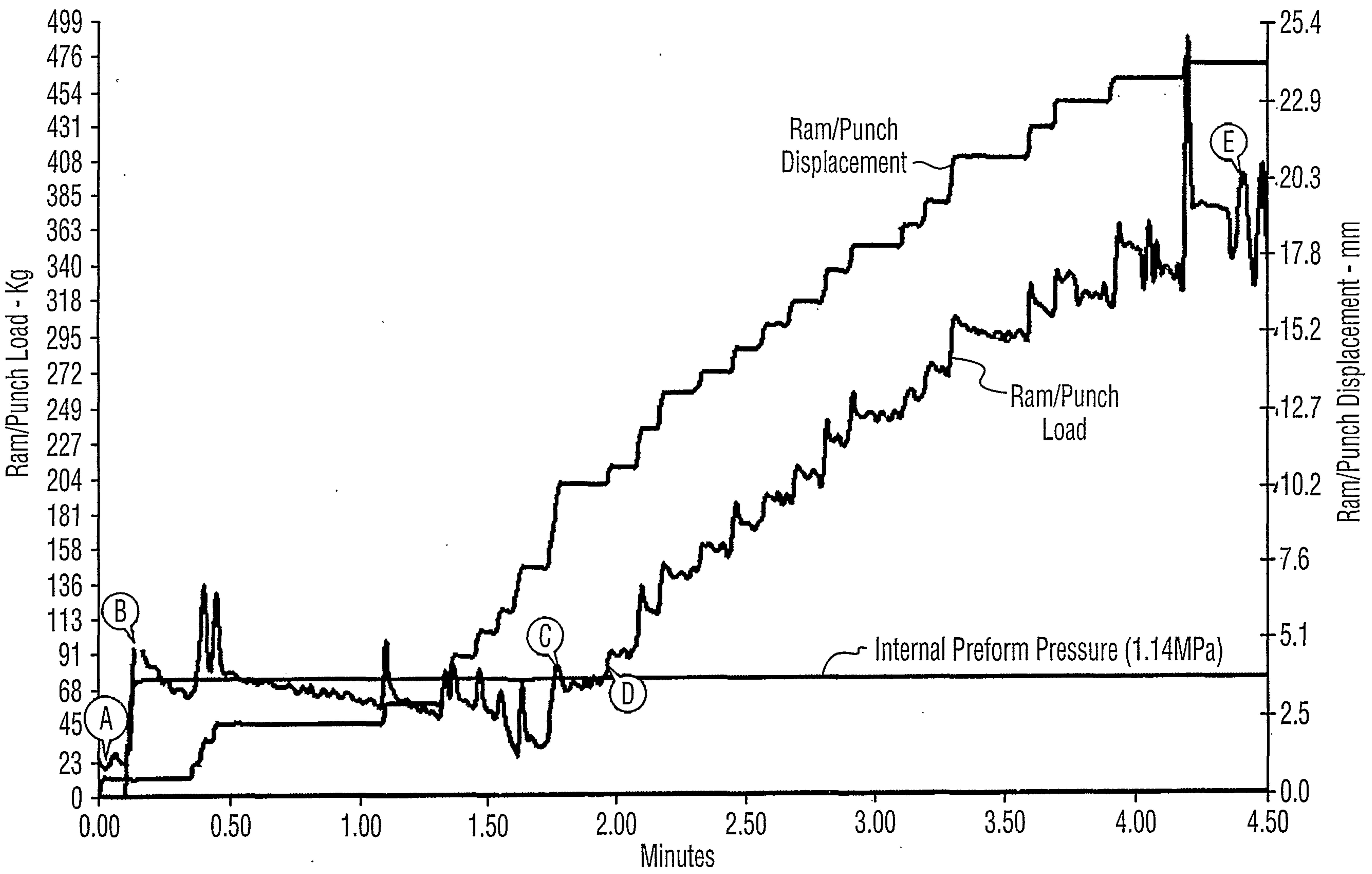

Ram/Punch Load - Kg
499
476
454
431
408
385
363
340
318
295
272
249
227
204
181
158
136
113
91
68
45
23
0
Ram/Punch Displacement - mm
25.4
22.9
20.3
17.8
15.2
12.7
10.2
7.6
5.1
2.5
0.0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
Minutes
Ram/Punch Displacement
Ram/Punch Load
Internal Preform Pressure (1.14MPa)
A
B
C
D
E

FIG. 11

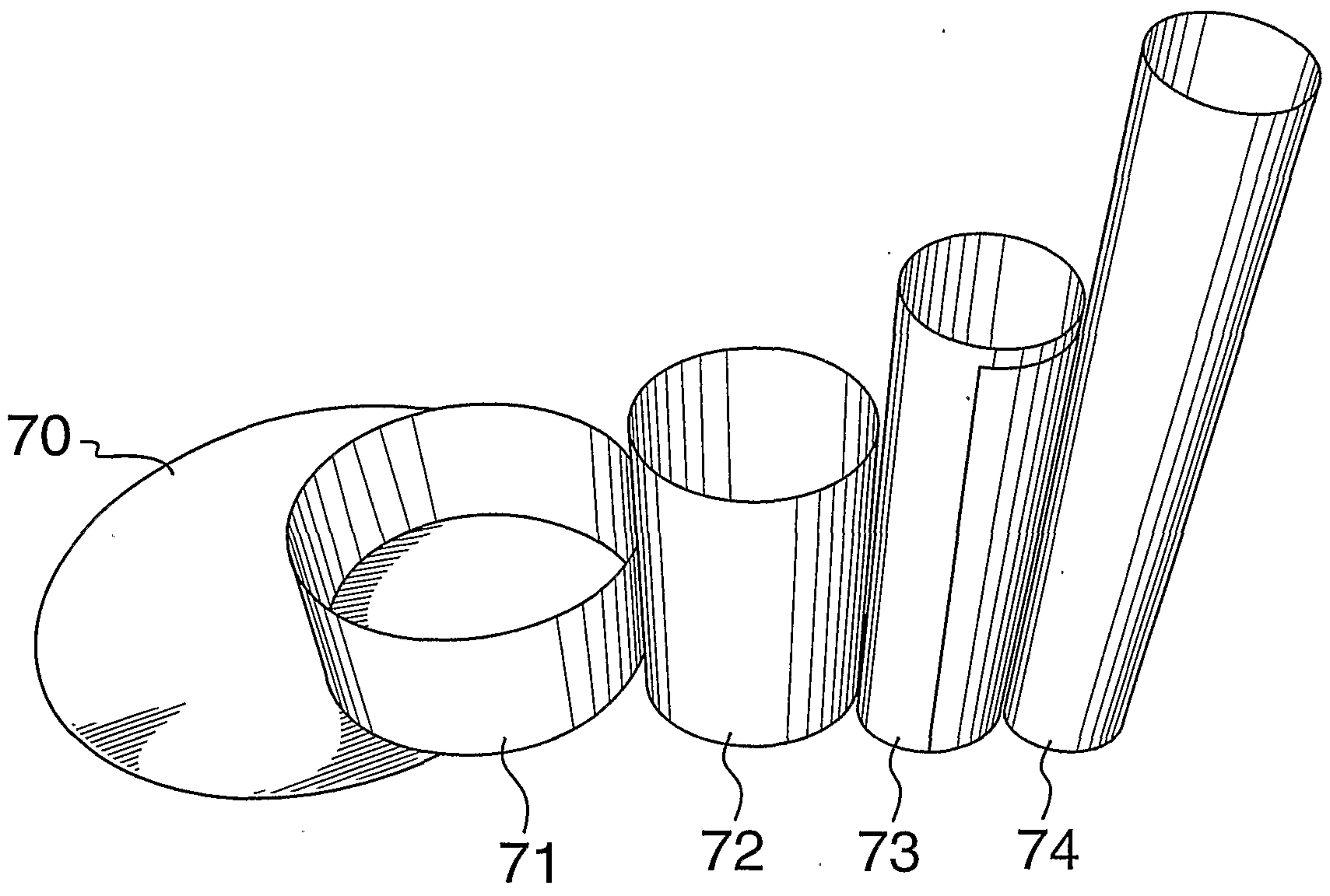
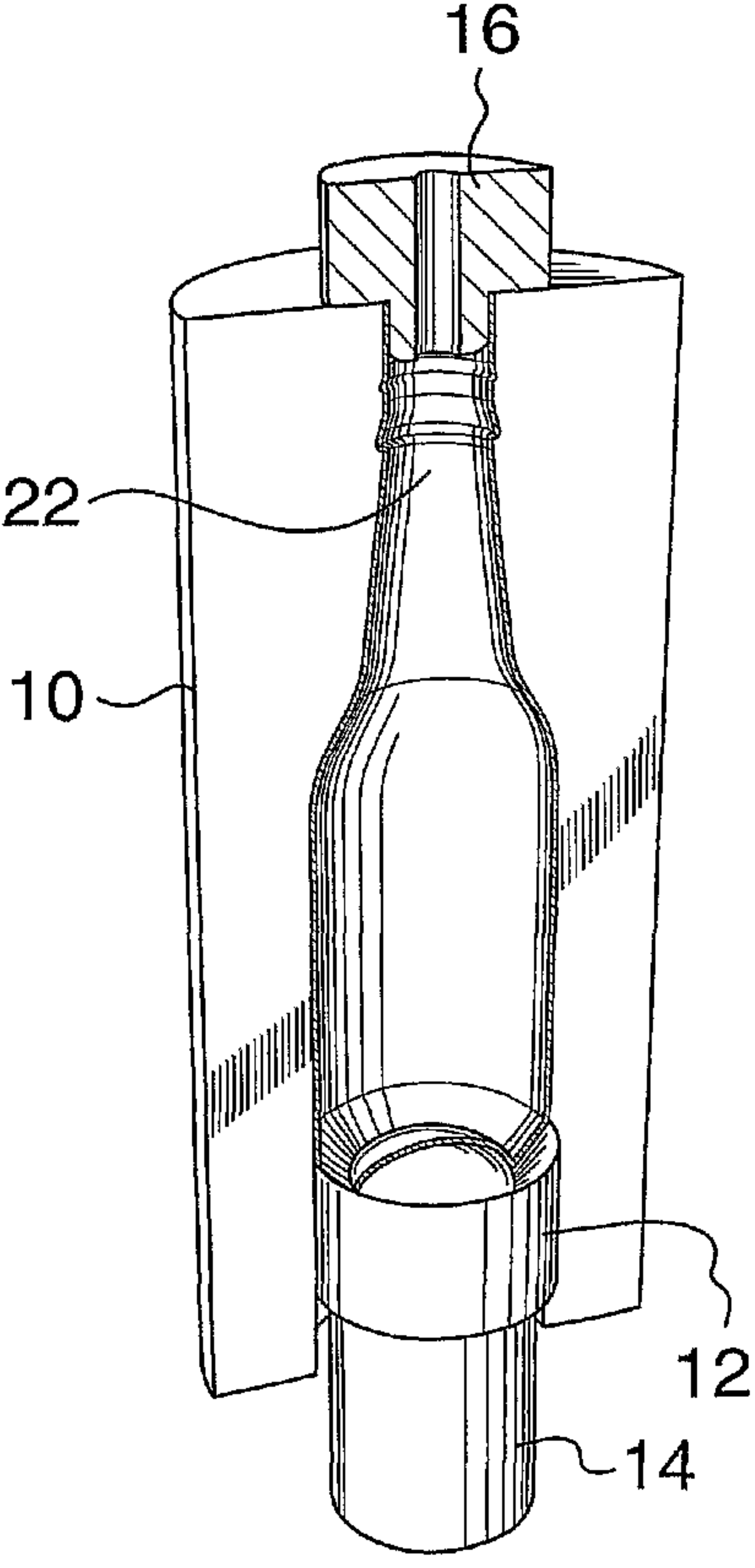


FIG. 12


16
22
10
12
14