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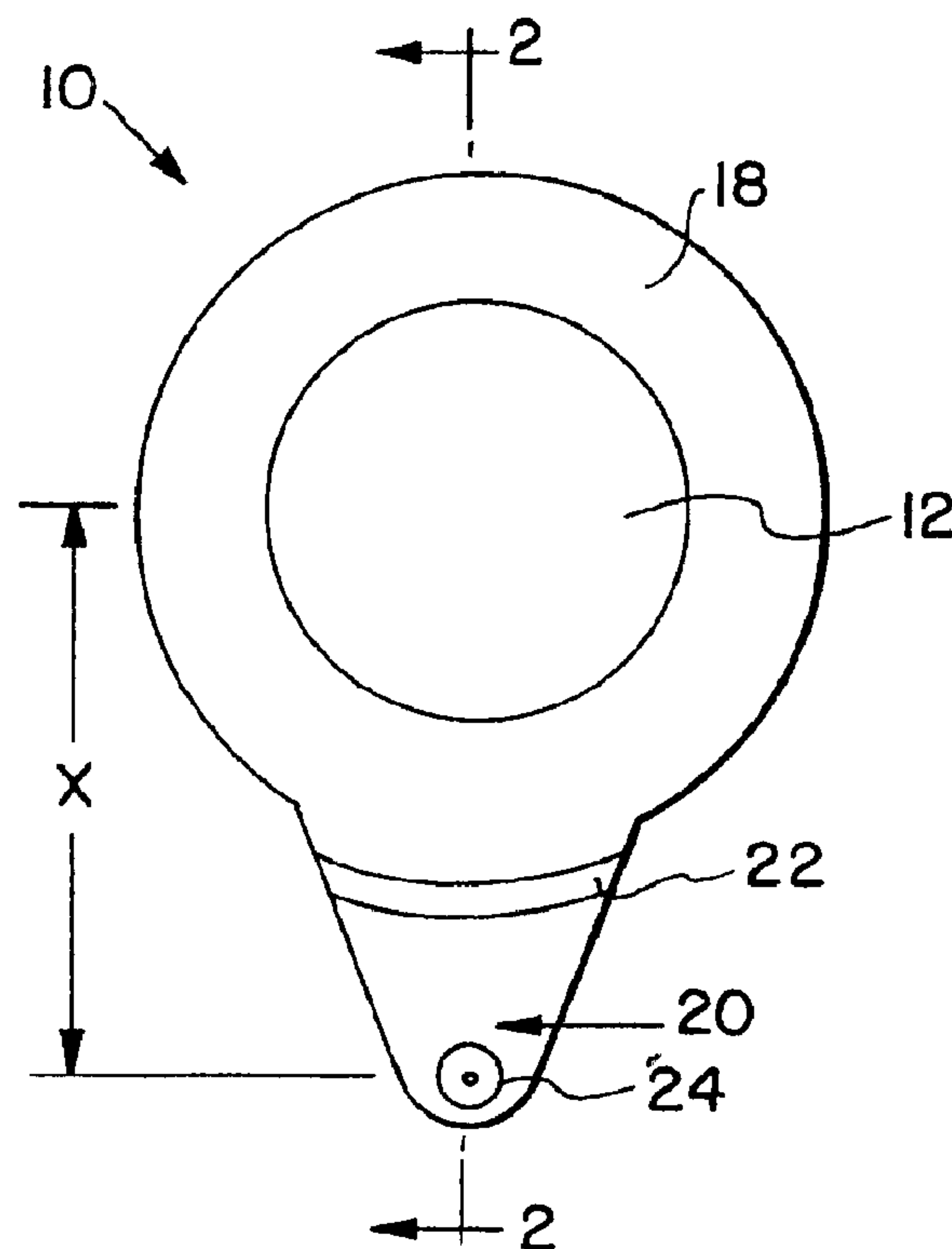
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(54) Titre : MOULE PERMETTANT D'OBTENIR UN CYCLE DE MOULAGE COURT

(54) Title: MOLDING ARRANGEMENT TO ACHIEVE SHORT MOLD CYCLE TIME



(57) Abrégé/Abstract:

An arrangement for molding a front or back polystyrene mold half which is used, with a second complementary back or front mold half, for subsequent molding of a soft contact lens such as a hydrogel soft contact lens. The arrangement is designed with heat flow considerations in mind to minimize the molding cycle time, while producing uniformly precise and accurate optical quality mold halves. Each mold half defines a convex curved surface and a concave curved surface spaced therefrom, with one of the surfaces defining an optical quality curved surface for the soft contact lens. A heated molding machine introduces molten polystyrene through a hot runner system to a plurality of mold cavities, each of which defines an optical quality curved surface and also a

(57) **Abrégé(suite)/Abstract(continued):**

second noncritical surface. The optical quality surface of the mold cavity is positioned further away from the heated hot runner side of the mold than the second surface, which allows faster cooling of the optical quality surface of the mold cavity. This allows quicker setting and locking of minimal temperature residual stresses on the optical quality side of the mold half and a faster molding cycle time. Each mold cavity has a first insert on the optical quality side of the mold cavity and a second insert on the second side. Each of the first and second inserts has a circumferential cooling passageway defined therearound or in proximity for the first inserts, and also includes a bubbler positioned internally therein. Coolant is circulated in a turbulent mode through the circumferential passageways and also through the bubblers against inner surfaces of the insert to provide rapid cooling of the mold cavity.

1 ABSTRACT OF THE DISCLOSURE

An arrangement for molding a front or back polystyrene mold half which is used, with a second complementary back or front mold half, for subsequent
5 molding of a soft contact lens such as a hydrogel soft contact lens. The arrangement is designed with heat flow considerations in mind to minimize the molding cycle time, while producing uniformly precise and accurate optical quality mold halves. Each mold half
10 defines a convex curved surface and a concave curved surface spaced therefrom, with one of the surfaces defining an optical quality curved surface for the soft contact lens. A heated molding machine introduces molten polystyrene through a hot runner system to a
15 plurality of mold cavities, each of which defines an optical quality curved surface and also a second noncritical surface. The optical quality surface of the mold cavity is positioned further away from the heated hot runner side of the mold than the second surface,
20 which allows faster cooling of the optical quality surface of the mold cavity. This allows quicker setting and locking of minimal temperature residual stresses on the optical quality side of the mold half and a faster molding cycle time. Each mold cavity has a first insert
25 on the optical quality side of the mold cavity and a second insert on the second side. Each of the first and second inserts has a circumferential cooling passageway defined therearound or in proximity for the first inserts, and also includes a bubbler positioned
30 internally therein. Coolant is circulated in a turbulent mode through the circumferential passageways

1 and also through the bubblers against inner surfaces of the insert to provide rapid cooling of the mold cavity.

1 MOLDING ARRANGEMENT TO ACHIEVE SHORT MOLD CYCLE TIME

BACKGROUND OF THE INVENTION

1. Field of the Invention

5 The present invention relates generally to an arrangement and method for molding a front or back mold half which is used, with a second complementary back or front mold half, for subsequent molding of a soft contact lens such as a hydrogel soft contact lens.

10 More particularly, the subject invention pertains to an arrangement and method as described for molding a front or back polystyrene mold half in a manner which is designed with heat flow considerations in mind to minimize the molding cycle time, which has
15 been reduced to approximately three to six seconds, depending upon the wall thickness, while producing uniformly acceptable, optical quality mold halves.

2. Discussion of the Prior Art

U.S. Patent 4,565,548 to Larsen discloses a
20 typical prior art approach to manufacturing mold halves similar to the present invention. Pursuant to this prior art approach, the mold halves are molded as a set of eight mold halves carried on a frame in a 2x4 array. Figure 3 of the Larsen patent illustrates a molded frame
25 carrying a 2x4 array of concave front or female mold halves, while Figure 5 therein shows a molded frame carrying a 2x4 array of convex back or male mold halves. The cluster assembly of the frame and molds is manufactured by injection molding the assembly as one
30 piece with the molds being secured within an outer rectangular frame by small struts extending between the frame and the molds. The height of the frame is such

-2-

1 that the surfaces of the molds are protected from
scratching and mechanical damage during handling, and
the frame in general has a shape facilitating stacking
and handling. This prior art approach of molding such
5 polystyrene mold halves in a cluster assembly typically
takes approximately twenty-four (24) seconds, which is
considered to be too long for the efficient production
of such polystyrene mold halves. In contrast thereto,
pursuant to the present invention, the molding of such
10 polystyrene mold halves takes approximately three to six
seconds, depending upon the wall thickness.

A complementary pair of front and back mold
halves is used in the production of hydrogel contact
lenses by direct molding of a monomer mixture wherein
15 the mixture is dissolved in a non-aqueous, water-
displaceable solvent. The mixture is initially placed
in a two part mold consisting of the front and back mold
halves which define the shape of the final desired
hydrogel (i.e. water-swollen) lens. After a dosing step
20 in which the front concave mold halves are substantially
filled with the polymerization mixture, the concave
front mold halves are covered with the back mold halves
in a manner in which no air bubbles are trapped beneath
the back mold halves, which are brought to rest on the
25 concave front mold halves properly aligned and without
distortion. This is preferably performed with back mold
halves which are put on as individual units on the pools
of polymerizable mixture held in the front concave mold
halves. Accordingly, prior to the mold covering step,
30 the plurality of back mold halves are separated from the
frame by breaking or cutting. The back mold members are

-3-

1 preferably held by a mechanical device while they are
separated from the frame and which thereafter is used to
guide them down and place them all simultaneously on
each of the concave front mold halves containing the
5 polymerizable mixture. The monomer/solvent mixture is
then subjected to conditions whereby the monomer(s)
polymerize, such as irradiation with actinic visible or
ultraviolet radiation, to thereby produce a polymer/
solvent mixture in the shape of the reduced final size
10 of the desired hydrogel lens.

After the polymerization process is completed,
the two halves of the mold are separated (called
demolding), typically leaving the contact lens in the
front mold half, from which it is subsequently
15 displaced. The front and back mold halves are used for
only a single molding, after which they are disposed of.
After the polymerization is complete, the solvent is
displaced with water to produce a hydrated lens the
final size and shape of which are quite similar to the
20 size and shape of the original molded polymer/solvent
article. The direct molding of hydrogel contact lenses
is disclosed in U.S. Patent 4,495,313 to Larsen, U.S.
Patent 4,680,336 to Larsen et al., U.S. Patent 4,565,348
to Larsen, and U.S. Patent 4,640,489 to Larsen et al.

25 SUMMARY OF THE INVENTION

Accordingly, it is a primary object of the
present invention to provide a molding arrangement with
a mold insert design, heat removal process, and
processing to achieve a short mold cycle time.

-4-

1 The molding of the mold halves involves the
separate molding of each front mold half and of each
back mold half. The inner concave surface of the front
mold half defines the outer surface of the contact lens,
5 while the outer convex surface of the back mold half
defines the inner surface of the contact lens which
rests upon the eye. Accordingly, the shape of the inner
concave surface of the female mold half and the shape of
the outer convex surface of the male mold half must have
10 acceptable optical quality surfaces. However, the outer
convex surface of the front mold half and the inner
concave surface of the back mold half need not have the
same high optical quality surfaces, and in fact the side
of each mold half having one of those surfaces is used
15 by robotic handling equipment to handle the mold halves.
The present invention takes advantage of this latter
feature to provide molding and very rapid cooling of the
critical optical quality surfaces of the contact lens
molds, i.e., the inner concave surface of the front mold
20 half and the outer convex surface of the back mold half.

A further object of the subject invention is
the provision of a molding arrangement designed to
simultaneously mold a plurality of mold halves in a
plurality of separate mold cavities, each of which is
25 positioned to space the optical quality surface of the
mold cavity further from the heat source of a heated hot
runner system of an extruding machine than the second
(non-optical quality) surface of the mold cavity. This
arrangement allows the optical quality surface of the
30 mold cavity to be cooled as rapidly as possible, to
allow quicker setting and locking of temperature

-5-

1 residual stresses on the optical quality side of the
mold half, thereby resulting in a faster molding and
cycle time. This results in the slightly cooler optical
quality side of the mold half having slightly less
5 dimensional variation than the second (non-optical
quality) surface of the mold half. Moreover, each
individual mold surface (optical and non-optical) is
cooled separately by coolant circulated around the mold
cavity.

10 The present invention takes a different
approach from the prior art as exemplified by Larsen
U.S. Patent 4,565,348, and molds individual mold halves
in individual mold cavities, each of which produces a
nonattached mold half (i.e., not attached to a cluster
15 of similar mold halves). Each individual mold surface
is positioned and cooled to achieve a reduced cycle
molding time. Moreover, the flow length distance of the
polymer has been significantly reduced relative to prior
designs, which greatly enhances the ability to optimize
20 the optical attributes of the resultant mold half.
There is less probability of freezing the flow
passageway as mold temperatures are reduced further to
improve cycle time.

Each mold half defines an optical quality
25 surface (i.e., the concave surface in the front mold
half and the convex surface in the back mold half).
Each mold half also defines a circumferential flange
around the convex and concave surfaces. In general, the
mold halves are processed and handled by robotic
30 handling systems which handle (as by vacuum grasping)

-6-

1 the back side of the flange which is on the opposite
side from the optical quality surface of the mold half.

In accordance with the teachings herein, the
present invention provides a molding arrangement and
5 method for molding a mold half which is used, with a
second complementary mold half, for the subsequent
molding of a soft contact lens. Each mold half defines
a convex curved surface and a concave curved surface
spaced therefrom, with one of the convex and concave
10 surfaces defining an optical quality curved surface for
the soft contact lens. A heated mold (to ensure the
flow rate does not decrease and shear stresses increase)
introduces a molten mold material, such as from a family
of thermoplastics, such as polystyrene, polycarbonate,
15 poly [4-methyl-pentene 1] (TPX), polyvinyl chloride
(PVC), polyethylene, polypropylene, copolymers of
styrene with acrylonitrile or butadiene, acrylates such
as polymethyl methacrylate, polyacrylonitrile,
polyamides, polyesters, etc. through a hot runner system
20 to at least one (preferably more) mold cavity. Each
mold cavity defines an optical quality curved surface
and also a second noncritical curved surface for the
mold half.

Pursuant to the teachings of the present
25 invention, the optical quality surface of the mold
cavity is positioned further away from the heated hot
runner side of the mold system than the second surface
of the mold cavity, and a cooling system is provided for
cooling the mold cavity. The positioning of the optical
30 quality curved surface further away from the heated hot
runner system allows faster cooling of the optical

-7-

1 quality surface of the mold cavity. This allows quicker
setting and locking of temperature residual stresses on
the optical quality side of the mold half and a faster
molding cycle time. This results in the slightly cooler
5 optical quality side of the mold half having slightly
less dimensional variation than the second (non-optical
quality) surface of the mold half.

When the mold half is a front or female mold
half, the concave surface of the female mold half
10 defines the optical quality surface, and the concave
surface of the female mold half is positioned further
away from the heated hot runner system than the second
surface. When the mold half is a back or male mold
half, the convex surface of the male mold half defines
15 the optical quality surface, and the convex surface of
the male mold half is positioned further away from the
heated hot runner system than the second surface.

In a preferred embodiment, the material being
molded into the mold half is polystyrene, but could be
20 any suitable thermoplastic such as mentioned hereinabove
in the family of thermoplastics. Moreover, the mold
cavity comprises a first insert on the optical quality
side of the mold cavity and a second insert on the
second side of the mold cavity. Each insert can be
25 manufactured as one integral component, or can be a two-
piece design as described hereinbelow. When the mold
cavity is for the production of a front mold half, the
first insert on the optical quality side of the mold can
include a bushing, with a power insert positioned within
30 the bushing. The power insert has a convex end surface
which defines the optical quality surface, which also

-8-

1 defines the optical power of a contact lens which is
subsequently produced by the front mold half, hence the
name power insert. Moreover, different optical power
(diopter) lenses can be produced by merely changing the
5 power insert to substitute a different power insert
having a different curvature convex end surface.
Alternatively, the bushing and power insert could also
be manufactured as one integral component. The second
insert on the second side of the mold cavity does not
10 define as high an optical quality surface, and so can
easily be manufactured as one integral component.

Moreover, each of the first and second inserts
has a circumferential cooling passageway therearound,
either defined in the insert or defined in the steel
15 mold block retaining the insert, through which coolant
is circulated in a turbulent mode by the cooling system.
Each of the first and second inserts includes a bubbler
positioned internally therein, through which coolant is
circulated by the cooling system in a turbulent mode
20 against inner surfaces of the insert. In a preferred
embodiment, the molding arrangement includes a plurality
(such as four or eight) of mold cavities positioned at
one end of, and spaced around, the hot runner system.

In a further aspect of the present invention,
25 a molding arrangement and method is provided for molding
a mold half, which is used with a second complementary
mold half, for the subsequent molding of a soft contact
lens. The mold half defines a convex curved surface and
a concave curved surface spaced therefrom, with one of
30 the convex and concave surfaces defining an optical
quality curved surface for the soft contact lens. In

-9-

1 the arrangement and method, a heated molding machine
introduces a molten mold material through a hot runner
system to at least one mold cavity. Each mold cavity
defines an optical quality curved surface and also a
5 second curved surface for the mold half. Pursuant to
the teachings of the present invention, the mold cavity
comprises a first insert on the optical quality side of
the mold cavity and a second insert on the second side
of the mold cavity. Each of the first and second
10 inserts has a circumferential cooling passageway
therearound or in proximity of the insert, through which
coolant is circulated by a cooling system to provide for
faster cooling of the mold cavity. This allows quicker
setting and locking of minimal temperature residual
15 stresses in the mold half and a faster molding and
cycling time. Also, the direct polymer flow path
reduces the cooling time (locks in the minimal residual
stresses) to reduce the cycle time.

BRIEF DESCRIPTION OF THE DRAWINGS

20 The foregoing objects and advantages of the
present invention for a molding arrangement having a
mold insert design to achieve short mold cycle time may
be more readily understood by one skilled in the art
with reference being had to the following detailed des-
25 cription of several preferred embodiments thereof, taken
in conjunction with the accompanying drawings wherein
like elements are designated by identical reference
numerals throughout the several views, and in which:

Figures 1 and 2 are respectively top
30 elevational and side views of one embodiment of a front

-10-

1 (female) mold half which is produced pursuant to the present invention;

Figures 3 and 4 are respectively top elevational and side views of one embodiment of a back 5 (male) mold half which is produced pursuant to the present invention;

Figure 5 is a side elevational sectional view of a mold assembly which includes a front mold half and a back mold half;

10 Figure 6 is a sectional view through a hot runner mold constructed pursuant to the teachings of the present invention, in which one of eight similar mold cavities for a front mold half is shown in section to illustrate the construction of each mold cavity;

15 Figure 7 is a sectional view through a hot runner mold similar to that of Figure 6, but for a back mold half; and

Figure 8 is a sectional view of a bushing employed in an insert on the optical quality side of the 20 mold cavity of Figure 6 or 7.

DETAILED DESCRIPTION OF THE DRAWINGS

Referring to the drawings in detail, Figures 1 and 2 illustrate respectively top elevational and side views of one embodiment of a front mold half 10 useful 25 in the production of a contact lens by the polymerization of a polymerizable composition in a mold assembly composed of two complementary front and back mold halves. The front mold half 10 is preferably formed of polystyrene, but could be any suitable 30 thermoplastic such as mentioned hereinabove in the family of thermoplastics, which is transparent to

-11-

1 visible and ultraviolet light to allow irradiation
therethrough with light to promote the subsequent
polymerization of a soft contact lens. A suitable
thermoplastic such as polystyrene also has other
5 desirable qualities such as being moldable to surfaces
of optical quality at relatively low temperatures,
having excellent flow characteristics and remaining
amorphous during molding, not crystallizing, and having
minimal shrinkage during cooling.

10 The front mold half 10 defines a central
curved section with an optical quality concave surface
12, which has a circular circumferential well defined
edge 14 extending therearound. The edge 14, shown in
detail A of Figure 2, is desirable to form a well
15 defined and uniform plastic radius parting line (edge)
for the subsequently molded soft contact lens. The well
defined edge 14 actually has a very small curvature
which can be in the range of 3-45 μm , or less preferably
5-30 μm , and the surfaces defining the edge can form an
20 angle in the range of 75° - 90° . A generally parallel
convex surface 16 is spaced from the concave surface 12,
and an annular essentially uniplanar flange 18 is formed
extending radially outwardly from the surfaces 12 and
16. The concave surface 12 has the dimensions of the
25 front curve (power curve) of a contact lens to be
produced by the front mold half, and is sufficiently
smooth such that the surface of a contact lens formed by
polymerization of a polymerizable composition in contact
with the surface is of an optically acceptable quality.
30 The front mold half is designed with a thickness to
transmit heat therethrough rapidly (typically in the

-12-

1 range of 0.4 to 1.2 mm, preferably in the range of 0.5
to 1.0 mm, and most preferably in the range of 0.6 to
0.8 mm, and in one embodiment was selected to be 0.8 mm)
and rigidity to withstand prying forces applied to
5 separate the mold half from the mold assembly during
demolding.

The front mold half or curve thickness was
reduced from 1.5 mm in prior designs to 0.8 mm. This
had a direct impact on cycle time reduction. Using a
10 one dimensional heat flow, the cooling differential
equation is:

$$\frac{\partial T}{\partial t} = a \frac{\partial^2 T}{\partial^2 t} \quad a = \frac{k}{eCp} = \text{thermal diffusivity}$$

$$15 \quad \text{cooling time} = \frac{-t^2}{\pi^2 a} \ln \left[\frac{4}{\pi} \frac{T_{\text{melt}} - T_{\text{mold}}}{T_{\text{demold temp}} - T_{\text{mold}}} \right]$$

The thermal diffusivity is proportional to specific
heat, thermal conductivity, density. The cooling rate
is determined by the thermal diffusivity of the
material. The higher the thermal diffusivity, the
20 faster the cooling rate.

The front mold half or curve 10 further
defines a tab 20 integral with the flange 18 which
projects from one side of the flange. The tab 20
extends to the injection hot tip (by the notation GATE)
25 which supplies molten thermoplastic to the mold. The
gate diameter is typically in the range of 0.4 to 1.4
mm, preferably in the range of 0.6 to 1.2 mm, and most
preferably in the range of 0.8 to 1.0 mm, and is
selected to result in minimal shear stress in the molten
30 thermoplastic which is injected. Control of the gate
size also helps to control the flow rate of the molten

-13-

1 thermoplastic, which (in conjunction with temperature
and rate of heat removal) helps control the final
dimensional characteristics of the molded part and
optimizes the processing of the molded part. The
5 optimum size of the gate is calculated by considering
the material flow index of the thermoplastic polymer,
the wall thickness, part volume, and also considering the
hot runner tip temperature and mold temperature.

The injection point feeds into a planarizing
10 zone which fulfills several important functions. The
planarizing zone is generally thin and flat, preferably
having the same thickness as the rest of the mold
cavity. The planarizing zone preferably is generally
triangular, having an apex near which the injection gate
15 point feeds molten thermoplastic into the planarizing
zone. The planarizing zone diverges gradually in width
from the apex region toward the rest of the mold cavity.
Where the planarizing zone intersects the flange portion
of the mold, the width diverges more, preferably
20 uniformly from both sides of the zone. Thus, the
planarizing zone is preferably symmetrical about the
plane formed by the injection point and the axis of the
concave surface of the molds.

One function of the planarizing zone is
25 planarizing the flow of the injected molten
thermoplastic into a smoothly steadily advancing flow of
material filling the zone and feeding directly into the
flange and concave-convex regions of the mold.
Controlling the flow characteristics imparted by the
30 dimensions of the planarizing zone, in conjunction with
the feed pressure, flow rate, and temperature of the

-14-

1 molten thermoplastic and the rate of heat withdrawal
therefrom, enables obtaining the desired characteristics
of the completed mold half.

The planarizing zone also serves to form the
5 tab 20 which is integral with the rest of the completed
mold half and is an essential part of that article.

The tab 20 defines therein an angled (e.g.,
45°) web section 22, which is included in the design to
break up the flow of molten thermoplastic in the molding
10 process prior to the flow entering the optical quality
portion of the mold. A step is created in the tab to
break the polymer flow and smooth out the advancing melt
flow, thus reducing and preferably eliminating jetting
of the flowing molten thermoplastic which could lead to
15 sink marks, dimensional inconsistency, and unacceptable
irregularities in the surface of the molded mold half.
The step forces a reversal of the melt momentum back to
the start. This in turn causes the polymer to form an
advancing front which fills the cavity more smoothly.
20 This also moves the air in the mold cavity towards the
vent lines and results in an optical part free of
weakness lines, thus producing a dimensionally superior
part.

Vent lines are provided in the mold to assist
25 in removing air therefrom and preventing possible melt
flow stagnation. In a preferred embodiment, the vent
lines are provided outside and spaced around the annular
flange at locations spaced furthest from the mold gate.
If this concept is not properly engineered, the flange
30 opposite the hot runner side can have weld lines at the
converging melt flows. The hot runner gate is

-15-

1 positioned, and the tab is designed, to allow for even
and uniform polymer flow so that the advancing polymer
flow does not produce weld lines, which are a source of
surface imperfection, mechanical stress, and a point of
5 weakness.

Moreover, the front mold half 10 also defines
a small circular projection 24 which is positioned
across from the injection hot tip which supplies molten
thermoplastic to the mold. The projection 24 functions
10 as a trap to immobilize a small slug of cold
thermoplastic which may form at the injection hot tip
between molding cycles. The plastic well immobilizes a
small slug of cold thermoplastic which may form at the
injection hot tip between molding operations, and
15 essentially captures the initial melt flow from the hot
runner gate tip. Thus, the well is positioned
adjacent to the point at which the molten thermoplastic
is injected into the mold. Preferably, the well is
directly across from that point, the better to catch the
20 first injected thermoplastic. It is imperative that
during initial injection this mass of cold polymer be
trapped in the cold well and not enter the melt stream.
This could cause part dimensional variations due to melt
temperature and possible shrinkage variation, jetting,
25 and freezing of the melt flow. Variations of the tab
length in conjunction with the size of the cold well can
vary, for example, with a longer tab length and smaller
cold slug well.

The location of the hot runner gate on the tab
30 with respect to the optical surface ensures minimal heat
distortion and part dimensional stability. The location

-16-

1 of the gate and tab geometry is designed to prevent
polymer jetting (which causes marks and dimensional
variations). When the melt flow hits the cold slug
plane and then the web section 22, impinging occurs which
5 smooths out the melt flow. The abrupt transition at the
step prevents transportation of a cold surface layer
into the rest of the mold. The radius at the transition
step and divergence angle of the tab, in conjunction
with the flow rate and the injection pressure, results
10 in a laminar flow of the melt flow into the optical
cavity and prevents the jetting phenomena. The cold
slug well opposite the gate captures the first part of
the polymer stream, which allows a more homogeneous melt
front which relates to optical quality.

15 The design of the flange 18 helps demolding
and part handling, and also protects the optical
surfaces and the well defined edge as described earlier.
The geometry of the tab 20 serves an additional function
in straightening and orientating the assembled front
20 curve/back curve prior to demolding. When a front mold
half or curve is assembled with a back mold half or
curve, a gap is formed between the two projecting tabs
which is important for demolding. The gap between the
tabs typically has a range of 0.5 to 3.0 mm, preferably
25 has a range of 1.0 to 2.5 mm, and most preferably has a
range of 2.0 to 2.25 mm and is needed to initiate the
demolding operation.

A finite element analysis enabled a better
design of the part geometry from the following points:
30 hot runner gate location;
filling time for cycle time reduction;

-17-

- 1 weld lines, air traps, flow direction;
ease of filling the mold;
shear rate, shear stress and temperature
profiles;
5 cooling requirements.

This type of analysis based on fluid dynamics (rheology) and thermodynamics is used to give approximations for momentum and energy of the melt flow.

The flow length distance of the polymer has
10 been significantly reduced relative to prior designs, which greatly enhances the ability to optimize the optical attributes. There is lesser probability of freezing the flow passageway as mold temperatures are reduced further to improve cycle time. One unexpectedly
15 advantageous aspect of the present invention is that operations are carried out at higher thermoplastic temperatures while still realizing successful production within shortened cycle times.

Figures 3 and 4 illustrate respectively top
20 elevational and side views of one embodiment of a back mold half 30. The back mold half 30 is designed with all of the same design considerations mentioned hereinabove with respect to the front mold half 10.

Figure 5 illustrates a mold assembly in which
25 a back mold half 30 is positioned on top of a front mold half 10, and illustrates the mold cavity 42 formed therebetween, as well as the defined gap between the opposed flanges of the back and front mold halves.

The back mold half 30 is also preferably
30 formed of polystyrene, but could be any suitable thermoplastic such as mentioned hereinabove in the

-18-

1 family of thermoplastics. The back mold half 30 defines
a central curved section with an optical quality convex
surface 32, a generally parallel concave surface 34
spaced from the convex surface 32, and an annular
5 essentially uniplanar flange 36 formed extending
radially outwardly from the surfaces 32 and 34. The
convex surface 32 has the dimensions of the rear curve
(which rests upon the cornea of the eye) of a contact
lens to be produced by the back mold half, and is
10 sufficiently smooth such that the surface of a contact
lens formed by polymerization of a polymerizable
composition in contact with the surface is of optically
acceptable quality. The back mold half is designed with
a thickness to transmit heat therethrough rapidly
15 (typically in the range of 0.4 mm to 1.2 mm, preferably
in the range of 0.5 to 0.8 mm, and most preferably in
the range of 0.6 to 0.8 mm, and in one embodiment was
selected to be 0.6 mm) and rigidity to withstand prying
forces applied to separate the mold half from the mold
20 assembly during demolding.

The back curve is designed with a back curve
sag typically in the range of 1.5 to 6.5 mm, preferably
in the range of 2.5 to 6.0 mm, and most preferably in
the range of 5.1 to 5.8 mm (see Fig. 4 for the
25 predetermined sag, dimension "Y"). The back curve sag
and above specified ranges of thickness serve two
purposes:

1. The back curve sag results in a gap
typically in the range of 0.5 to 3.0 mm, preferably in
30 the range of 1.0 to 2.5 mm, and most preferably in the
range of 2.0 to 2.25 mm between the assembled back curve

-19-

1 and front curve, which assists in mechanically removing the back curve from the front curve matrix after polymerization.

2. With a part thickness in the above specified ranges, the back curve was designed to reduce the occurrence of weld lines on the distal side of the flange (where two melt flows converge) which could detrimentally cause a fracture line on the back curve.

The back mold half or curve 30 also defines a tab 36 integral with the flange which projects from one side of the flange. The tab 36 extends to the injection hot tip which supplies molten thermoplastic to the mold, and also defines therein an angled (e.g., 45°) section 38 for the same reasons as in the front mold half 10.

15 The back mold half 30 also defines a small circular projection 40 for the same reasons as in the front mold half 10.

The tab design length "X," Figure 3, is important for the following reasons:

20 minimizes heat distortion to the optical side of the part;

the location and the distance are important; consistency of roundness for optical power radius;

25 cycle time reduction;

length X can vary typically in a range of 10 to 30 mm, preferably in a range of 12 to 26 mm, and most preferably in a range of 16 to 24 mm.

To achieve a minimized molding time, the thickness of each mold half should be reduced as much as possible, while considering other design constraints

-20-

1 such as the desired rigidity of each mold half. In
general, the back mold half 30 should be more flexible
than the front mold half 10 and so is slightly thinner.
The thickness of the front mold half 10 is thinner than
5 a comparable prior art mold half which generally had a
thickness on the order of 1.4 mm.

In one designed embodiment, the back curve and
front curve thicknesses were chosen to be in the
specified ranges, specifically 0.6 mm and 0.8 mm,
2 respectively, to ensure adequate polymer flow without
freezing the advancing melt flow, maintain the proper
strength and rigidity during demolding, minimize weld
line formations, and optimize cycle time reduction.

The inner concave surface of the front mold
3 half defines the outer surface of the contact lens,
while the outer convex surface of the back mold half
defines the inner surface of the contact lens which
rests upon the eye. Accordingly, the shape of the inner
concave surface of the female mold half and the shape of
4 the outer convex surface of the male mold half must have
acceptable optical quality surfaces. The outer convex
surface of the front mold half and the inner concave
surface of the back mold half need not have optical
quality surfaces, and in fact the side of each mold half
having one of those surfaces is used by robotic handling
equipment to handle the mold halves. The present
invention takes advantage of this latter feature to
provide molding and very rapid cooling of the critical
optical quality surfaces of the contact lens molds,
i.e., the inner concave surface of the front mold half
and the outer convex surface of the back mold half.

-21-

1 Pursuant to the present invention, the master
molds to mold the thermoplastic mold halves or curves
are designed to achieve excellent heat transfer
characteristics to quickly reduce the temperature of the
5 molds from approximately 200-300°C at the injection tip
(by the arrow designated GATE) at which the molten
thermoplastic enters the mold to approximately 80-90°C,
when the mold halves can be opened in approximately
three to six seconds, as compared with a typical 24
10 second mold cycle for the prior art.

Pursuant to the present invention, and
referring to Figure 6, molten thermoplastic material is
initially extruded by a screw extruder 50. When
polystyrene is used as the molten thermoplastic
15 material, the discharge end of the screw extruder 50 has
a temperature of approximately 200-300°C. The molten
thermoplastic material is then introduced into a heated
manifold 52 having heaters 54 therein to raise the
temperature of the molten thermoplastic material
20 further, in the case of polystyrene to approximately
270-280°C. The molten thermoplastic material then flows
into a hot runner system 56 which feeds two multi-tip
extruders 58 (only one of which is shown in Figure 6),
each of which has four hot tip extrusion apertures 60,
25 two of which are illustrated in Figure 6; at this point
molten polystyrene is approximately 200-300°C. One or
more temperature sensors, such as thermocouples, may be
strategically positioned in the molding arrangement to
monitor the temperature of the molten thermoplastic, to
30 control heaters or other parameters for control of the
molding operation. Each hot tip extrusion aperture

-22-

1 feeds a single mold cavity 62, one of which is
illustrated in Figure 6. One preferred molding
arrangement includes eight mold cavities of the type
illustrated in Figure 6 which are positioned at the end
5 of, and spaced around, the multi-tip extruders 58.

One of the features of the present invention
is that the optical quality surface of the mold half is
positioned away from the heat source of the extrusion
equipment, while the second non-optical quality surface
10 of the mold half is positioned towards the heat source
of the extrusive equipment. The arrangement illustrated
in Figure 6 is for molding the front half mold 10 of the
mold halves. The concave surface 12 of the front mold
half defines the optical quality surface, and
15 accordingly the concave surface 12 of the front mold
half is positioned on the left side in the molding
arrangement of Figure 6.

The molding cavity 62 illustrated in Figure 6
includes a two piece molding insert 64 on the left side,
20 having an outer bushing 66 which is sealed relative to
the molding machine by O-rings 68. A power insert 70 is
positioned in the outer bushing 66 and is sealed
relative thereto by an O-ring 72. The power insert 70
is so named because its right end convex surface
25 defines the optical power of the optical quality surface
of the front mold half and also of the hydrogel soft
contact lens which is subsequently molded in the
polystyrene mold half. The two piece insert design on
the left side of Figure 6 allows the optical quality
30 surface 74 of the power insert 70 to be machined on the
relatively simpler construction of just the power

-23-

1 insert, which simplifies the engineering and construction of the two piece insert 64. Moreover, different optical power (diopter) lenses can be produced by merely changing the power insert to substitute a 5 different power insert having a different curvature convex end surface.

The outer surface of the bushing 66 defines an outer circumferential cooling passageway 76 therearound, through which a coolant is continuously circulated. The 10 circumferential cooling passageway could also be defined in the mold block which retains the bushing 66, rather than in the bushing 66, to reduce manufacturing costs.

A bubbler 78 is positioned within the power insert, through which coolant is continuously circulated 15 and ejected against the inner internal surfaces of the power insert, and then flows outwardly in a reverse direction through the annular passageway around the bubbler insert.

The right side of the mold cavity of Figure 6 20 defines the non-optical quality surface of the front mold half, and accordingly, in view of its simpler and less critical construction, is designed as a single piece insert bushing 80 which is sealed relative to the molding arrangement by O-rings 82. The bushing 80 25 includes an outer circumferential cooling passageway 84 through which a coolant is continuously circulated, and also mounts therein a bubbler insert 86, through which coolant is continuously circulated and ejected against the internal end surfaces of the bushing 80, and then 30 flows outwardly in a reverse direction through the annular passageway around the bubbler insert.

-24-

1 The coolant can be a solution of water and
anticorrosion inhibitors, such as a 50/50 mixture of
water and ethylene glycol. The coolant is continuously
circulated in a turbulent flow mode by a cooling system
5 having high power pumps to provide maximum cooling.
Turbulent flow mode cooling is preferred to laminar flow
cooling as it is approximately three times more
effective than laminar flow cooling. Two separate
coolant flow circuits are provided. The first coolant
10 circuit has a high power pump with an 80 psi pressure
head which circulates coolant at approximately 45-85°C
at a flow rate from the pump of approximately 30±5
gallons per minute to cause the coolant to circulate
continuously in a turbulent flow mode through the
15 circumferential cooling passages of each mold cavity.
The eight separate mold cavities as described
hereinabove are typically connected in series in the
first coolant circuit, with coolant flowing in series
from one mold cavity to an adjacent mold cavity, etc.
20 The second coolant circuit also has a high power pump
with an 80 psi pressure head which circulates coolant at
approximately 45-85°C at a flow rate from the pump of
approximately 30±5 gallons per minute to cause the
coolant to circulate continuously in a turbulent flow
25 mode through the bubbler inserts in each mold cavity. A
differential temperature range can be set to improve
part quality.

The continuous flow of coolant through the
outer circumferential cooling passages 76, 84 and the
30 inner bubblers 78, 86 results in rapid cooling of the
molded curves or mold halves to approximately 80-90°C,

-25-

1 at which temperature residual stresses are substantially
locked into the molded component, particularly at the
optical quality surface side, and the master mold halves
can be opened along parting line (PL) to remove the
5 molded curves or mold halves without damaging the
optical quality surface of the mold halves. After
opening of the master mold, a plurality of ejector pins
90, four positioned circumferentially around the mold
cavity and a fifth 90' positioned at the mold tab, are
10 displaced to the right as illustrated in Figure 5, to
eject the mold half from each cavity.

The systematic arrangement of the five ejector
pins serves a useful purpose. The ejector pins are
positioned to ensure minimal stress buildup in the part
15 during part ejection; this is very important to ensure
part dimensional consistency. One ejector pin is
located at the distal end of the part (opposite side of
the hot runner gate) to ensure adequate mold gas venting
during the final filling phase, and the reduction of
20 weld lines. The arrangement ensures smooth and reliable
ejection after the part has reasonably cooled down and
to minimize stress formation. This again ensures
dimensional consistency. This concept lends well to
cycle efficiency and deters parts from sticking to the
25 wrong side of the mold.

Figure 6 illustrates molding of the front mold
halves 10. The back mold halves 30 are molded in a
similar arrangement as illustrated in Figure 7, with
similar mold inserts, except that the power insert 94
30 now has a concave optical quality end surface as the
back mold halves 30 have an optical quality surface on

-26-

1 their convex surface rather than on their concave
surface.

Figure 7 is a sectional view through a hot
runner mold similar to that of Figure 6, but for a back
5 mold half 30. The convex surface of the back mold half
defines the optical quality surface, and accordingly the
convex surface of the back mold half is positioned on
the left side in the molding arrangement of Figure 7.

While several embodiments and variations of
10 the present invention for a molding arrangement with a
mold insert design to achieve short mold cycle time are
described in detail herein, it should be apparent that
the disclosure and teachings of the present invention
will suggest many alternative designs to those skilled
15 in the art.

-27-

1. A molding arrangement for molding a mold half which is used for subsequent molding of a soft contact lens, with the mold half defining a convex curved surface and a concave curved surface spaced from the convex surface, with one of the convex and concave surfaces defining an optical quality curved surface for the soft contact lens, comprising a heated mold for introducing a molten mold material through a hot runner system to at least one mold cavity, said at least one mold cavity defining an optical quality curved surface for the mold half and a second curved surface for the mold half, wherein said at least one mold cavity comprises a first insert on the optical quality side of the mold cavity and a second insert on the second side of the mold cavity, and each of said first and second inserts has a circumferential cooling passageway therearound, through which coolant is circulated by a cooling system to provide for faster cooling of the mold cavity to allow quicker setting and locking of minimal temperature residual stresses in the mold half and a faster molding and cycling time for the molding arrangement.

2. A molding arrangement as claimed in claim 1, wherein the material being molded into the mold half is polystyrene, and the molding machine includes means for introducing molten polystyrene into the at least one mold cavity.

3. A molding arrangement as claimed in claim 1, wherein said first insert on the optical quality side of the mold includes a bushing, and a power insert positioned within the bushing, with the power insert

-28-

having an end surface which defines the optical quality surface of the mold half.

4. A molding arrangement as claimed in claim 1, wherein each of said first and second inserts includes a bubbler positioned internally therein, through which coolant is circulated by said cooling system against inner surfaces of the insert.

5. A molding arrangement as claimed in claim 4, wherein said cooling system includes means for circulating coolant in a turbulent flow mode through the circumferential cooling passageways, and also through the bubblers.

6. A molding arrangement as claimed in claim 1, wherein the molding arrangement includes a plurality of mold cavities positioned at one end of, and spaced around, the hot runner system.

7. A method of molding a mold half which is used for subsequent molding of a soft contact lens, with the mold half defining a convex curved surface and a concave curved surface spaced from the convex surface, with one of the convex and concave surfaces defining an optical quality curved surface for the soft contact lens, comprising introducing a molten mold material through a hot runner system to at least one mold cavity, defining in the at least one mold cavity an optical quality curved surface for the mold half and a second curved surface for the mold half by positioning a first insert on the optical quality side of the mold cavity and a second insert on the second side of the mold cavity, defining a circumferential

-29-

cooling passageway around or in proximity to each of said first and second inserts, and circulating a coolant through each circumferential cooling passageway to provide for faster cooling of the mold cavity to allow quicker setting and locking of minimal temperature residual stresses in the mold half and a faster molding and cycling time.

8. A method of molding as claimed in claim 7, wherein the material being molded into the mold half is polystyrene, and including introducing molten polystyrene into the at least one mold cavity.

9. A method of molding as claimed in claim 7, wherein said first insert on the optical quality side of the mold includes a bushing, defining said circumferential cooling passageway around or in proximity to said bushing, positioning a power insert within the bushing, and defining the optical quality surface of the mold half by an end surface of the power insert.

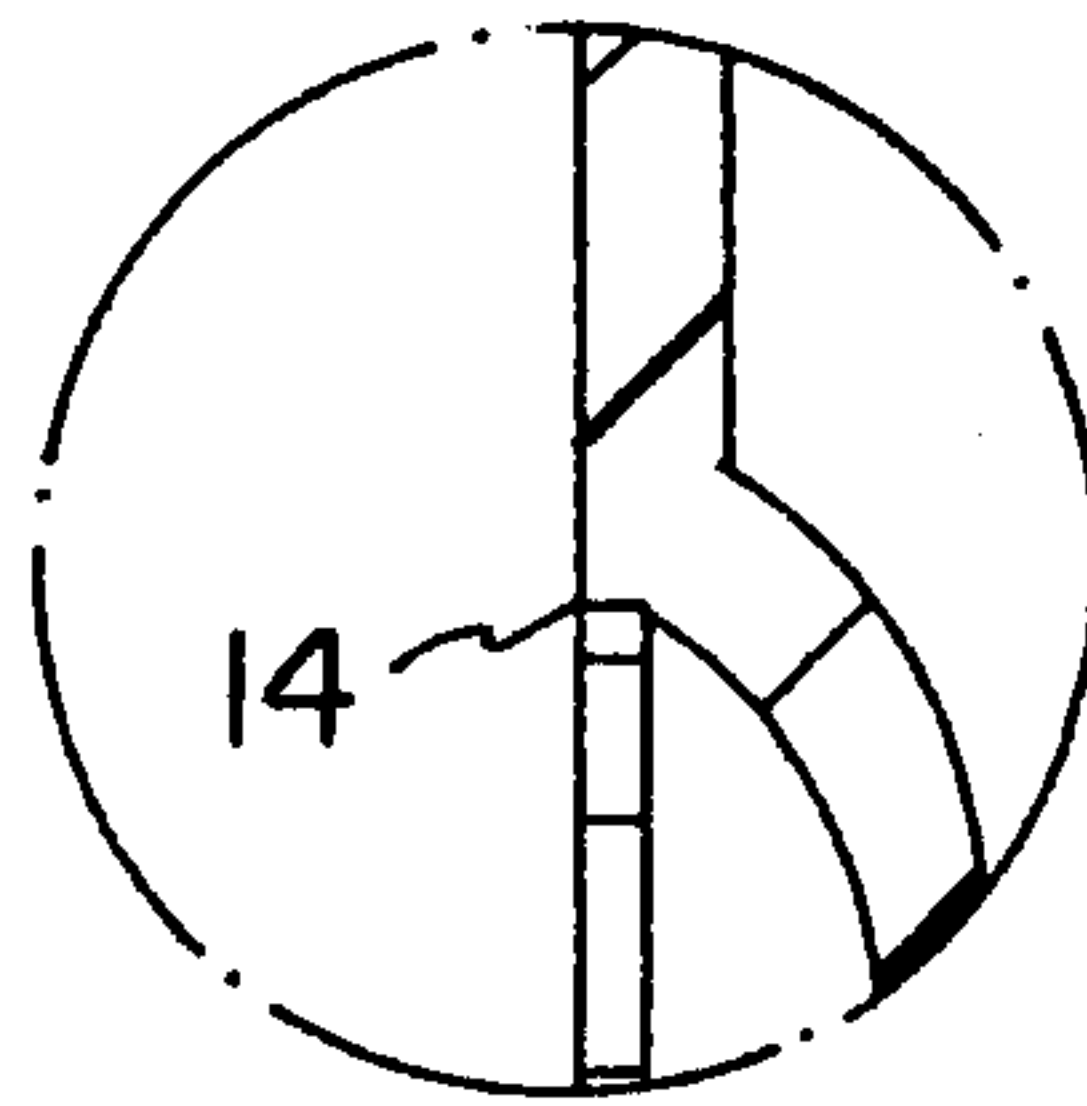
10. A method of molding as claimed in claim 7, including positioning a bubbler internally within each of said first and second inserts, and circulating a coolant against inner surfaces of the inserts.

11. A method of molding as claimed in claim 10, including circulating coolant in a turbulent flow mode through the circumferential cooling passageways and also through the bubblers.

-30-

12. A method of molding as claimed in claim 7, including positioning a plurality of mold cavities at one end of, and spaced around, the hot runner system.

FIG. 2A



A cross-sectional view of a semiconductor device. A central vertical layer is labeled 18. To its right, a curved, hatched layer is labeled 16. A dashed circle labeled 14 is centered on the vertical layer 18. A horizontal line segment labeled 12 is positioned between the vertical layer 18 and the curved layer 16. Below the curved layer 16, a hatched layer labeled 22 is shown. A horizontal arrow labeled 20 points to the interface between the curved layer 16 and the hatched layer 22. At the bottom, a hatched layer labeled 24 is shown, with an arrow labeled GATE pointing to it.

FIG. 4

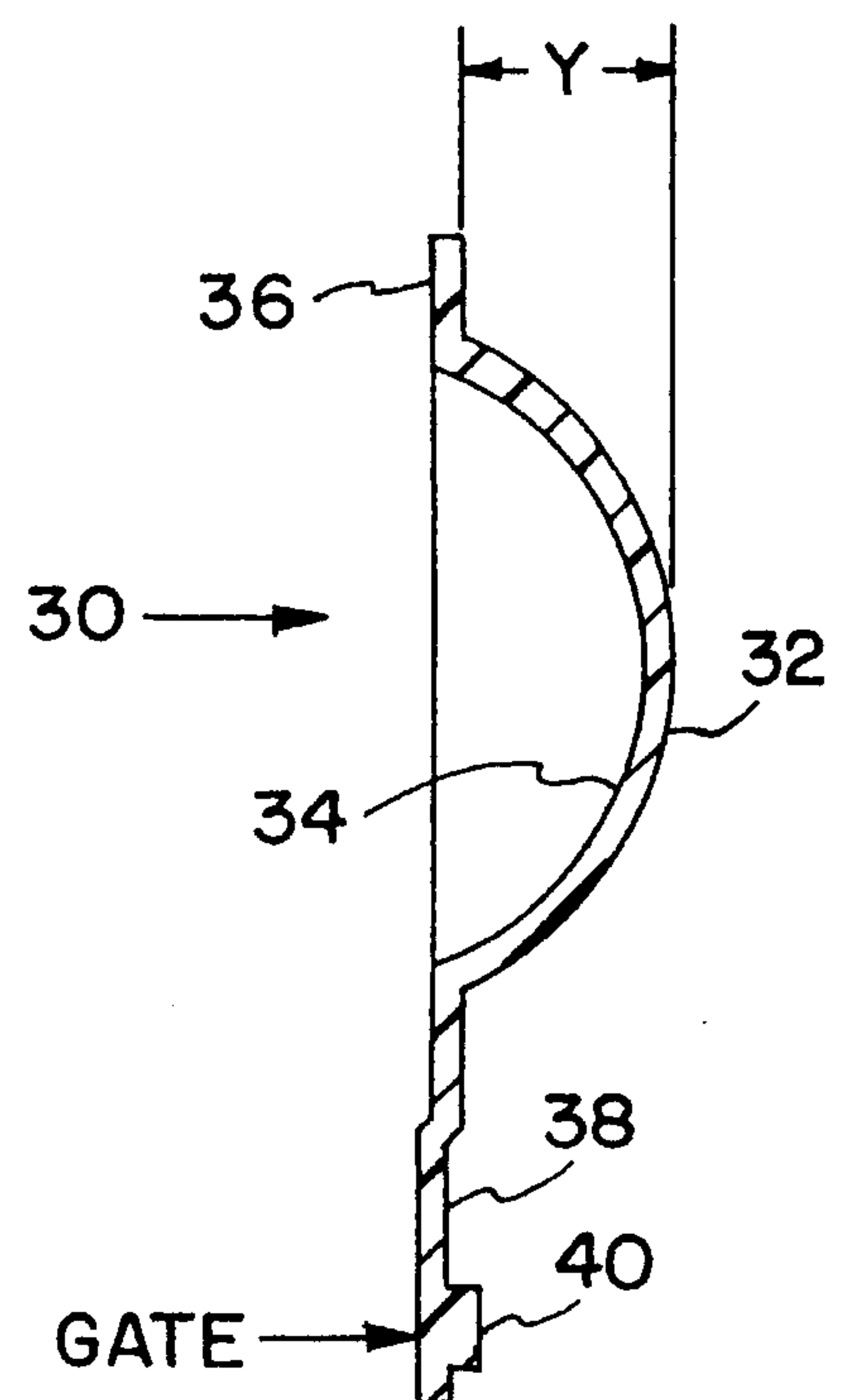


FIG. 5

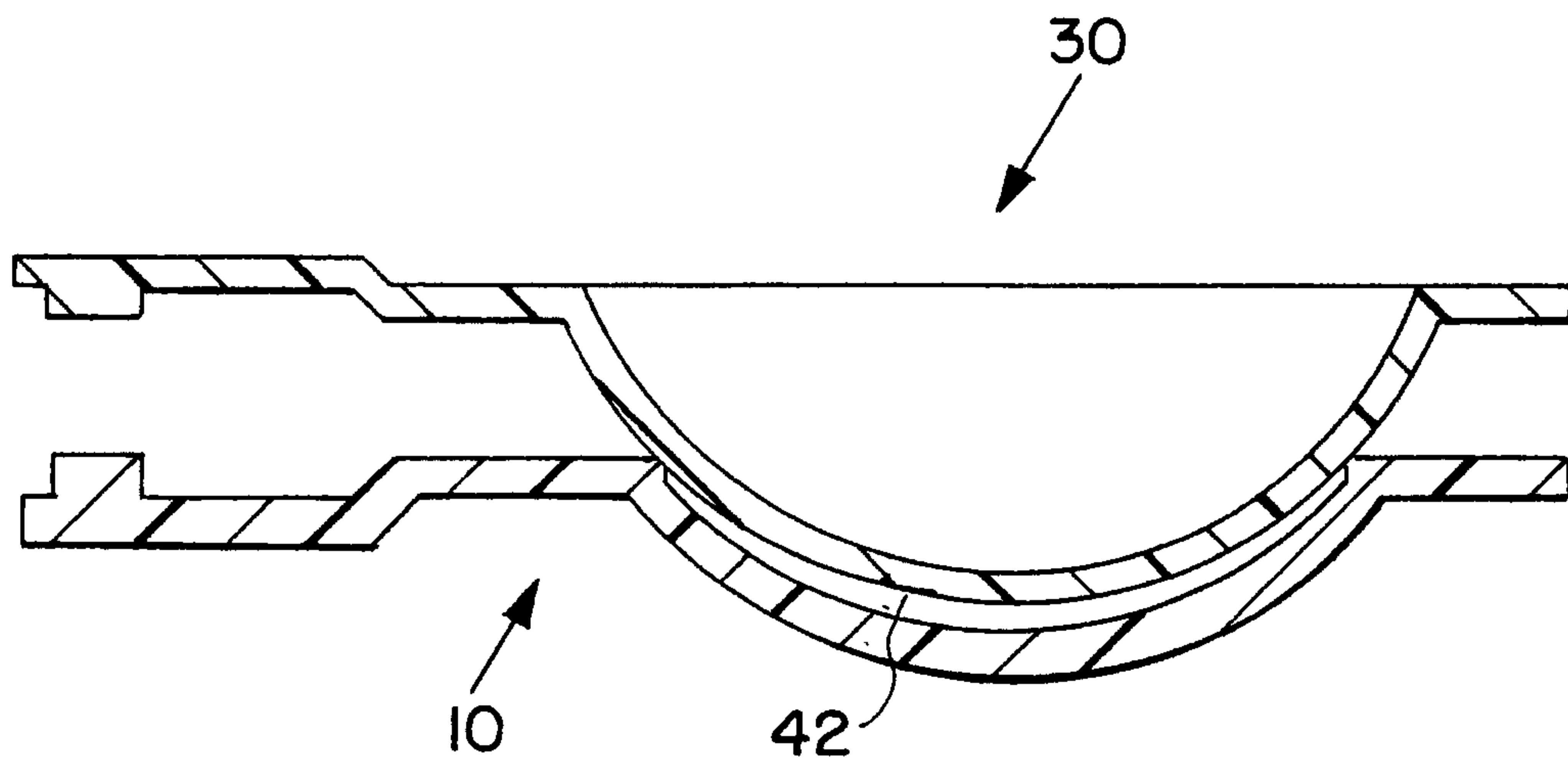


FIG. 8

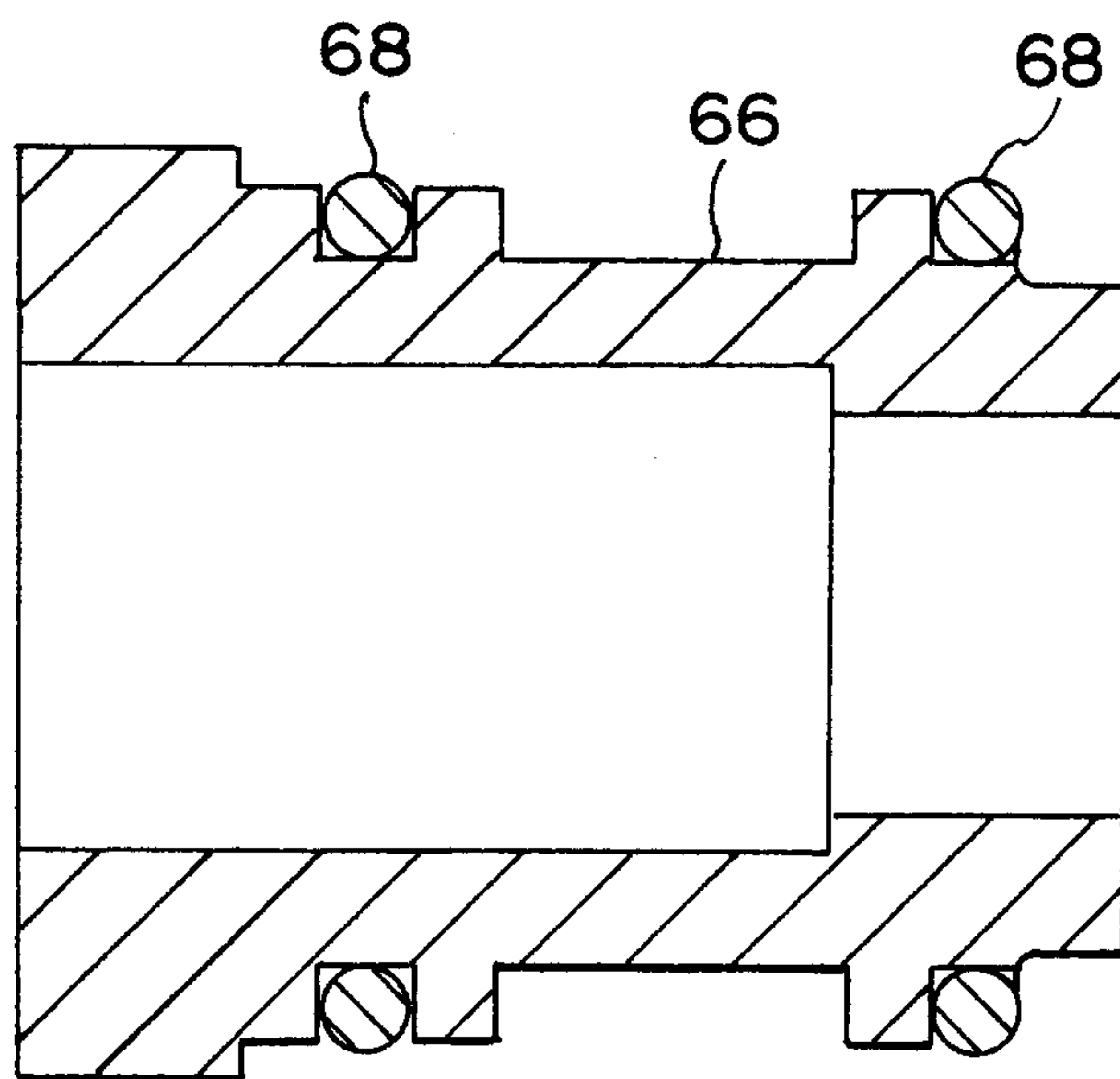


FIG. 6

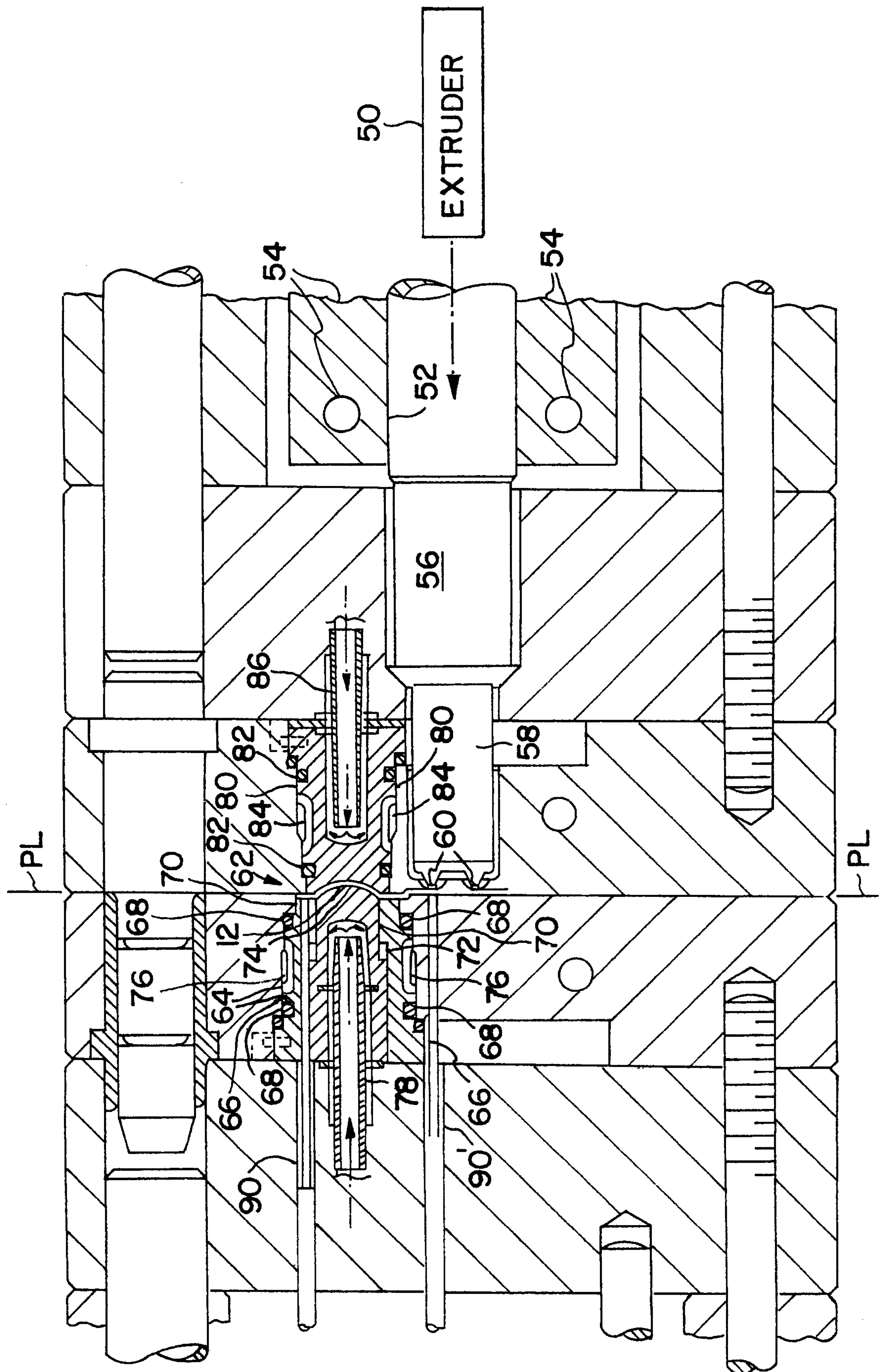


FIG.7

