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Swanson et al.

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(54) **METHOD FOR LOADING FILAMENT IN AN EXTRUSION APPARATUS**

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(22) Filed: **Dec. 19, 2003**

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Related U.S. Application Data

(60) Division of application No. 09/804,401, filed on Feb. 27, 2001, now Pat. No. 6,776,602, and a continuation-in-part of application No. PCT/US00/17363, filed on Jun. 23, 2000.

(60) Provisional application No. 60/218,642, filed on Jul. 13, 2000, provisional application No. 60/140,613, filed on Jun. 23, 1999.

(51) **Int. Cl.**
B29C 41/34 (2006.01)

(52) **U.S. Cl.** **264/39**; 264/308

(58) **Field of Classification Search** 264/39, 264/40.1, 308
See application file for complete search history.

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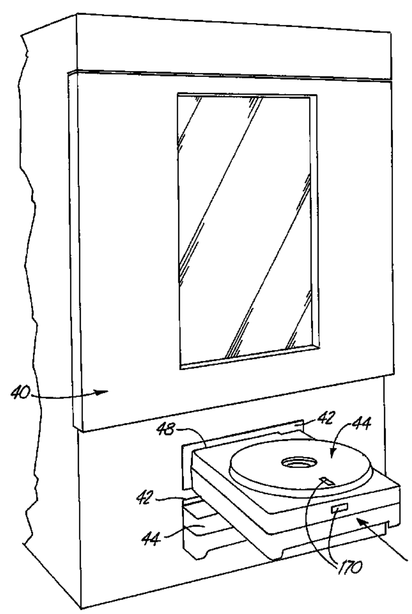
(74) *Attorney, Agent, or Firm*—Kinney & Lange, P.A.

(57) **ABSTRACT**

Filament is loaded into an extrusion apparatus, such as a three-dimensional deposition modeling machine, by inserting a cassette containing filament into the apparatus. A filament strand from the cassette is then advanced into the machine, such as by operating a thumb wheel or a follower wheel on the cassette. The filament loading method of the present invention provides a convenient manner of loading and unloading filament in a three-dimensional modeling machine, and can be implemented in a manner that protects the filament from environmental moisture.

20 Claims, 20 Drawing Sheets



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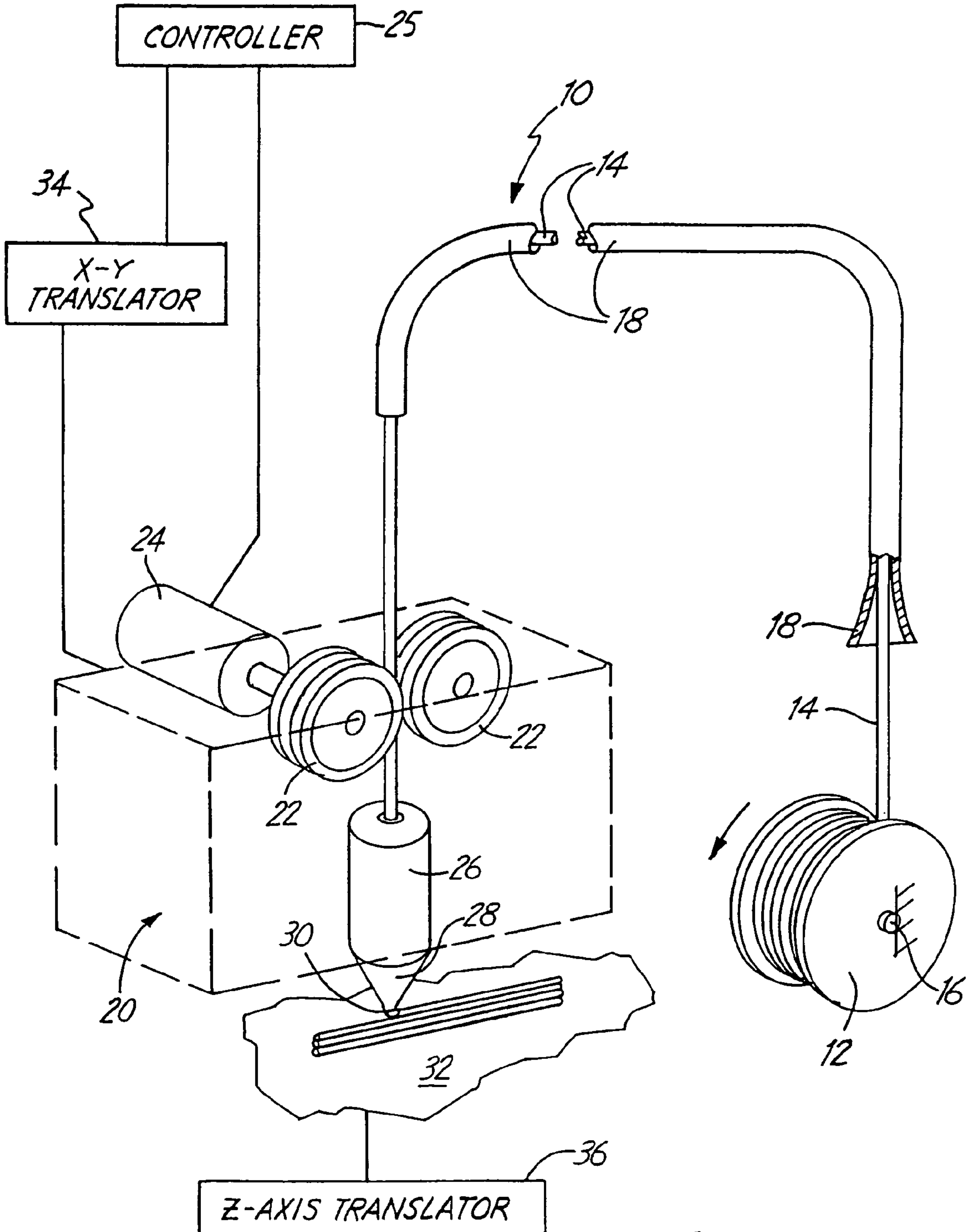

FIG. 1

PRIOR ART

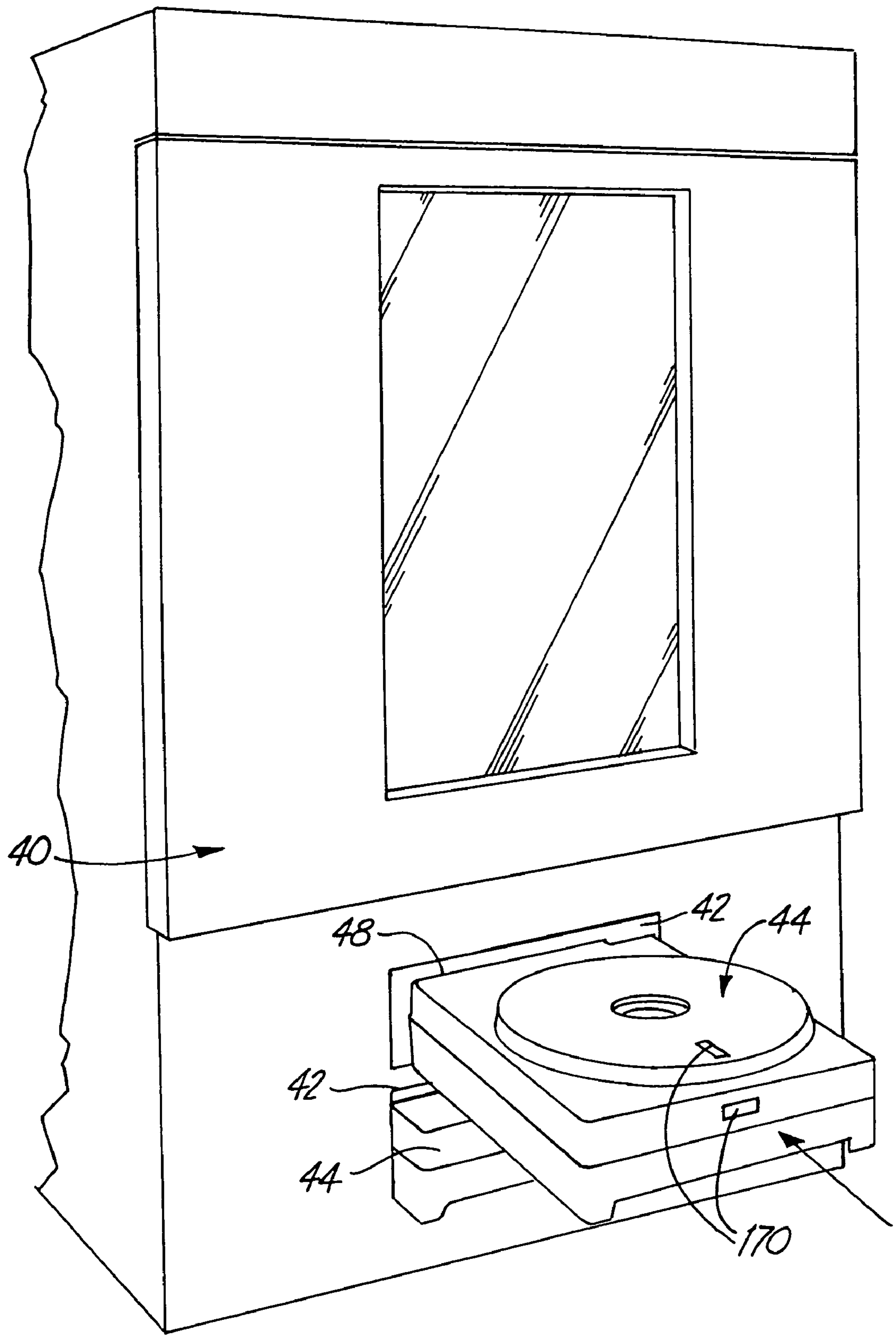

FIG. 2

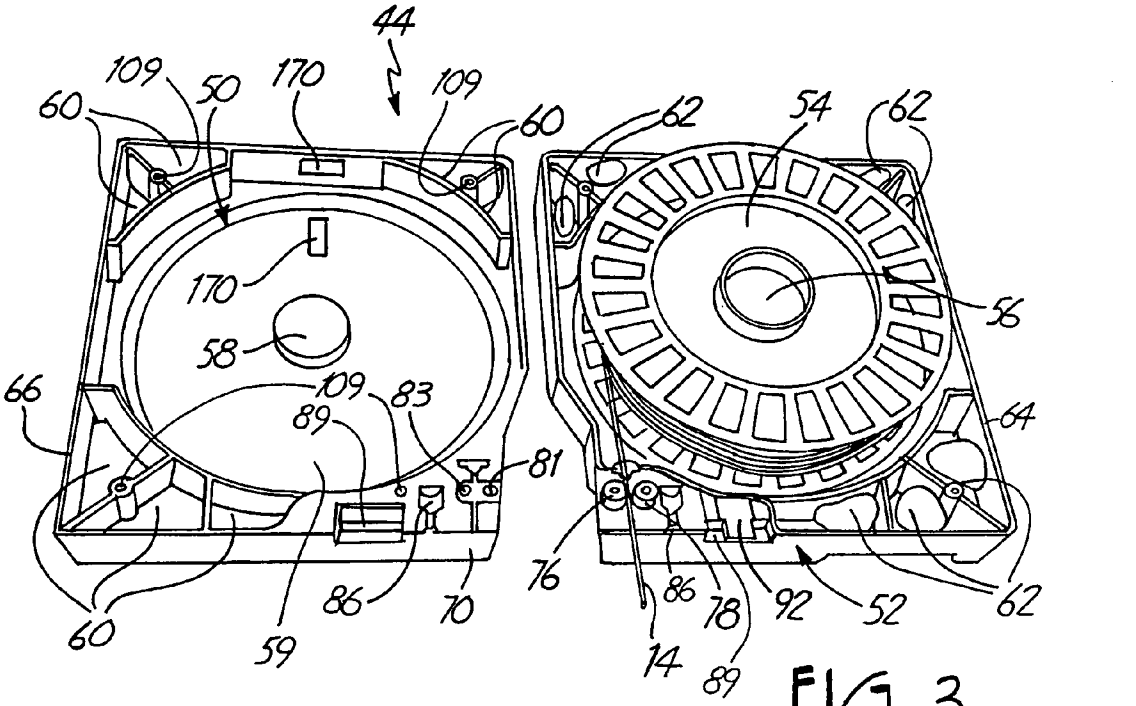
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FIG. 3

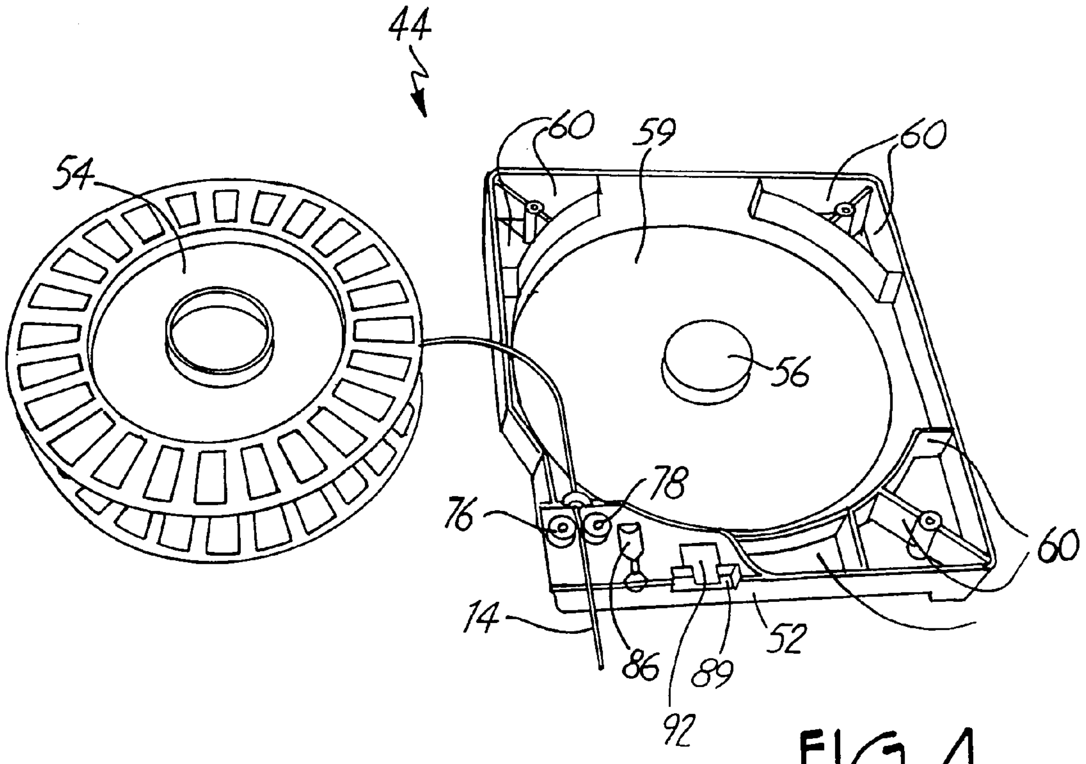
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FIG. 4

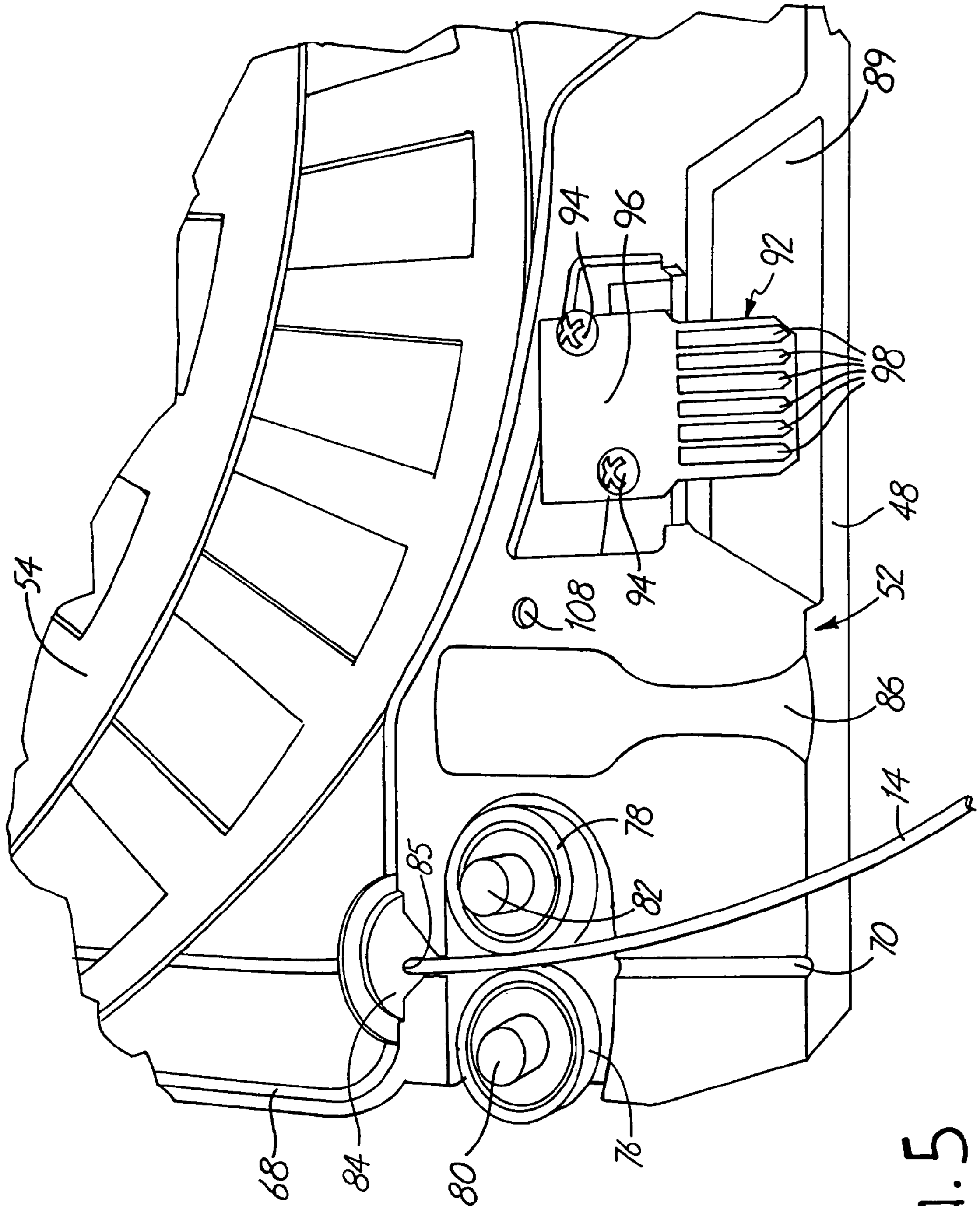

FIG. 5

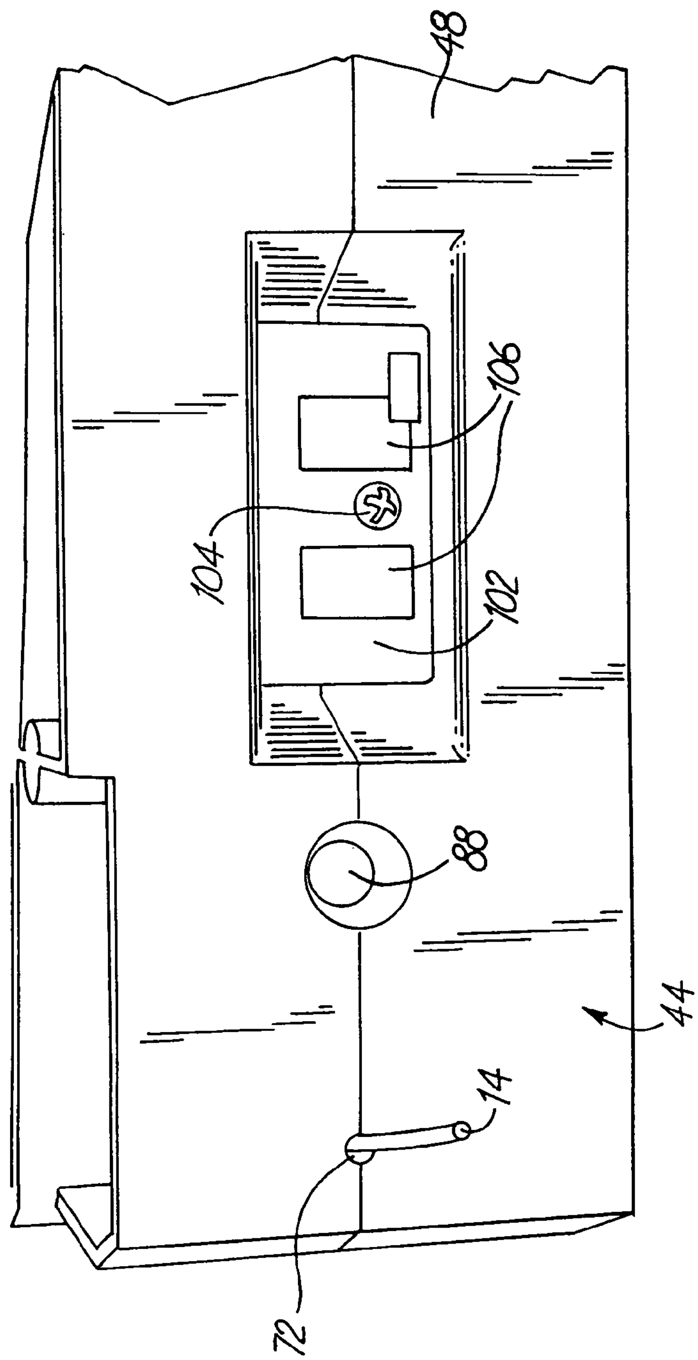

FIG. 5A

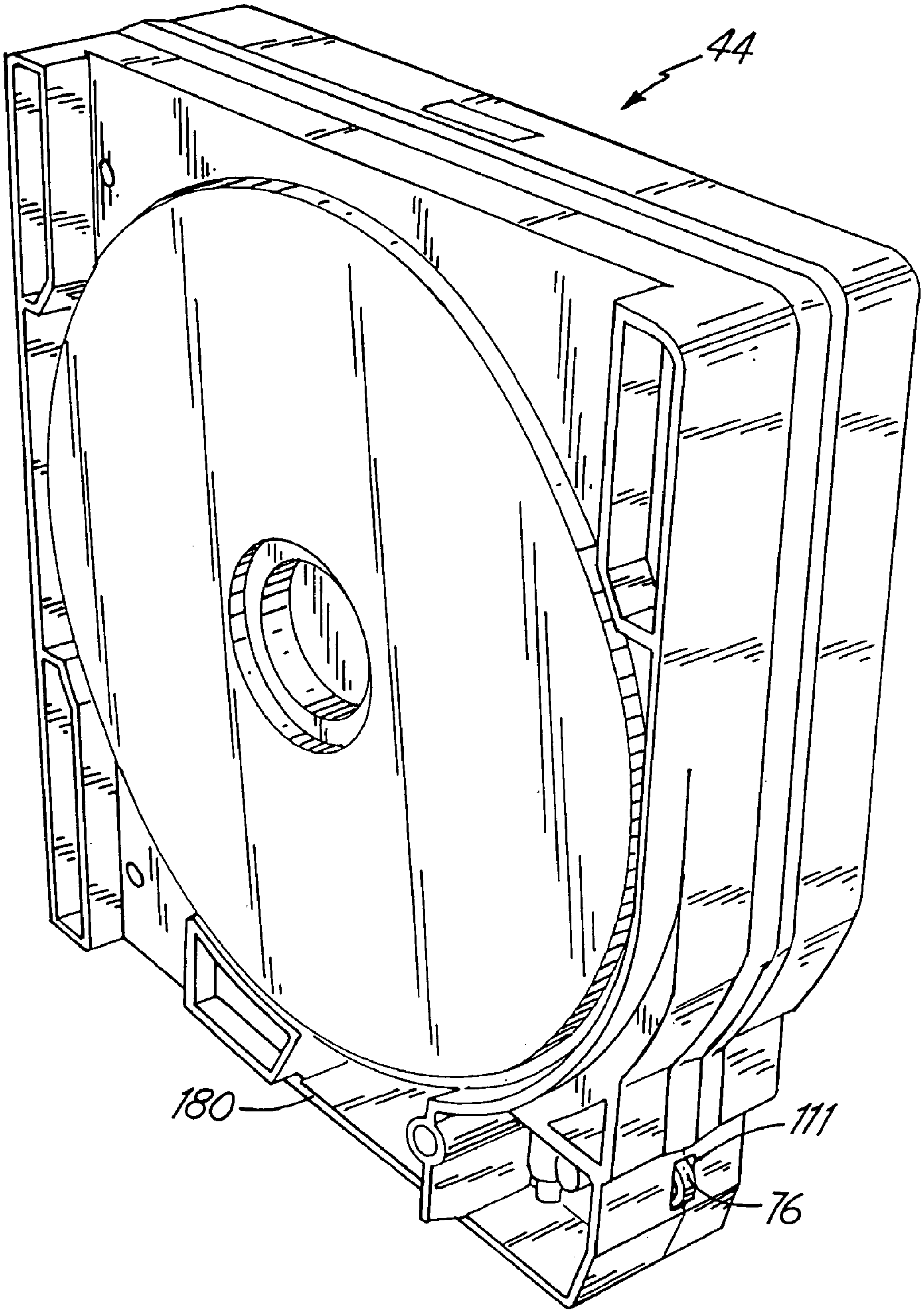

FIG. 6

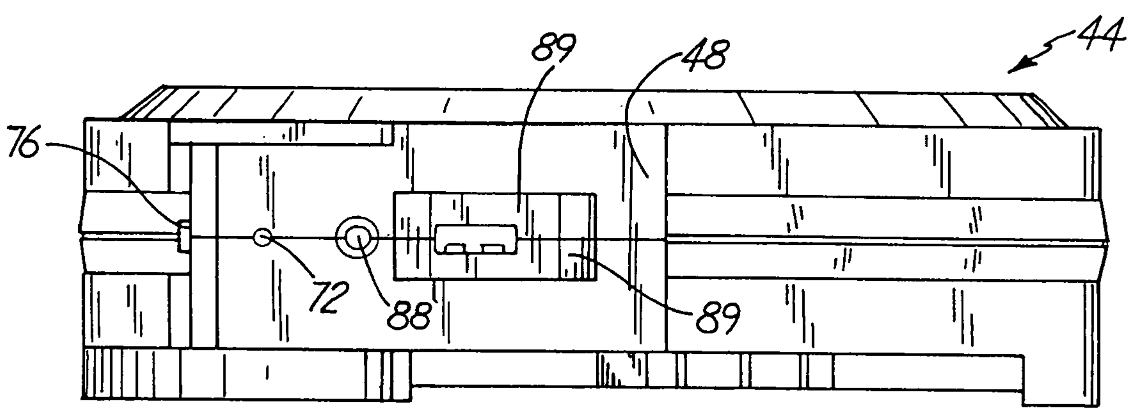

FIG. 7

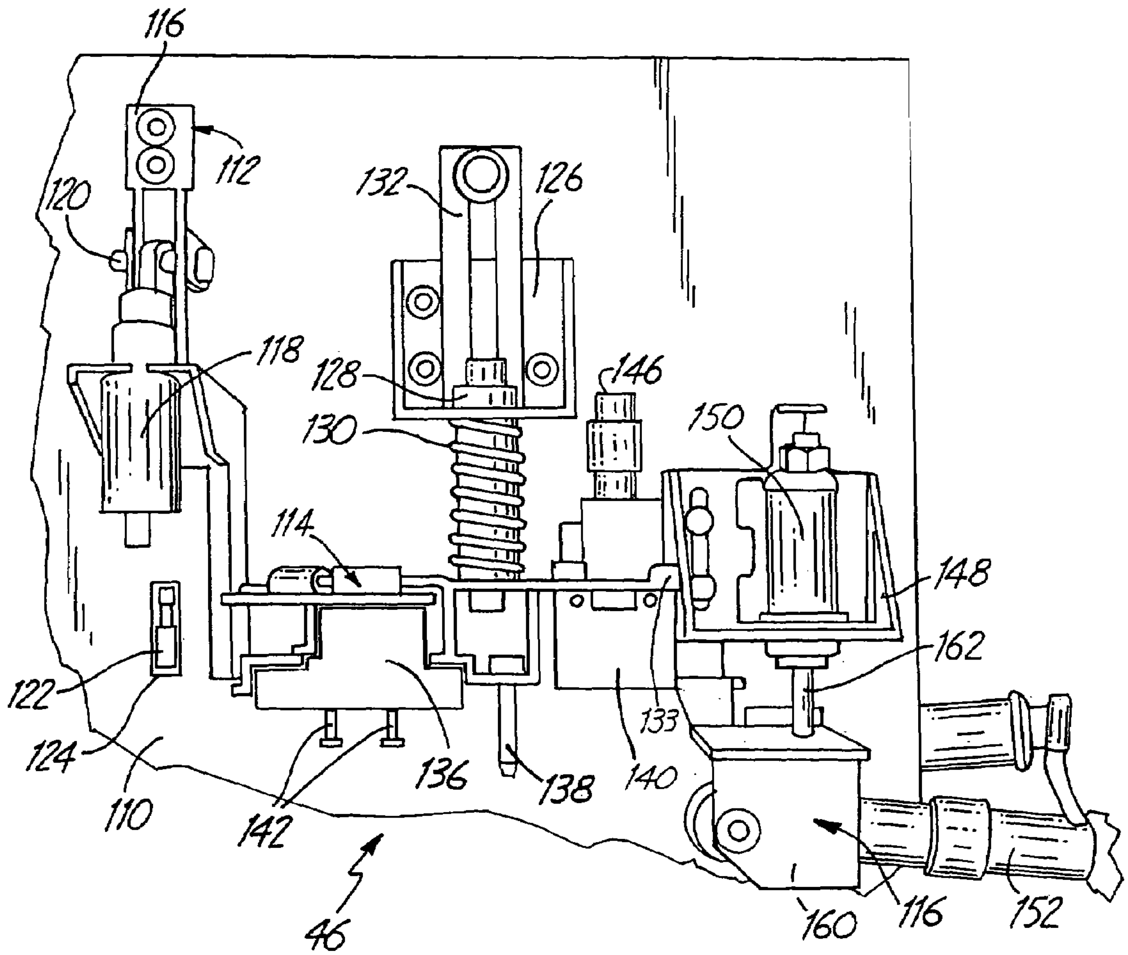
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FIG. 8

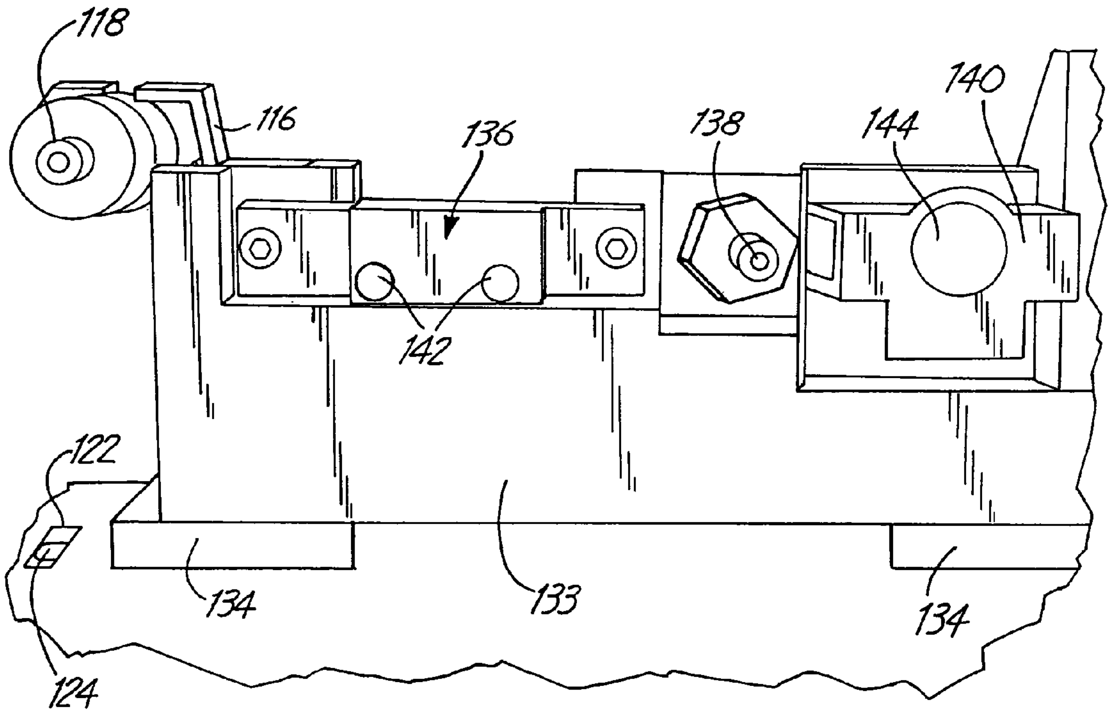


FIG. 9

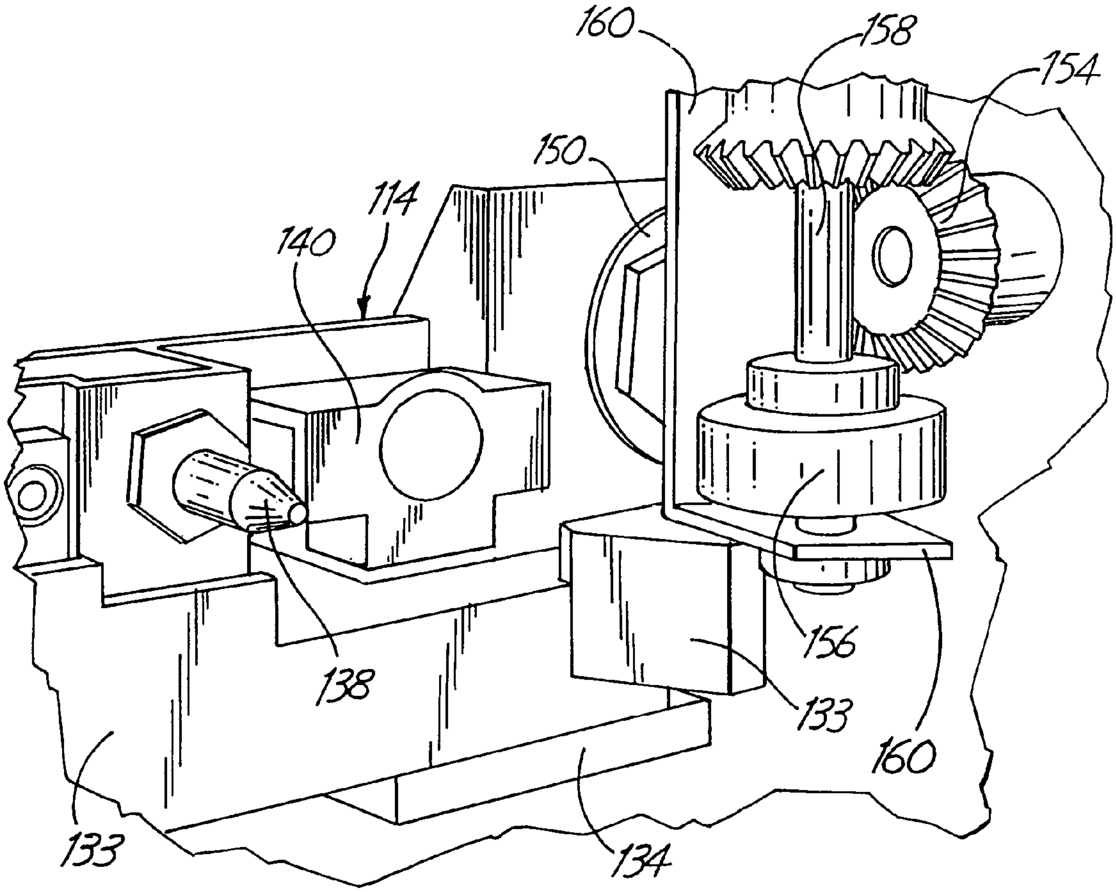


FIG. 10

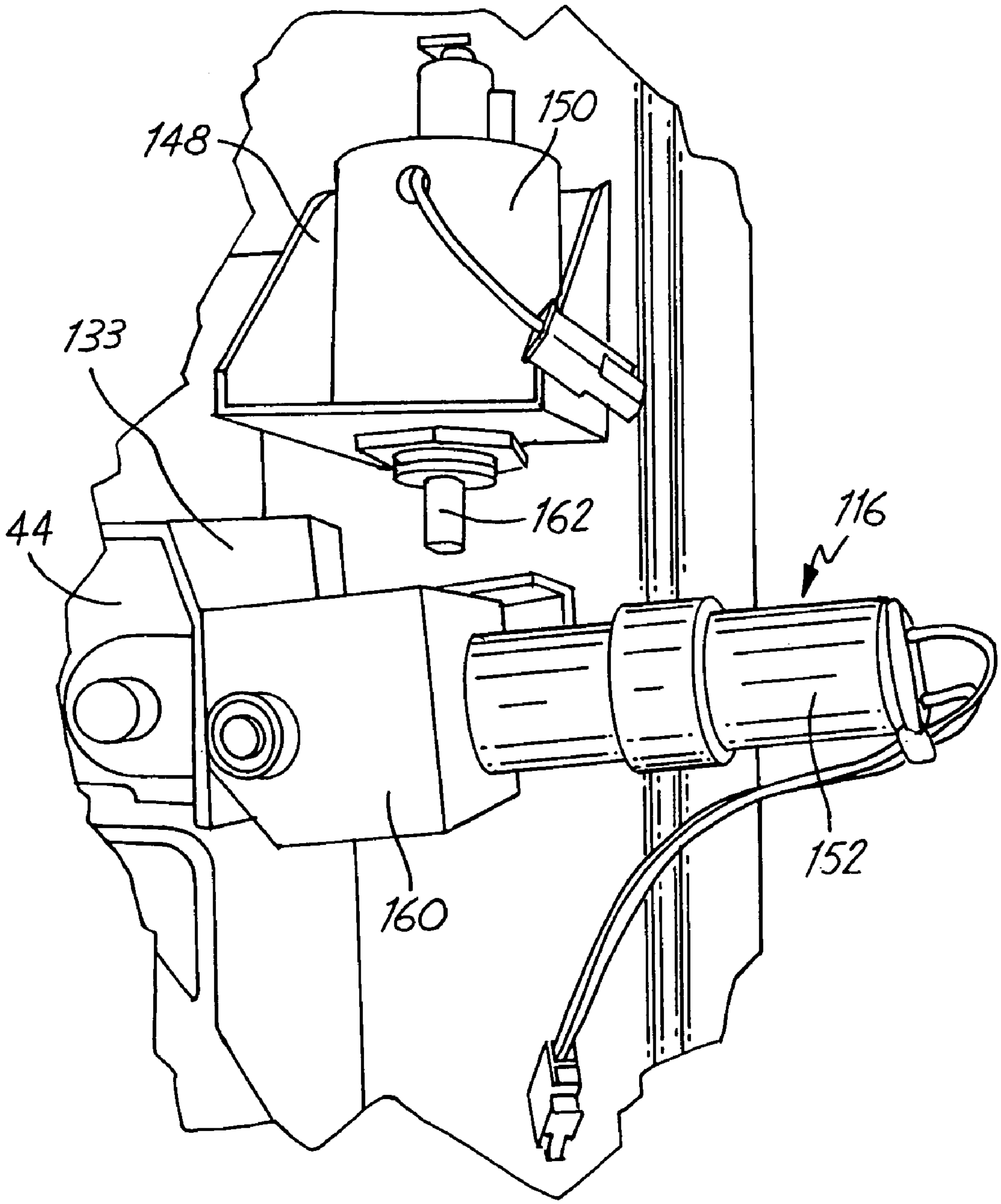


FIG. 11A

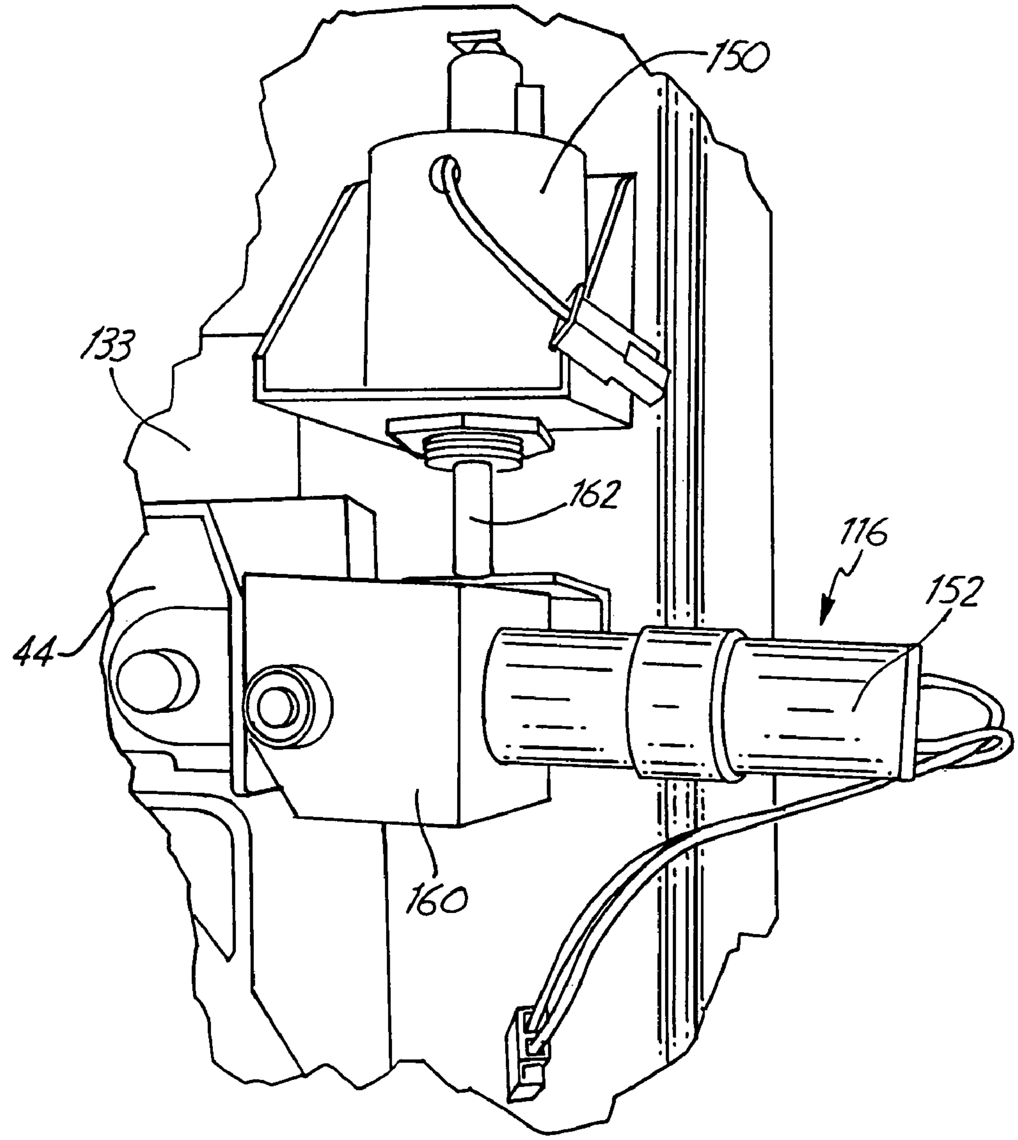


FIG. 11B

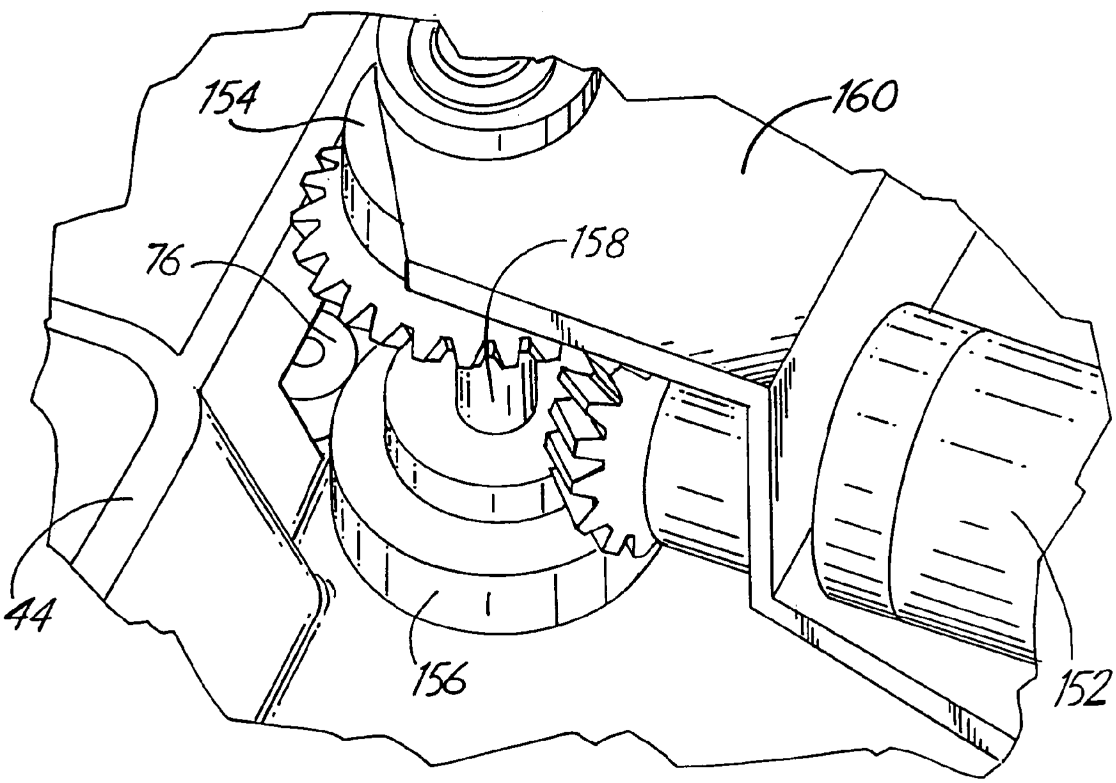
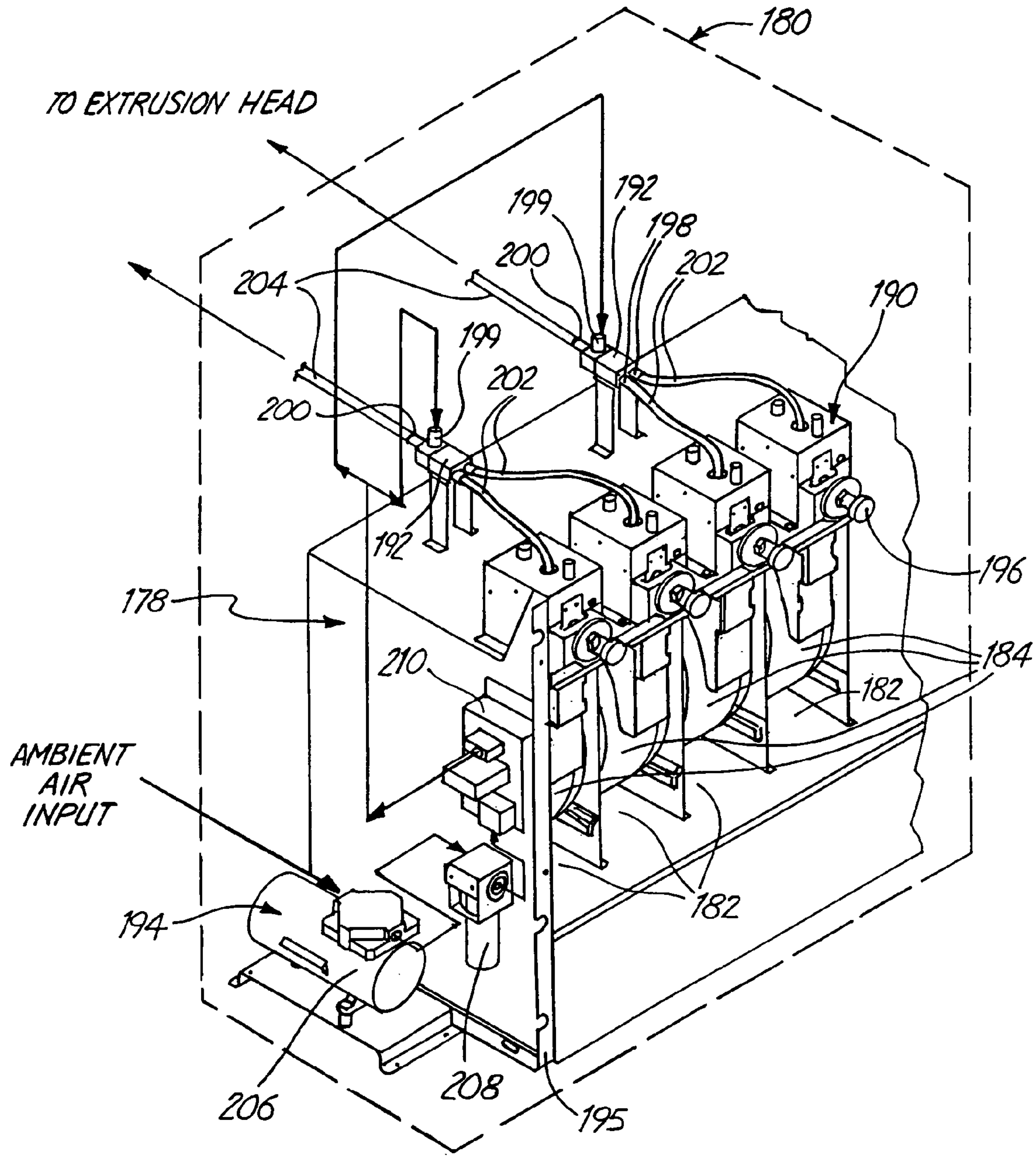


FIG. 12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TO EXTRUSION HEAD
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AMBIENT
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INPUT
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FIG. 13

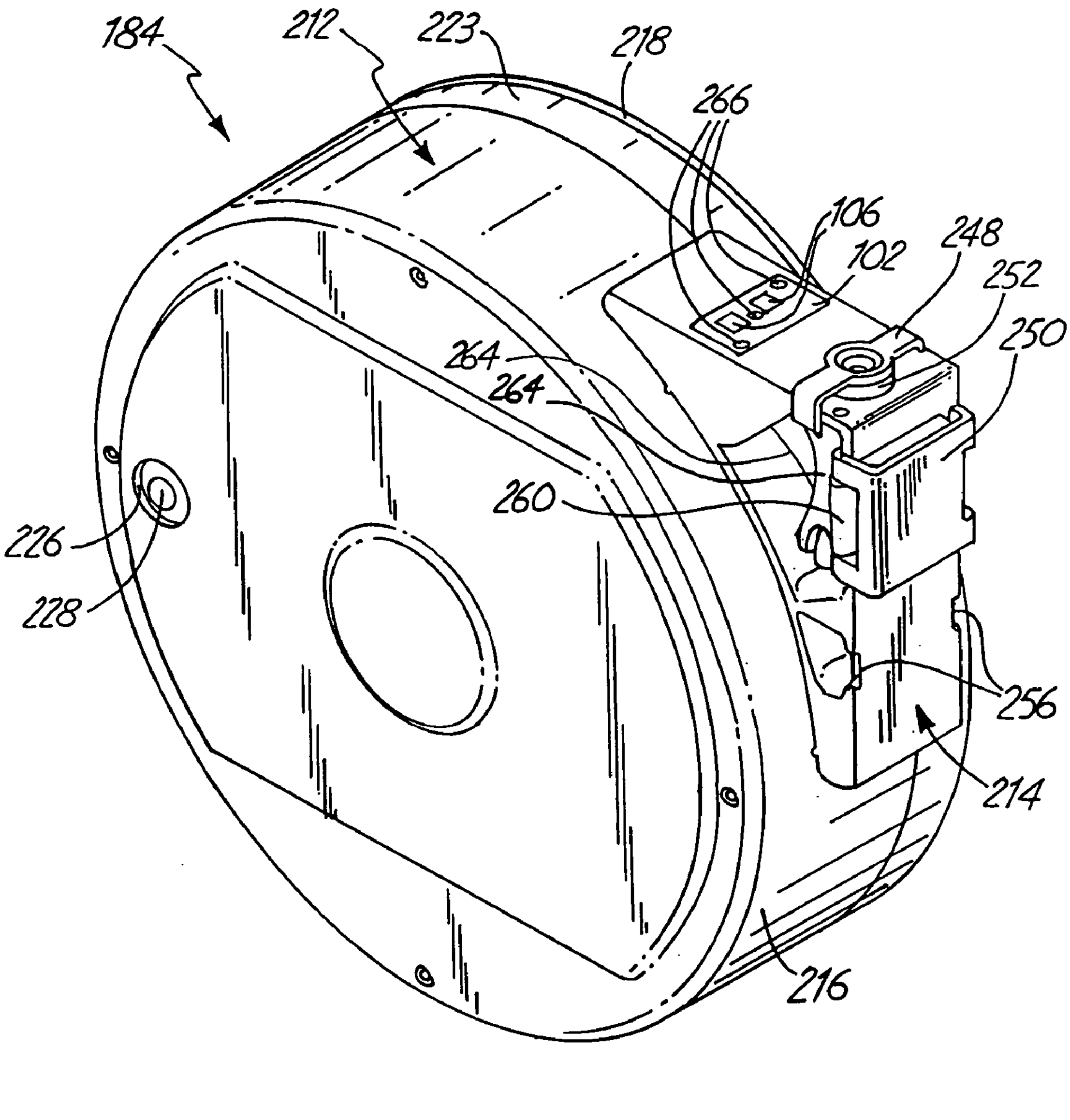
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FIG. 14

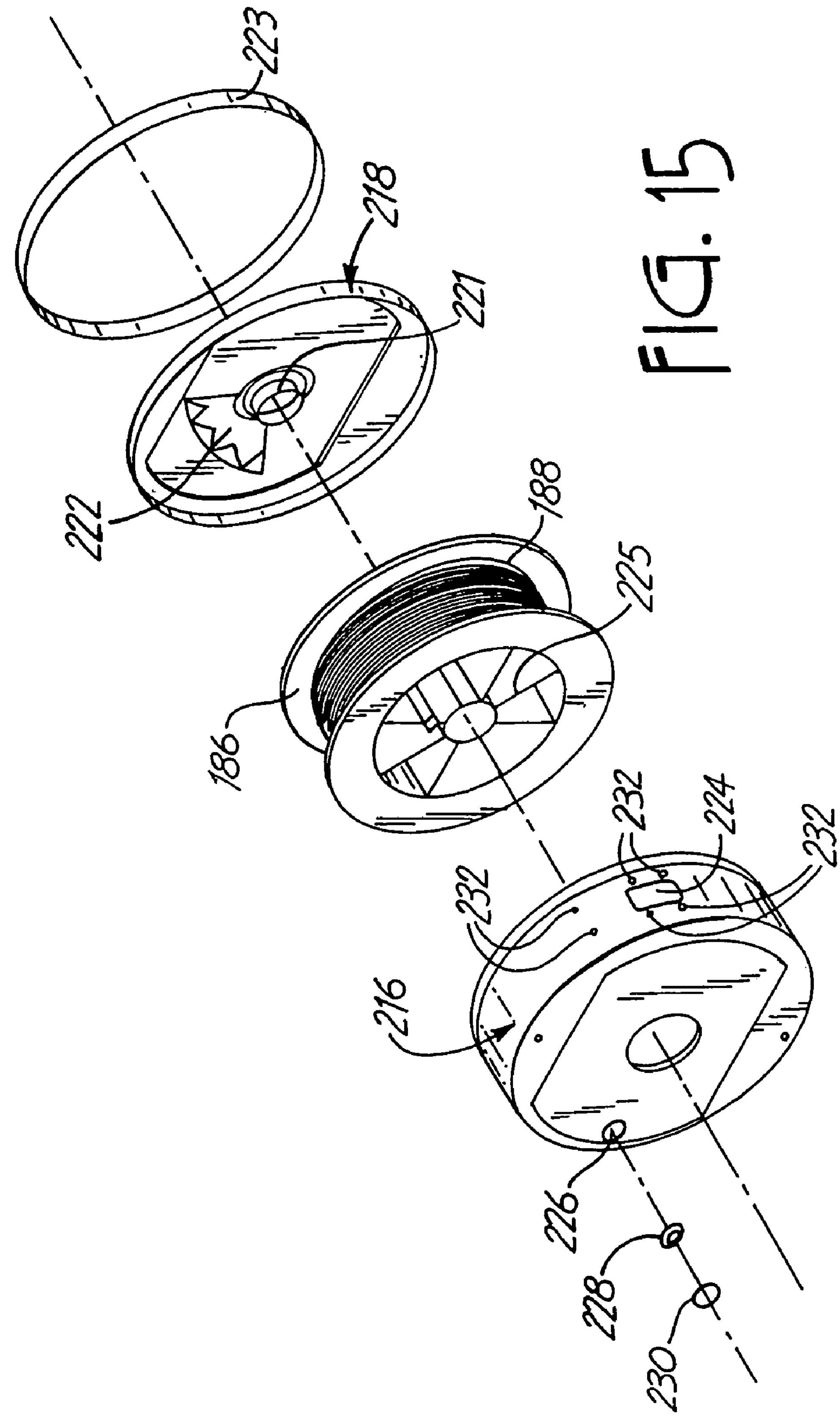

FIG. 15

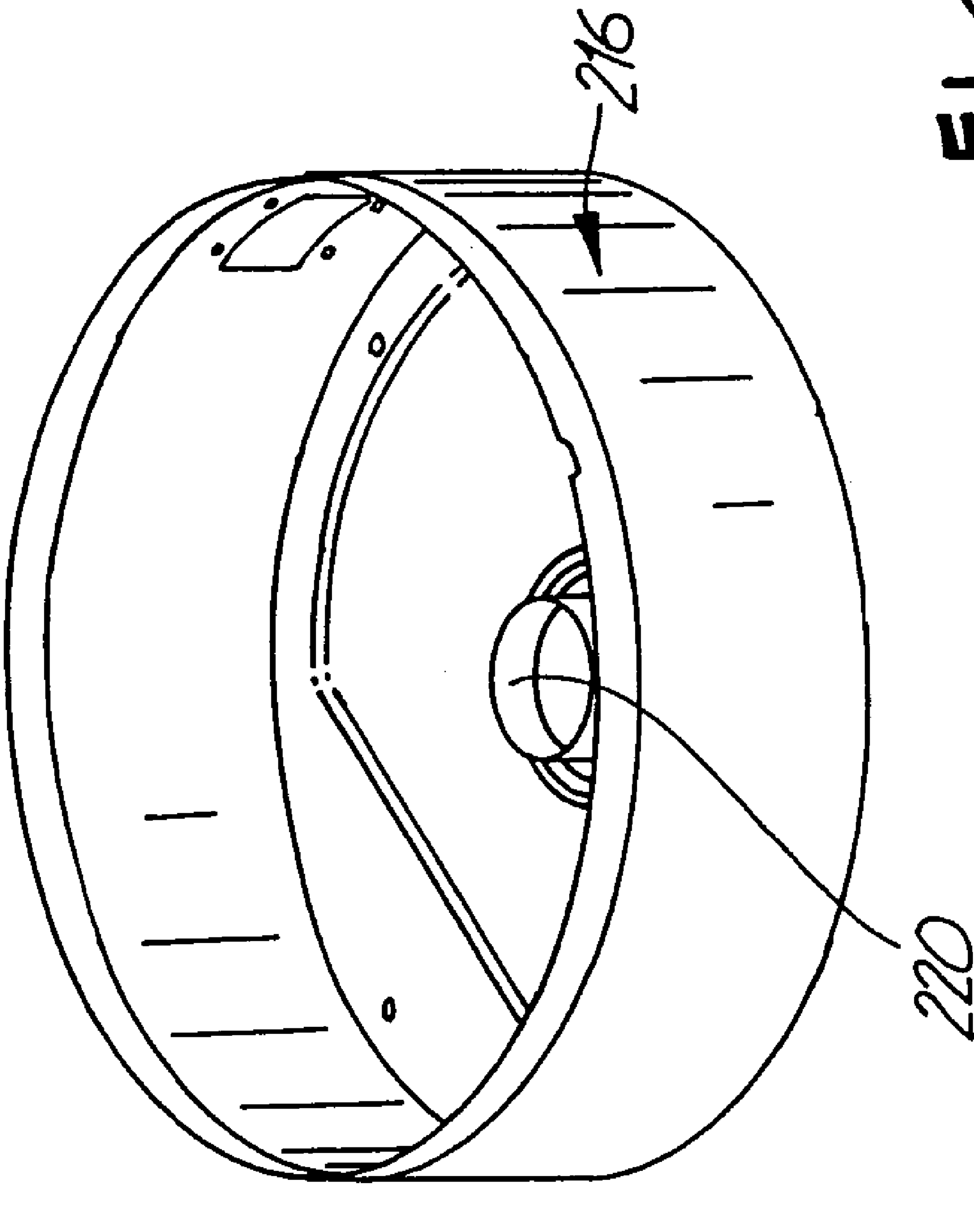

FIG. 16

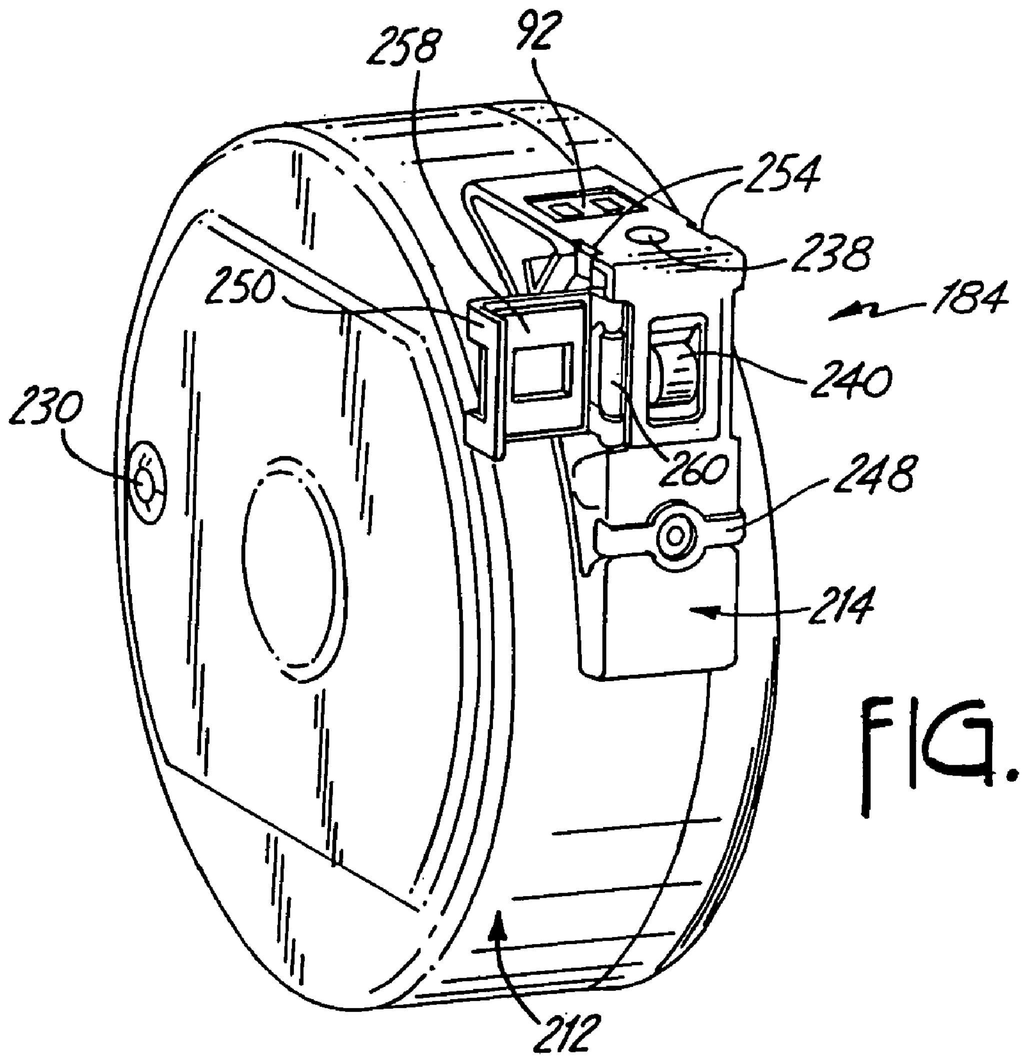

FIG. 17

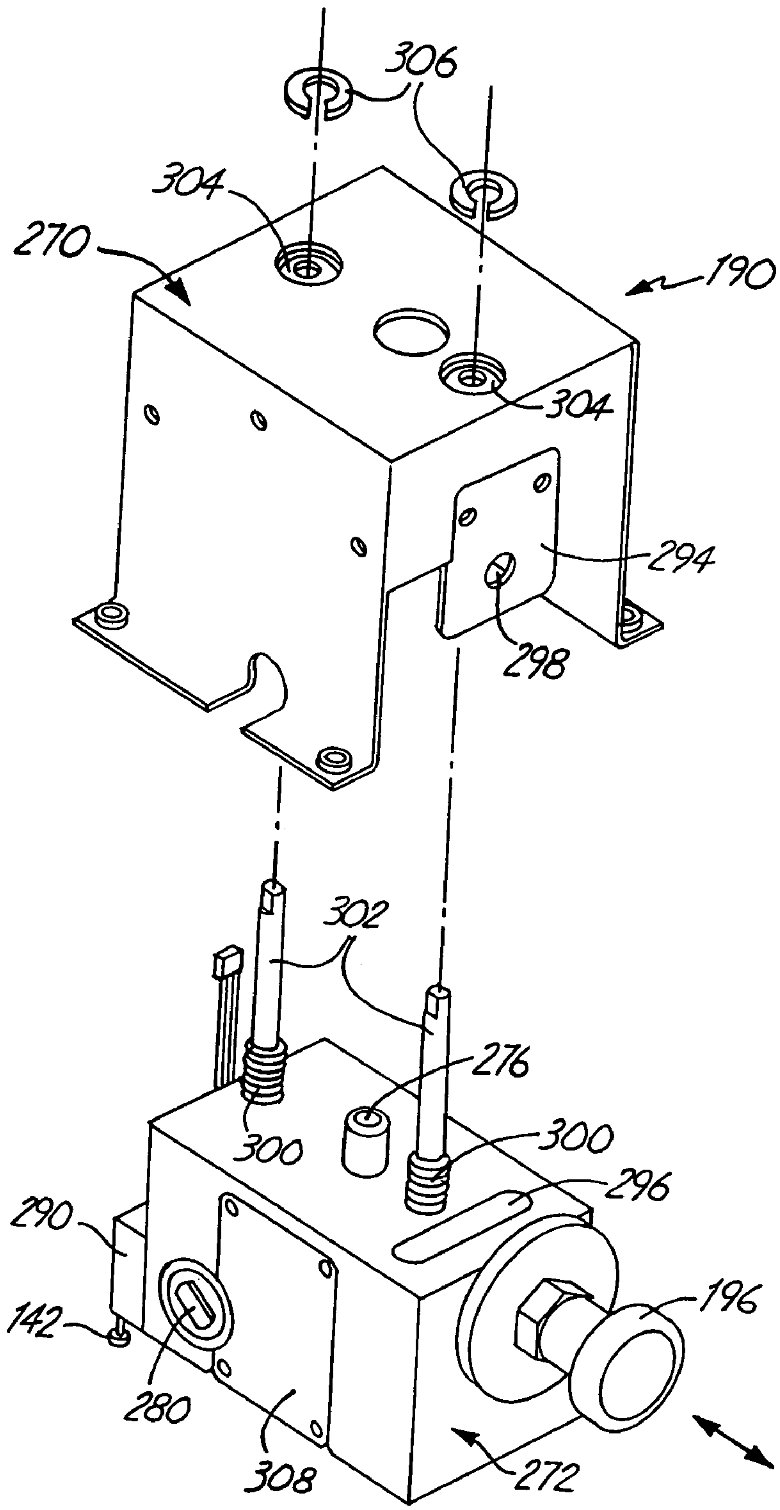
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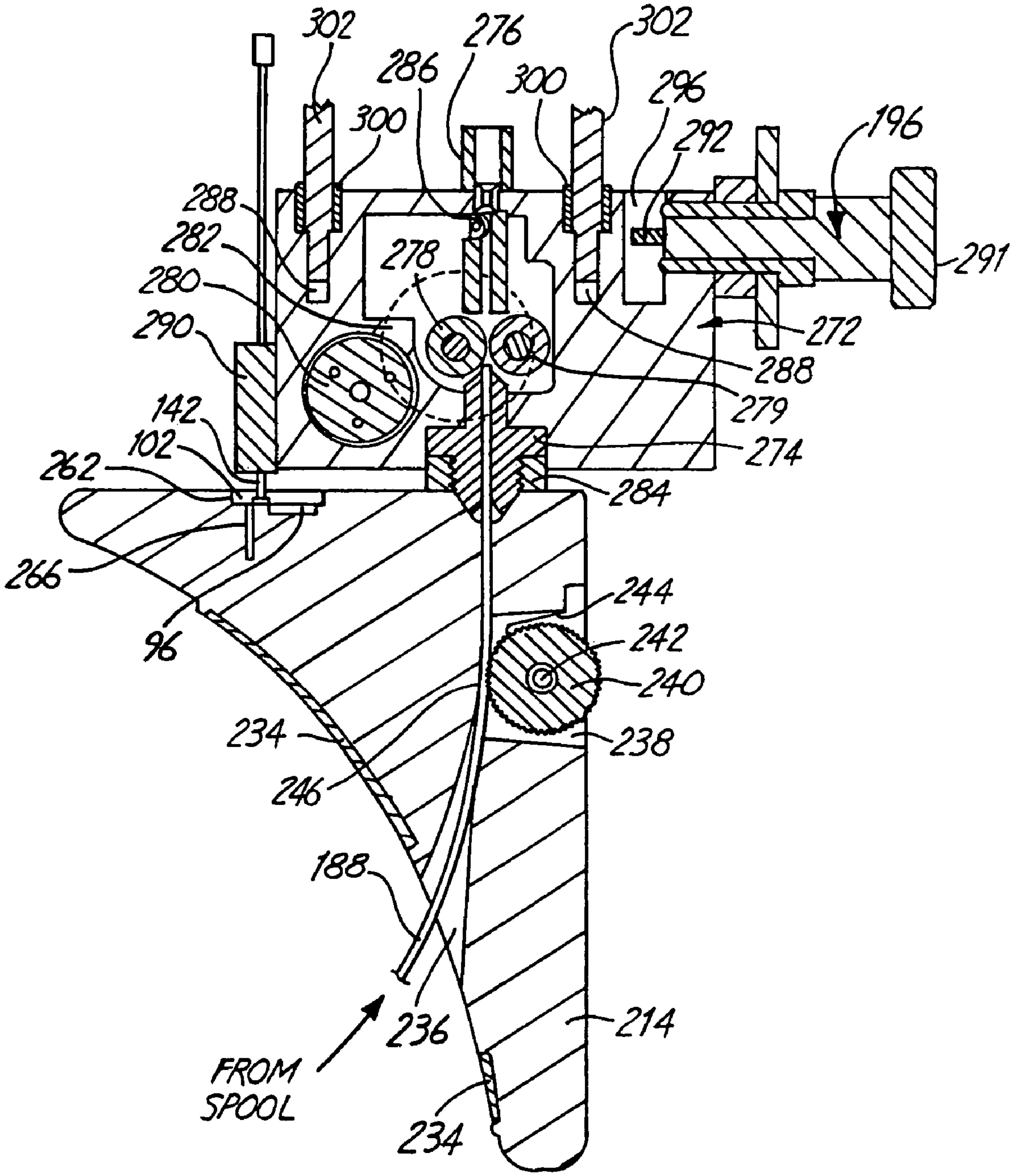
FIG. 18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FROM
SPOOL
234

FIG. 19

METHOD FOR LOADING FILAMENT IN AN EXTRUSION APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application is a divisional of application Ser. No. 09/804,401, filed on Feb. 27, 2001, issued on Oct. 17, 2004 as U.S. Pat. No. 6,776,602, which claims priority to provisional application Ser. No. 60/218,642, filed Jul. 13, 2000, and which is also a continuation-in-part of PCT International Application No. PCT/US00/17363, filed on Jun. 23, 2000 (designating the United States), which is hereby incorporated by reference as if set forth, and which is a non-provisional of provisional application Ser. No. 60/140,613, filed Jun. 23, 1999.

BACKGROUND OF THE INVENTION

This invention relates to the fabrication of three-dimensional objects using extrusion-based layered manufacturing techniques. More particularly, the invention relates to forming three-dimensional objects by extruding solidifiable modeling material in a flowable state in three dimensions with respect to a base, wherein the modeling material is supplied in the form of a filament.

Three-dimensional models are used for functions including aesthetic judgments, proofing the mathematical CAD model, forming hard tooling, studying interference and space allocation, and testing functionality. Extrusion-based layered manufacturing machines build up three-dimensional models by extruding solidifiable modeling material from an extrusion head in a predetermined pattern, based upon design data provided from a computer aided design (CAD) system. A feedstock of either a liquid or solid modeling material is supplied to the extrusion head. One technique is to supply modeling material in the form of a filament strand. Where the feedstock of modeling material is in solid form, a liquifier brings the feedstock to a flowable temperature for deposition.

Examples of extrusion-based apparatus and methods for making three-dimensional objects are described in Valavaara U.S. Pat. No. 4,749,347, Crump U.S. Pat. No. 5,121,329, Crump U.S. Pat. No. 5,340,433, Crump et al. U.S. Pat. No. 5,503,785, Danforth, et al. U.S. Pat. No. 5,900,207, Batchelder, et al. U.S. Pat. No. 5,764,521, Dahlin, et al. U.S. Pat. No. 6,022,207, Stuffle et al. U.S. Pat. No. 6,067,480 and Batchelder, et al. U.S. Pat. No. 6,085,957, all of which are assigned to Stratasys, Inc., the assignee of the present invention.

In the modeling machines employing a filament feed, modeling material is loaded into the machine as a flexible filament wound on a supply reel, such as disclosed in U.S. Pat. No. 5,121,329. A solidifiable material which adheres to the previous layer with an adequate bond upon solidification and which can be supplied as a flexible filament is used as the modeling material. The extrusion head, which includes a liquifier and a dispensing nozzle, receives the filament, melts the filament in the liquifier, and extrudes molten modeling material from the nozzle onto a base contained within a build envelope. The modeling material is extruded layer-by-layer in areas defined from the CAD model. The material being extruded fuses to previously deposited material and solidifies to form a three-dimensional object resembling the CAD model. In building a model from a modeling material that thermally solidifies upon a drop in temperature, the build envelope is preferably a chamber which is heated

to a temperature higher than the solidification temperature of the modeling material during deposition, and then gradually cooled to relieve stresses from the material. As disclosed in U.S. Pat. No. 5,866,058, this approach anneals stresses out of the model while is being built so that the finished model is stress free and has very little distortion.

In creating three-dimensional objects by depositing layers of solidifiable material, supporting layers or structures are built underneath overhanging portions or in cavities of objects under construction, which are not supported by the modeling material itself. For example, if the object is a model of the interior of a subterranean cave and the cave prototype is constructed from the floor towards the ceiling, then a stalactite will require a temporary support until the ceiling is completed. A support structure may be built utilizing the same deposition techniques and apparatus by which the modeling material is deposited. The apparatus, under appropriate software control, produces additional geometry acting as a support structure for the overhanging or free-space segments of the object being formed. Support material is deposited either from a separate dispensing head within the modeling apparatus, or by the same dispensing head that deposits modeling material. A support material is chosen that will adhere to the modeling material during construction, and that is removable from a completed object. Various combinations of modeling and support materials are known, such as are disclosed in U.S. Pat. No. 5,503,785.

In Stratasys FDM® three-dimensional modeling machines of the current art which embody a filament feed as disclosed in the above-referenced patents, a coil of modeling filament wrapped on a spool is loaded into the machine by mounting the spool onto a spindle. The filament is made of a thermoplastic or wax material. The user manually feeds a strand of the filament through a guide tube made of low friction material, unwinding filament from the spool until the filament strand reaches a pair of motor-driven feed rollers at the extrusion head. The filament strand is advanced by the feed rollers into a liquifier carried by the extrusion head. Inside the liquifier, the filament is heated to a flowable temperature. As the feed rollers continue to advance filament into the extrusion head, the force of the incoming filament strand extrudes the flowable material out from the dispensing nozzle where it is deposited onto a substrate removably mounted to a build platform. The flow rate of the material extruded from the nozzle is a function of the rate at which the filament is advanced to the head and the size of the dispensing nozzle orifice. A controller controls movement of the extrusion head in a horizontal x, y plane, controls movement of the build platform in a vertical z-direction, and controls the rate at which the feed rollers advance filament into the head. By controlling these processing variables in synchrony, the modeling material is deposited at a desired flow rate in "beads" or "roads" layer-by-layer in areas defined from the CAD model. The dispensed modeling material solidifies upon cooling, to create a three-dimensional solid object.

The Stratasys FDM® modeling machines use modeling filaments which are made from moisture sensitive materials, e.g., ABS thermoplastic. In order for the machines to function properly and to build accurate, robust models, the material must be kept dry. Therefore, filament spools for use in the machines are shipped, together with packets of desiccant, in moisture-impermeable packages. Each filament spool is to remain in its package until it is loaded into a modeling machine. The spindle onto which the spool is mounted is contained in a "drybox", an area of the machine maintained at low humidity conditions. The user is instructed to place the desiccant packets packaged with the filament spool into the drybox, and to remove any desiccant packets placed in the machine with prior spools. After manually feeding the filament to the feed rollers, the user latches a door of the drybox and may instruct the machine to begin building a model. To unload the filament spool from the machine, the user manually winds the filament back onto the spool. U.S. Pat. No. 6,022,207 shows and describes a spool of the current art loaded into the drybox of a three-dimensional modeling machine.

Manually feeding filament to the head, as is presently done, can be tedious. Additionally, as a practical matter, users often leave old desiccant in the drybox and fail to replace it with new desiccant, allowing humidity in the drybox to reach unacceptable levels. Further, frequent switching of spools results in moisture-contaminated material. Opening and closing the drybox door allows humid air to get trapped inside of the sealed area. A partially used spool unloaded from the machine is exposed to moisture and becomes contaminated as well. These moisture contamination problems result in wasted material when the user switches the type or color of modeling material. Moreover, some materials desirable for use as modeling materials in the Stratasys FDM® machines are highly vulnerable to moisture and can get contaminated within minutes. The time during which the drybox door is opened for loading and unloading filament introduces a level of moisture into the drybox unacceptable for some desirable materials, limiting the choice of modeling materials for use in these machines.

It would be desirable to provide modeling filament to a three-dimensional modeling machine in a manner that would simplify the loading and unloading operation, and that would reduce the moisture introduced into the machine. Additionally, it would be desirable to be able to readily remove unused filament from the machine and store it for later use.

BRIEF SUMMARY OF THE INVENTION

The present invention is a method for loading filament in an extrusion apparatus, such as a three-dimensional modeling machine, of the type having a liquifier that receives a feedstock of material in filament form and delivers the material in a flowable state. Filament is loaded into the extrusion apparatus by inserting a cassette containing filament into the apparatus. A filament strand from the cassette is then advanced into the machine, such as by operating a thumb wheel or a follower wheel on the cassette. In the exemplary embodiments, the filament strand is advanced out of an exit orifice of the cassette into a conduit of the machine. The filament strand is then further advanced to feed rollers associated with the liquifier.

Multiple filament cassettes may be loaded into single extrusion apparatus using the method of the present invention. When a primary cassette becomes depleted of filament, the method can be utilized to automatically remove from the liquifier filament from the primary cassette and advance to the liquifier filament from a secondary cassette, thus switching the feedstock source from the primary cassette to the secondary cassette.

The filament loading method of the present invention provides a convenient manner of loading and unloading filament in a three-dimensional modeling machine, and can be implemented in a manner that protects the filament from environmental moisture.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective, diagrammatic view of a generic filament-feed used in an extrusion-based three-dimensional modeling machine.

FIG. **2** shows a first embodiment of a filament cassette being loaded into a first embodiment of a three-dimensional modeling machine.

FIG. **3** is a partially exploded view of the first embodiment of a filament cassette.

FIG. **4** is an exploded view of the spool and lower shell of the filament cassette shown in FIG. **3**.

FIG. **5** is a detailed view of the (partially) exploded filament cassette shown in FIG. **3**, showing a strand of filament in the filament path and a mounted circuit board.

FIG. **5**A is a detailed view of an alternative configuration of a circuit board mounted onto the first embodiment of a filament cassette.

FIG. **6** is a perspective view of the first embodiment of the filament cassette, showing the bottom surface, side and trailing edge of the cassette.

FIG. **7** is a front elevation of the first embodiment of the filament cassette.

FIG. **8** is top plan view of a first embodiment of a filament cassette receiver of the present invention.

FIG. **9** is a front elevation of the first embodiment of the filament cassette receiver.

FIG. **10** is a perspective, detailed view of the filament drive shown in FIG. **8** as part of the filament cassette receiver.

FIG. **11**A is a top plan view of the first embodiment of a filament cassette loaded into the filament cassette receiver of FIG. **8**, showing the filament drive assembly in a disengaged position.

FIG. **11**B is a top plan view of a filament cassette loaded into the cassette receiver of FIG. **6**, showing the filament drive assembly in an engaged position.

FIG. **12** is a perspective detailed view of the filament drive assembly of FIG. **11**B engaging a roller on the first embodiment of the filament cassette.

FIG. **13** is a perspective view of a filament loading assembly in a second embodiment of the three-dimensional modeling machine.

FIG. **14** is a perspective view of a second embodiment of the filament cassette.

FIG. **15** is an exploded view of the second embodiment of the filament cassette (guide block not shown).

FIG. **16** is a perspective view of the canister base of the second embodiment of the filament cassette.

FIG. **17** is a perspective view of the guide block shown in FIG. **14**, with the access door open.

FIG. **18** is an exploded view of the filament cassette receiver shown in FIG. **13**.

FIG. **19** is a sectional view of the filament loading assembly of FIG. **13**, taken along a line **19**—**19** thereof.

DETAILED DESCRIPTION

A filament feed **10** used generally to feed filament to an extrusion head **20** in an extrusion-based three-dimensional modeling machine is shown in FIG. **1**. A spool **12** carrying a coil of filament **14** is mounted on a spindle **16**. The filament **14** is made up of a modeling material from which a three-dimensional model (or a support structure for the three-dimensional model) is to be built. Typically, the filament has a small diameter, such as on the order of 0.070 inches.

A strand of the filament **14** is fed through a guide tube or tubes **18**, made of a low-friction material, which also preferably provides a moisture barrier, such as Teflon™. The guide tube **18** routes the strand of filament **14** to the extrusion head **20**. A pair of feed rollers **22**, shown mounted on the extrusion head **20**, receive the strand of filament **14** and feed the strand of filament **14** to a liquifier **26** carried by the extrusion head **20**. As shown, the feed rollers **22** are rubber-coated so as to grab the strand of filament **14** therebetween. Also as shown, one of feed rollers **22** is a drive roller, driven by a motor **24** under the control of a controller **25**. The other roller **22** is an idler roller. The liquifier **26** is heated so as to melt the filament **14**. The liquifier **26** terminates in a nozzle **28** having a discharge orifice **30** for dispensing the molten modeling material. The liquifier **26** is pressurized by the "pumping" of the strand of filament **14** into the liquifier **26** by feed rollers **22**. The strand of filament itself acts as a piston, creating a "liquifier pump". The pressurization impels the molten modeling material out of the orifice **30** at a volumetric flow rate. The volumetric flow rate is a function of the size of the dispensing orifice **30** and the rate of rotation of the feed rollers **22**. By selective control of the motor **24**, the rate of advancement of the strand of filament **14**, and thus the volumetric dispensing rate of the molten modeling material, can be closely controlled.

The extrusion head **20** is driven in a horizontal x,y plane by an x-y translator **34**, which receives drive signals from the controller **25** in accordance with design data derived from a CAD model. As the extrusion head **20** is translated in the x-y plane, molten modeling material is controllably dispensed from the orifice **30** layer-by-layer onto a planar base **32** (shown in part in FIG. **1**). After each layer is dispensed, the base **32** is lowered a predetermined increment along a vertical z-axis by a z-axis translator **36**, which also receives drive signals from the controller **25**. The dispensed material fuses and solidifies to form a three-dimensional object resembling the CAD model. Support material may be dispensed in a like fashion in coordination with the dispensing of modeling material, to build up supporting layers or a support structure for the object.

As will be understood by those in the art, many variations of the modeling machine and process are possible. For example, any relative movement in three-dimensions between the extrusion head **20** and the base **32** may be used to built up the object. The feed rollers and the motor may take various forms. For example, as is disclosed in U.S. Pat. No. 5,121,329, both rollers may be driven (such as by coupling the rollers by a timing belt), more rollers be added, or the rollers may be spring-biased towards each other, rather than rubber coated, to maintain gripping frictional contact on the filament. Any type of motor that can drive the feed rollers at a controlled rate may be employed, for instance a servo motor or a stepper motor. Likewise, different arrangements of extrusion heads may be utilized for receiving and dispensing different types or colors of filament from separate filament feeds. For example, the extrusion head may carry two sets of feed rollers, each driven by its own motor, for advancing two different filament strands from two different spools, such is disclosed in U.S. Pat. Nos. 5,121,329; 5,503,785; and 6,004,124.

Embodiment One

In the present invention, the spool carrying a coil of filament is contained within a filament cassette. FIG. **2** shows a first exemplary embodiment of a modeling machine **40** which has two loading bays **42** stacked vertically, each for receiving a first embodiment of a filament cassette **44**. As shown, one filament cassette **44** is loaded into the lower loading bay. A second cassette **44** is being loaded into the upper loading bay **42**. Each filament cassette contains a spool carrying a coil of filament. Preferably, one cassette **44** supplies filament formed of modeling material, while the other cassette **44** supplies filament formed of support material. The modeling machine **40** has two liquifiers **26**, such as shown in FIG. **1**, which each receive a strand of filament from one of the cassettes **44**.

As will be described in detail below, each loading bay **42** contains a cassette receiver **46** which engages the filament cassette **44** and advances a strand of the filament **14** from the cassette **44** into the guide tube **18** of filament feed **10**. A user loads the filament cassette **44** into the modeling machine **40** by holding the cassette **44** in an upright position and lining up a leading edge **48** of the cassette **44** with one of the loading bays **42**. The user pushes the cassette **44** into the loading bay **42** until a hard stop is reached. At such time, the cassette **44** is engaged by the cassette receiver **46**.

Detail of the filament cassette **44** is shown in FIGS. **3**–**7**. As shown in FIGS. **3** and **4**, the filament cassette **44** is comprised of an upper shell **50**, a lower shell **52**, and a spool **54** carrying the filament **14**. The upper shell **50** and lower shell **52** fasten together, with the spool **54** between them, by a set of four screws **55** (not shown). The lower shell **52** has a hub **56** and the upper shell **50** has a hub **58**. A circular recess **59** within upper shell **50** and lower shell **52** surrounds each of hubs **56** and **58**. The upper shell **50** and lower shell **52** each have seven compartments **60** along the periphery of the recess **59**. Together, hubs **56** and **58** form a spindle on which the spool **54** rotates within a chamber defined by the circular recesses **59**. Packets of desiccant **62** are placed in the compartments **60** so as to maintain dry conditions in the chamber of cassette **44**. A narrow channel **64** is routed in lower shell **52** in a closed-loop around the periphery of the circular recesses **59** and the compartments **60**. A gasket **68** is seated in the channel **64**, and a ridge **66** in the upper shell **50** mirrors the channel **64**. The gasket **68** blocks air from reaching the spool **54** within the cassette **44** when the upper shell **50** and the lower shell **52** are fastened together.

Each of shells **50** and **52** have a narrow channel **70** leading from the circular recess **59** to the leading edge **48** of the cassette **44**, as best shown in FIG. **5**. Together, the channels **70** define a filament path which terminates in an exit orifice **72** of the cassette **44**, as shown in FIG. **7**. As is best shown in FIG. **5**, a roller **76** is mounted opposite a roller **78** along the channel **70** of the lower shell **52**. As shown, roller **76** rotates on a floating axle **80**, while roller **78** rotates on a fixed axle **82**. The floating axle **80** is seated in an oblong depression **81** of the upper and lower shells **50** and **52**, oriented perpendicular to the filament path. The fixed axle **82** is seated in a cylindrical depression **83** of the upper and lower shells **50** and **52**. A force applied against roller **76** will force roller **76** towards roller **78** to grip a strand of filament **14** in the filament path. Alternatively, both rollers could have a fixed axle, and be positioned close enough to one another to grip a filament strand in the path. The rollers may have an elastomeric surface, to aid in gripping the strand of filament **14**.

The channel **70** of lower shell **52** forming the filament path crosses the channel **64** at a position located between the circular recess **59** and the roller pair **76** and **78**. A retainer **84**, which is integral with the gasket **68**, is positioned at this location. The retainer **84** has a center hole **85** of a diameter approximately equal to the filament diameter.

Each of shells **50** and **52** have another channel **86** which runs parallel to the channel **70**. Together, the channels **86** define a registration pin receiving cavity **88**, which begins at the leading edge **48** of the cassette **44** and terminates before reaching the gasket **68**. Cavity **88** has a flared mouth followed by a narrow neck. The mouth of cavity **88** is shown in FIG. **7**. Each of upper shell **50** and lower shell **52** have a recess **89** to the right of the channel **86**, which together form a recess in the leading edge **48** of the cassette **44**. On the lower shell **52**, a circuit board is mounted in the recess **89**.

In one embodiment, as shown in FIG. **5**, a circuit board **92** is mounted horizontally at the base of the recess **89** by two screws **94**, and carries an EEPROM **96** on its upper surface. The circuit board **92** has conductive tabs **98** on a portion thereof which extends across the recess **89**, so that it may be received by a card-edge connector. In an alternative embodiment, shown in FIG. **5**A, a circuit board **102** is mounted vertically in the recess **89** by screws **104**. The circuit board **102** has an inner face (not shown) which carries the EEPROM **96** and an outer face which carries a pair of electrical contacts **106**.

The EEPROM **96** acts as an electronic tag for the cassette **44**. The EEPROM **96** contains information identifying the cassette **44** and the filament **14**, such as the type of material from which the filament is formed. The EEPROM **96** additionally may keep a count of the lineal feet of filament **14** that is in the cassette **44**. When the cassette **44** is loaded into the modeling machine **40**, the EEPROM **96** is electrically connected to the controller **25**, as described below. As filament **14** is advanced from the cassette **44** into the modeling machine **40**, the controller **25** continually updates the lineal feet count of the filament **14** remaining in the cassette **44**. This allows the controller **25** to prevent the machine **40** from attempting to model without filament. EEPROM **96** may be any electronically readable and writeable data store. The use of such a data store as a filament tag is described in U.S. Pat. No. 5,939,008.

The filament cassette **44** is assembled by placing the spool **54** carrying the filament **14** on the hub **56** of the lower shell **52**. The lower shell **52** is prepared by pressing the gasket **68** into the channel **64**, so that the center hole **85** of the retainer is aligned in the channel **70**. One of the circuit boards **92** or **102** is fastened to the lower shell **52**. The fixed axle **82** carrying roller **78** is placed into the cylindrical depression **82** of the lower shell **52**, while the floating axle **80** carrying roller **76** is placed into the oblong depression **81** of the lower shell **52**. A strand of the filament **14** from the spool **54** is threaded through the hole in retainer **84**, and placed in the channel **70** of lower shell **52** between the rollers **76** and **78**. A packet of desiccant is placed in each of the compartments **60**. Once each of these items are in position on the lower shell **52**, the upper shell **50** and lower shell **52** are fastened together by the four screws **55** (alternatively, any known fastening device could be used). The screws **55** are set into four screw holes **108** of the lower shell **52**, and extend into four threaded screw holes **109** of the upper shell **50**. The cassette **44** is then ready for loading into the modeling machine **40**.

Once the cassette **44** is assembled, it may be placed in a moisture-impermeable package, which package may then be vacuum sealed, for shipping or later use. Vacuum sealing is desirable where the filament **14** is made from a moisture sensitive material. Additionally, for moisture sensitive materials, the chamber of the cassette **44** containing the spooled filament should be dried just prior to the vacuum sealing. The cassette **44** then remains in the package until a user is ready to load the cassette **44** into the modeling machine **40**.

After the filament **14** contained within the cassette **44** is depleted or otherwise becomes unusable, the cassette **44** can be refilled and reused by detaching the shells **50** and **52** and replacing the filament **14** on the spool **54**. The EEPROM **96** carried by circuit board **92** or **102** can be reset or the circuit board replaced to provide a new EEPROM **96**.

FIG. **6** shows the bottom surface, trailing edge and right side of filament cassette **44**. As shown, the roller **76** protrudes from an opening **111** in the right side of the cassette **44** so that it may receive an external rotational force. As will be described in more detail below, the roller **76** is preferably driven by a drive wheel **156** on the cassette receiver **46** to advance the strand of filament **14** out of the exit orifice **72**.

The cassette receiver **46** which engages filament cassette **44** is shown in FIGS. **8**–**12**. The cassette receiver **46** is mounted on the floor **110** of each loading bay **42**. Preferably, the loading bay floor **110** is made of sheet metal. The cassette receiver **46** comprises a latching mechanism **12**, a reciprocating assembly **114** and a drive assembly **116**. The latching mechanism **112** is mounted to the floor **110** by a bracket **116**. The latching mechanism **112** is comprised of a solenoid **118**, an arm **120** and a latch **122**. The arm **120** is coupled to the solenoid **118** at one end thereof and is integral with the latch **122** at the other end thereof. The arm **120** extends downward from the solenoid **118** through an opening in the floor **110**, sits below and generally parallel to the floor **110**, and then angles upward so that it will pivot to position the latch **122** alternately above and below the floor **110**. The latch **122** moves up and down through a cutout **124** in the floor **110**.

The solenoid **118**, operating under control of the controller **25**, alternately rocks the arm **120** up and down to engage and disengage the latch **122**. When the solenoid **118** is energized, the arm **120** rocks upward at the latch end, placing the latch **122** in an engaged position. When the solenoid **118** is de-energized, the latch end of arm **120** rocks downward, moving the latch **122** to a disengaged position.

The reciprocating assembly **114** is fastened to the loading bay floor **110** by a bracket **126**. The reciprocating assembly **114** comprises a piston **128**, an ejection spring **130**, a track **132** and a frame **133**. The piston **128** sits parallel to and above the floor **110**. The piston **128** extends through a hole in the bracket **126** and moves forward and back in the loading bay **42**, guided by track **132**. The forward end of the piston **128** is coupled to the frame **133**, which extends generally perpendicular to the piston **128**. The frame **133** moves back and forth with the motion of piston **128**. The ejection spring **130** is coiled around the piston **128**, connecting to the bracket. **126** at the rearward end thereof and connecting to the frame **133** at the forward end thereof. A horizontal force applied against the frame **133** will compress the ejection spring **130**. When said force is released, the spring **130** will decompress, causing the frame **133** and piston **128** to move forward. A pair of bearings **134** are mounted to the floor **110** underneath the frame **133**. The bearings **134** provide a low friction surface which supports frame **133** in a plane parallel to the floor **110**, while allowing the frame **133** to slide back and forth.

Attached to the frame **133** are an electrical connector **136**, a registration pin **138** and a conduit **140**. The electrical connector **136** is configured to mate with the circuit board of the filament cassette **44** on a forward face thereof and is configured to provide an electrical connection to the controller **25** at a rear face thereof. As shown, the forward face of electrical connector **136** carries two pogo pins **142** configured to mate with the electrical contacts **106** of circuit board **102** carried by the cassette **44**. (Alternatively, the electrical connector could be a card-edge connector for receiving the conductive tabs **98** of circuit board **92**). The registration pin **138** is mounted on the frame **133** to the right of the electrical connector **136**. The registration pin **138** extends forward in the loading bay **42** and has a diameter approximately equal to the diameter of the neck of cavity **88** within the filament cassette **44**. The conduit **140** is located to the right of the registration pin **138**. The conduit **140** has an entrance **144** which faces forward in the loading bay **42**, and an exit **146** facing to the rear of the loading bay **42**. The entrance **144** of the conduit **140** is configured to align with the exit orifice **72** of the cassette **44**, and to receive the strand of filament **14** from the exit orifice **72**. Optionally, the conduit **140** may make an airtight seal with the exit orifice **72** and the guide tube **18**. A strand of the filament **14** fed into the conduit entrance **144** will exit through the conduit exit **146** where it can then be provided into the guide tube **18** and routed to the liquifier **26**.

The drive assembly **116** is mounted to the loading bay floor **110** by a bracket **148**. The drive assembly **116** comprises a solenoid **150**, a motor **152**, a gear train **154**, a drive wheel **156** which rotates on a shaft **158**, and a housing **160**. The drive assembly **116** is shown in detail in FIGS. **10**–**12**. The solenoid **150** having an actuator **162** is mounted in the bracket **148** so that the actuator **162** reciprocates forward and back in the loading bay **42**. Energization of the solenoid **150** is controlled by the controller **25**. The actuator **162** moves forward in the loading bay **42** when the solenoid **150** is actuated, and moves towards the back of the loading bay **42** when the solenoid **150** is deactuated. The housing **160**, which carries the motor **152**, the gear train **154** and the drive wheel **156**, is pivotably mounted onto the floor **110** in front of the actuator **162**. When the solenoid **150** is energized, the actuator **162** pivots the housing **160** in a clockwise rotation. Absent a force imparted against the housing **116** by the actuator **162**, the housing **160** is in an upward resting position. When the actuator **162** rotates the housing **116** in a counterclockwise direction, the drive wheel **156** is placed in an actuated position at which it will press against the floating-axis roller **76** of the cassette **44** when the cassette **44** is loaded in the loading bay **42**.

The motor **152**, in response to control signals from the controller **25**, causes rotation of the shaft **158** via gear train **154**, as best shown in FIG. **10**. Rotation of the shaft **158** rotates the drive wheel **156**. When in its actuated position, the drive wheel **156** will then rotate the cassette roller **76**. Release of the actuator **162** from the housing **160** allows the housing **160** to rotate back into a resting position. In an alternative embodiment wherein the cassette roller has a fixed axis, the solenoid **150** could be eliminated and the drive wheel **156** could remain fixed in the actuated position where it would impart a constant force against the cassette roller.

As mentioned above, a user loads the cassette **44** into the modeling machine **40** by pushing the cassette **44** into one of the loading bays **42** until a hard stop is reached. The hard stop is provided by a backstop **164**, which is mounted to the loading bay floor **110** (as shown in FIG. **8**), and the compression of the ejection spring **130**. As the user releases the cassette **44**, it moves back until the latch **122** catches on a ridge **180** on the bottom surface of the cassette **44** (shown in FIG. **6**). The latch **122** is set in an upward position prior to loading the cassette **44**, under commands from the controller **25** to the solenoid **118**, so that it is ready to catch the cassette **44**. The latch **122** remains in this upward position until the user desires to remove the cassette **44**, at which time the controller **25** de-energizes the solenoid **118** to lower the latch **122**.

As the cassette **44** is pushed into the loading bay **42**, the registration pin **138** slides into the cavity **88** of the cassette **44**. The registration pin **138** serves to properly align the cassette **44** with the cassette receiver **46**, and specifically to counteract a torque imparted against the cassette **44** by engagement of the drive system **116**. With the cassette **44** properly aligned with the cassette receiver **46**, the pogo pins **142** mate with the electrical contacts **106** of the circuit board **102**. Electrical contact is then established between the cassette **44** and the controller **25**. The controller **25** knows that the cassette **44** is loaded when it senses that the EEPROM **96** is present. The controller **25** reads the count that is stored on the EEPROM **96**. If the count indicates that the amount of filament **14** contained in the cassette **44** is below a set “cassette empty” threshold value, the user is alerted to load a new cassette **44**.

When the controller **25** senses that the cassette **44** is loaded, it energizes the solenoid **150** of the drive assembly **116**. As described above, actuation of the solenoid **150** rotates the housing **160** such that the drive wheel **156** moves to its actuated position, at which it presses against the roller **76** of the cassette **44**. The drive wheel **156** imparts a force against the roller **76**, pushing the roller **76** towards the roller **78**, thus pinching the strand of filament **14** that is in the filament path. When the drive wheel **156** is driven in a counterclockwise rotation by the motor **152**, the roller **76** is driven in a clockwise rotation so as to advance the strand of filament **14** into the conduit **140**, and then into the guide tube **18**.

The cassette receiver **46** continues to advance the strand of filament **14** until it reaches the feed rollers **22**. The controller **25** senses presence of the filament **14** at the feed rollers **22**. Preferably, motor **24** is a DC servo motor, and the sensing is achieved by monitoring the current load of the motor **24**. To monitor the current load, the controller **25** activates the motor **24** at the start of the auto-load process. When filament is present between the rollers **22**, the current load will increase. When the controller **25** senses the increase in motor current load, the controller **25** signals the motor **24** and the cassette receiver **46** to stop. Additionally, the controller **25** de-energizes the solenoid **150** to remove the force of drive wheel **156** against the roller **76**. This serves to remove the frictional force of the rollers from the filament **14** during modeling. Filament **14** from each of the cassettes **44** is loaded in a like manner. Once both materials have been loaded, modeling may begin.

Optionally, as mentioned above, the drive assembly **116** could be designed so that the drive wheel **156** remains in a fixed position where it applies a constant force. In such an arrangement, it would be possible to eliminate the roller pair **22**, and instead use the roller pair on the cassette **44** to feed the filament **14** into the liquifier **26**. Then, the drive wheel **156** would be driven at a controlled rate to control the rate of advancement of the filament **14** into the liquifier **26**.

To unload the filament, a controller **25** drives the motor **24** backwards for a short time sufficient to pull the strand of filament **14** out of the liquifier **26** and feed rollers **22**. The controller **25** then disengages the cassette receiver **46** from the cassette **44**, allowing the user to remove the cassette **44** from the loading bay **42**. To eject the cassette **44** from the machine **40**, the user pushes the cassette **44** to the hardstop to allow disengagement of the latch **122**. The spring **130** then forces forward the reciprocating assembly **114**, ejecting the cassette **44**.

The top surface and trailing edge of cassette **44** each have a window **170** which allow the user to visually inspect the amount of filament **14** contained within the cassette **44** when the cassette **44** is loaded or unloaded. If a useable amount of filament **14** remains in the cassette **44** when it is removed from the loading bay **42**, the cassette can be stored for later use. If there is not a usable amount of filament remaining, the cassette **44** can be refilled and reused.

Embodiment Two

FIG. **13** shows a filament loading assembly **178** in a second embodiment of a modeling machine **180**, which builds models from filament supplied from a second exemplary embodiment of a filament cassette **184**. The filament loading assembly **178** and the filament cassette **184** are particularly suited for building models from moisture-sensitive materials. The filament loading assembly **178** comprises four loading bays **182**, four filament cassettes **184** each containing a spool **186** carrying a coil of filament **188**, four filament cassette receivers **190**, two junction blocks **192** and a drying system **194**. The four loading bays **182** are aligned horizontally across the front of the modeling machine **180**. Each loading bay **182** receives one filament cassette **184** and has associated with it one filament cassette receiver **190**, mounted in a ceiling thereof. The junction blocks **192** are mounted to a frame **195** of the filament loading assembly **178**, and are each associated with a pair of cassette receivers **190**.

A user loads the filament cassette **184** into the modeling machine **180** by holding the cassette **184** in an upright position, pushing the cassette **184** into one of the loading bays **182**, grasping a latch **196** on the filament cassette receiver **190**, and pulling the latch **196** forward to drop the filament cassette receiver **190** to a lowered position. In the lowered position, the filament cassette receiver **190** mates with the filament cassette **184** and latches the cassette **184** into place. A strand of filament is manually fed from each filament cassette **184** to the associated cassette receiver **190** (as will be described in detail below). The cassette receiver **190**, under control of the controller **25**, then automatically advances the filament strand through tubing **202** and the associated junction block **192** toward the extrusion head **20**.

Each junction block **192** has two input ports **198**, one air port **199**, and one output port **200**. The input ports **198** are coupled to the associated cassette receivers **190** by lengths of tubing **202**, which provides a path for filament strands from the receivers **190** to the associated junction block **192**. The output ports **200** of each junction block **192** are connected to lengths of tubing **204**. Tubing **204** provides a filament path from each junction block **192** to a liquifier **26** (such as shown in FIG. **1**). For filament **188** that is made of a moisture sensitive material, the drying system **194**, which comprises a compressor **206**, a filter **208**, and a regenerative dryer **210**, is used to maintain dry conditions in the path of the filament strand as it travels from the cassette **184** to the liquifier **26**, as will be described in more detail below.

At a given time, only one strand of filament is provided to each junction block **192** and to each pair of feed rollers **22**. The other filament strands remain in the associated cassette receivers **190**. A cassette **184** that provides the filament strand to the junction box **192** is termed a primary material supply cassette, while a cassette **184** which provides the filament strand that remains in the cassette receiver **190** is termed a standby material supply cassette. The machine **180** can switch from the primary to the standby material supply cassette **184** without user intervention, by winding the filament strand from the primary cassette **184** back towards its receiver **190**, and advancing the filament strand from the standby cassette **184** through the junction block **192** to the feed rollers **22**. The standby cassette then becomes the primary cassette. In a typical modeling application, it will be preferable for one junction block **192** to receive modeling material filament and the other junction block **192** to receive support material filament. Then, the machine **180** can automatically switch to the standby supply when the primary supply is depleted, and no modeling time will be lost. The depleted cassette can be replaced at the user's convenience while the modeling machine **180** continues to run. Alternatively, if the primary and standby cassettes **184** contain different types of filament **188**, switching can be done before depletion of material to allow building from a different material type or color.

The filament cassette **184** is shown in detail in FIGS. **14**–**17**. As shown, the filament cassette **184** is comprised of a canister **212**, a guide block **214**, and spool **186** carrying a coil of the filament **188**. The canister **212** is formed of a body **216**, and a lid **218** that presses onto the body **216**. The interior of canister **212** defines a chamber containing the spool **186**. The spool **186** rotates on a hub **220** of the body **216** and a hub **221** of the lid **218**. Optionally, a spring plate **222** is attached to the inside of the lid **218**. The spring plate **222** has spiked fingers which are bent so as to allow rotation of the spool **186** in only the direction that will advance filament out of the cassette **184**. The guide block **214** is attached to the body **216** at an outlet **224**, and provides a exit path for the filament **188**. The guide block **214** is fastened to the canister body **216** by a set of screws (not shown) which extend through six screw holes **232** in the body **216** (shown in FIG. **15**).

For filament **188** made of moisture sensitive material, the cassette **184** is made air tight. The canister **212** and guide block **214** are made of materials that block water vapor transmission, such as sheet metal and polypropylene, respectively. A strip of moisture-impermeable tape **223** seals the lid **218** to the body **216**. Moisture can be withdrawn from the interior chamber of canister **212** through a hole **226** in the canister body **216**, and the hole **226** sealed with a plug **228**. Preferably, a piece of moisture-impermeable tape **230** is placed over the plug **228** to further seal the hole **226**.

As shown in FIG. **19**, a strand of the filament **188** inside the canister **212** is fed through outlet **224** into a filament path **236** in the guide block **214**. The filament path **236** extends through the guide block **214**, terminating in an exit orifice **238**. Adjoining the filament path **236**, the guide block **214** has a chamber **238** in which a knurled roller **240** is mounted on a pin **242**. The pin **242** is mounted so that the knurled roller **240** pinches the strand of filament in the path **236** against a wall **246**. A user can advance the filament strand out of the exit orifice **238** and along the filament path **236** by manually rotating the roller **240** in a clockwise direction. To prevent a counterclockwise rotation of roller **240** (which would push the filament strand towards the canister **212** where it could be accessed only by opening the canister), an anti-rotation plate **244** is preferably mounted in the chamber **238**, juxtaposed with the roller **240**. It will be apparent to those skilled in the art that the knurled roller **240** could be replaced with some other means for advancing the filament strand. For example, the wall **246** could have a raised contour allowing a user to apply a manual propulsion force to the filament over the contour. Further, the raised counter could be defined by an idler rollers or an idler roller could be used in combination with the knurled roller **240**.

For filament **188** formed of moisture sensitive material, air flow to the filament path **236** is prevented. The guide block **214** has a removable plug cap **248** that seals the exit orifice **238**, and a door **250** that encloses the chamber **238**. The plug cap **248** snap-fits onto a pair of grooves **254** on the guide block **214**, so that a compressible seal **252** on the underside of the plug cap **248** covers the exit orifice **238**. The plug cap **248** is removed by the user at the time of inserting the cassette **184** into the machine **180**. Preferably, the guide block has a second set of grooves **256** on which the plug cap **248** may be parked when it is removed from the first set of grooves **254**. The door **250** has a compressible seal **258** on an interior surface thereof, and pivots on a hinge **260**. When the door **250** is open, the roller **240** is accessible to a user. The door **250** is opened by a user to load filament into the machine **180**, and kept closed otherwise. A compressible seal **234** is placed between the guide block **214** and the canister body **216** to further seal the cassette **184**.

The guide block **214** may carry an EEPROM **96** (described with respect to embodiment one above). The circuit board **102** carrying EEPROM **96** is mounted in a depression **262** of the guide block **214**, with the pair of electrical contacts **106** facing out and the EEPROM **96** facing in. The circuit **102** is fastened to the guide block **214** by three screws **266**. For ease of use, the guide block **214** preferably functions as a handle for the cassette **184**. In the embodiment shown, the guide block **214** includes a pair of grips **264** (shown in FIG. **14**) on opposite sides thereof.

The filament cassette **184** is assembled by placing the spool **186** carrying the filament **188** on the hub **220** of the body **216**, and feeding a filament strand into the guide block **214**. The filament strand is positioned along the filament path **236** so that it contacts the roller **240**. Optionally, packets of desiccant **62** (such as shown in regards to embodiment one) may be placed in compartments defined by spokes **225** of the spool **186**. Then, the lid **218** is pressed onto the body **216**, and the tape **223** is applied. It is then ready for use. The cassette **184** may likewise be refilled and reused after the filament **188** that it contains becomes depleted or unusable, by removing the lid **218** of the canister **212** and replacing the filament **188** on the spool **186**. When refilling a cassette **184**, the EEPROM **96** carried by circuit board **102** can be reset or the circuit board replaced to provide a new EEPROM **96**.

For moisture sensitive materials, the cassette **184** containing the spooled filament should be dried to a level at which the moisture content will not impair model quality. For most high-temperature thermoplastics, for example polycarbonate, polyphenylsulfone, polycarbonate/ABS blend and Ultem™, an acceptable moisture content is a level less than 700 parts per million (ppm) water content (as measured using the Karl Fischer method). Multiple techniques may be used to dry the filament.

The material may be dried by placing the cassette **184** containing spooled filament in an oven under vacuum conditions. The cassette **184** is placed in the oven prior to attaching the circuit board **102** and prior to plugging the hole **226**. The oven is set to a temperature suitable to the specific modeling material type. For high-temperature thermoplastics, a temperature of between 175–220° F. is typical. The oven has a vacuum pump which maintains a dry environment in the oven. The hole **226** in canister **212** facilitates bringing the chamber of the canister **212** to the oven environment, so that the modeling material will be dried. When the moisture content of the material reaches a level desirable for the modeling material, the hole **226** is promptly sealed and the cassette **184** removed from the oven. For high-temperature thermoplastics, an expected drying time is between 4–8 hours to reach less than 300 ppm water content. The circuit board **102** is then attached. The fully-assembled cassette **184** may be vacuum-sealed in a moisture-impermeable package, until its installation in a machine.

Alternatively, the packets of desiccant **62** alone may be used to dry the material in the chamber of canister **212** without use of the oven. It has been demonstrated that placing packets **62** containing Tri-Sorb-molecular sieve and calcium oxide (CaO) desiccant formulations in the cassette **184** and sealing the cassette **184** in a moisture-impermeable package will dry the material to a water content level of less than 700 ppm, and will dry the material to the preferred range of 100–400 ppm. This desiccant-only drying method has advantages over the oven-drying method in it requires no special equipment, and is faster, cheaper and safer than oven drying. Suitable Tri-Sorb-molecular sieve desiccant formulations include the following: zeolite, NaA; zeolite, KA; zeolite, CaA; zeolite, NaX; and magnesium aluminosilicate.

Modeling filament in the cassette **184** can later be re-dried by oven-drying or by replacing the desiccant packets if the cassette **184** becomes moisture contaminated while a usable amount of filament **188** remains. Moisture contamination may occur, for example, if the access door **250** is left open for a prolonged time period, if the cassette **184** is removed from the machine **180** without replacing the plug cap **248**, or it the cassette **184** is opened by a user.

The filament cassette receiver **190**, which engages filament cassette **184**, is shown in detail in FIGS. **18** and **19**. Each cassette receiver **190** comprises a lift **270** and a drive block **272**. As shown in FIG. **19**, drive block **272** houses an entry conduit **274**, an exit conduit **276**, a pair of rollers **278** and **279**, a motor **280** and the latch **196**. Roller **278** is a drive roller and roller **279** is an idler. The drive roller **278** is driven by the motor **280**. The motor **280** is preferably a DC motor with a current supply controlled by the controller **25**. Motor **280** extends laterally through the drive block **272** and couples to the drive roller **278** by a drive gear **282** attached to the shaft of the roller **278**.

The exit conduit **276** is connected to the tubing **202**. The filament strand provided from the guide block **214** passes through the entry conduit **274** to the rollers **278** and **279**. The entry conduit **274** mates with the exit orifice **238** of the guide block **214** when the cassette **184** is loaded and latched into modeling machine **180**. To provide an airtight path for the filament strand entering the drive block **272**, a seal **284** surrounds the entry conduit **274** near the entrance thereof, and compresses against the guide block **214** of the loaded cassette **184**. From the rollers **278** and **279**, the filament strand is provided to the exit conduit **276**, and from there to the tubing **202**. The tubing **202** makes an airtight seal with the exit conduit **276**. Likewise, tubing **202** and tubing **204** make an airtight seal with the ports **198** and **200** of the junction block **192**, providing an airtight filament path from the cassette **184** to the feed rollers **22**.

The drive roller **278** and idler roller **279** must maintain gripping, frictional contact on the filament strand to advance it along the filament path. To grip the filament strand, the rollers **278** and **279** may be have elastomeric surfaces, or idler roller **279** may be spring-biased towards the drive roller **278**, such as is described in U.S. Pat. No. 5,121,329. An advantage of a spring-biased configuration is that the roller surfaces can be hard and more wear resistant. Preferably, the surfaces of rollers **278** and **279** each also have a groove around the circumference thereof to align the filament strand on its course from the entry conduit **274** to the exit conduit

276. The rollers **278** and **279** are accessible to a user for maintenance through cover plate **308**.

The drive block **272** also contains a filament sensor **286**, which is positioned along the filament path between the roller pair **278** and **279** and the exit conduit **276**. Sensor **286** is electrically connected to the controller **25**, and provides a signal indicating whether or not filament is present at the position of the sensor **286**. In the exemplary embodiment shown, the sensor is a floating axis microswitch sensor. The drive block **274** further carries an electrical connector **290**. The electrical connector **290** has two pogo pins **142** that mate with the electrical contacts **106** of circuit board **102**, connecting the EEPROM **96** carried by circuit board **102** to the controller **25**. The EEPROM **96**, when contacted by the pogo pins **142**, signals the controller **25** that the cassette **182** is present. In-this manner, the machine **180** knows whether or not each cassette **184** has been loaded.

The drive block **272** is manually raised and lowered by the use of the latch **196**. The latch **196** has a handle **291** at one end thereof and a latch pin **292** at the other end thereof. The latch **196** extends through the drive block **272** such that the handle **291** is accessible to a user and the latch pin **292** projects into a vertical slot **296** of the drive block **272**. The slot **296** receives a latch plate **294** which extends vertically downward from the lift **270**. The latch plate **294** has a hole **298** for receiving the latch pin **292**. Pulling on the handle **291** of the latch **196** retracts the latch pin **292**, allowing insertion and removal of the pin **292** from the hole **298**. When the latch pin **292** is inserted into the hole **298**, the drive block **272** is maintained in a raised position, allowing loading and unloading of the cassette **184** from the loading bay **182**. When the latch pin **292** is removed from the hole **298**, the drive block **272** drops to its lowered position where it engages the cassette **184** in the loading bay **182**. A user manually raises or lowers the drive block **272** by grabbing the latch handle **291**, pulling forward, and either lifting or lowering the latch **196**.

A pair of guide rods **302** are provided on the drive block **272**, which couple the drive block **272** to the lift **270**, and align the latch plate **294** in the slot **296**. The guild rods **302** are mounted in two receptacles **288** on a top surface of the drive block **272**. The guide rods **302** extend vertically upward from the drive block **272** and through a pair of guide bearings **304** in the lift **270**. A pair of e-clips **306** clip to the guide rods **302** above the lift **270** to support the drive block **272** in its lowered position. Preferably, a pair of springs **300** surround the guide rods **302** in the receptacles **272**. In the raised position, the springs **300** compress beneath the lift **270**. When the latch **196** is pulled to remove the pin **292** from the hole **298**, springs **302** force the drive block **272** to its lowered position.

The drying system **194** creates an active moisture barrier along the filament path, keeping the filament **188** dry while in the machine **18**. In the exemplary embodiment, the drying system **194** is a dry-air purge system which provides dry air under pressure into air port **199** of the junction blocks **192**. The dry air flows through the tubing **204** and exits the tubing **204** near the liquifier **26**. If the feed rollers **22** are used to advance the filament strand into the liquifier **26**, the filament will exit the tubing **204** as it enters the feed rollers **22**. Alternatively, the feed rollers **22** can be eliminated by using the roller pair **278** and **279** in the drive block **272** to advance filament into the liquifier **26** at a controlled rate. The exit of tubing **204** serves as a vent through which any moisture that may have been trapped along the filament path is released. For instance, the air flow provided by drying system **194** will purge any humid air that enters the drive block **272** during the time that the entry conduit **274** of the drive block **272** is not sealed to a filament cassette **184**. Additionally, the positive pressure maintained in the tubing **204** prevents humid air from entering the open end of the tubing **204**. By maintaining a positive pressure in the tubing **202** and **204** and purging the filament path of any moisture, the drying system **194** allows use of the modeling machine **180** in a humid environment with moisture sensitive modeling material.

As mentioned above, the drying system **194** of the exemplary embodiment comprises a compressor **206**, a filter **208** and a regenerative dryer **210**. The compressor **206** intakes ambient air and provides the air under pressure to filter **208**. Filter **208** removes water particles from the air. A Norgren™ F72G general purpose filter is suitable for this application. From the filter **208**, the air under pressure flows to the dryer **210**, which is preferably a regenerative dryer, such as an MDH Series dryer available from Twin Tower Engineering, Inc. of Broomfield, Colo. Dry air under pressure flows from the dryer **210** into each junction block **192**. In alternative embodiments of the drying system, any source of dry air under pressure may be utilized successfully to purge moisture from the filament path, and other dry gases may be utilized as well. Importantly, the drying system should continuously feed dry air or other gas under pressure to the filament path, disallowing humid air from remaining in or entering the filament path, and should be vented at or near the end of the filament path. One alternative to drying system **194** is to provide a compressed nitrogen tank as the dry gas source. Another alternative is a regenerative drying system, such as a hot air desiccant dryer having an output of less than or equal to about −40° F. dew point.

To install one of the cassettes **184** into the modeling machine **180**, the machine **180** is first turned on. The user then removes the plug cap **248** from the filament cassettes **184**, and promptly inserts the cassette **184** into one of the loading bays **182**. The plug cap **248** can be parked on the grooves **256** of the guide block **214**, saving it for later use. The user latches the cassette **184** into place by pulling on latch **196**, as has been described. Once latched, the pogo pins **142** will contact the circuit board **102**, thereby connecting the EEPROM **96** to the controller **25**. Once the controller **25** senses that the cassette **184** is loaded, the controller **25** will turn on the motor **280**. The drive roller **278** will then begin turning.

The user next opens the door **250** of the guide block **214** to access the roller **240**, and manually turns roller **240** by exerting a downward force on the roller. The rotation of roller **240** will advance the strand of filament **188** out of the guide block **214** and into the entry conduit **274** of the drive block **272**. When the filament strand reaches the already rotating drive roller **278**, the roller pair **278** and **279** will grab the filament strand and take over advancement of the strand from the user. The user promptly shuts the door **250** to seal the filament path. The roller pair **278** and **279** then advance the filament strand at least as far as the position of the filament sensor **286**. If the filament cassette **184** is to be a standby cassette, the controller **25** will signal the motor **280** to stop turning, so that advancement of the filament strand ceases at the sensor **286**. Alternatively, if the cassette **184** is to be a primary cassette, the roller pair **278** and **279** feed the filament strand through the junction block **192** to the feed rollers **22** (or alternatively to the liquifier **26**). When the filament strand reaches the feed rollers **22**, the feed rollers **22** take over control of the filament strand advancement. If the current on the motor **280** is set low enough and the filament is rigid enough, the motor **280** may be allowed to remain on and continue supplying a constant push, but will stall out when the feed rollers **22** are not in motion. This arrangement avoids having to turn the motor **280** on and off in synchrony with the operation of the feed rollers **22**. In an alternate embodiment, the roller pair **278** and **279** may serve as the material advance mechanism in place of the feed rollers **22**. In such a case, the operation of motor **280** would be closely controlled by controller **25** to control advancement filament into the extrusion head **20**.

During modeling, the controller **25** can keep track of the amount of filament remaining in each cassette **184** by use of a count maintained by each EEPROM **96**. When one of the primary cassettes **184** becomes depleted of filament, the modeling machine **180** will automatically switch to the standby cassette **184** without operator intervention. To unload the filament, the controller **25** drives the motor **24** backwards for a short time sufficient to pull the strand of filament **188** out of the liquifier **26** and feed rollers **22**. The controller **25** then drives the motor **280** backwards to pull the filament strand out of the tubing **204**, the junction block **192**, the tubing **202**, and past the sensor **286**. The machine **180** knows that the junction block **192** is clear to receive filament from the standby cassette **184** when the sensor **286** of the primary cassette drive block **272** indicates that filament is no longer present. The machine **180** then loads filament from the standby cassette **184** to the extrusion head **20**. This auto-unload/reload process is particularly beneficial for modeling of large objects and when the modeling machine **180** is operated beyond business hours. The user can replace the depleted cassette **184** while the machine **180** continues to build a model. The depleted cassette **184** can then be refilled and reused.

In the case that the user desires to remove one of the cassettes **184** from the machine **180** before the cassette **184** is depleted of filament, the user may command the machine **180** to execute the unload process. If a useable amount of filament **188** remains on cassette **184** when it is removed from the modeling machine, the cassette **184** may be stored for later use without contamination. In such a case, the user should seal the exit orifice **238** with the plug cap **248**. If the cassette **184** has a useable amount of filament **188** remaining but the filament has been moisture contaminated, the cassette **184** may be re-dried as described above.

As disclosed in U.S. Pat. No. 5,866,058, in building a model from a thermally solidifiable material, it is preferable to build the model in a chamber heated to a temperature higher than the solidification temperature of the modeling material, and to cool the material gradually following deposition so as to relieve stresses from the material. A number of desirable thermoplastic modeling materials have high melting points, for example, polycarbonate, polyphenylsulfone, polycarbonate/ABS blend and Ultem™, and additionally are moisture sensitive. A deposition modeling apparatus which is particularly suitable for building models at a high temperature is disclosed in PCT Application No. US00/17363, which has been incorporated by reference herein. The modeling machine **180** which uses a moisture-sealed material delivery apparatus according to the second embodiment of the present invention may be an apparatus of the type that is a subject of PCT Application No. US00/17363, thereby providing a dry, high temperature modeling environment. Various high-temperature, moisture sensitive thermoplastics have been successfully utilized in such a machine, namely, polycarbonate, polyphenylsulfone, polycarbonate/ABS blend and Ultem™ having a viscosity at the modeling temperature of less than 1200 Pa/sec at a shear rate of $10E^{-1}$ sec^{-1} and having a water content ranging between 100–400 ppm. These materials are stronger than ABS thermoplastic and have suitable thermal properties, melt viscosity, shrink characteristics and adhesion for use in three-dimensional deposition modeling.

Although the present invention has been described with reference to exemplary embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. For example, the various features of embodiment 1 may be used and interchanged with the features of embodiment 2, and vice-versa. For example, the drying system of embodiment 2 may be used with the design of embodiment 1, and embodiment 1 may be used to provide primary and standby cassettes as disclosed with respect to embodiment 2. Additionally, it will be apparent to those in the art that the filament cassette and loading system of the present invention may be used to advantage in extrusion applications other than the building of three-dimensional models by a fused deposition process. Other changes may be made as well in keeping with the scope of the invention. As an example, the motor for driving a roller carried by a filament cassette may be carried by the cassette rather than mounted on the modeling machine. These and other changes will be apparent to one skilled in the art.

The invention claimed is:

1. A method for loading filament into an extrusion apparatus of the type having a liquifier that receives a feedstock of material in filament form and delivers the material in a flowable state, the method comprising the steps of:

inserting into the apparatus a cassette containing filament;

advancing a filament strand from the cassette into the machine.

2. The method of claim **1**, wherein the filament strand is advanced out of an exit orifice of the cassette into a conduit of the machine.

3. The method of claim **2**, wherein the filament strand is further advanced to feed rollers associated with the liquifier.

4. The method of claim **1**, wherein the filament strand is advanced to a roller pair mounted in the machine proximate the inserted cassette, and wherein the advancing step comprises operating a thumb wheel carried by the cassette.

5. The method of claim **1**, wherein the filament strand is advanced to a roller pair mounted in the machine proximate the inserted cassette.

6. The method of claim **5**, wherein the advancing step comprises the steps of:

rotating a thumb wheel carried by the cassette until the filament strand advances to the roller pair; and

driving the roller pair until the filament strand advances to feed rollers associated with the liquifier.

7. The method of claim **1**, wherein the advancing step comprises operating a thumb wheel carried by the cassette.

8. The method of claim **1**, wherein the advancing step comprises operating a follower wheel carried by the cassette using a drive wheel mounted on the apparatus.

9. The method of claim **8**, and further comprising the step of:

ceasing operation of the follower wheel when the filament strand reaches feed rollers associated with the liquifier.

10. The method of claim **1**, and further comprising the step of:

engaging the filament strand inside of the cassette prior to commencing the advancing step.

11. The method of claim **10**, wherein the engaging step comprises forcing a drive wheel mounted on the apparatus against a follower wheel carried by the cassette, and wherein the filament strand is advanced by rotating the drive wheel while it is forced against the follower wheel.

12. The method of claim **1**, wherein the filament strand is advanced in the machine along a path to the liquifier, and further comprising the step of:

creating a moisture barrier along the path.

13. The method of claim **1**, wherein the filament strand is advanced in the machine along a path towards the liquifier, and further comprising the step of:

ceasing advancement of the filament strand before it reaches the liquifier in response to a control signal indicating that the filament strand is detected at a sensing position.

14. The method of claim **1** and further comprising the step of:

continuing to advance the filament strand until it reaches feed rollers associated with the liquifier.

15. The method of claim **14** and further comprising the steps of:

identifying that the filament remaining in the cassette has reached a predetermined minimum length; and

automatically driving the filament strand in reverse to remove it from the feed rollers, in response to the minimum length identification.

16. A method for loading filament into a three-dimensional modeling apparatus of the type having a liquifier that receives a feedstock of modeling material in filament form and delivers the material in a flowable state so as to build-up a three-dimensional model, the method comprising the steps of:

inserting into the apparatus a cassette containing filament;

engaging a filament strand inside of the cassette; and

advancing the filament strand out of an exit orifice of the cassette.

17. The method of claim **16**, and further comprising the step of:

aligning the exit orifice of the cassette with an entrance of a conduit of the apparatus, prior to advancing the filament strand.

18. The method of claim **16**, wherein the advancing step comprises operating a thumb wheel carried by the cassette.

19. The method of claim **16**, wherein the advancing step comprises operating a follower wheel carried by the cassette using a drive wheel mounted on the apparatus.

20. The method of claim **16**, wherein the engaging step comprises forcing a drive wheel mounted on the apparatus against a follower wheel carried by the cassette, and wherein the filament strand is advanced by rotating the drive wheel while it is forced against the follower wheel.

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