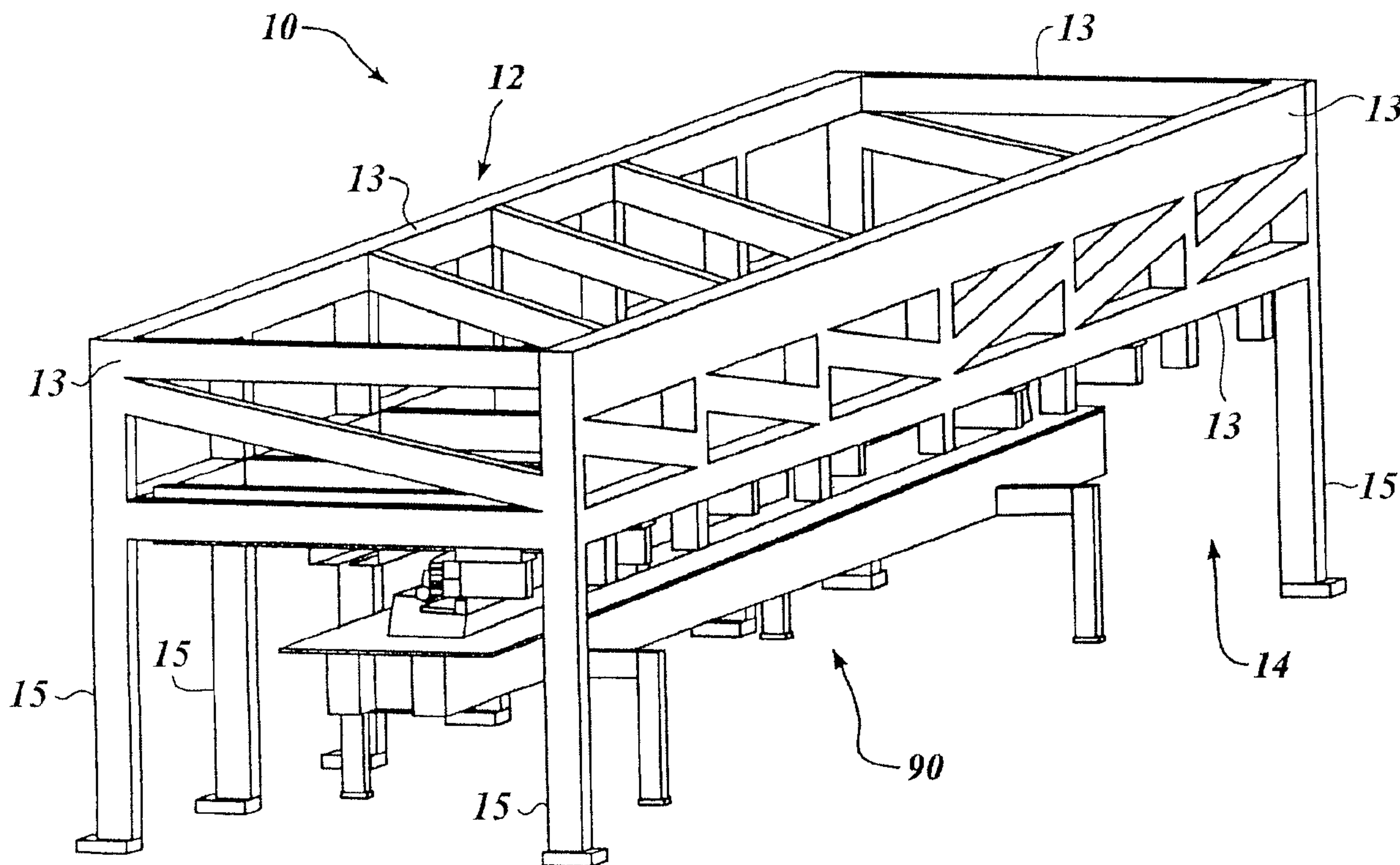




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(57) Abrégé/Abstract:

A machine and a method for forming composite materials are provided. The machine includes a frame and at least one forming beam attached to the frame, the at least one beam being arranged to align with a mandrel. The forming beam is pivotally segmented into at least two segments to conform to the shape of the mandrel, or alternately is bendable to conform to the shape of the mandrel. The mandrel is receivable within the frame in alignment with the forming beam. An apparatus is also provided to position a composite charge over the mandrel, and to position the mandrel within the frame. A further apparatus is provided to transport the mandrel, and to urge the mandrel toward the forming beam, forming a composite charge.

COMPOSITE SPAR DRAPE FORMING MACHINE**ABSTRACT OF THE DISCLOSURE**

A machine and a method for forming composite materials are provided. The
5 machine includes a frame and at least one forming beam attached to the frame, the at
least one beam being arranged to align with a mandrel. The forming beam is pivotally
segmented into at least two segments to conform to the shape of the mandrel, or
alternately is bendable to conform to the shape of the mandrel. The mandrel is receivable
within the frame in alignment with the forming beam. An apparatus is also provided to
10 position a composite charge over the mandrel, and to position the mandrel within the
frame. A further apparatus is provided to transport the mandrel, and to urge the mandrel
toward the forming beam, forming a composite charge.

COMPOSITE SPAR DRAPE FORMING MACHINE

FIELD OF THE INVENTION

This invention relates generally to the forming of composite fiber laminate parts, and, more specifically, to machine forming of composite materials.

5

BACKGROUND OF THE INVENTION

Composite materials, including carbon fiber epoxy impregnated laminates, are commonly used in applications requiring high strength and light weight. Forming composite material ply packages or charges has generally been done by hand, especially when the laminate plies of the composite materials exceed .25 inch in thickness. Forming large compound shaped composite material charges over a forming tool or mandrel can often take 2 to 3 days. The laid-up parts are then cured.

Machines have been utilized to form composite material charges over forming mandrel. However, these methods and systems have not been able to form composite charges with aggregate laminate ply thicknesses greater than .25 inches without buckling or out-of-plane fiber distortion. Further, machine forming systems have been configured for single part manufacturing and have not been reconfigurable. Alignment of the composite charges over the mandrels prior to forming has been difficult. Also, in multiple part manufacturing facilities, the storage, transport, and handling of mandrels and forming devices for different parts has been cumbersome, especially when multiple large parts, such as spars for aircraft, are being fabricated.

Therefore, a need exists for composite charge forming methods and systems which flexibly form a multitude of parts, including parts with complex surfaces or ply thicknesses greater than .25 inches, quickly align the composite charges relative to the forming mandrels, and provide efficient and space effective means for handling and operating the machine components required for forming large scale composite parts.

SUMMARY OF THE INVENTION

In accordance with one aspect of the invention, there is provided an apparatus for forming composite materials. The apparatus includes a frame, a mold attached to the frame, a mandrel receivable within the frame and the mold, a pulling device movably arranged to pull a composite charge onto the mandrel, and an indexing device that is arranged to stop the pulling device when the composite charge is at a predetermined location on the mandrel.

The indexing device may be movably attached to the frame.

The indexing device may include an indexing boom movably attached to the frame.

The mandrel may define a marker for positioning the indexing device.

The indexing device may include a projector arranged to project an indicator on the mandrel.

5 The indexing device may include a projector arranged to project an indicator on the composite charge.

10 In accordance with another aspect of the invention, there is provided an apparatus for positioning a composite charge for forming composite materials. The apparatus includes a pulling device movably attached to a frame to pull a composite charge onto a mandrel, an indexing boom movably attached to the frame, an indexing device attached to the indexing boom, the indexing device being arranged to position the indexing boom relative to the mandrel. The apparatus also includes provisions for stopping the pulling device at a location defined by the indexing boom to cause the composite charge to be located at a predetermined location on the mandrel.

15 The stopping provisions may include a proximity switch arranged to activate when in proximity to the pulling device.

The stopping provisions may include a hard stop arranged to stop the pulling device

The indexing device may include a projector arranged to project an indicator onto the mandrel.

20 The indexing device may include a projector arranged to project an indicator onto the composite charge.

The composite charge may have a mark arranged to show the indicator for positioning of the composite charge.

The apparatus may include a clamp removably attachable to the pulling device and removably attachable to the composite charge.

25 The clamp may define a second marker and the composite charge may define a third marker, such that when the second marker is aligned with the third marker, the clamp is positioned at a predetermined location on the composite charge.

The apparatus may further include provisions for guiding the composite charge when the composite charge is pulled into the predetermined location.

30 The apparatus may further include provisions for guiding the composite charge includes at least one lateral guide.

In accordance with another aspect of the invention, there is provided a method for positioning a composite charge for forming composite materials. The method involves attaching to a composite charge a pulling device for pulling the composite charge, positioning an indexing boom at a first predetermined location in with respect to a mandrel, 5 pulling the composite charge over the mandrel with the pulling device, and stopping the pulling device at a second predetermined position with respect to the indexing boom to cause the composite charge to be located at a predetermined location on the mandrel.

The method may involve verifying the pulling device at the second predetermined location using a marker defined on the composite charge.

10 The method may further involve attaching a composite charge including attaching a clamp at a third predetermined location on the composite charge.

The method may further involve attaching the clamp including defining a first marker on the composite charge and a second marker on the clamp.

Positioning the indexing boom may include projecting an indicator on the mandrel.

15 Positioning the indexing boom may include projecting an indicator on the composite charge.

The composite charge may include a plurality of laminate plies.

The method may involve lifting the mandrel to move the composite charge from a first elevation to a second elevation relative to a plurality of former beams, the second elevation 20 being closer to the plurality of former beams than the first elevation.

The method may involve inflating forming bladders of the plurality of former beams to force the composite charge to conform to the mandrel.

The method may involve heating the composite charge between the forming bladders and the mandrel with heater plates.

25 The method may involve inflating lowering the mandrel from the second elevation to a third elevation to move the heated composite charge away from the plurality of former beams, the second elevation being closer to the plurality of former beams than the third elevation.

30 The method may involve curing the composite charge on the mandrel at a vacuum bag location.

The method may involve deflating the forming bladders of the plurality of former beams prior to lowering the mandrel from the second elevation to a third elevation.

Stopping may involve using a proximity switch on the indexing boom to stop the pulling device at the second predetermined position in proximity to the indexing boom.

5 In accordance with another aspect of the invention, there is provided a method for forming composite materials. The method involves attaching a mold to a frame, receiving a mandrel within the frame and the mold, pulling a composite charge onto the mandrel with a pulling device movably arranged to pull the composite charge, stopping the pulling device when the composite charge is at a predetermined location on the mandrel, and urging the
10 composite charge against the mandrel to form the composite material.

BRIEF DESCRIPTION OF THE DRAWINGS

The preferred and alternative embodiments of the present invention are described in detail below with reference to the following drawings.

FIGURE 1 is an isometric drawing of an example forming machine of the present
15 invention;

FIGURE 2 is an end view of a forming machine of the present invention;

FIGURE 3A is a top view of an example mandrel tool of the present invention;

FIGURE 3B is a top view of an example forming machine of the present invention;

FIGURE 4A is a top view of an example alignment of the mandrel tool and frame
5 of the present invention;

FIGURE 4B is an enlarged view of an example taper slot and locating pin of the present invention;

FIGURE 5A is a side view of an example tool transport and lifting device of the present invention;

FIGURE 5B is a top view of an example tool transport and lifting device of the present invention;

FIGURE 6 is an isometric view of an example charge pulling device of the present invention;

FIGURE 7A is a left side view of an example charge alignment device of the present invention;

FIGURE 7B is a right side view of an example charge alignment device of the present invention; and

FIGURE 7C is a front view of an example charge alignment device of the present invention.

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DETAILED DESCRIPTION OF THE INVENTION

A machine and a method for forming composite materials are provided. By way of overview, the machine includes a frame and at least one forming beam attached to the frame, the at least one beam being arranged to align with a mandrel. The forming beam is pivotally segmented into at least two segments to conform to the shape of the mandrel
25 or alternately is bendable to conform to the shape of the mandrel. The mandrel is receivable within the frame in alignment with the forming beam.

An apparatus is also provided to position a composite charge over the mandrel and to position the mandrel within the frame. A further apparatus is provided to transport the mandrel and to urge the mandrel toward the forming beam.

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FIGURE 1 illustrates an example drape forming machine **10** of the present invention. In this embodiment, the machine **10** has a frame **12** with an open side **14**. A mandrel tool **90** removably fits within the open side **14** of the frame **12**. Composite parts such as beams and aircraft spars may be formed by the machine **10**. Any suitable configuration of the frame **12** that allows the mandrel tool **90** to removably fit within the

frame **12** may be utilized. By way of example, in lieu of an open side **14**, the mandrel tool **90** may suitably be fitted into the frame **12** through an end.

In the embodiment shown in FIGURE 1, the frame **12** is approximately **48** feet long, and the open side **14** allows access for a **43**-foot long mandrel tool **90**. The frame
5 has a plurality of cross members **13** and legs **15**. The frame **12** rests on a floor that has been leveled to plus or minus **.1** inch. It will be appreciated that any suitable uniform floor or support may be utilized for the machine **10** and the mandrel tool **90**.

FIGURE 2 is an end view of the example machine **10** illustrated in FIGURE 1 and shows the details of the forming machine **10** and the mandrel tool **90**. Movably
10 attached to the frame **12** are forming beams **20** utilized to form a composite material charge (not shown) over a mandrel **92** attached to the mandrel tool **90**. The mandrel **92** is shaped to form the part being molded by the machine **10** when the composite charge is molded over the mandrel **92**. In this embodiment, the forming beams **20** are held by forming beam supports **22** which ride on linear bearings **23** attached to the frame **12**. The
15 linear bearings **23** allow the forming beams **20** to be positioned against the mandrel **92** for forming the composite charge over the mandrel **92**. The forming beams are positioned utilizing acme screwjacks and servo motors (not shown). The forming beams **20** are suspended beneath the frame **12** of the machine **10** with the large linear bearings **23** allowing lateral movement of the beams. The forming beams **20** are
20 segmented at the linear bearing **23** locations so that the forming beams can be bent or reconfigured to match tapers, doglegs, or large contours of the mandrel. It will be appreciated that flexibly positioning the segments of the forming beams **20** allows the machine **10** to be configured to match the shape of many different mandrels, and thus to form a wide variety of composite parts, such as spars with tapers or joggles or curved
25 beams.

Actuators are located at the pivot points (not shown) between the segments of the forming beams **20**. Although in this embodiment the actuators utilize acme screwjacks and servo motors (not shown), it will be appreciated that any suitable method of moving the forming beams and holding them in position relative to the mandrel **92** may be
30 utilized. For example, the forming beams **20** are suitably actuated with pneumatic cylinders and set pins, hydraulic cylinders, electrical solenoids, linear motors, or scissor jacks. Forming bladders **28** are attached to the forming beams **20**. In one embodiment, the forming bladders **28** suitably are inflated fire hose. It will be appreciated that any suitable flexible or pivoting material may be utilized to press the composite charge
35 against the mandrel **92**.

Also attached to the forming beams **20** are charge supports **26** which support the portions of the composite charge (not shown) which overhang the mandrel **92** before they are pressed against the mandrel tool by the forming bladder **28**.

5 The combination of the forming beams **20**, mandrel **92**, and charge supports **26** implement the forming method of the above-identified related application, "Forming Method for Composites." It will also be appreciated that the machine of this invention and its component systems may be utilized in other forming methods.

10 The overhanging portions of the composite charge being urged against the mandrel **92** are held in an "S" shape by the forming bladder **28** and the charge support **26**. This method minimizes the area and the amount of sliding where the composite charge laminate plies slide past one another as they are bent over the mandrel **92**. The method also assists in maintaining the laminate plies in tension as the forming process occurs. Supporting the unformed portions of the composite charge and progressively bending the composite charge to maintain an "S" shape minimizes out-of-plane fiber distortion.

15 In the embodiment shown in FIGURE 2, pinch bladders or plates are not utilized to hold the composite charge against the charge supports **26** during forming. Instead, the stiffness of the composite charge serves to hold the unformed portions of the composite charge against the charge supports **26**, and thus substantially parallel with the upper surface of the mandrel **92**. Substantially parallel suitably includes an angle ranging from parallel with the upper surface of the mandrel **92** (0°) to a small angle up to 20° . Thus, in this embodiment, forming occurs without a pinch bladder or a pinch plate.

20 The mandrel tool **90** with the mandrel **92** is lifted up within the frame **12** between the forming beams **20**, thereby forming and molding the composite charge. In other embodiments, the forming beams **20** are lowered over a fixed mandrel **92**. It will be appreciated that any suitable method and orientation of moving the forming beams **20** toward the mandrel **92** will accomplish forming of the composite charge.

25 Attached to the charge supports **26** are heater plates **24** that heat the composite charge, and soften it during the forming process. The heater plates **24** are positioned on the charge supports **26**. The heater plates **24** can be extended or retracted toward the mandrel **92** by pneumatic cylinders **27** controlled by a drape former controller (not shown). Given by way of non-limiting example, the heater plates **24** are suitably **480** volts alternating current (VAC) resistance heaters sandwiched between aluminum plates with a non-metallic bumper on the edge that will touch the mandrel **92**. However, other heat sources may be used as suitable for a particular application. By way of example, alternate heat sources may include hot air heat guns or infrared heaters. It will be appreciated that in some forming applications heater plates suitably would not be

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required to form the composite charge, and fixed or movable charge supports **26**, without heater plates **24**, would then support the composite charge during forming.

Movably attached to the frame **12** is a charge pulling device **50** that pulls the composite charge (not shown) lengthwise along and over the mandrel **92** and charge supports **26**. The charge pulling device **50** thus loads the composite charge into the machine **10**. The charge pulling device **50** is described in detail in connection with FIGURE **6** below.

The machine **10** is equipped with a backing film remover **30**. The backing film remover **30** removes a backing film (not shown) from the lower side of the composite charge (not shown) as it is drawn into the machine **10**. Backing film (not shown) is utilized in some forming applications as a foundation for composite plies laid down by a computer numerically controlled (CNC) tape laying machine. The backing film remover includes a backing film roller **32** driven by a motor (not shown) which draws the backing film off the composite charge and onto the backing film roller **32**. The backing film is typically a plastic sheet and is broken from the composite charge as the composite charge is drawn across a breaking bar **34**. The breaking bar is attached to the frame **12**. In this embodiment, the motor driving the backing film roller **32**, through a slip clutch (not shown), operates at a slightly faster speed than the charge pulling device **50** pulling the composite charge across the breaking bar. This keeps the backing film under tension to remove the film from the composite charge without ripping. The backing film remover **30** is located at the end of the frame **12** where the composite charge is loaded into the machine **10**. Given by way of non-limiting example, backing film roller **32** is suitably a disposable or replaceable roller. This system peels and removes the backing film from the bottom of the composite charge as it is being loaded into the machine **10** by the charge pulling device **50**. A small radius corner of a square bar serves as the breaking bar **34** and breaks the bond between the backing film and the bottom of the composite charge. The film is then wound around the disposable backing film roller **32**.

During forming, the mandrel tool **90** holding the mandrel **92** is lifted vertically within the frame **12**. This pushes the mandrel **92** up between the forming beams **20** and molds the composite charge over the mandrel **92**. The mandrel tool **90** is lifted by the tool transport and lifting device illustrated in FIGURES **5A** and **5B**.

The location and configurations of the forming beams **20** and the heater plates **24** are controlled by a drape former controller (not shown) which configures the forming beams **20** and the heater plates **24** in alignment with the mandrel in proper positions for forming the composite charge. The forming beams **20** match the shape of the mandrel **92**. The heater plates **24** are positioned near or against the mandrel **92**. The

mandrel **92** may have curves, joggles, bends or offsets that are matched by the forming beams and heater plates, and are set in position by the drape former controller. It will be appreciated that any suitable machine controller may be utilized to configure the machine **10** for a given mandrel **92**. Alternately, the forming beams **20** and heater plates **24** may be positioned manually using manual measurements.

FIGURE 3A is a top view of an example mandrel tool **90**. The mandrel tool is supported on legs **91**. In this embodiment, the legs **91** are attached to the mandrel tool **90** and remain attached to the mandrel tool **90**, even during forming. Thus, separate storage for the legs is not required, and the mandrel tool **90** may be stored on its own legs **91**. Attached to the mandrel tool **90** is the mandrel **92** over which the composite materials or charges are formed. The mandrel **92** shown in FIGURE 3A is curved along its length. The mandrel **92** may have any shape or configuration that permits forming of the composite charges with acceptable levels of out-of-plane fiber distortion.

FIGURE 3B shows an exemplary embodiment of the machine **10** of the present invention configured to match the contours of the mandrel **92** (FIGURE 3A). The two forming beams **20** are each divided into four independently positionable segments **20A**. The segments **20A** are connected to each other by beam hinges **21**. There are also beam hinges **21** at the ends of each forming beam **20**. The beam hinges **21** are attached to actuators (not shown). The actuators are linked to the frame **12** of the machine **10**, allowing the segments **20A** to be positioned to match the shape of the mandrel **92**. The example embodiment shown in FIGURE 3B shows the forming beams **20** configured for the mandrel **92** of FIGURE 3A. In this example configuration, the forming beams **20** are more widely separated at one end than the other. The forming beams **20** also form convex and concave curves matching the mandrel **92**. It will be appreciated that the segments **20A** may be positioned and held in any suitable manner to match any mandrel **92**. For example, the segments **20A** need not be hinged but may be pivoted. By way of further example, the segments **20A** need be not be directly connected to each other, but may be suitably separately and independently positionable, allowing greater flexibility for forming composite charges over complex shaped mandrels. Similarly, the forming beams **20** may be attached to the frame **12** in any suitable manner permitting the adjustment of their position relative to the mandrel **92**. It will be appreciated that a frame **12** may not be necessary where suitable means are provided for positioning and moving the segmented forming beams **20** relative to the mandrel **92**. For example, hydraulic systems mounted to the mandrel tool **90** or to a fixed surface could position and move the forming beams **20** relative to the mandrel **92** or could hold the forming

beams **20** in a fixed position as the mandrel **92** is moved relative to the forming beams **20**.

It will also be appreciated that a unitary flexible or bendable forming beam **20** would form a shape conformable to the mandrel **92** of Figure **3A**, in the same manner as a segmented forming beam **20**. Similarly, one or more of the segments **20A** may be flexible or bendable, providing versatility in conforming to complex mandrel **92** surfaces. By way of example, a bendable or flexible forming beam **20** or segment **20A** may be flexed and held in place by actuators (not shown) in the same manner as a segmented forming beam **20**.

In the example shown in FIGURE **3B**, the forming beams **20** each have **4** segments. In other embodiments a different number of segments may be used, such as a forming machine with **5** segment forming beams **20**.

FIGURE **4A** shows an embodiment of the mandrel tool **90** positioning system and method of the present invention. The mandrel tool **90** is positioned against the frame **12**. The mandrel tool **90** carries the mandrel **92**. The mandrel tool **90** has two socket plates **94** which fit into slots **16** attached to the frame **12**. The socket plates **94** fit into the slots **16**. The mandrel tool **90** is then lowered, with locating holes **95** in the socket plates **94** sliding over chamfered locating pins **18** that position the mandrel tool **90** in a fixed location relative to the frame **12**. When the socket plates **94** are inserted into the slot **16** and the mandrel tool **90** is lowered over the locating pins **18**, the center line of the mandrel tool **90** is in alignment with the center line of the frame **12**. It will be appreciated that the slots **16** and socket plates **94** may be tapered or rounded to suitably mate with each other, positioning the mandrel tool **90**. It will also be appreciated the locating pin **18** need not be cylindrical or chamfered, but may be any suitable shape to match with the corresponding locating hole **95**. By way of example the locating pin **18** may be tab shaped or pyramidal shaped. Alternately, by way of example, the slot **16** and the locating pin **18** may be attached to the mandrel tool **90**, and the socket plates **94** and locating holes **95** maybe attached to the frame **12**, positioning the mandrel tool **90** in a fixed location relative to the frame **12** in the same manner as the embodiment shown in FIGURE **4A**.

FIGURE **4B** is an enlarged top view of the mandrel tool **90** with its attached socket plate **94**. The socket plate is rounded and slides into the corresponding slot **16** attached to the frame **12**. The mandrel tool **90** with its attached socket plate **94** is then lowered over the chamfered pin **18**, thereby positioning the mandrel tool **90**. Positioning the mandrel tool **90** is accomplished by lifting and moving the mandrel tool **90** with a tool transport and lifting device, such as that shown in FIGURES **5A** and **5B**. The mandrel

tool **90** is transported on air bearings to the machine **10** and positioned against the frame **12**. The mandrel tool **90** is approximately located within the frame **12**. Operators maneuver the mandrel tool **90** so that the rounded ends of the socket plates **94** line up with the tapered slots **16** attached to the frame **12** above the locating pins **18**. In this example embodiment, tapered shape of the slot **16** helps guide the socket plates **94** into position. Air bearings on the tool transport and lifting device are deflated and the tool transport lifting device settles to the floor with the location of the mandrel tool **90** controlled by the locating holes **95** and the locating pins **18**. The mandrel tool **90** is thus aligned with the center line of the frame **12**. With the air bearings deflated, the horizontal location of the mandrel tool **90** is fixed by friction on the floor. The mandrel tool **90**, attached with the mandrel **92**, may then be lifted up into the forming beams of the drape forming machine (not shown) in proper position for molding the composite charge. The position of the mandrel during forming is held fixed by the weight of the tool transport lifting device (not shown) underneath the mandrel tool **90** against the underlying floor. The mandrel tool **90** is thus located within plus or minus .1 inch relative to the forming machine frame **12**. This system permits the location of a plurality of different mandrel tools **90** in the frame assembly **12**. The socket plates **94** thus accurately locate the mandrel tool **90** within the frame **12**. However, it will be appreciated that the precise position of the tool transport and lifting device (not shown) underneath the mandrel tool **90** is not critical to the process of positioning the mandrel tool **90** and lifting it up within the frame **12**.

FIGURE 5A is a side view of a tool transport and lifting device (TTLD) **100** which carries and lifts the mandrel tool **90** (shown in phantom). The TTLD **100** has a frame **105**. Connected to the frame **105** are air bearings **110**. Air bearings are commercially available items that are a low friction method to move the TTLD **100** and the mandrel tool **90** across a floor. Air bearings allow operators to roughly position the TTLD **100** and the mandrel tool **90** within the drape forming machine (not shown), without the need for additional power or assistance from the forming machine or any other equipment. It will be appreciated that any suitable method of moving the TTLD **100** may be utilized. For example, any acceptable form of high-load bearings or rollers could be used to move the TTLD **100**.

Attached to the frame **105** are screwjacks **120** which lift the mandrel tool **90**. In this embodiment, the TTLD **100** has four sets of air bearings **110** and four sets of screwjacks and motors **120**. It will be appreciated that any suitable combination or number of air bearings **110** and screwjacks and motors **120** that lift the mandrel tool **90**

for transport and uniform lifting into the drape forming machine (not shown) may be used.

Given by way of non-limiting example, the screwjacks and motors each suitably include a pair of acme screws driven by a drive motor. It will be appreciated that any
5 suitable lifting devices, such as hydraulic lifts or the like, may be utilized.

FIGURE 5B is a top view of the TTLD 100. The frame 105 is configured to removably fit under the mandrel tool 90. The frame 105 is configured to fit around the legs 91 of the mandrel tool 90. This allows the TTLD 100 to be removably moved and slipped under mandrel tool 90, thereby allowing the mandrel tool 90 to be stored while
10 the TTLD 100 is utilized with other mandrel tools. Attached to the frame 105 are four sets of screwjacks and motors 120 which lift the mandrel tool 90. In this embodiment, the TTLD 100 lifts the mandrel tool 90 without removing the legs 91 from the tool. As a result, separate jacks for each mandrel tool 90 and storage space for the legs is not required.

FIGURE 6 is an isometric view of the charge pulling device 50 which pulls a composite charge (not shown) into the drape forming machine (not shown). The charge pulling device 50 is suspended from linear bearings 36 attached to the frame 12 (not shown). The charge pulling device 50 has a pulling arm 58 which holds a charge clamp 54. The charge clamp 54 is removably attached to the charge pulling arm 58. In
15 this embodiment, the charge pulling device has a locating feature (not shown) which is aligned with a target on the flat composite charge (not shown). A toggle-type clamp is then activated to accurately attach the charge clamp 54 to the composite charge. Accurately locating the charge clamp 54 on the composite charge permits the composite charge to be accurately positioned over the mandrel (not shown).

In one presently preferred embodiment, the composite charge is assembled by a
25 CNC tape laying machine that lays plies in precise locations in the charge at alternating angles. After the charge clamp 54 is attached to the composite charge (not shown), the composite charge is brought to the drape forming machine and the charge clamp 54 is attached to the pulling arm 58.

The charge pulling device 50 rides on the linear bearings 36 attached to the drape former frame (not shown) with suitable charge pulling bearings or supports 56. The linear bearings 36 are located under the center line of the frame (not shown) of the drape forming machine.

The charge pulling device 50 is moved along the linear bearings 36 by a suitable
35 drive system 52. The charge pulling device 50 loads the composite charge by towing it down the length of the drape forming machine. The drive system 52 engages suitable

drive tracks **38** that are attached to the drape former frame (not shown). When the composite charge (not shown) is pulled lengthwise by the charge pulling device **50** into the drape forming machine, the composite charge slides on top of the top surface of the mandrel (not shown) and the heater plates (not shown).

5 FIGURE 7A shows a side view of the charge pulling device **50** and the composite charge alignment device **40**. The charge pulling device **50** has a charge pulling arm **58** attached to a charge clamp **54**. The charge pulling device **50** pulls the charge until it is stopped by the alignment device **40**. The alignment device **40** has a projector boom **44** movably attached along the centerline of the drape forming machine frame (not shown).
10 The projector boom **44** holds a projector **41**, such as without limitation a laser projector, used to position the projector boom relative to the mandrel **92**. The mandrel **92** has a tooling hole **96**. The projector **41** is precisely aligned with the tooling hole **96** by moving the projector beam **44** along the centerline of the frame of the drape forming machine. This occurs when cross hairs or indicator projected by the projector **41** line up with the
15 tooling hole **96**. This fixes the projector boom **44** in a fixed position relative to the mandrel **92**. The projector boom **44** has a proximity switch **42** which senses the presence of the charge pulling device clamp **54** as the charge pulling device **50** pulls the composite charge lengthwise into the drape forming machine. When the proximity switch **42** senses the charge clamp **54**, the drape former controller (not shown) stops the charge pulling
20 device **50** within a fixed distance. This positions the composite charge to within +/- $1/64$ inch lengthwise on the mandrel **92**. The composite charge is pulled into the forming machine centered side to side on the mandrel **92**, in this embodiment to within +/- $1/8$ inch. However, other tolerances may be used as desired for a particular application. It will also be appreciated that any suitable stopping method, including, by way of example,
25 a hard stop that physically stops the charge pulling device **50**, may be used to stop the charge pulling device **50**.

Precise location of the composite charge with respect to the mandrel is often required for proper composite part fabrication. This is common for specialized parts such as aircraft spars. Precise location of the composite charge lengthwise within the drape
30 forming machine permits ply drops, or the points where ply thicknesses change, to be positioned accurately with respect to the forming mandrel **92**. For aircraft spars, typically, ply drops are positioned lengthwise along the spar to within +/- $.1$ inch. This permits the composite parts to be precisely formed with the shapes, thicknesses and strengths for which they are designed. However, other tolerances may be used as desired
35 for a particular application.

The method of aligning the composite charge in this embodiment thus includes projecting a cross-hair pattern or indicator on to the top surface of the mandrel **92**. An operator aligns the projector **41** laser cross-hairs to the marker or tooling hole **96** on the mandrel **92**, and then locks the projector boom **44** into place. The boom **44**, with its proximity switch **42**, is then properly located with respect to the mandrel **92**. The proximity switch **42** is then used by the drape former controller (not shown) to stop the flat composite charge in the correct location with respect to the mandrel tooling hole **96**. The projector **41** is also used by the operator to verify that the flat composite charge is properly located after the charge is pulled into the drape forming machine. The operator visually verifies that the laser cross-hairs projected by the projector **41** fall within the borders of a mark or a target on the flat composite charge, thereby verifying its proper alignment. In one embodiment, the mark on the composite charge is an inkjet target placed by a CNC laminate tape laying machine at the end of the composite charge lay up process. This provides verification that the composite charge is properly located laterally and longitudinally on the mandrel **92** surface.

It will be appreciated that the charge pulling device **50** and alignment device **40** properly position the composite charge lengthwise across the mandrel **92** and ensure the proper side-to-side position of the composite charge at the end being pulled. At the opposite end of the drape forming machine (not shown), suitable lateral sliding guides linked to the heater plates center the composite charge side-to-side as the composite charge is being pulled into the drape forming machine by the charge pulling device **50**. It will be appreciated that any suitable method may be used to ensure that the end of the composite charge away from the charge pulling device **50** is centered side-to-side over the mandrel **92**.

FIGURE 7B is a right side view of the charge pulling device **50** and the alignment device **40**. The charge pulling device **50** rides on linear bearings **36** attached to the drape former frame (not shown) held on suitable charge pulling supports **56**. The charge pulling device is driven by a charge pulling device drive system (not shown) utilizing pulling drive tracks **38** attached to the drape former frame (not shown). The charge pulling device **50** has a pulling arm **58**, with a detachable charge clamp **54**. The charge pulling device **50** is shown here in alignment with the alignment device **40**. The alignment device **40** has a projector boom **44** which holds a projector **41**. The projector **41** allows indexing of the projector boom **44** relative to the tooling hole **96** in the mandrel **92**. The mandrel **92** is attached to the mandrel tool **90** which has been previously positioned by the tool transport and lifting device within the frame of the drape forming device (not shown).

It will be appreciated that alternate indexing systems other than a laser light projector may be utilized by the alignment device **40**. Any suitable indexing or measuring system that allows the position of the composite charge to be precisely located may be utilized by the present invention.

5 FIGURE 7C is a front view of the charge pulling device **50** and the alignment device **40** positioned over the mandrel **92**. The charge pulling device **50**, pulling supports **56**, and the supporting linear bearings **36** attached to the drape former frame (not shown) are shown in cross-section. The charge pulling device **50** rides on the linear bearings **36** thereby pulling the composite charge utilizing the pulling arm **58** attached to
10 the charge clamp **54**.

The alignment device **40** includes the projector **41** and the proximity switch **42** attached to the projector boom **44** (not shown). The projector **41** is aligned with the tooling hole **96** in the mandrel **92** thereby properly positioning the alignment device **40**. The alignment device **40** through the drape former controller (not shown) controls and
15 stops the charge pulling device **50** at the proper location over the mandrel **92**. The mandrel **92** is attached to the mandrel tool **90**. After the charge is positioned, the entire mandrel tool **90** is lifted up within the drape forming machine molding and forming the composite charge.

Forming a composite charge using the present invention is thus a multi-step
20 process. In one present embodiment, the mandrel tool **90** is brought to the drape forming machine **10**. The operator scans a barcode on the mandrel tool **90** and a related work order, so that the drape forming machine can be configured properly. The drape former controller (not shown) compares part number information from the barcode scans, and then configures the forming beams **20** to match the forming mandrel **92**.

25 After the forming beams **20** are configured properly, the tool transport lifting device **100** has its air bearings **110** inflated and the tool transport and lifting device **100** is removed from its storage position under the drape forming machine **10**. The tool transport and lifting device **100** is moved under the mandrel tool **90**. The tool transport lifting device **100** is roughly positioned under the mandrel tool **90**, and the air
30 bearings **110** are deflated. The acme screwjacks and motors **120** on the tool transport and lifting device **100** are extended to lift the mandrel tool **90** to a transportation elevation. Air bearings **110** on the tool transport and lifting device **100** are then reinflated and the operators move the mandrel tool to under the drape forming machine **10**.

The mandrel tool **90** on the tool transport and lifting device **100** is then
35 approximately located in the drape former frame **12**. The operators maneuver the mandrel tool **90** so that the rounded ends of the socket plates **94** line up with the slots **16**

over the chamfered locating pins **18**. The tool transport and lifting device air bearings **110** are deflated and the pins **18** keep the mandrel tool **90** from moving as the tool transport and lifting device **100** and the mandrel tool **90** settle to the floor. This locates the mandrel tool **90** to within approximately .1 inch within the drape forming machine **10**. The drape former controller then activates the tool transport and lifting device **100** to raise the mandrel tool **92** up to a charge loading position. The charge loading position is suitably defined as the top of the mandrel **92** just above the drape former heater plates **24**. The heater plates **24** on their charge supports **26** are then moved so that their bumpers rest against the side of the mandrel **92**.

10 The operators then prepare the drape forming machine **10** so that the composite charge can be loaded. The operators first set and lock the alignment device **40** so that the cross-hairs projected by the projector **41** is located on a tooling hole **96** in the mandrel **92**. The operator next has the drape forming machine controller move the charge pulling device **50** to the loading end of the drape forming machine **10**. The removable charge clamp **54** is removed from the charge pulling device **50** and accurately attached to the flat composite charge. The charge clamp **54** is aligned to the composite charge by locating a feature on the clamp **54** with a target on the flat composite charge. The operator attaches the removable charge clamp **54** to the charge pulling device arm **58**. The operator then connects the protective backing film from the bottom of the flat composite charge to the backing film roller **32** of the backing film remover **30**. Preparation for charge loading is then complete.

20 The operator then directs the drape forming machine controller to load the charge on the drape forming machine by activating the charge pulling device **50** and the backing film remover **30**. The charge is towed lengthwise into the drape forming machine **10** at a constant speed by the charge pulling device **50**. As the charge is pulled into the drape forming machine **10**, the backing film remover **30** operates at a higher speed than the charge pulling device **50** and with a slip clutch maintains tension on the backing film thereby removing the backing film from the composite charge. Just before the stopping point for the charge pulling device **50**, a target on the charge pulling device activates a proximity switch **42** on the alignment device **40**. The drape forming machine controller then decelerates the composite charge and accurately stops the composite charge a precise distance later. The composite charge is then located directly in reference to the mandrel **92**. The operator then visually verifies the location of the composite charge by checking to see if cross-hairs projected by the projector **41** fall on a target on the charge. Guides on the loading end of the forming machine **10** keep the composite charge centered side-to-side over the mandrel **92**. The operator then removes the charge clamp **54** from

the composite charge and moves the charge pulling device **50** out of the way of the forming beams **20**. The alignment device **40** is similarly moved out of the way. The operator then verifies that the backing film remover **30** has removed all of the film from the bottom of the charge.

5 The operator then activates the drape former controller to implement the composite forming method described in the related application, "Forming Method for Composites." This process includes heating the charge with the heater plates **24** and then using the tool transport and lifting device **100** to lift the mandrel **92** up into the drape forming machine **10** past the forming beams **20**. Forming bladders **28** force the charge to conform to the mandrel **92** contours as the unformed portions of the composite charge are held substantially parallel to the upper surface of the mandrel **92** by the heater plates **24** and charge supports **26**. Substantially parallel suitably may be an angle ranging from parallel with the upper surface of the mandrel **92** (i.e. 0°) to a small angle of up to 20° . This process molds the composite part in a manner that minimizes out-of-plane fiber distortion and buckles even when complex shapes with joggles, off-sets, and contours are formed.

15 The heater plates **24** are turned off and the molded composite charge is allowed to cool. The forming bladders **28** then are deflated and the heater plates **24** and charge supports **26** are retracted. The forming beams **20** are retracted. The tool transport and lifting device **100** then lowers the mandrel **92** and mandrel tool **90** along with the molded part back to an elevation where they may be transported. The operators then activate the air bearings **110** on the tool transport and lifting device **100** and move the mandrel with the molded composite charge to a vacuum bagging location where the molded charge is cured. The tool transport and lifting device **100** then lowers the mandrel tool **90** to the floor, and the tool transport and lifting device **100** can be returned to the drape forming machine **10** for further use.

25 While the preferred embodiment of the invention has been illustrated and described, as noted above, many changes can be made without departing from the spirit and scope of the invention. Accordingly, the scope of the invention is not limited by the disclosure of the preferred embodiment. Instead, the invention should be determined entirely by reference to the claims that follow.

**THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE
PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:**

1. An apparatus for forming composite materials, the apparatus comprising:
5 a frame;
a mold attached to the frame;
a mandrel receivable within the frame and the mold;
a pulling device movably arranged to pull a composite charge onto the mandrel;
and
10 an indexing device that is arranged to stop the pulling device when the
composite charge is at a predetermined location on the mandrel.
2. The apparatus of Claim 1, wherein the indexing device is movably attached to
the frame.
3. The apparatus of Claim 1, wherein the indexing device includes an indexing
15 boom movably attached to the frame.
4. The apparatus of Claim 1, wherein the mandrel defines a marker for positioning
the indexing device.
5. The apparatus of Claim 1, wherein the indexing device includes a projector
arranged to project an indicator on the mandrel.
- 20 6. The apparatus of Claim 1, wherein the indexing device includes a projector
arranged to project an indicator on the composite charge.
7. An apparatus for positioning a composite charge for forming composite
materials, the apparatus comprising:
25 a pulling device movably attached to a frame to pull a composite charge onto a
mandrel;
an indexing boom movably attached to the frame;
an indexing device attached to the indexing boom, the indexing device being
arranged to position the indexing boom relative to the mandrel; and

means for stopping the pulling device at a location defined by the indexing boom to cause the composite charge to be located at a pre-determined location on the mandrel.

8. The apparatus of Claim 7, wherein the stopping means includes a proximity switch arranged to activate when in proximity to the pulling device.

9. The apparatus of Claim 7, wherein the stopping means includes a hard stop arranged to stop the pulling device.

10. The apparatus of Claim 7, wherein the indexing device includes a projector arranged to project an indicator onto the mandrel.

11. The apparatus of Claim 7, wherein the indexing device includes a projector arranged to project an indicator onto the composite charge.

12. The apparatus of Claim 11, wherein the composite charge has a mark arranged to show the indicator for positioning of the composite charge.

13. The apparatus of Claim 7, further comprising a clamp removably attachable to the pulling device and removably attachable to the composite charge.

14. The apparatus of Claim 13, wherein the clamp defines a second marker and the composite charge defines a third marker, such that when the second marker is aligned with the third marker the clamp is positioned at a predetermined location on the composite charge.

15. The apparatus of Claim 7, further comprising means for guiding the composite charge when the composite charge is pulled into the predetermined location.

16. The apparatus of Claim 15, wherein the means for guiding the composite charge includes at least one lateral guide.

17. A method for positioning a composite charge for forming composite materials, the method comprising:

attaching to a composite charge a pulling device for pulling the composite charge;

positioning an indexing boom at a first predetermined location with respect to a mandrel;

pulling the composite charge over the mandrel with the pulling device; and stopping the pulling device at a second predetermined position with respect to the indexing boom to cause the composite charge to be located at a predetermined location on the mandrel.

5 **18.** The method of Claim **17**, further comprising verifying the pulling device is at the second predetermined location using a marker defined on the composite charge.

19. The method of Claim **17**, wherein attaching to a composite charge includes attaching a clamp at a third predetermined location on the composite charge.

10 **20.** The method of Claim **19**, wherein attaching the clamp includes defining a first marker on the composite charge and a second marker on the clamp.

21. The method of Claim **17**, wherein positioning the indexing boom includes projecting an indicator on the mandrel.

22. The method of Claim **17**, wherein positioning the indexing boom includes projecting an indicator on the composite charge.

15 **23.** The method of Claim **17**, wherein the composite charge comprises a plurality of laminate plies.

20 **24.** The method of Claim **17**, further comprising lifting the mandrel to move the composite charge from a first elevation to a second elevation relative to a plurality of former beams, the second elevation being closer to the plurality of former beams than the first elevation.

25. The method of Claim **24**, further comprising inflating forming bladders of the plurality of former beams to force the composite charge to conform to the mandrel.

26. The method of Claim **25**, further comprising heating the composite charge between the forming bladders and the mandrel with heater plates.

25 **27.** The method of Claim **26**, further comprising lowering the mandrel from the second elevation to a third elevation to move the heated composite charge away from the plurality of former beams, the second elevation being closer to the plurality of former beams than the third elevation.

28. The method of Claim 27, further comprising curing the composite charge on the mandrel at a vacuum bag location.

5 29. The method of Claim 27, further comprising deflating the forming bladders of the plurality of former beams prior to lowering the mandrel from the second elevation to a third elevation.

10 30. The method of Claim 17, wherein the stopping includes using a proximity switch on the indexing boom to stop the pulling device at the second predetermined position in proximity to the indexing boom.

15 31. A method for forming composite materials, the method comprising:
attaching a mold to a frame;
receiving a mandrel within the frame and the mold;
pulling a composite charge onto the mandrel with a pulling device movably
arranged to pull the composite charge;
stopping the pulling device when the composite charge is at a predetermined
location on the mandrel; and
20 urging the composite charge against the mandrel to form the composite material.

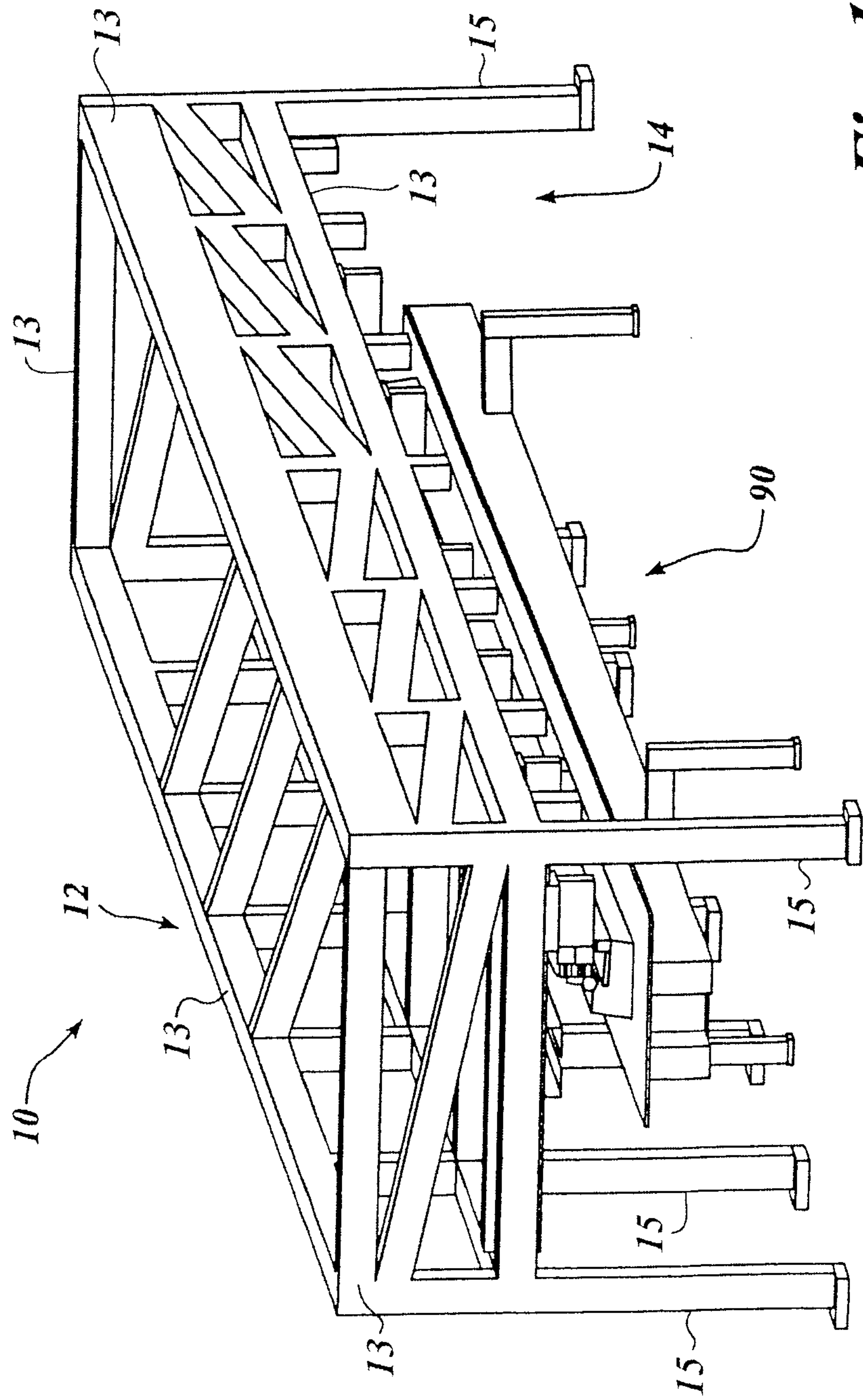


Fig. 1.

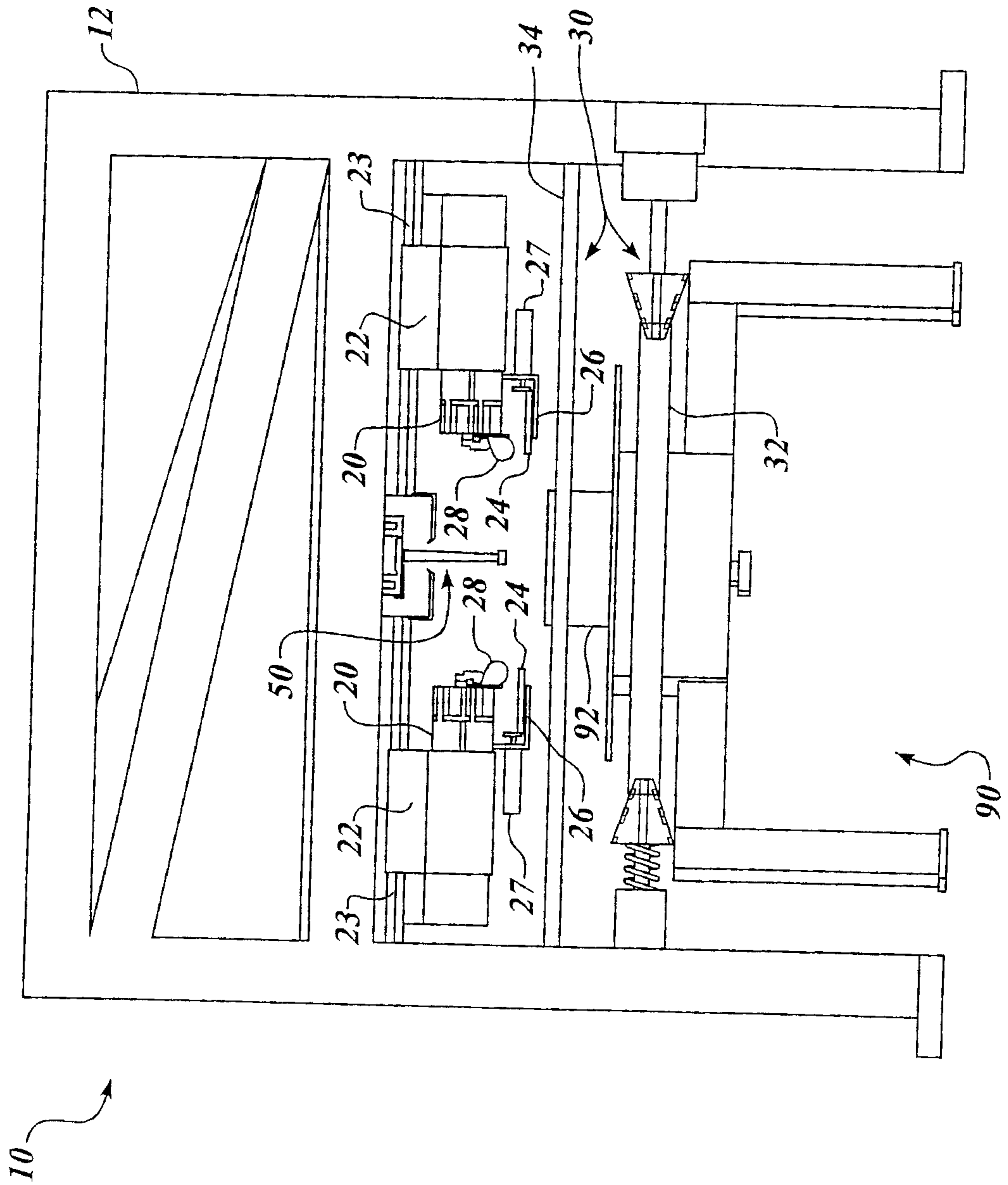
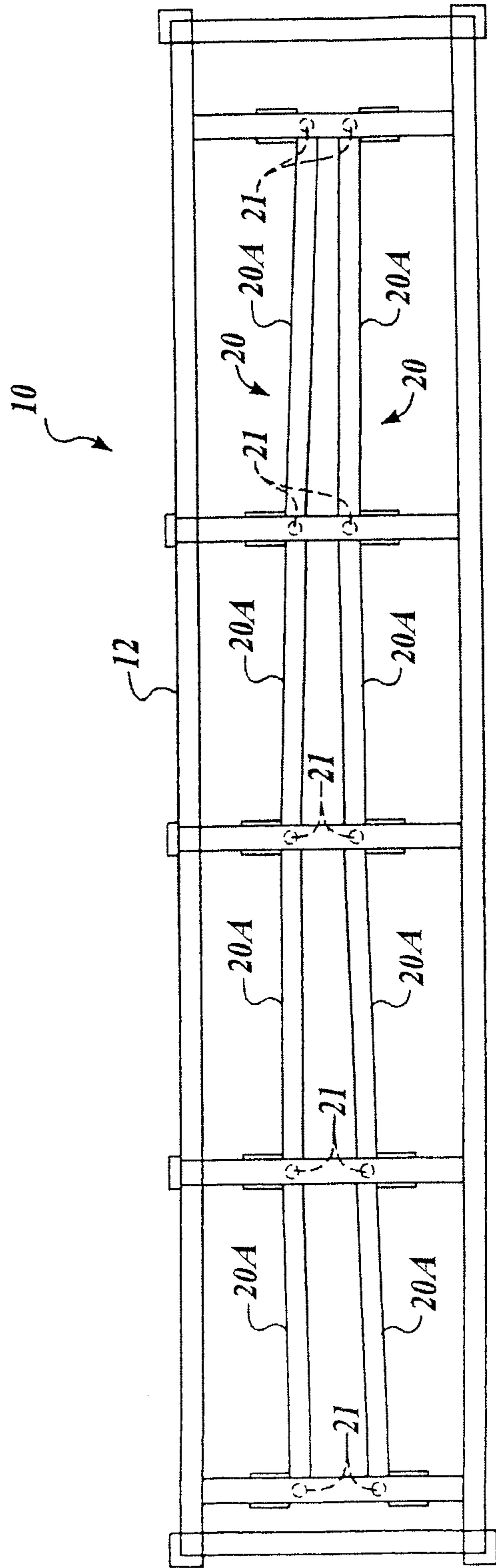
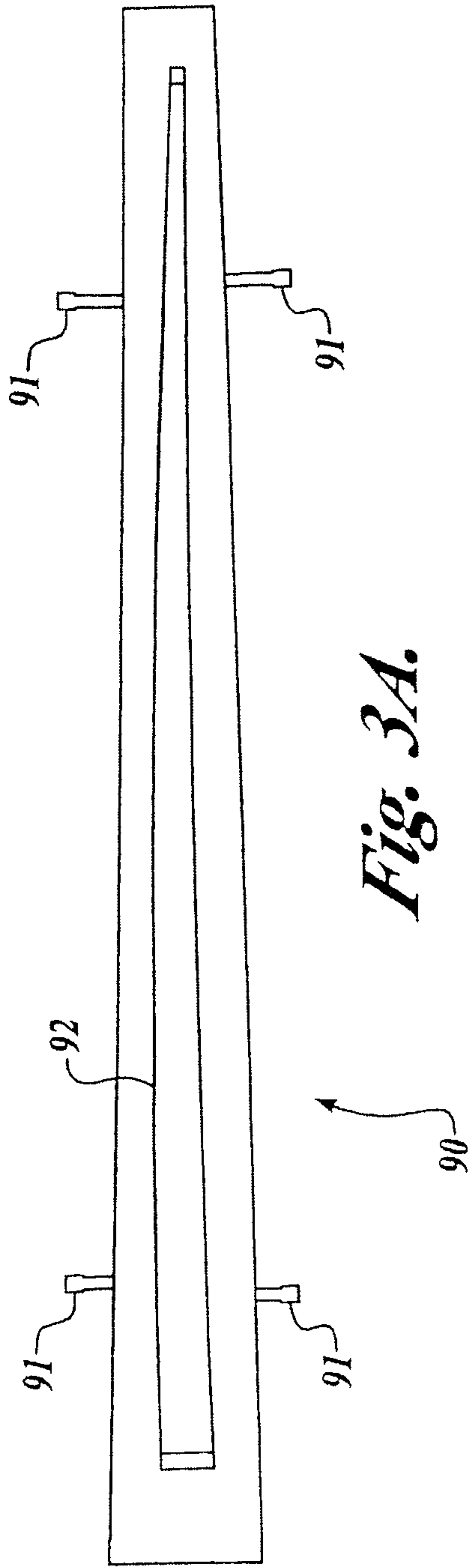
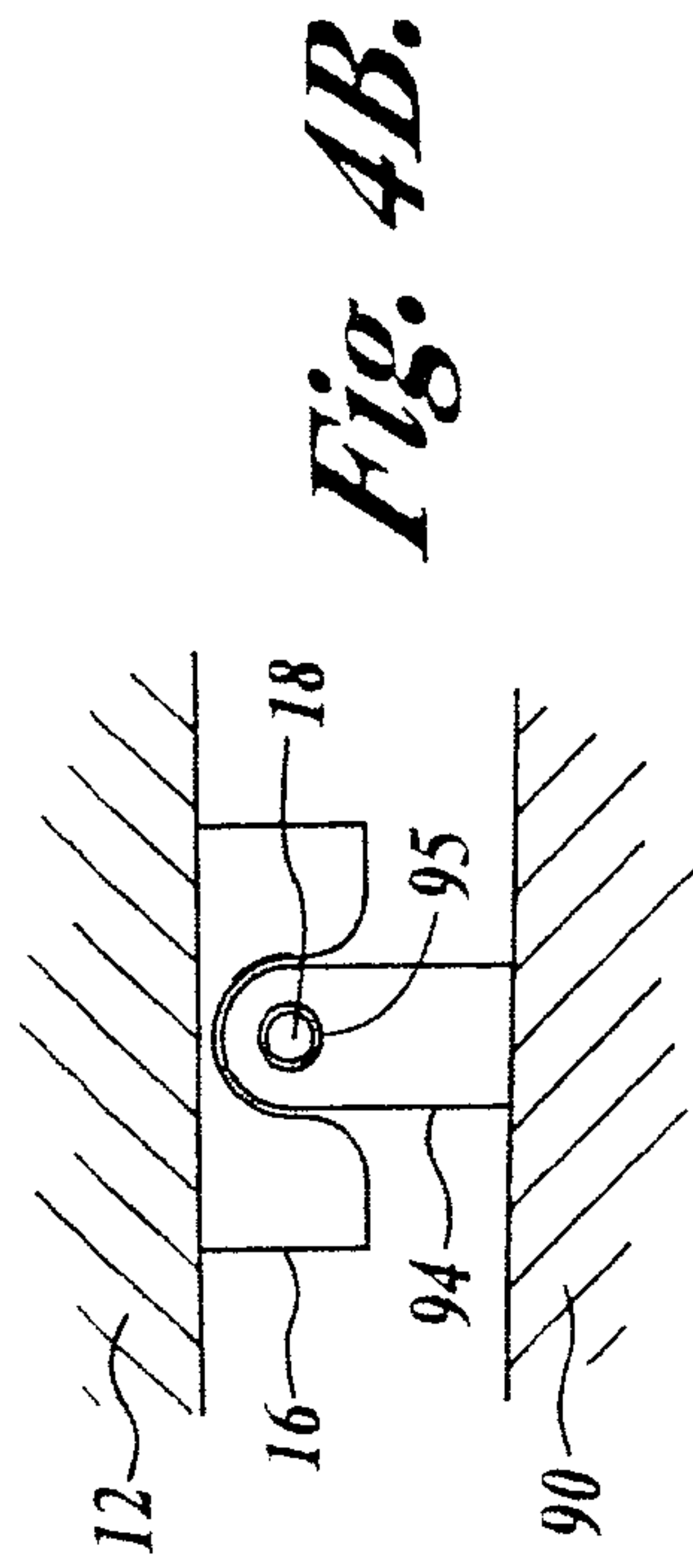
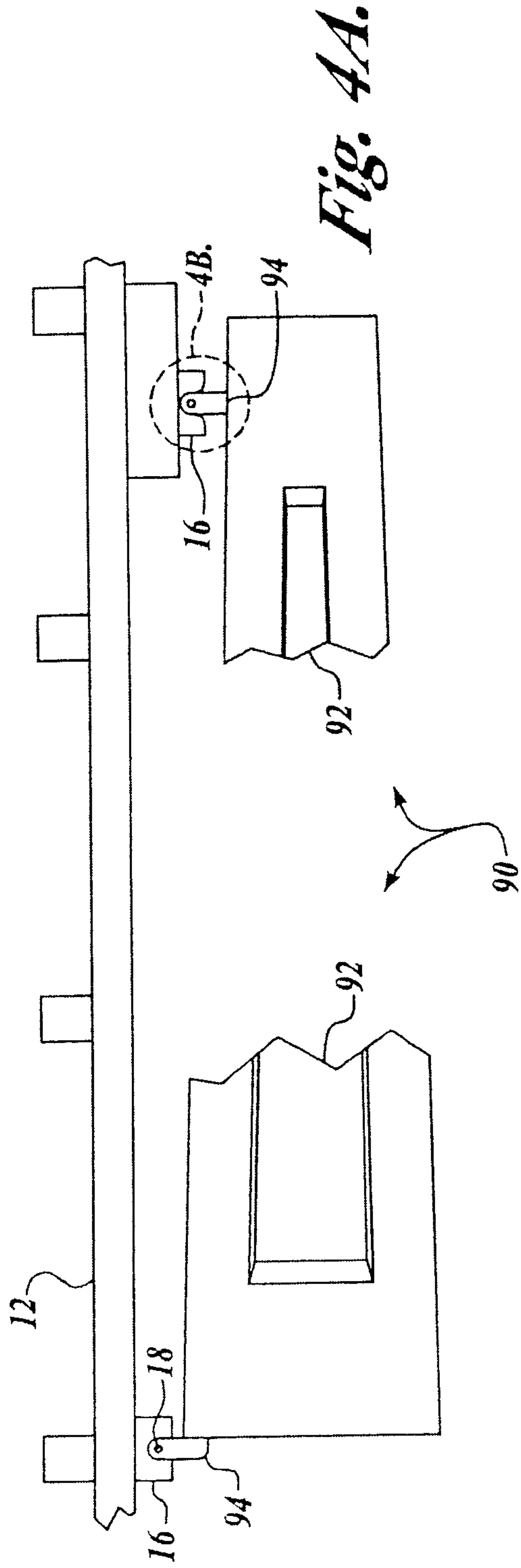
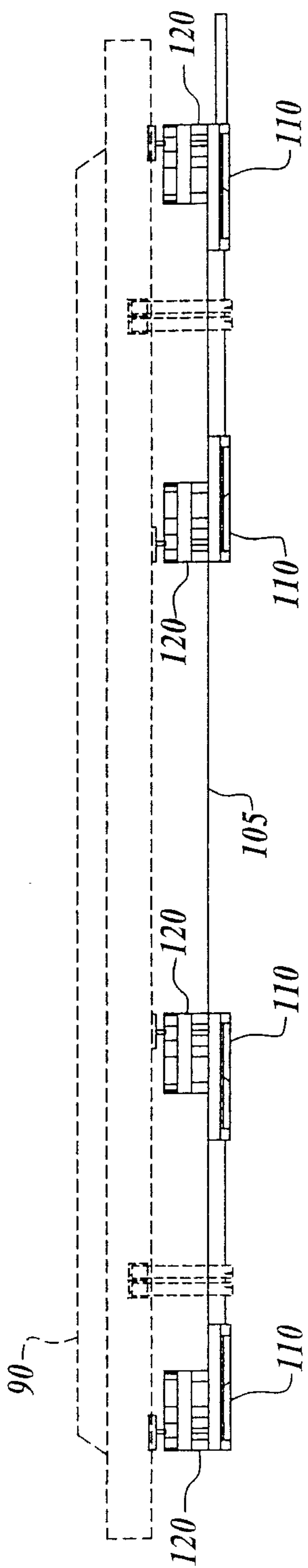


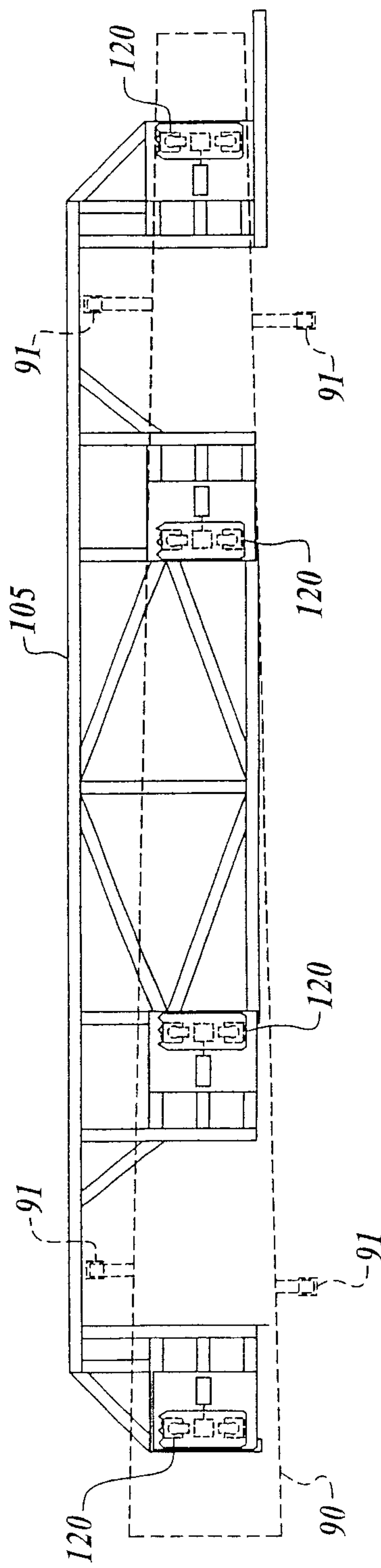
Fig. 2.







100 *Fig. 5A.*



100 *Fig. 5B.*

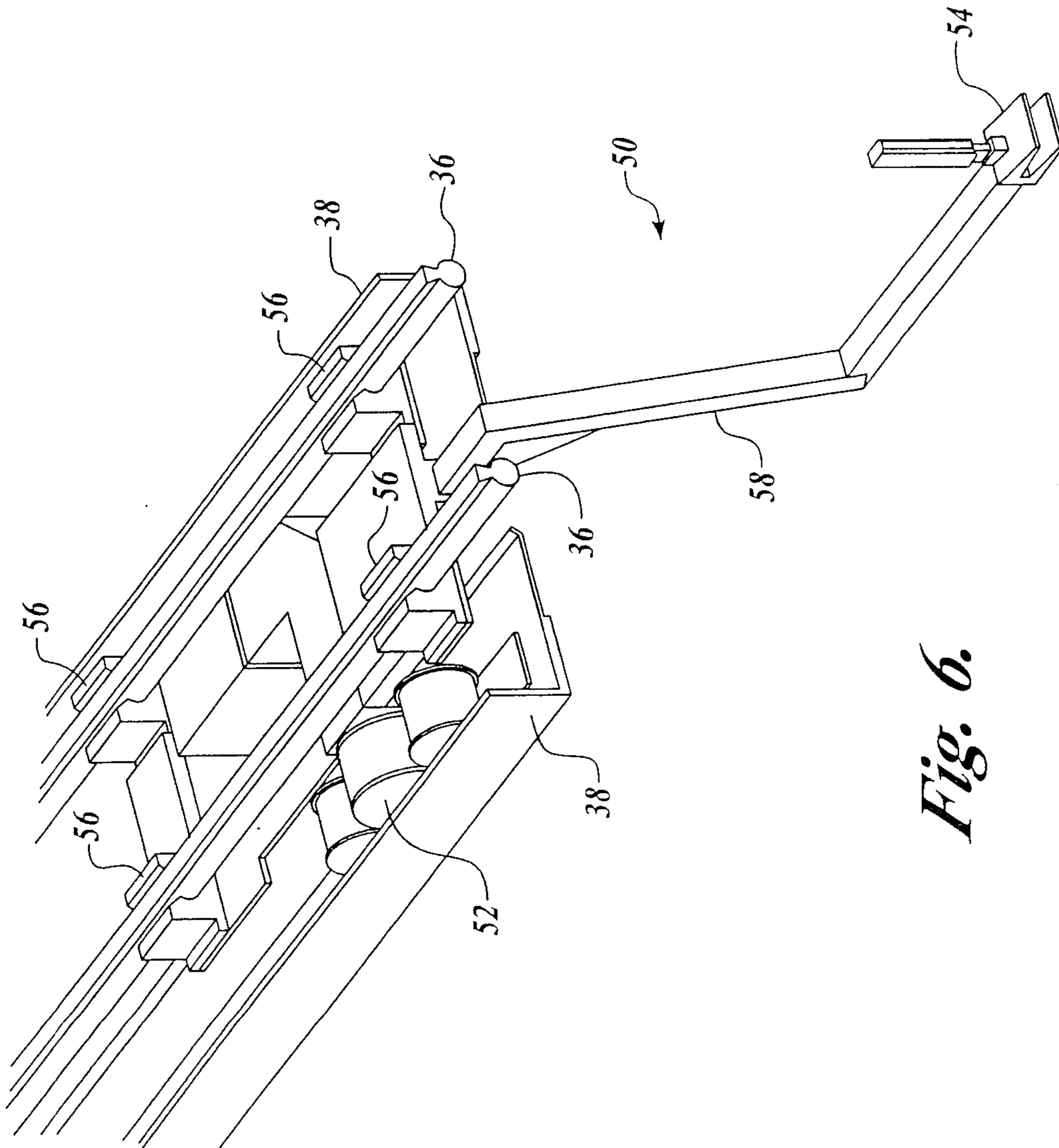


Fig. 6.

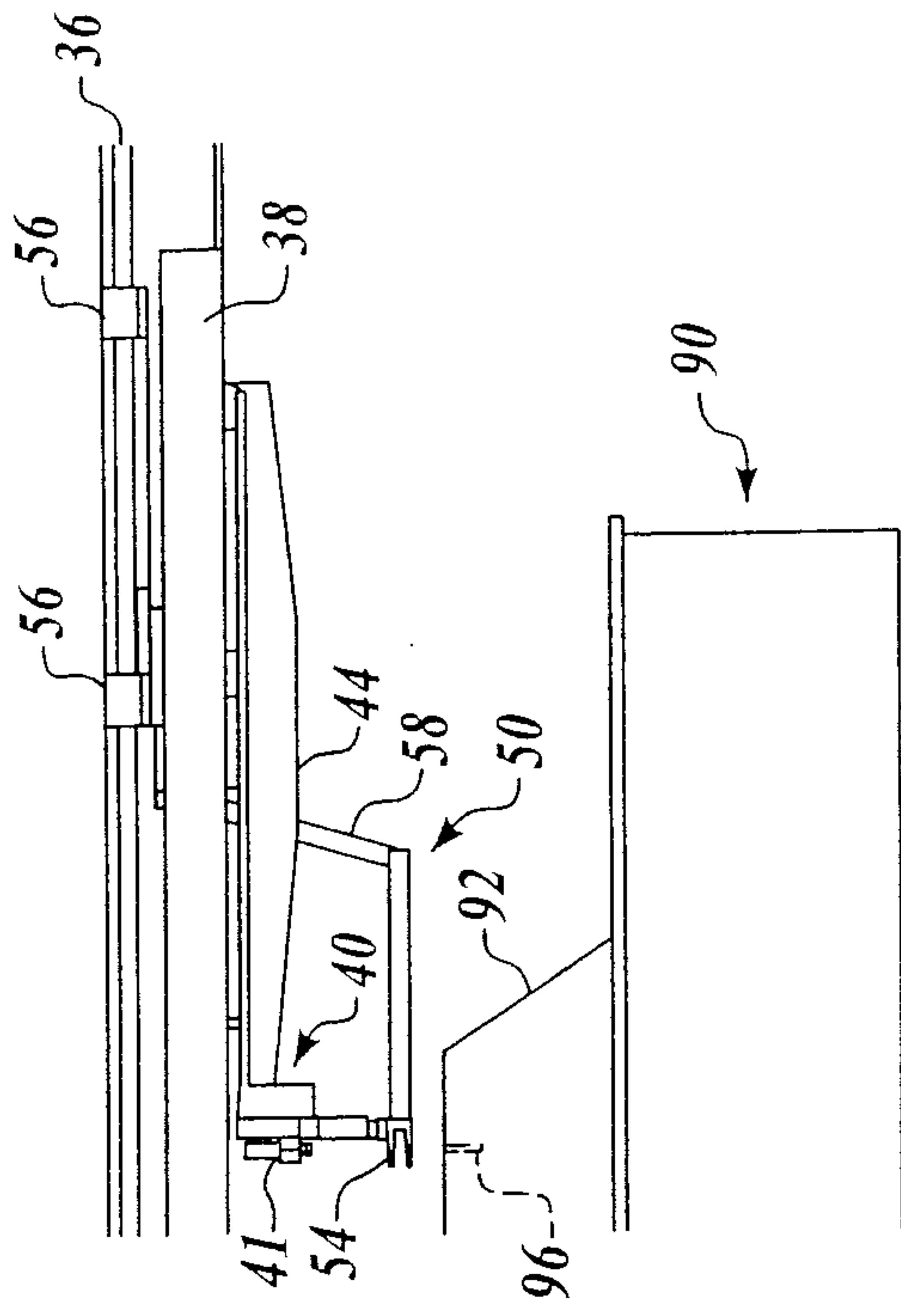


Fig. 7A.

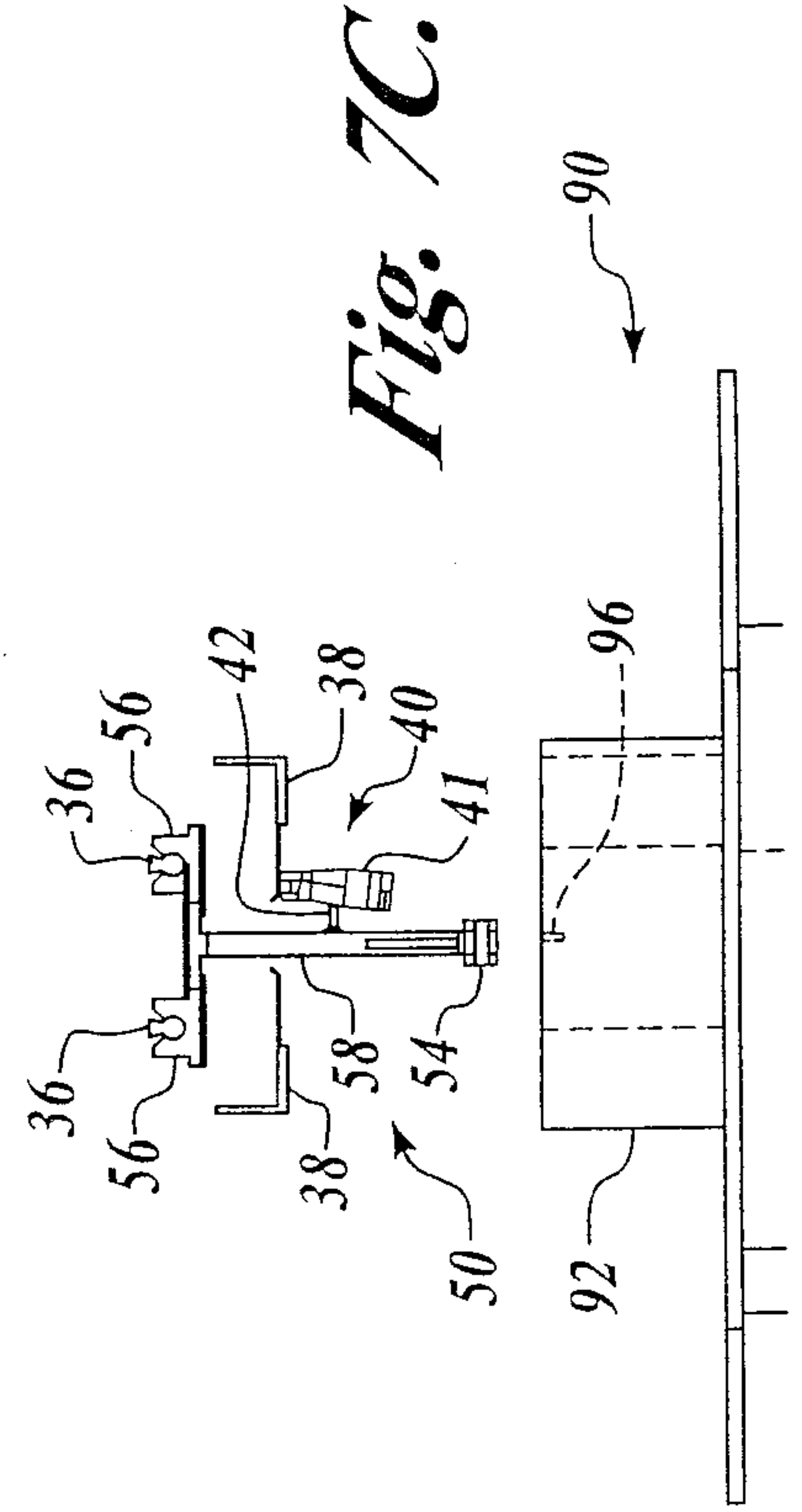


Fig. 7B.

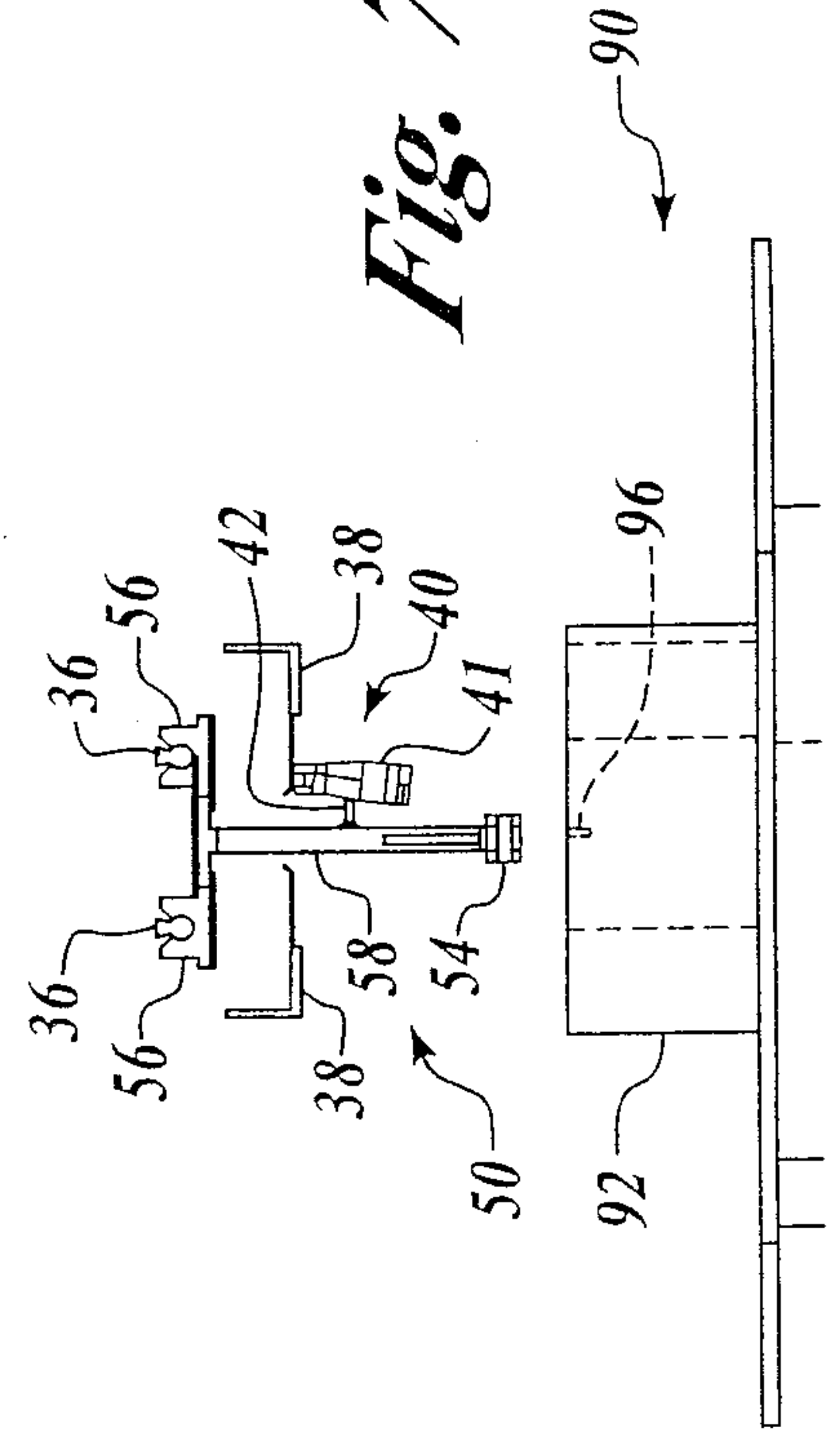


Fig. 7C.

