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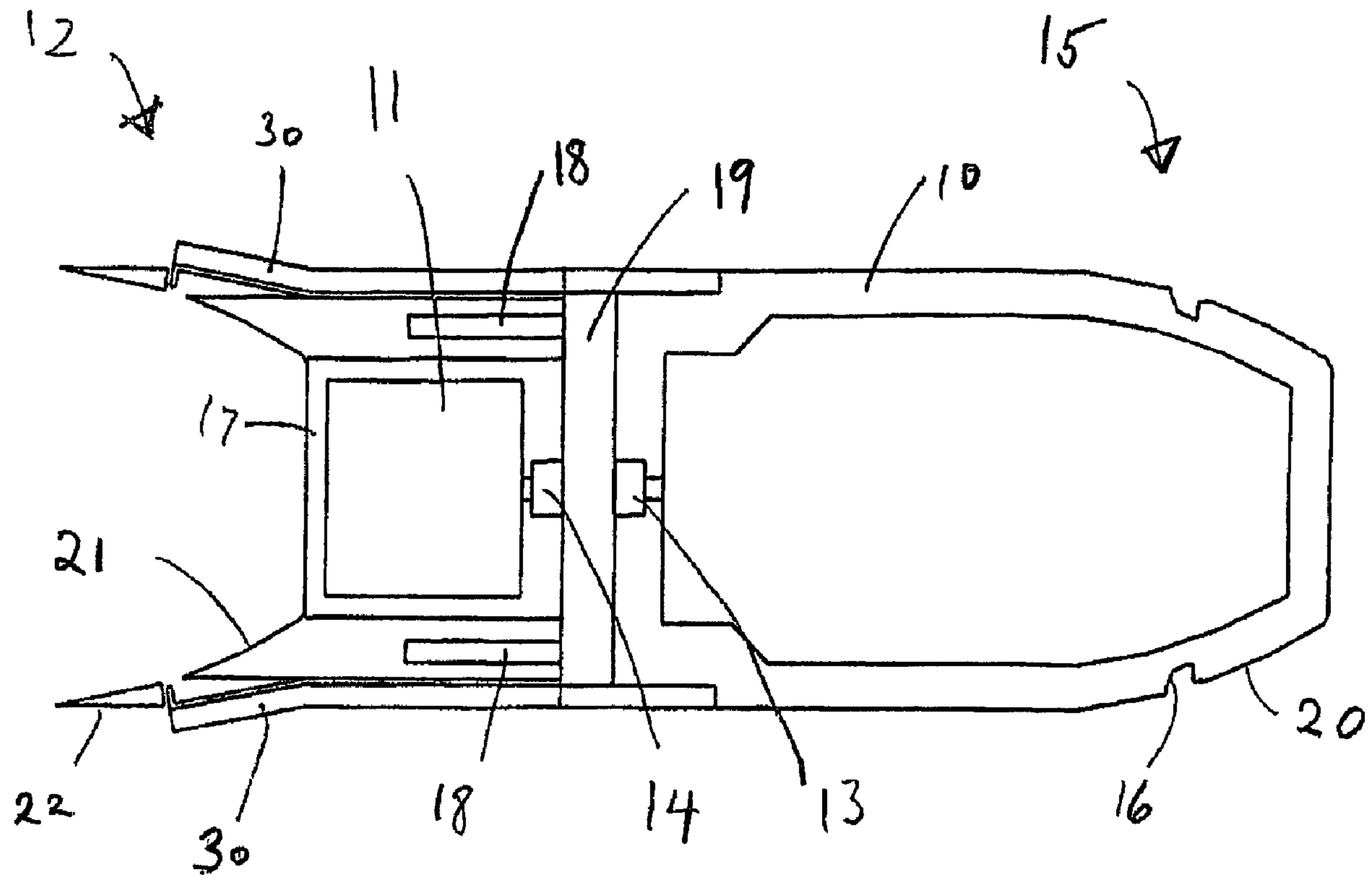
(54) **Titre : PROJECTILE POUR ARME A PROJECTILES EMPILES**
(54) **Title: PROJECTILE FOR A STACKED PROJECTILE WEAPON**



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Projectile stacking systems in which individual projectiles are clipped together to form a stack. The projectiles may be joined individually by a user before loading in a barrel, or during a loading process assisted by features on the breech of the barrel. The tail of each projectile includes a set of clips which engage the nose of a trailing projectile in the stack. Projectiles may be withdrawn from barrel and undipped as required by the user.

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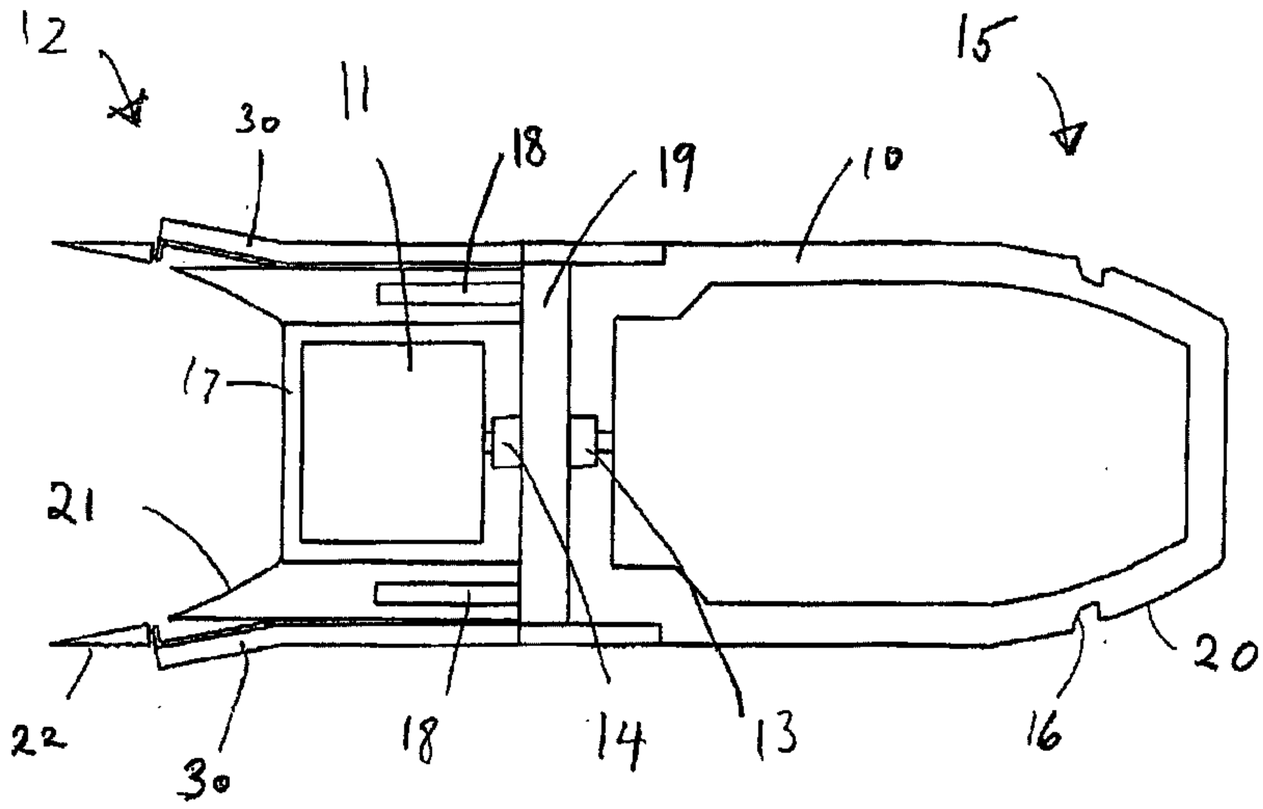

(57) Abstract: Projectile stacking systems in which individual projectiles are clipped together to form a stack. The projectiles may be joined individually by a user before loading in a barrel, or during a loading process assisted by features on the breech of the barrel. The tail of each projectile includes a set of clips which engage the nose of a trailing projectile in the stack. Projectiles may be withdrawn from barrel and undipped as required by the user.

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PROJECTILE FOR A STACKED PROJECTILE WEAPON

FIELD OF THE INVENTION

This invention relates to stacked projectile weapons, in particular but not only to projectiles which may be individually loaded into a stacked projectile weapon, or may be joined together to form a stack before loading, by an operator in the field.

BACKGROUND TO THE INVENTION

In a stacked projectile weapon the projectiles are fired sequentially from a stack contained in the barrel. These weapons offer an advantage in that the projectiles have no cartridges and can be fired electronically and relatively rapidly. However, propellant gases created by firing of the leading projectile can ignite the propellant charges that are provided for projectiles further down the stack. A sealing system is therefore required, such as forward or reverse wedging, in which a part of each projectile is forced into a circumferential contact with the bore the barrel. Alternatively the propellant charges may be sealed within chambers provided either externally to the barrel or internally to the projectiles themselves.

Another problem that must be overcome in stacked projectile weapons relates to the ease of loading and reloading. In some existing weapons the projectiles cannot be carried and loaded by operators in the field, so an empty weapon must be returned to base. In other weapons the projectiles must be carried and loaded as preformed stacks, so operators are faced with the dilemma of how to deal with a stack which has only been partially fired, in order to be fully prepared for the next event in a combat operation. An operator is unlikely to be comfortable carrying a partially loaded weapon into a life threatening situation, or carrying a partly empty stack back to base to be refilled.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an improved projectile for a stacked projectile weapon, or at least to provide an alternative to existing projectile systems.

In one aspect the invention may be said to reside in a projectile for a stacked projectile weapon, including: a propellant charge which is sealed against ignition of charges in other projectiles, an engagement mechanism having a nose part and a tail part for engagement respectively with leading and trailing projectiles during a loading process, a firing system for the propellant, and a payload.

Preferably the nose part of the engagement mechanism is engaged by the tail part of a leading projectile during the loading process. Similarly the tail part of the engagement mechanism is engaged by the nose part of a trailing projectile during the loading process. The loading process includes insertion of individual projectiles into a breech portion of the weapon to form a stack.

In one embodiment the nose part of the engagement mechanism includes a lateral groove around the nose of the projectile. The tail part of the engagement mechanism includes one or more longitudinal clips.

Preferably the tail part of the engagement mechanism is actuated by passage through the breech portion on insertion of a trailing projectile. The tail part of the engagement mechanism has a normally open condition which is closed on engagement with the trailing projectile. The tail part remains closed after firing of the projectile but reopens if the projectile is unloaded.

In another aspect the invention resides in a method of loading a weapon with projectiles, including: inserting a leading projectile into a breech portion of the weapon, inserting a trailing projectile into the breech portion behind the leading projectile to form a stack, and forming an engagement between a tail part of the leading projectile and a nose part of the trailing projectile.

Preferably the projectiles are inserted longitudinally through a common aperture and the trailing projectile urges the leading projectile further into the breech portion. A normally open mechanism on the tail part of the leading projectile is closed to engage the nose of the trailing projectile as the leading projectile is pushed further into the breech portion by the trailing projectile. Preferably a plug is inserted into the breech portion after the trailing projectile and forming an engagement between a tail part of the trailing projectile and the plug.

In one embodiment the engagement is formed between one or more longitudinal clips in the tail part of the leading projectile and a lateral groove in the nose part of the trailing projectile. The engagement between the projectiles is broken by firing the leading projectile or by withdrawing the trailing projectile from the breech portion.

In another aspect the invention resides in a stacked projectile weapon, including: a breech portion with a barrel which receives a series of projectiles to form a stack, and a firing system which is aligned with the stack and activates respective primers in the projectiles, wherein the barrel has an entry portion which actuates an engagement mechanism between consecutive projectiles.

Preferably the entry portion includes an aperture having an edge which closes a tail part of each leading projectile into engagement with a nose part of a corresponding trailing projectile as the stack is formed.

Preferably the weapon includes a plug which retains the stack within the barrel and engages the trailing projectile in the stack. Preferably the firing system includes an inductive subsystem for each projectile in the stack.

The invention also resides in any alternative combination of features that are indicated in this specification. All equivalents of these features are deemed to be included whether or not expressly set out.

LIST OF FIGURES

Preferred embodiments of the invention will be described with respect to the accompanying drawings, of which:

Figure 1 is a cross section through a projectile with stacking clips,

Figure 2 is an external view of the projectile in Figure 1,

Figures 3a, b, c give further details of the stacking clips,

Figure 4 shows a receiver for a stacked projectile weapon capable of firing the projectile,

Figures 5a, b show how the receiver may be extended to form a barrel,

Figures 6a, b show two projectiles entering the receiver during the loading process,

Figures 7a, b, c show how a breech plug is used to close the receiver once loaded,

Figures 8a, b, c are views of the projectile showing the clips in open, closed and fired positions,

Figures 9a, b, c, d show loading of a receiver and closure with a breech plug,

Figures 10a, b, c show clip variations,

Figure 11a, b show an alternative clipping system for projectiles,

Figures 12 shows how the clips may be included in a projectile arming system,

Figure 13 indicates an additional sealing action,

Figures 14a, 14b, 14c indicate a further clipping action,

Figures 15a, 15b, 15c, 15d indicate a further clipping action,

Figures 16a, 16b, 16c, 16d indicate a further clipping action,

Figures 17a, 17b indicate a further clipping action,

Figures 18a, 18b indicate a further clipping action,

Figures 19a, 19b show a clippable projectile for an alternative firing system, and

Figure 20 shows an alternative firing system with external propellant chambers, and

Figure 21 shows a stack or clipped projectiles.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to the drawings it will be appreciated that the invention may be implemented in a variety of different ways for a range of different weapons or other projectile launchers. Both military and civilian purposes may be envisaged. This description is provided by way of example only. It will also be appreciated that projectiles and barrels have generally cylindrical symmetry, so that most of the features shown in the drawings have a degree of rotational symmetry about a longitudinal axis.

Figure 1 is a cross sectional view of the main components of a projectile for a stacked projectile weapon. The projectile includes a payload container 10, such as a warhead, a propellant charge 11 and a tail assembly 12. Primer 13 activates the warhead and primer 14 ignites the propellant. The projectile is adapted to be stackable nose to tail with a number of identical projectiles in the barrel of the weapon. Nose portion 15 has a roughly convex outer surface 20 shaped to correspond with a roughly concave inside surface 21 of the tail assembly. The surface of the nose portion also includes a groove 16 while the tail assembly

includes a set of clips 30, so that the nose of each trailing projectile may engage the tail of a respective leading projectile in the stack.

Because the projectile in Figure 1 is to be used in a stack the propellant must be sealed against ignition gases which fill the barrel of the weapon after each projectile is fired. In this example the propellant is sealed within a casing 17 which is resistant to the ignition gases produced by other projectiles. The casing typically includes a portion which ruptures outwards under the higher pressures which are produced when propellant 11 is ignited. A range of other systems such as wedge sealing may be employed instead of or in addition to the casing system.

In Figure 1 the projectile is fired from the weapon by way of an inductive system having an inductor 18 which interacts with a corresponding inductor in the barrel, and a signal detector 19 which receives output from the inductor 18 and determines whether the projectile is required to fire. The detector is typically programmed with a code and on receiving a signal containing the code from the inductor, the detector triggers the primer 14 to ignite the propellant. The detector may also arm the warhead through primer 13. Otherwise the detector remains idle. Firing systems of this kind are known and need not be described in detail. A range of other electrical or mechanical firing systems are also possible for stacked projectile weapons.

Figure 2 is an external view of the projectile in Figure 1. The payload container 10 forms the nose portion 15 of the projectile in this example, and is shown connected to the tail assembly 12. When the projectile is stacked in a barrel the outer surface 20 of the nose portion is generally surrounded by skirt 22 of the tail assembly of a leading projectile (if any). The tail assembly also includes four clips 30 which engage groove 16 in the nose portion of a trailing projectile in the stack. Each portion also usually carries a driving band 23 which restricts forward gas flow along the barrel when the projectile is fired. There are many options for clipping a stack of projectiles together.

Figures 3a, b, c show a clip 30 in relation to parts of the tail assembly 12. Each clip is formed from a relatively stiff strip 31 which provides a spring action, and a larger flexible strip 32 which acts as a cover on the outer surface of the projectile. The strips are typically formed of suitable metals and fastened together and to the projectile using suitable means such as

adhesive, welding or screws. The spring strip 31 is shaped in three parts, namely a base 33 which is fastened to the tail assembly of the projectile, an arm 34 which extends from the base and is biased outwards from the projectile, and a pin 35 which is carried by the arm and engages a trailing projectile during the loading process. The pin may take a wide variety of structures such as a simple fold in the end of the spring strip 31. Clip 30 is fastened into a slot 36 in the tail assembly so that the outer surface of the cover strip is flush with the outer surface of the projectile, and the pin part of the stiff strip is aligned with an aperture 37 in the tail assembly. Arm 34 holds the pin 35 in an open position away from the projectile and above the aperture 37.

Figure 4 shows a projectile receiver which forms part of the barrel of a stacked projectile weapon. The receiver includes a tube 40 having a series of external ring-shaped inductors 41 which interact with inductors 19 in corresponding projectiles when the weapon is loaded. Breech 42 at one end of the tube receives individual projectiles from an operator during the loading process. The breech presents a tubular entry with a ramped portion 43 which interacts with the clips 30 to assist the engagement process between consecutive projectiles, as explained below. Unfired projectiles may also be removed through the breech if required. The other end of tube 40 is typically extended or joined to a further tube to form a full length barrel for the weapon. The barrel may take a wide range of structures and a wide range of firing mechanisms may also be employed.

Figures 5a, b show how the receiver in Figure 4 may be extended in length 50 or joined to a further tube 51 to form the barrel of a launcher for stacked projectiles. It will be appreciated that various other components of the launcher, such as aiming and triggering systems have not been included, but will readily be understood by a skilled person.

Figures 6a, b are a sequence showing how two projectiles are engaged nose to tail as an operator stacks the receiver. The tail assembly 12 of a first projectile at right is shown largely inside the breech of the receiver. The nose portion 15 of a second projectile at left is shown at the entry to the breech and in contact with the tail assembly of the first projectile. The operator is pushing the second projectile which in turn is urging the first projectile further into the receiver. In Figure 6a, clips 30 in the tail assembly of the first projectile are adjacent the ramped portion of the breech and are still in their open state. In Figure 6b, both projectiles have moved further into the receiver. Clips 30 have now been deflected and closed by the

ramped portion of the breech so that pins 35 have each engaged the clip ring 16. Further pushing by the operator will move the second projectile into the breech to take the original position of the first projectile. Conversely during an unloading process, the operator may pull the second projectile from the breech which will in turn pull the first projectile back into the breech. The clips 30 spring back to their initial open positions so that the projectile may be unloaded and loaded again in the same way.

Figures 7a, b are a sequence showing how a plug 70 is used to close the breech after projectiles have been loaded into the receiver. The tail assembly 12 of the last projectile in the stack is shown largely inside the breech. The plug has a central portion 71 including a clip ring 73, similar in shape to the nose portion 15 of a projectile. The plug also has an outer cylindrical portion 72 which engages the outside of the breech. A wide range of plug designs are possible. The operator is pushing the plug which in turn is urging the last projectile further into the receiver. In Figure 7a, the plug has not yet contacted the projectile or the breech. Clips 30 in the tail assembly of the projectile are adjacent the ramped portion of the breech and are still in an open state. In Figure 7b, the central portion 71 of the plug has contacted the tail assembly and the outer portion 72 has contacted the breech. In Figure 7c, both the projectile and the central portion of the plug have moved into the breech. Clips 30 have now been closed by the ramped portion of the breech so that pins 35 in each clip have engaged the clip ring 73. The outer cylindrical portion of the plug has engaged the outside of the breech. The weapon may now be fired. Conversely in an unloading process, the plug may be disengaged and the projectile pulled back through the breech to be removed from the receiver.

Figures 8a, b, c show a projectile in unloaded, loaded and fired conditions respectively. Clips 30 in the tail assembly are respectively open as a result of their respective spring strips 34, closed by the bore of the receiver, and then distorted on disengagement from the trailing projectile. In Figure 8a, the pins 35 of each clip have been bent into alignment with the arms 34 by the resistance of a respective clip ring 16 during the firing action.

Figures 9a, b, c, d are a sequence showing a loading process in which a receiver 90 is stacked with three projectiles 91, 92, 93. The projectiles are individually loaded according to Figures 6a, b to form the stack. The receiver is then closed with plug 94 according to Figures 7a, b, c.

Figures 10a, b, c show possible variations in the stacking clips. In Figure 10a, clip 100 has a pad 101 which corresponds in thickness to the driving band 102. The clip thereby contacts the bore of the receiver after the projectile is loaded and remains properly closed against flow of ignition gas in or out of the tail assembly. In Figure 10b, the cover strip of clip 104 provides a flange 105 which extends fully around the underlying spring strip. The clip thereby closes into slot 106 and seals more effectively with the outer surface of the projectile to further reduce any flow of ignition gas. In Figure 10c, the cover strip 107 includes a ledge 108 which interacts with the entry to the breech. This provides an increased level of resistance as the projectile is loaded into the receiver by the operator.

Figures 11a, b show an alternative clipping system for engagement between projectiles in the stack. In Figure 11a, the projectile has a tail assembly 110 and a nose portion 111. Skirt 112 in the tail assembly has a continuous lip 113, rather than a set of individual clips 30. The lip engages a clip ring 114 in the nose portion of a trailing projectile. Figure 11b indicates a pair of projectiles of this kind stacked in a receiver. A breech plug for the receiver would be similarly modified.

Figure 12 indicates a safety system which arms projectiles only after they are loaded into a receiver and engaged with another projectile or with the breech plug. In this example, the tail assembly 120 of a leading projectile forms an electrical circuit (shaded) with the nose part 121 of a trailing projectile. Clips 122 in the tail assembly are closed and engaged with the clip ring 123. The ends of the spring strip 124 in each clip form electrical contacts with the signal detector 125 of the leading projectile and with the nose part of the trailing projectile. A number of circuits are formed between each pair of adjacent projectiles depending on the number of clips. Inductor 126 in the projectile interacts with inductor 127 in the receiver. However, the signal detector cannot fire the projectile unless the circuit through the clips of that particular projectile and nose of the next projectile are complete.

Figure 13 indicates a wedge sealing action which may be provided to reduce the flow of ignition gas around projectiles in a stack. A force (arrowed) down the receiver 130 caused by firing of a leading projectile slightly compresses the trailing projectiles 131 and 132. This in turn forces the tail assembly of the first trailing projectile 131 to expand radially over the nose of the second trailing projectile 132 to form a more robust contact with the bore of the receiver. The contact extends around the circumference of the bore and reduces or prevents

passage of gas. A wedge action of this kind is preferably temporary and reversible, so that trailing projectiles return to their initial state in the barrel and can be unloaded if necessary, after leading projectiles have been fired. The tail assembly is constructed of a suitably resilient metal or synthetic material.

Figures 14a, 14b, 14c indicate an alternative clipping action which may be used to form a stack of projectiles either during loading into a barrel or separate from the barrel. Figure 14a shows a projectile 140 with a set of clips 141 in an open condition. Each clip has an arm 142 with a hand 143 which engages a groove 144 on the nose of the trailing projectile. A moveable band 145 on the tail of the projectile sits in a position forward of the clips. Figure 14b shows the band in motion towards the tail of the projectile, urging the arms inwards to a clipped position. The band can be moved as the projectile is loaded, or by hand if a stack is formed outside the barrel. Figure 14c shows the band in a final position around the tail, with the arms parallel to the body of the projectile and the clips in a closed position. The trailing projectile has not been shown.

Figures 15a, 15b, 15c, 15d indicate a further alternative clipping action. Typical angles are shown by way of example. These figures represent a clip which makes beneficial use of dual rest potential energy states of the material the clips are made from. Figure 15c shows a clip on a projectile in an open condition, the first position at which the clips are at rest potential energy state. In this position the clips are in a rest geometry. Figure 15b shows the clip in a maximum potential energy state due to tension and compression forces in the material. When the clip is forced into this position by the action of inserting it into the breech or by pressing on the clip manually outside of the receiver, the material will exert a force to return the clip arm to either of its rest potential energy states being fully open as in 15c or fully closed as in 15a. Figure 15a shows the second position at which the clips are at rest potential energy state, fully closed. The use of a clip design incorporating a dual rest potential energy state and a maximum potential energy state between the two rest potential energy state geometries enables the clip to be activated by the insertion of the projectile into the barrel or manually by pressing the clip by hand, outside the barrel. Once the projectiles have been clipped together by either means, the clips will be in a rest potential energy state and will not unclip unless forced to do so by applying a cross-longitudinal force between projectiles. This means that a reload stick can be formed outside the barrel and that the projectiles will not unclip on an individual basis as they are removed from the receiver.

Figures 16a, 16b, 16c, 16d show a further alternative clipping action, with similarities to those described above. Figure 16a shows an annular arm 161 with a hand including thumb 162 and finger 163. Figure 16b is a schematic end view of the flexible tail 164 of a projectile in an unclipped condition. Four thumbs 162 and fingers extend from the annular arm 161. Thumbs and fingers join to form a single member at four 'less curving' sections around the annulus of the projectile skirt. Figure 16c shows the tail 164 in a clipped condition with thumbs 162 held in place in an annular groove around the nose of a trailing projectile (not shown). In Figure 16b the general shape of the tail is square to allow entry of the nose of a trailing projectile and to catch on the ramped entry section of the breech in ready position to be pushed into the receiver by the next projectile and consequently engage the nose of the next projectile with the 4 thumbs. In Figure 16c the tail has been urged into the receiver and deformed by the nose of the trailing projectile into a generally circular shape to match the bore the barrel. Figure 16d indicates the bore of the barrel 165 in relation to the fingers and thumbs.

Figures 17a, 17b indicate a further alternative clipping action. A projectile 170 has flexible clips 151 on tail 155. Each clip may have an arm and hand structure as described above, for example. In Figure 17a the projectile is unclipped, with clips 151 are splayed outwards from the tail and are separated by triangular slots 152. In Figure 17b, the projectile is clipped to a trailing projectile (not shown) and the clips have engaged the nose of the trailing projectile. The triangular slots have closed as the clips bend inwards towards the nose of the trailing projectile. In flight the clips resume the unclipped orientation and may provide a small amount of drag to serve as tail fins or similar stabilisers.

Figures 18a, 18b indicate a further clipping variation. The tail 181 of projectile 180 includes a series of spring loaded clips 182. Each clip has a pin 183 slides in an aperture 184 on the tail. The pins are either retractable or within their respective arms or have matching slots in the tail, part of respective apertures 184. Figure 18a shows the projectile with the clips in an extended condition, urged rearwards on the tail with pins 183 extended. This represents the projectile after clipping, once clipped into a stack outside the reciver by manual operation or after formed into a stack by individually loading the projectiles into the receiver in similiar fashion to previous embodiments. Figure 18b shows the condition of the projectile and clips prior to the clipping process. As with prior embodiments, this clip abuts above the major

diameter of the projectile such that when the projectile is inserted into the receiver the clips engage the ramped section of the breech and slide rearwardly in the projectile. As the clips slide rearwardly in the projectile during the insertion process a springy leaf of material or sprung pin moves into a hooking engagement position and engages the nose of the trailing projectile. Thus the projectiles can be formed into a reload stick by the action of inserting them into the receiver individually or manually activating the clips to form a stick whilst the projectiles are outside the barrel. In this fashion the projectiles will not individually unclip during unloading from the receiver and will remain as a stick whilst outside the receiver.

Figures 19a, 19b show an alternative projectile 190 for use in an alternative stacked firing system with external propellant chambers. Figure 20 shows a barrel 200 with a firing system of this kind, such as described in WO 2000/62005 and WO 2004/102108. A stack of projectiles 190 are in place adjacent their respective propellant chambers 201. In Figure 19a, the tail of the projectile includes an expansion space for propellant gases, defined by apertures 191. Various clipping systems may be included in the tail. Figure 19b shows the end of the tail with a number of clips 192 such as described in relation to Figures 15a, 15b, 15c, for example. A range of other clipping systems may also be implemented.

Figure 21 shows a stack of projectiles 210 clipped together before insertion in a barrel. A range of clipping systems may be employed, such as the system in Figures 15a, 15b, 15c. A user could create a stack of projectiles of this kind in the field for example, for more convenient loading or for ease of transportation.

CLAIMS:

1. A method of loading a weapon with projectiles to form a stack, including:

inserting a leading projectile into a breech portion of the weapon,

inserting a separate trailing projectile into the breech portion behind the leading projectile, and

engaging the leading projectile with the trailing projectile to form the stack by forming an engagement between a tail part of the leading projectile and a nose part of the trailing projectile with an engagement mechanism;

the nose part of the engagement mechanism having a lateral groove around the nose of the projectile;

the tail part of the engagement mechanism includes at least one clip for engagement in the groove of the trailing projectile;

said at least one clip abutting above a major diameter of the projectile and said at least one clip being actuated by passage of the at least one clip through the breech such that projectiles are clipped together during loading.

2. A method according to claim 1 wherein the projectiles are inserted longitudinally through a common aperture and the trailing projectile urges the leading projectile further into the breech portion.

3. A method according to claim 1 wherein a normally open mechanism on the tail part of the leading projectile is closed to engage the nose of the trailing projectile as the leading projectile is pushed further into the breech portion by the trailing projectile.

4. A method according to claim 1 further including inserting a closure into the breech portion after the trailing projectile and forming an engagement between a tail part of the trailing projectile and the closure.

5. A method according to claim 1 wherein the engagement between the projectiles is disengaged by one of (a) firing the leading projectile; and (b) withdrawing the trailing projectile from the breech portion.

6. A stacked projectile weapon, including:

a barrel with a breech portion which receives a series of separate projectiles to form a stack, and a firing system on the barrel which is aligned with the stack and activates respective primers for the projectiles,

wherein the breech portion includes an entry portion which actuates an engagement mechanism between consecutive projectiles, and

the projectiles each comprising:

a propellant charge which is sealed against ignition of charges in other projectiles,

an engagement mechanism having a nose part and a tail part for engagement respectively with leading and trailing projectiles during a loading process,

a firing system for the propellant, and a payload;

the nose part of the engagement mechanism including a lateral groove around the nose of the projectile;

the tail part of the engagement mechanism including at least one clip for engagement in the groove of the trailing projectile;

the at least one clip abutting above a major diameter of the projectile and the at least one clip being actuated by passage of the at least one clip through breech during loading such that projectiles are clipped together during the loading process.

7. A projectile weapon according to claim 6 wherein the nose part of the engagement mechanism is engaged by the tail part of the leading projectile during the loading process.

8. A projectile weapon according to claim 6 wherein the tail part of the engagement mechanism is engaged by the nose part of a trailing projectile during the loading process.

9. A weapon according to any one of claims 6 to 8 wherein the entry portion includes an aperture having an edge which closes a tail part of each leading projectile into engagement with a nose part of a corresponding trailing projectile as the stack is formed.

10. A weapon according to any one of claims 6 to 8 wherein the barrel is a receiver which forms part of a relatively longer barrel in the weapon.

11. A weapon according to any one of claims 6 to 8 further including a breech closure which engages the last trailing projectile in the stack.

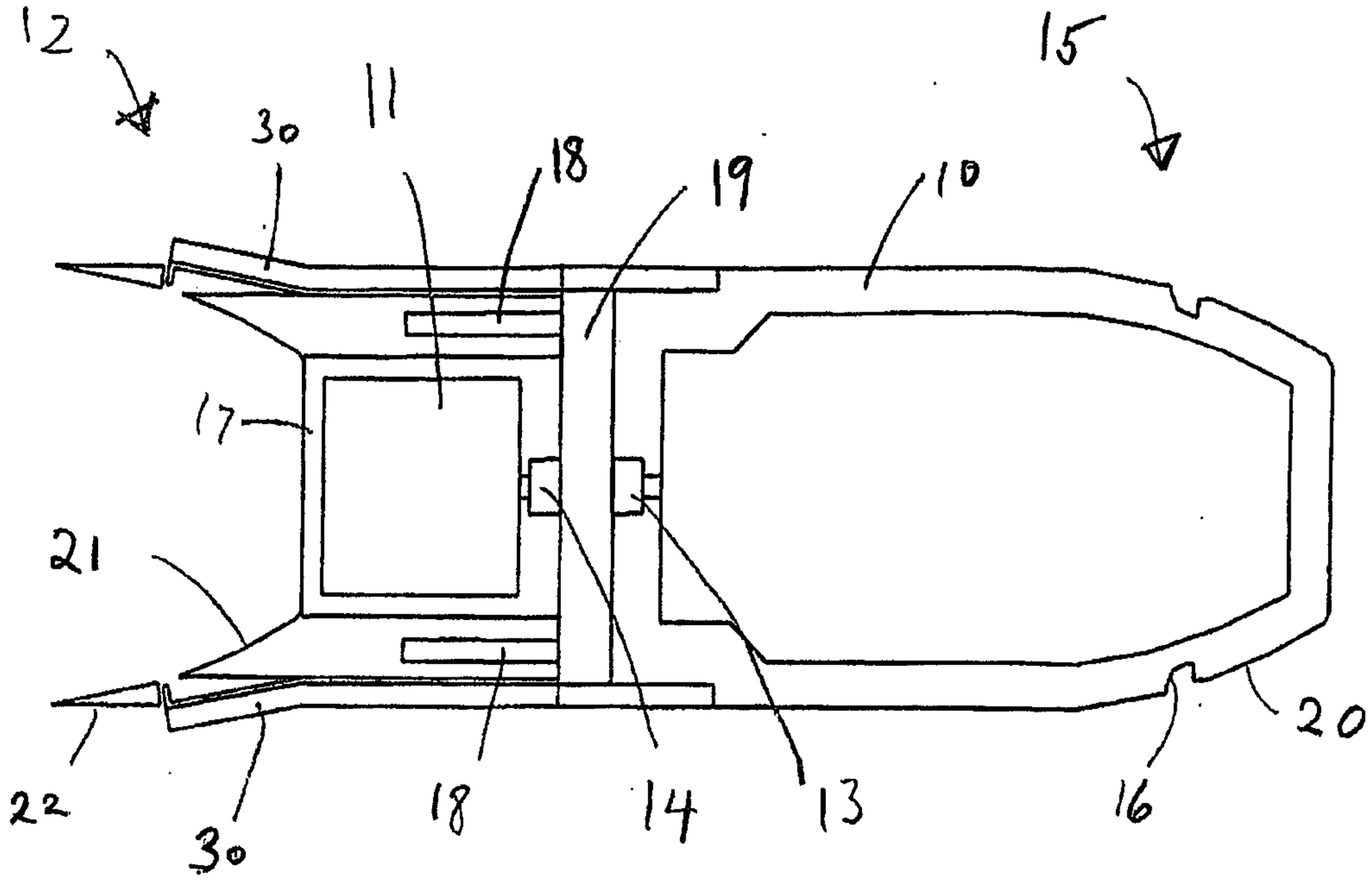


FIGURE 1

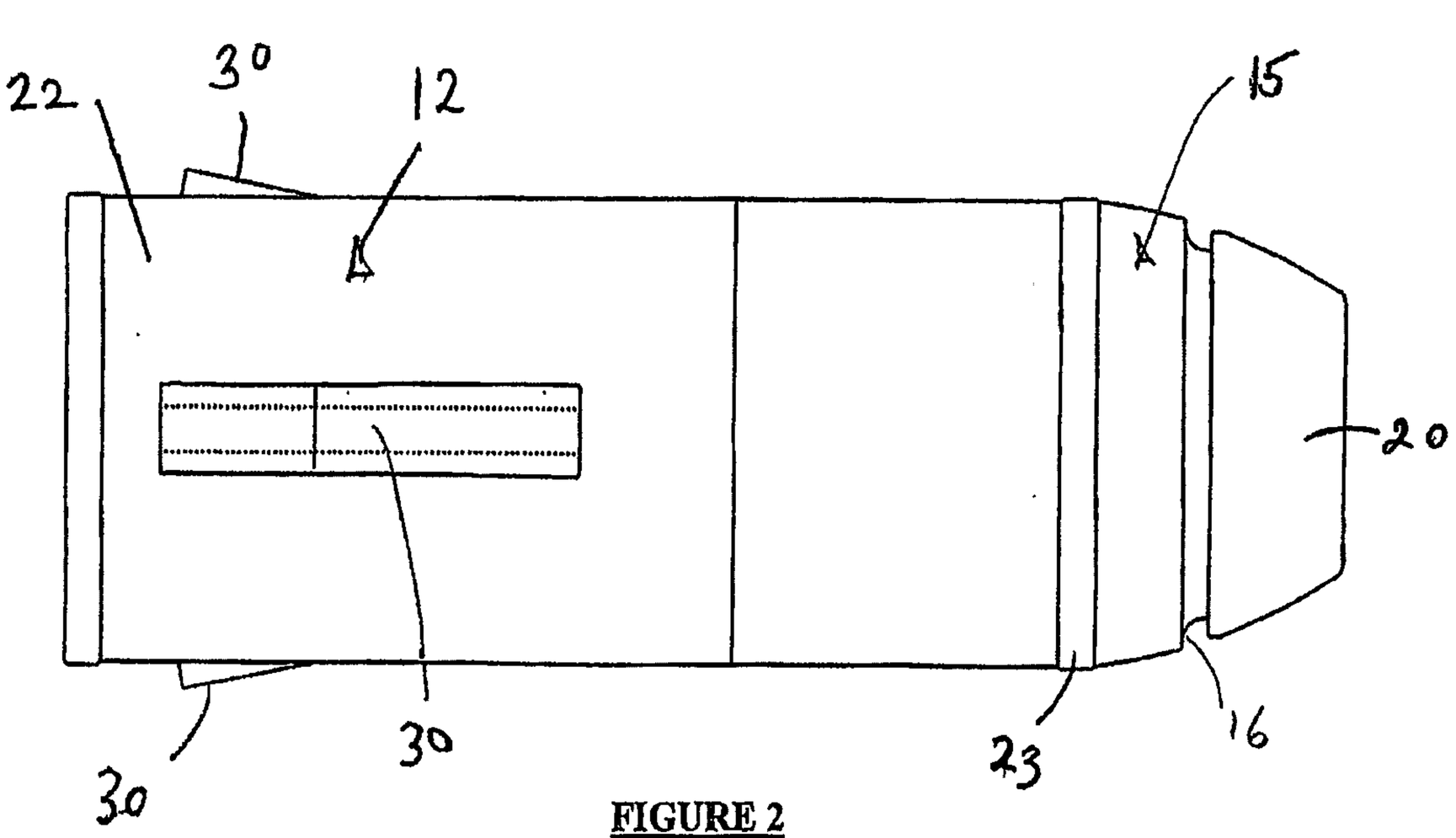


FIGURE 2

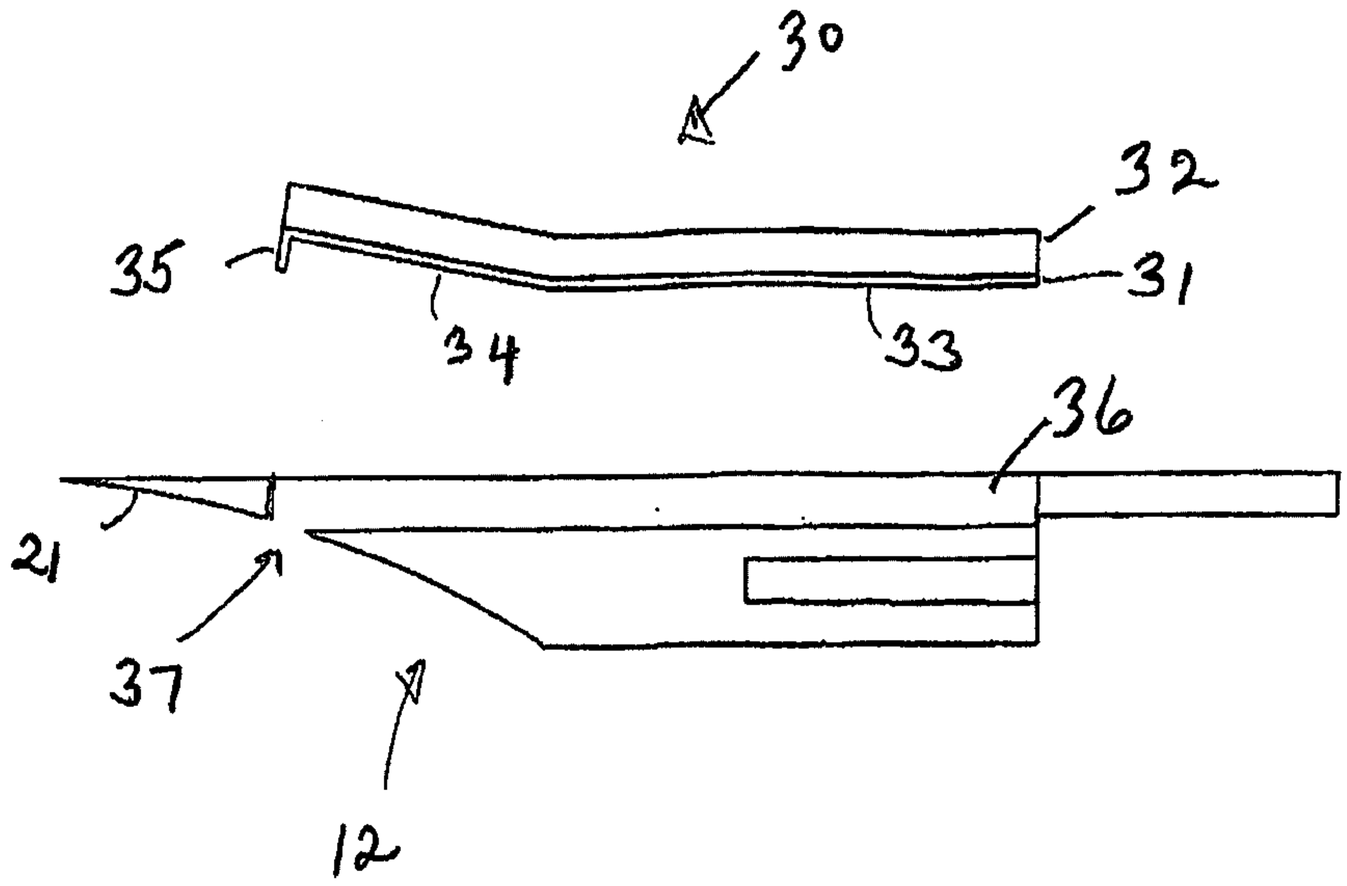


FIGURE 3a

FIGURE 3b

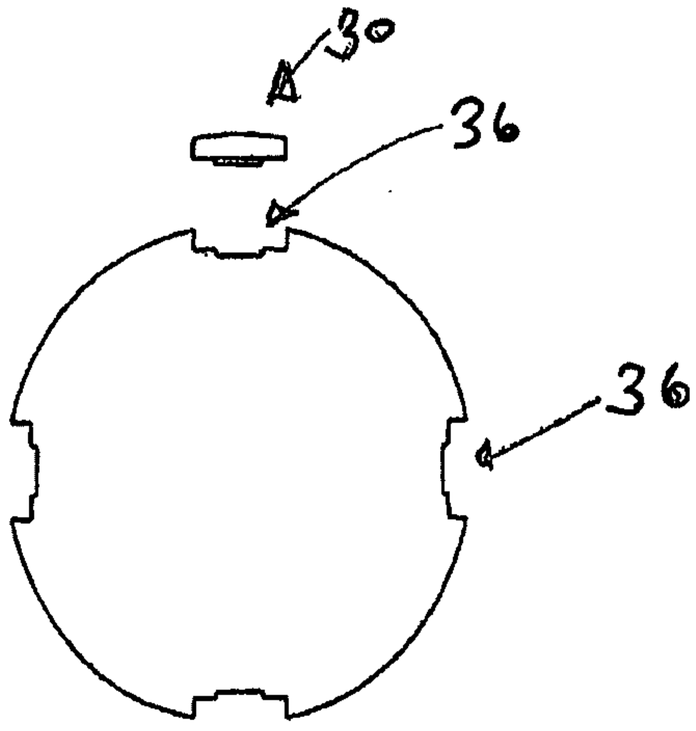


FIGURE 3c

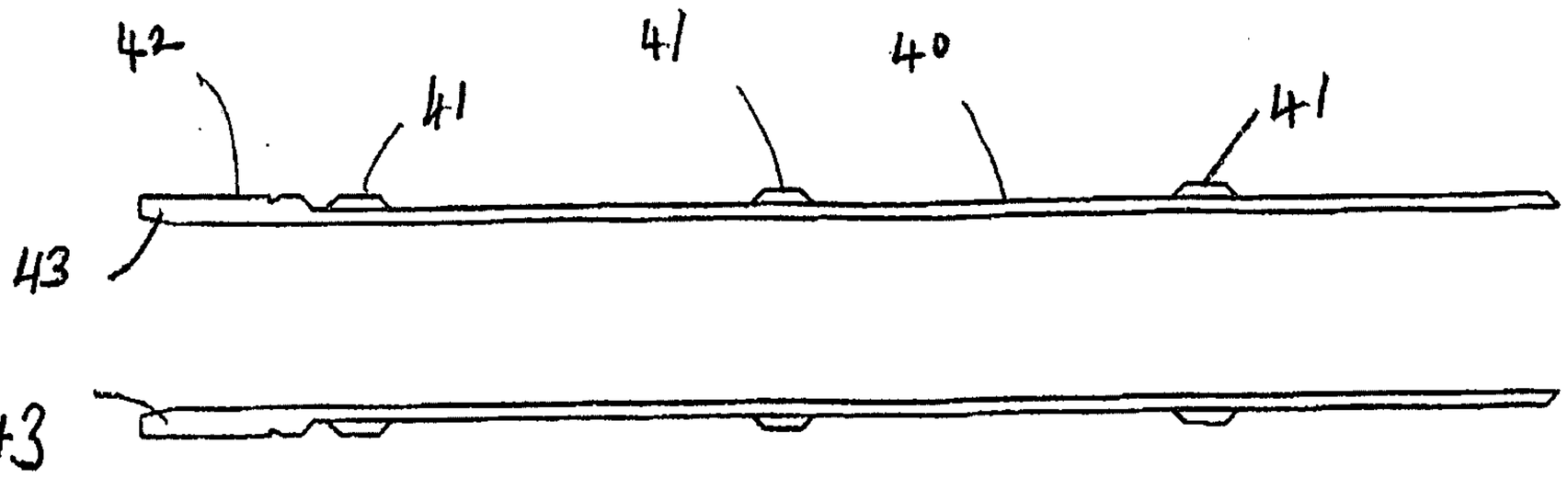


FIGURE 4

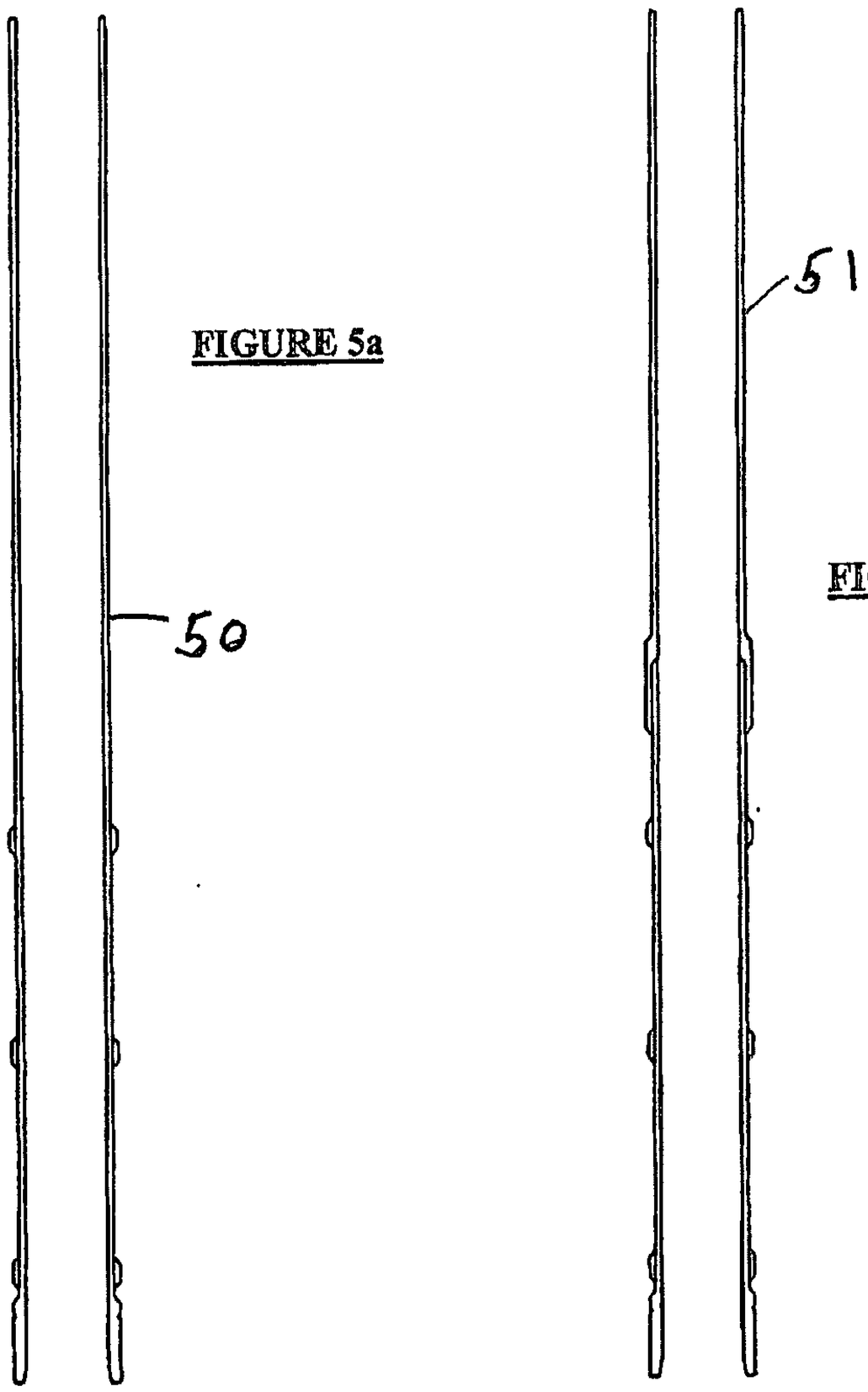


FIGURE 5a

FIGURE 5b

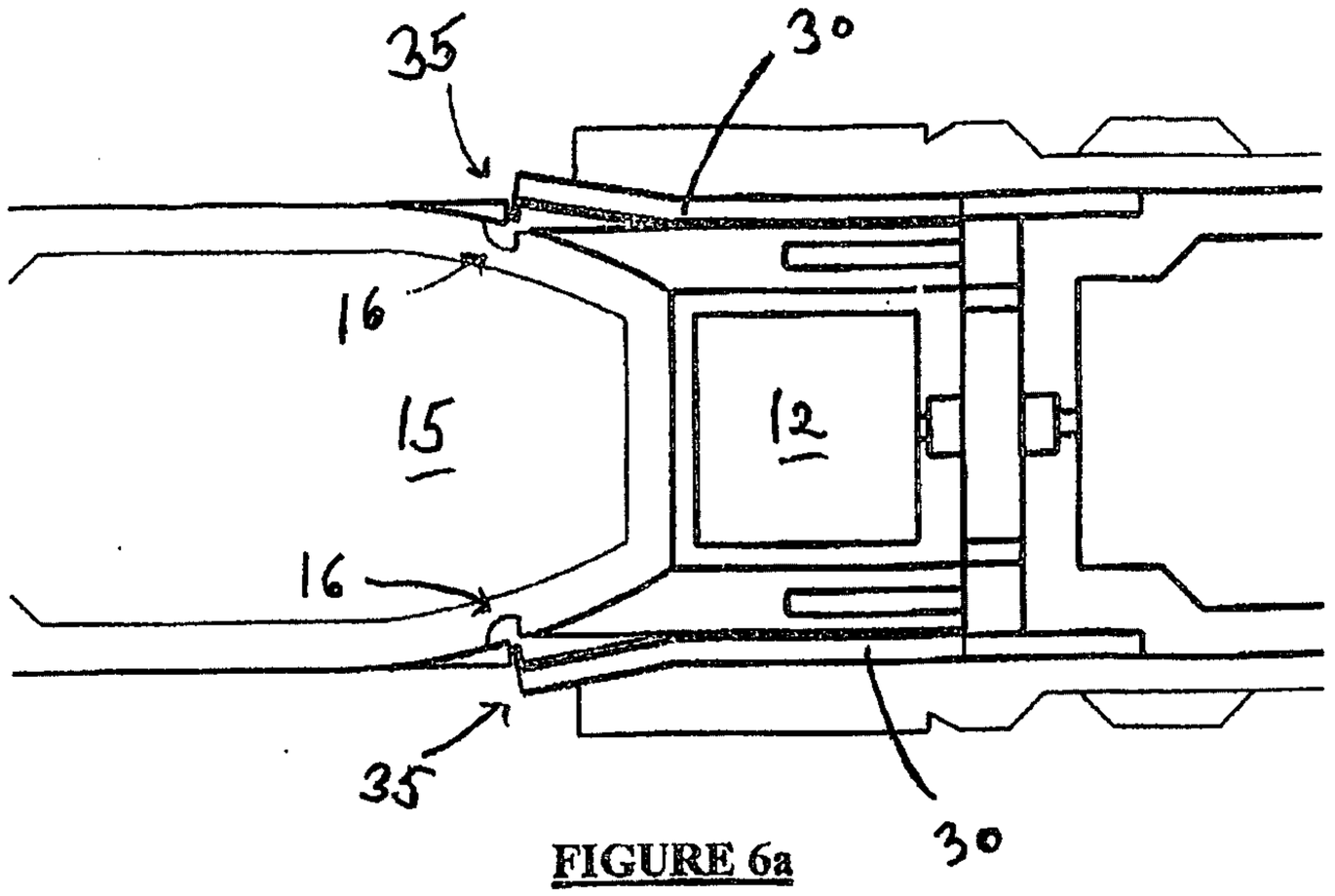


FIGURE 6a

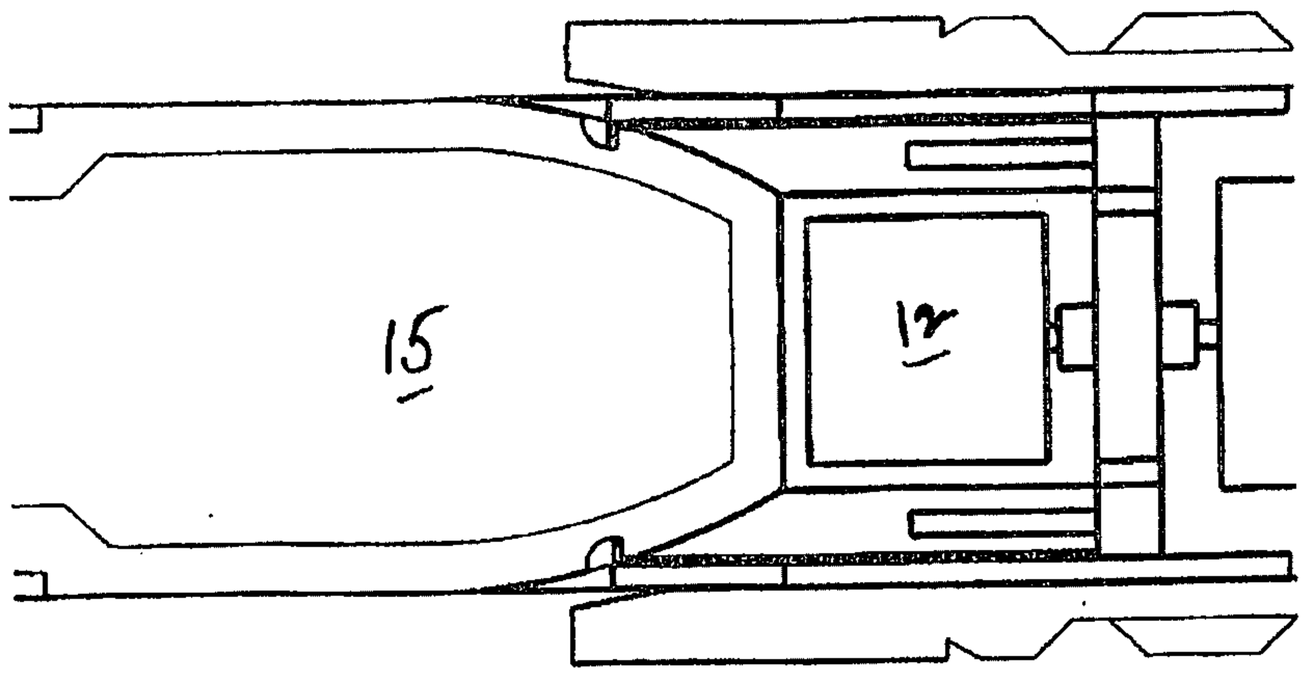


FIGURE 6b

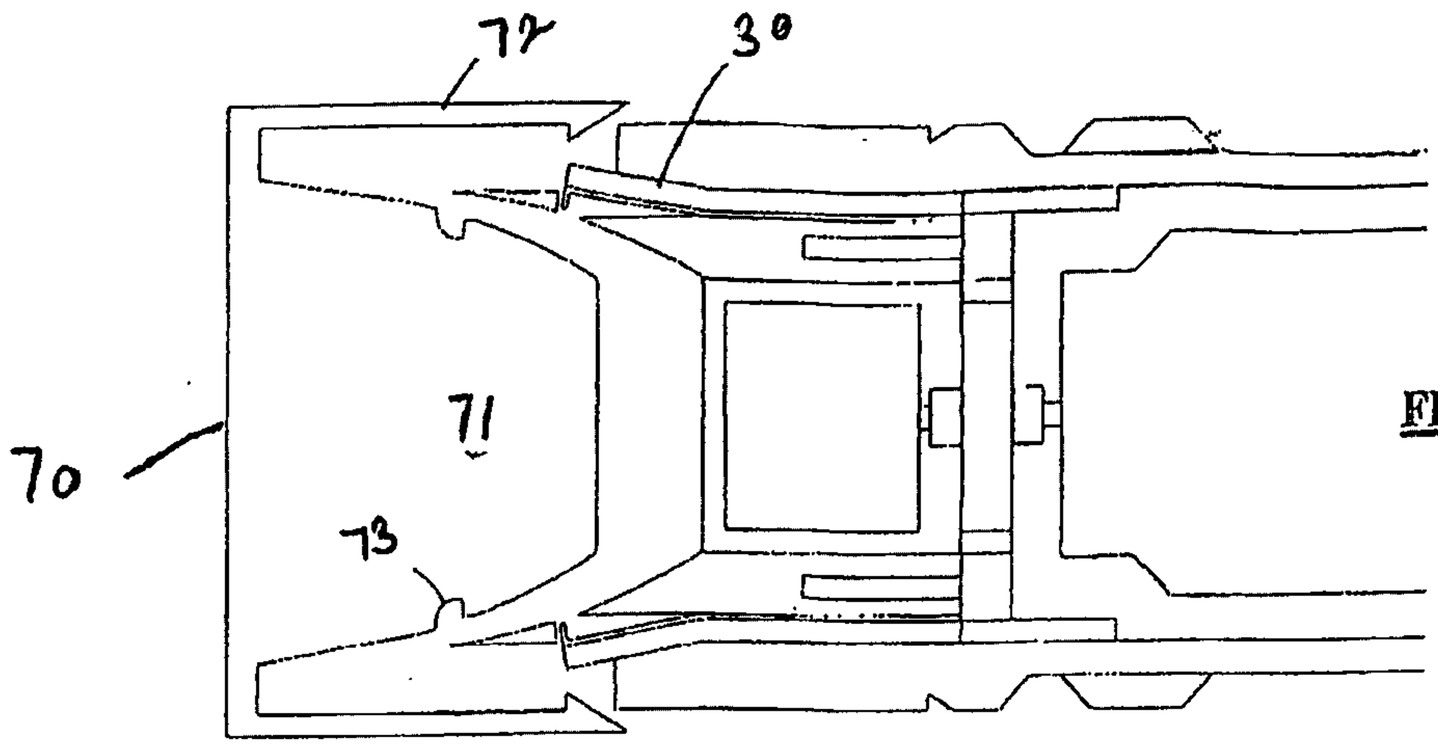


FIGURE 7a

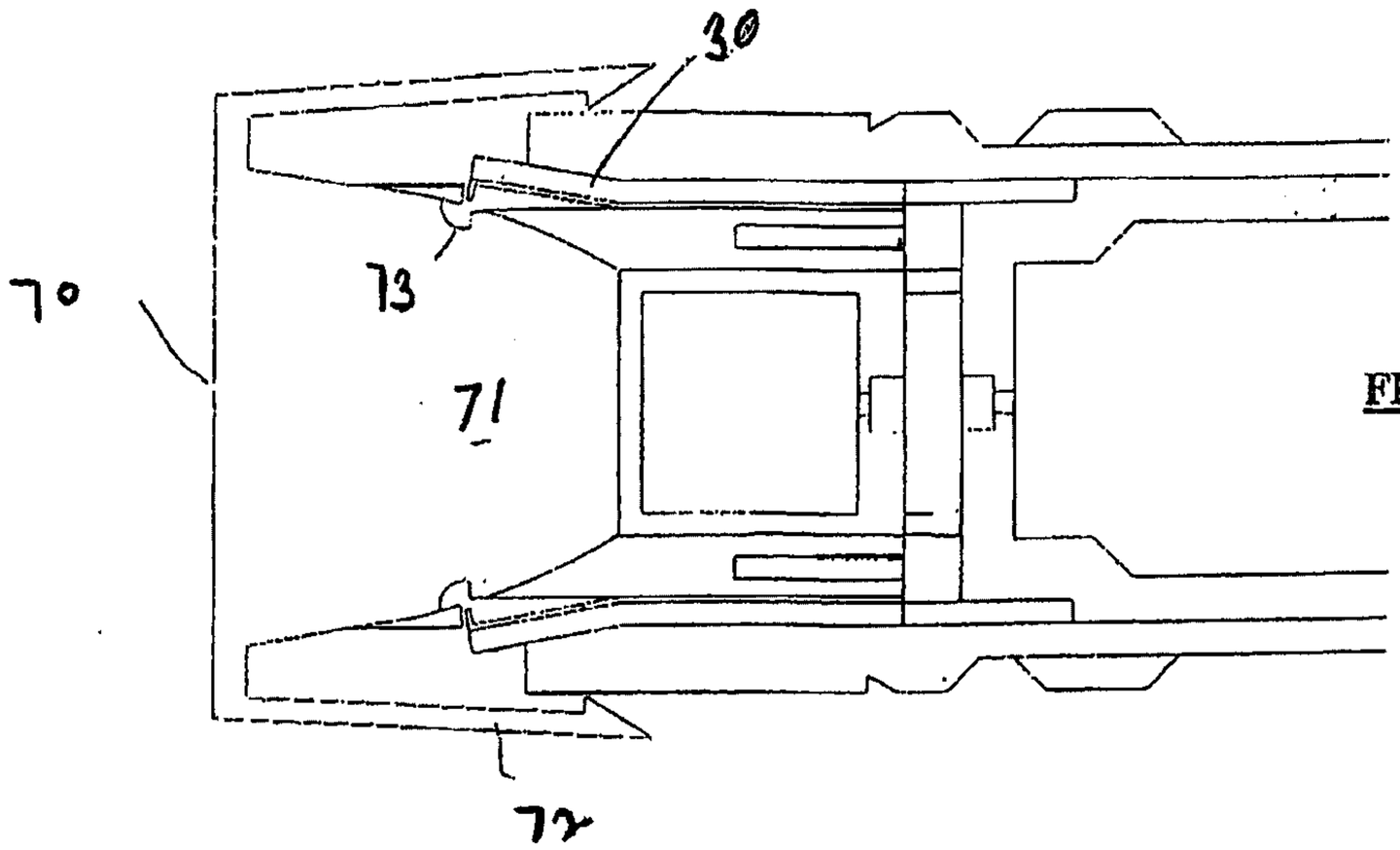


FIGURE 7b

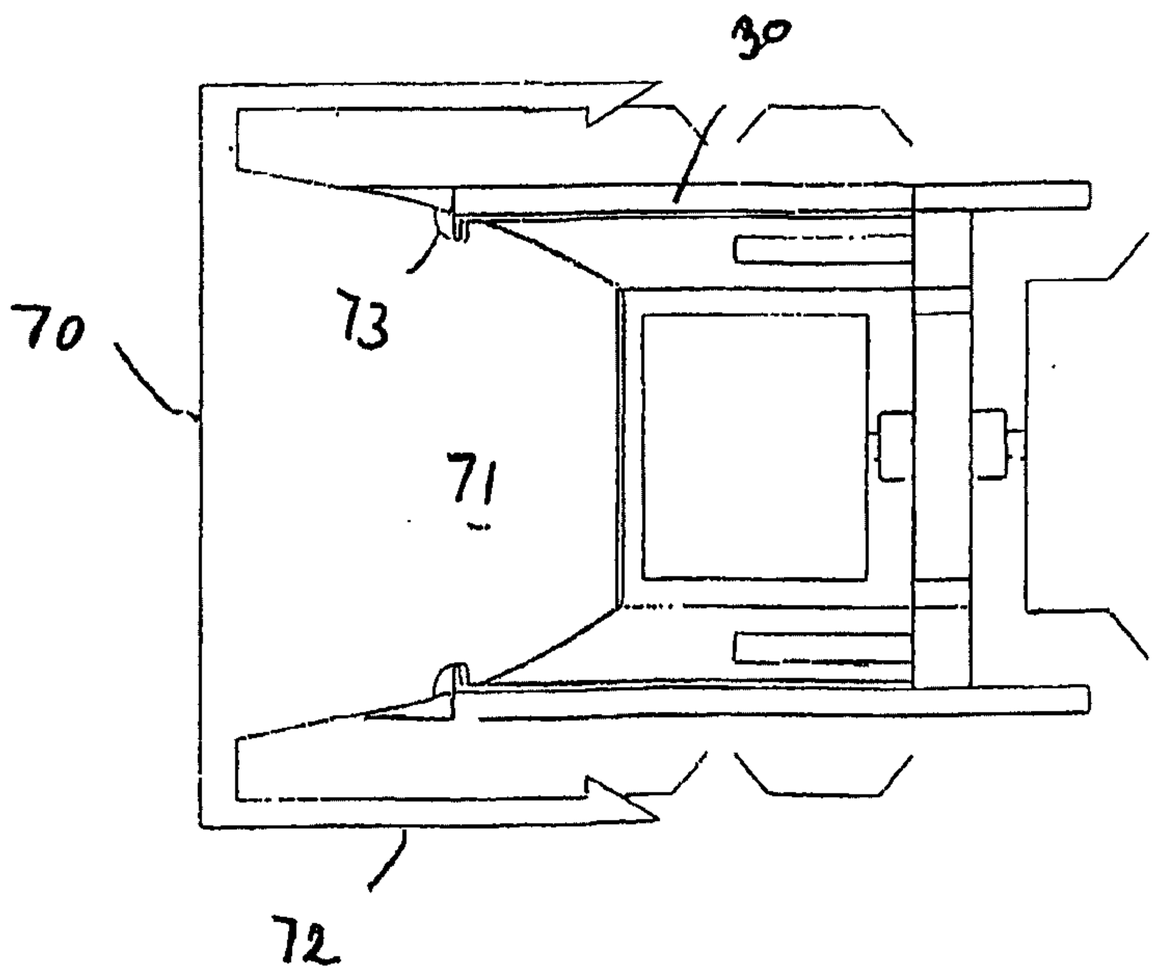


FIGURE 7c

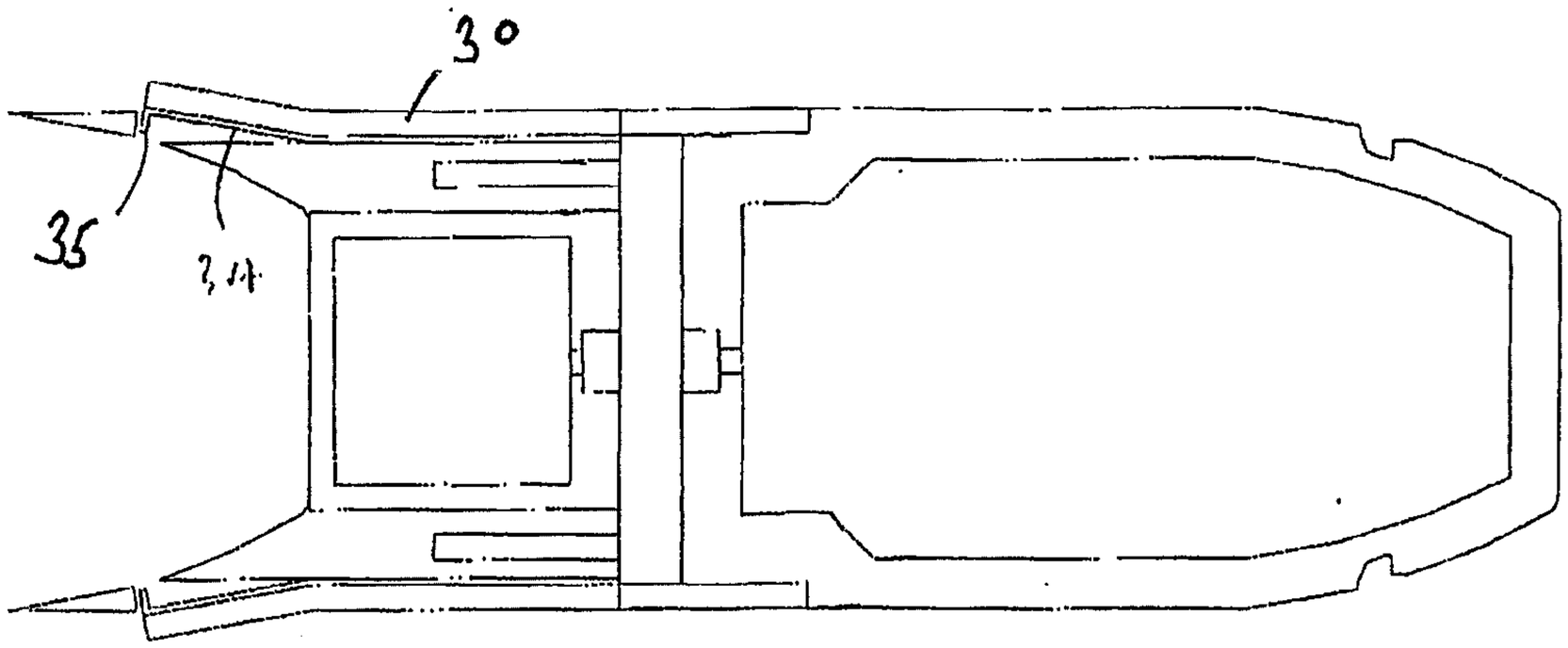


FIGURE 8a

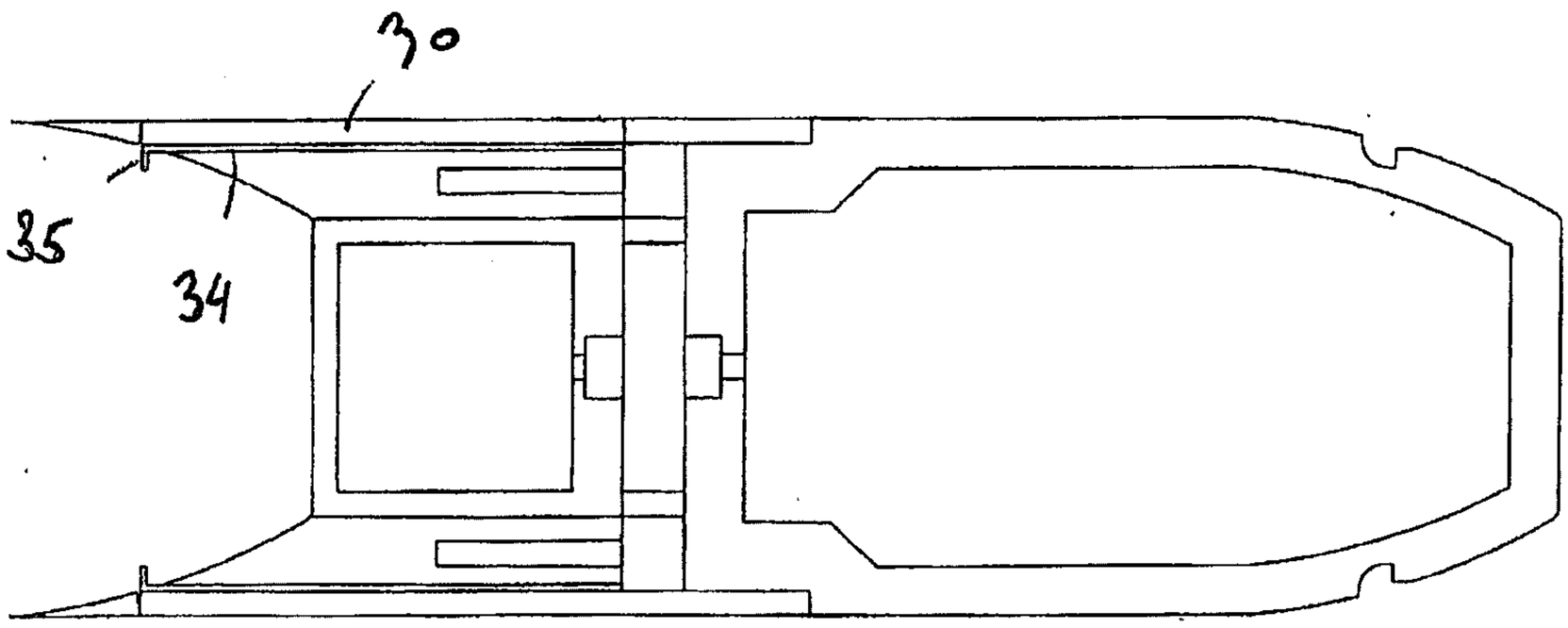


FIGURE 8b

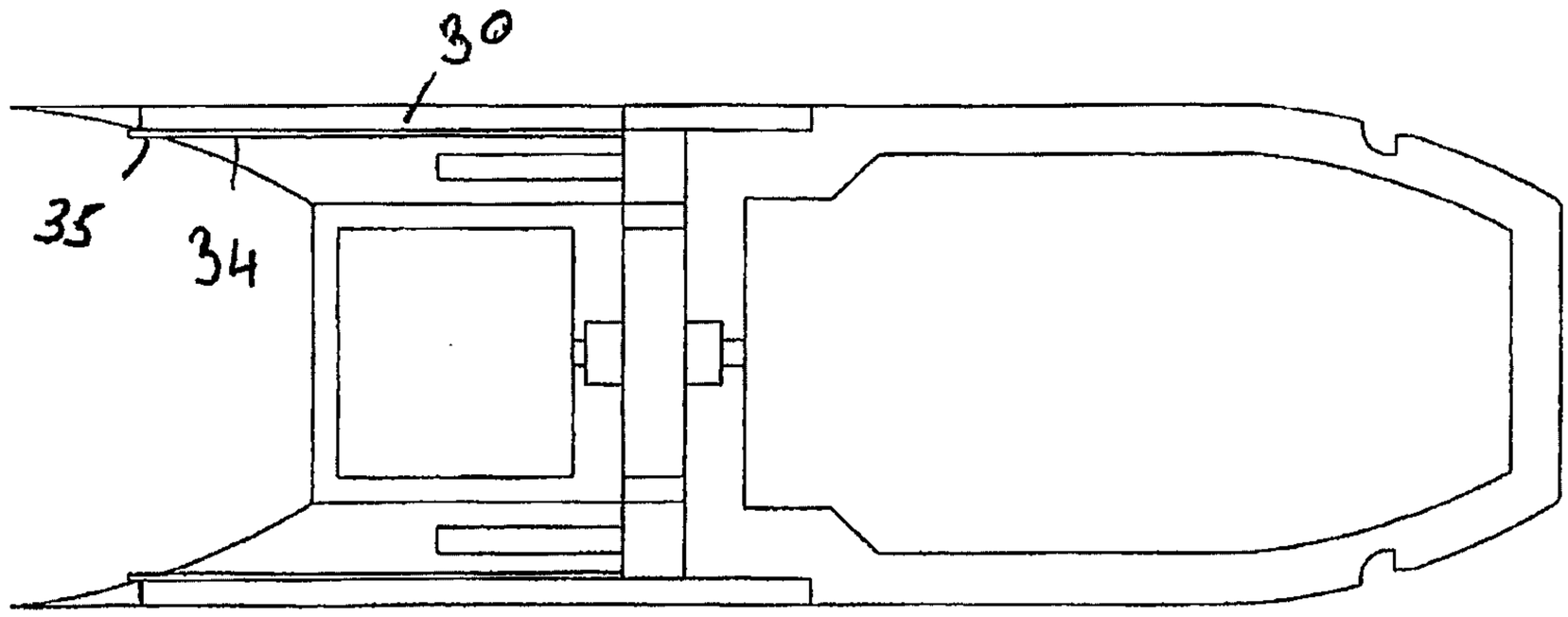


FIGURE 8c

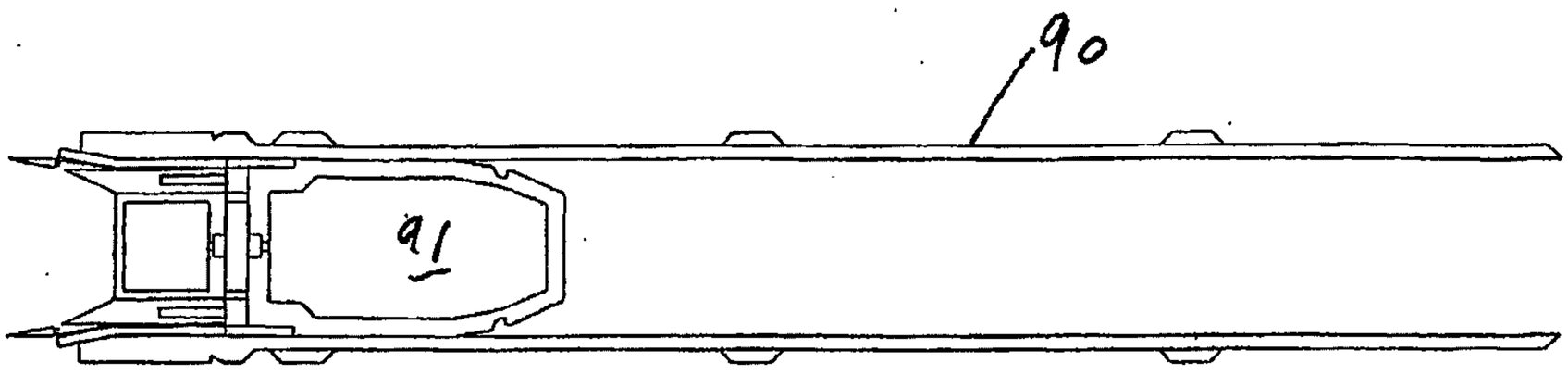


FIGURE 9a

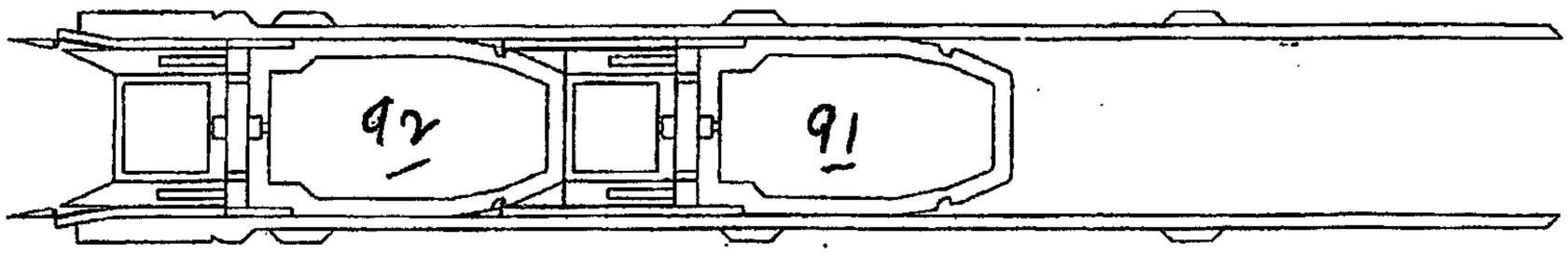


FIGURE 9b

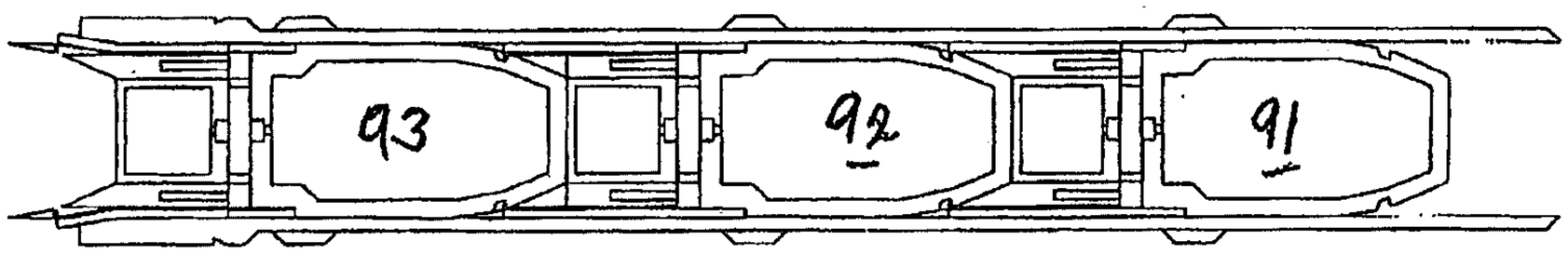


FIGURE 9c

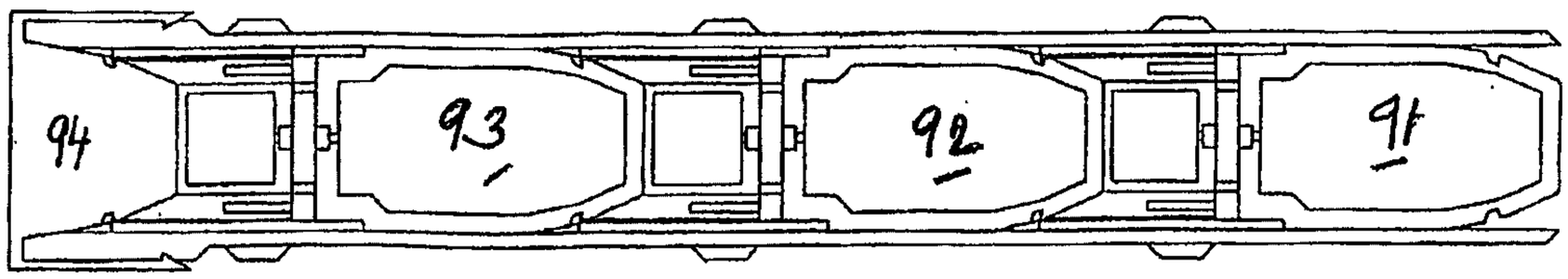


FIGURE 9d

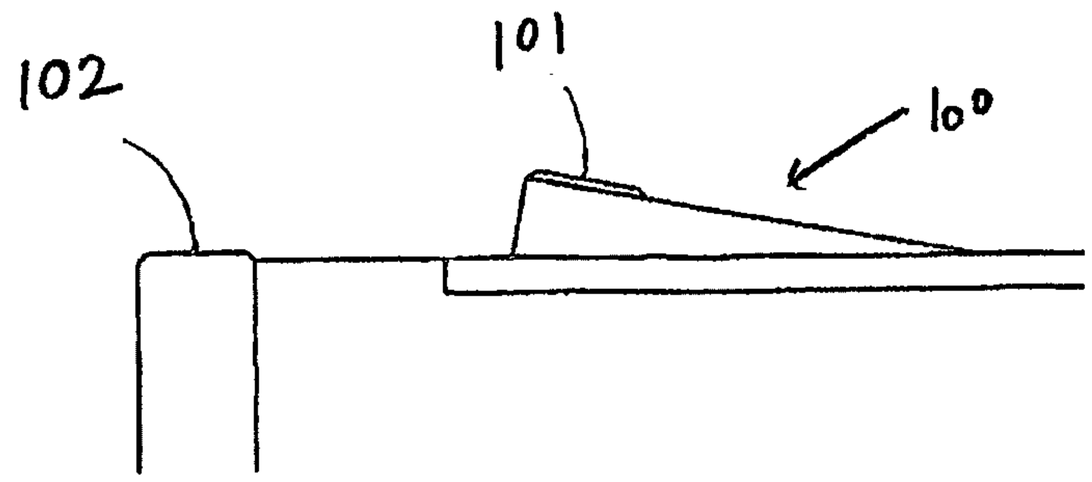


FIGURE 10a

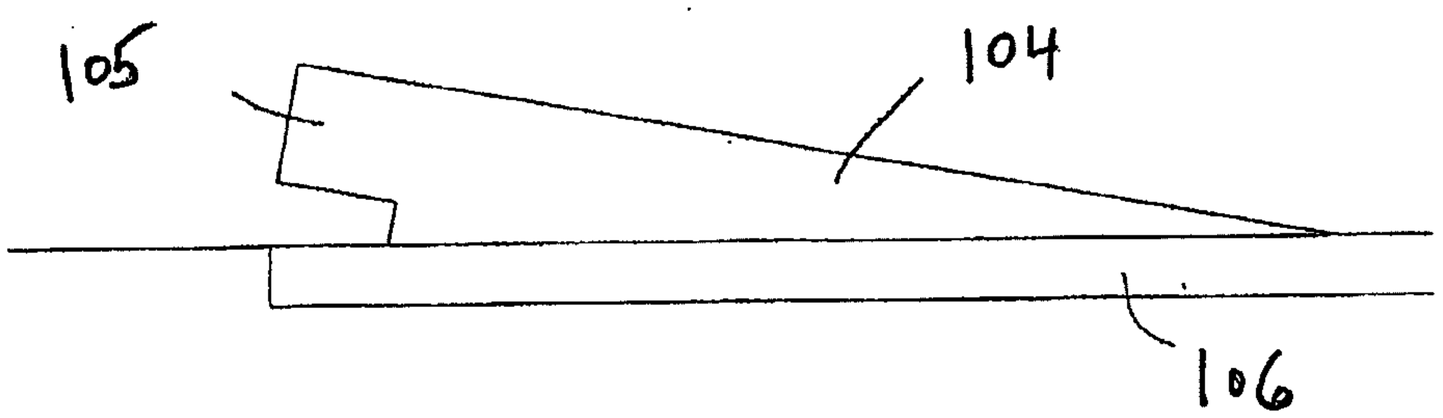


FIGURE 10b

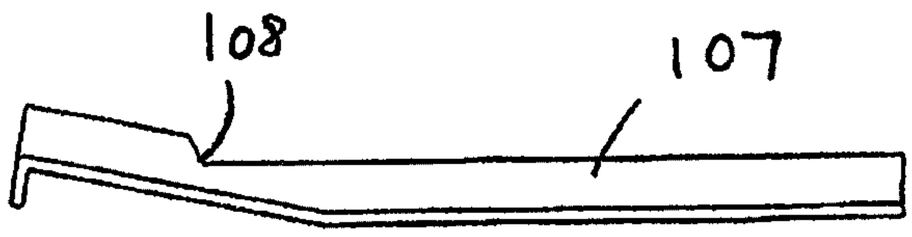


FIGURE 10c

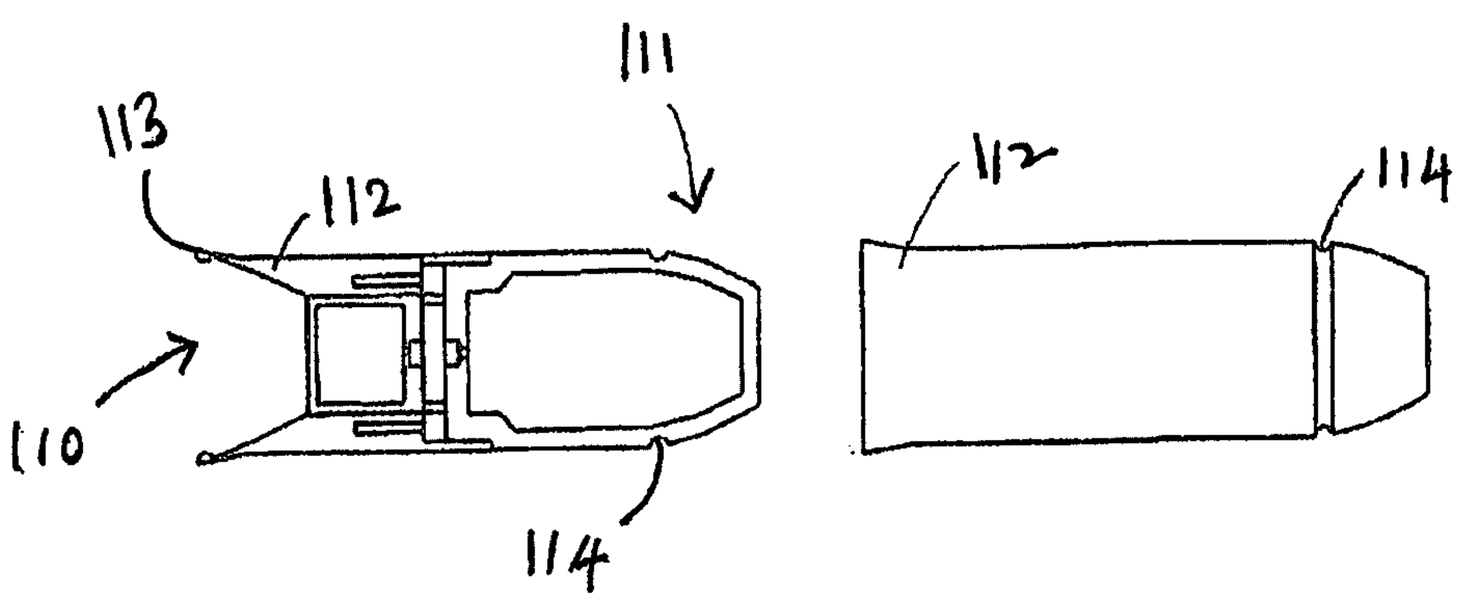


FIGURE 11a

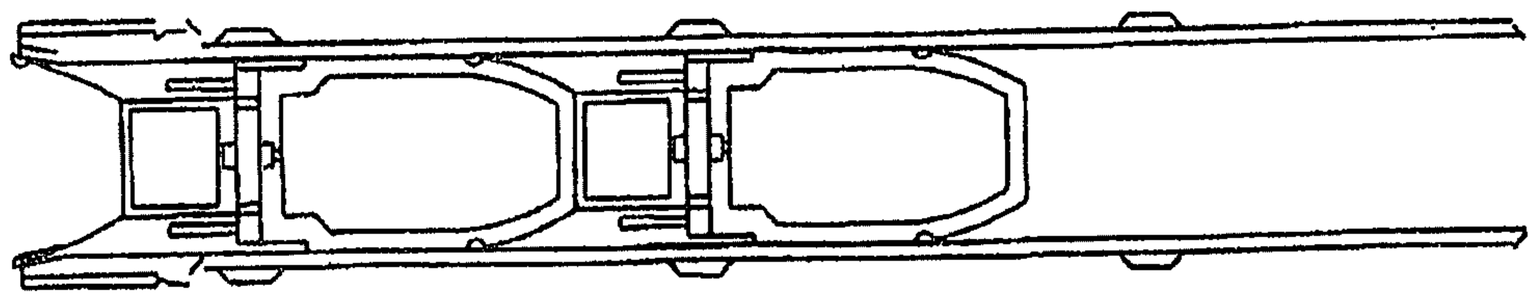


FIGURE 11b

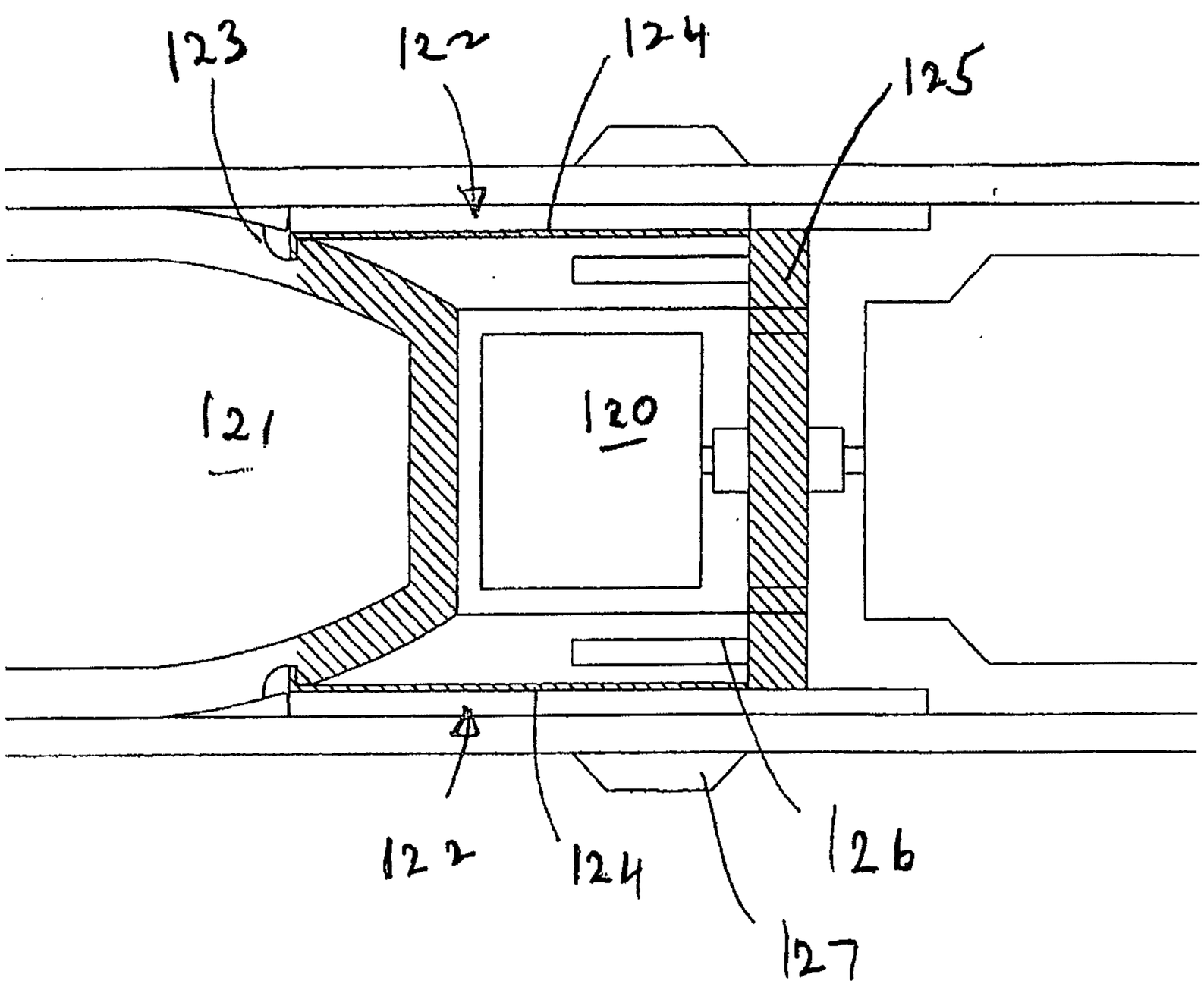


FIGURE 12

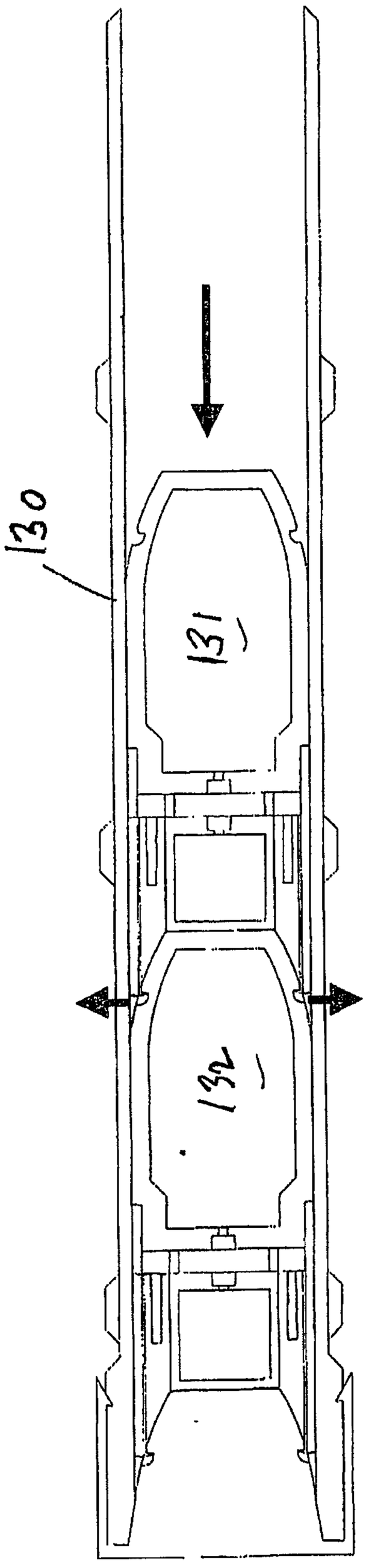


FIGURE 13

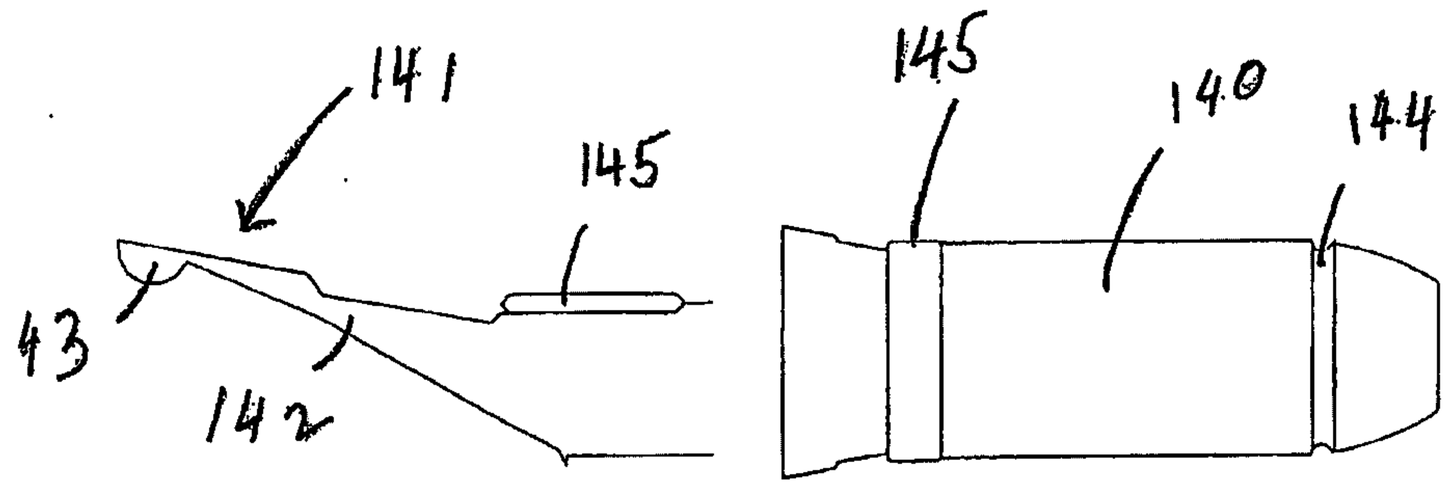


FIGURE 14a

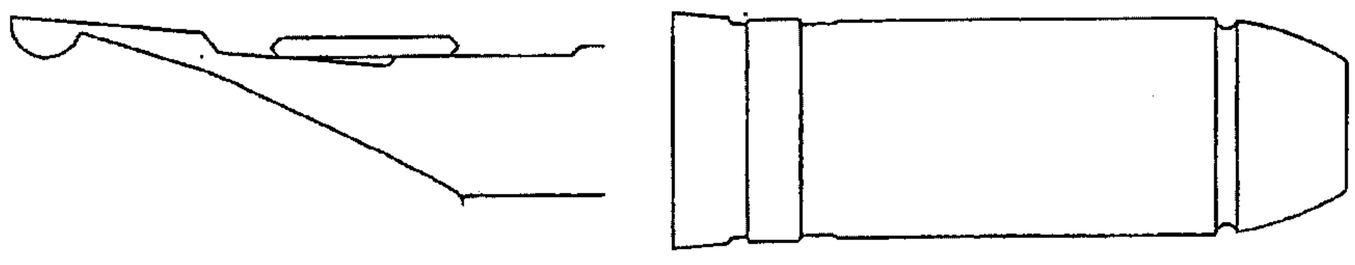


FIGURE 14b

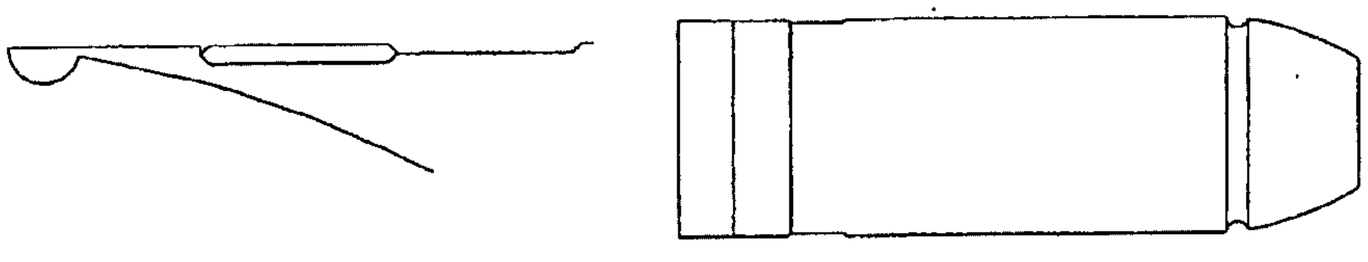


FIGURE 14c

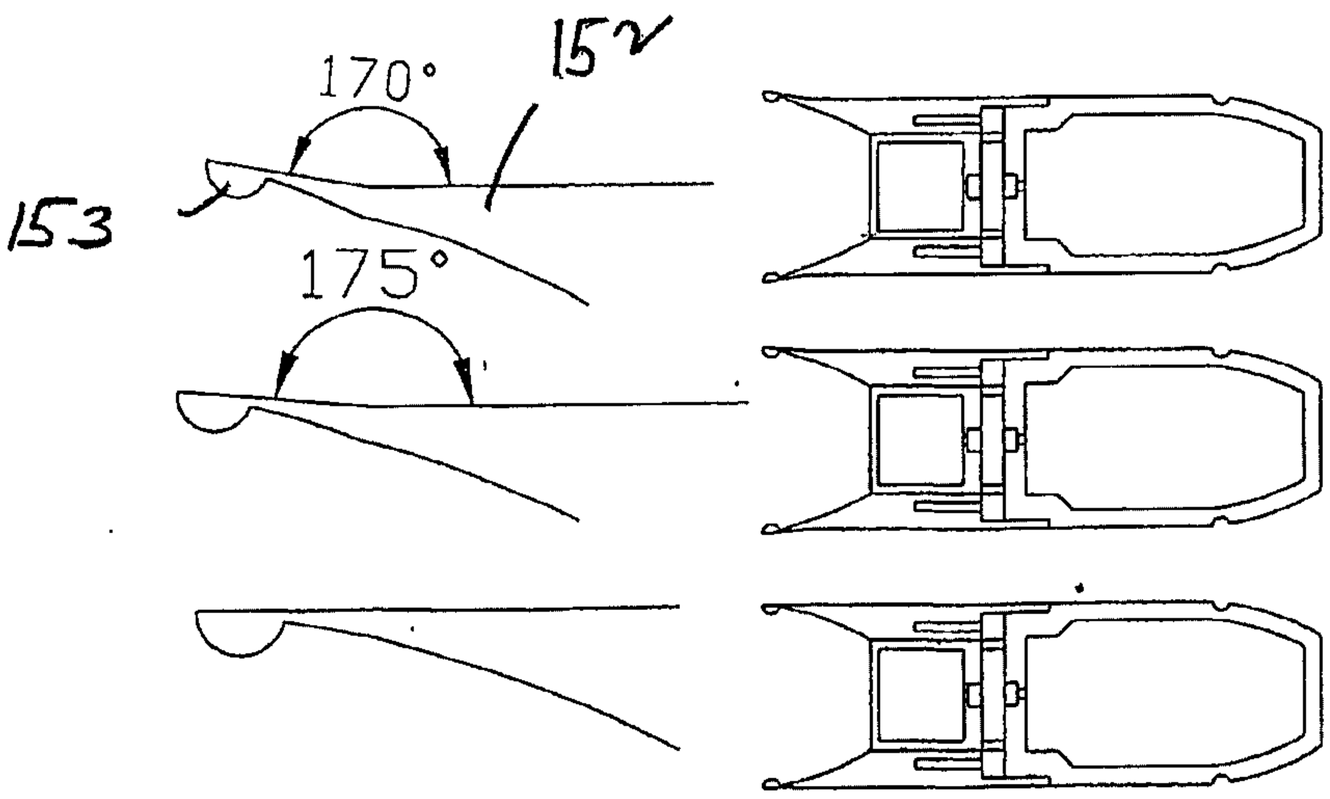


FIGURE 15a

FIGURE 15b

FIGURE 15c

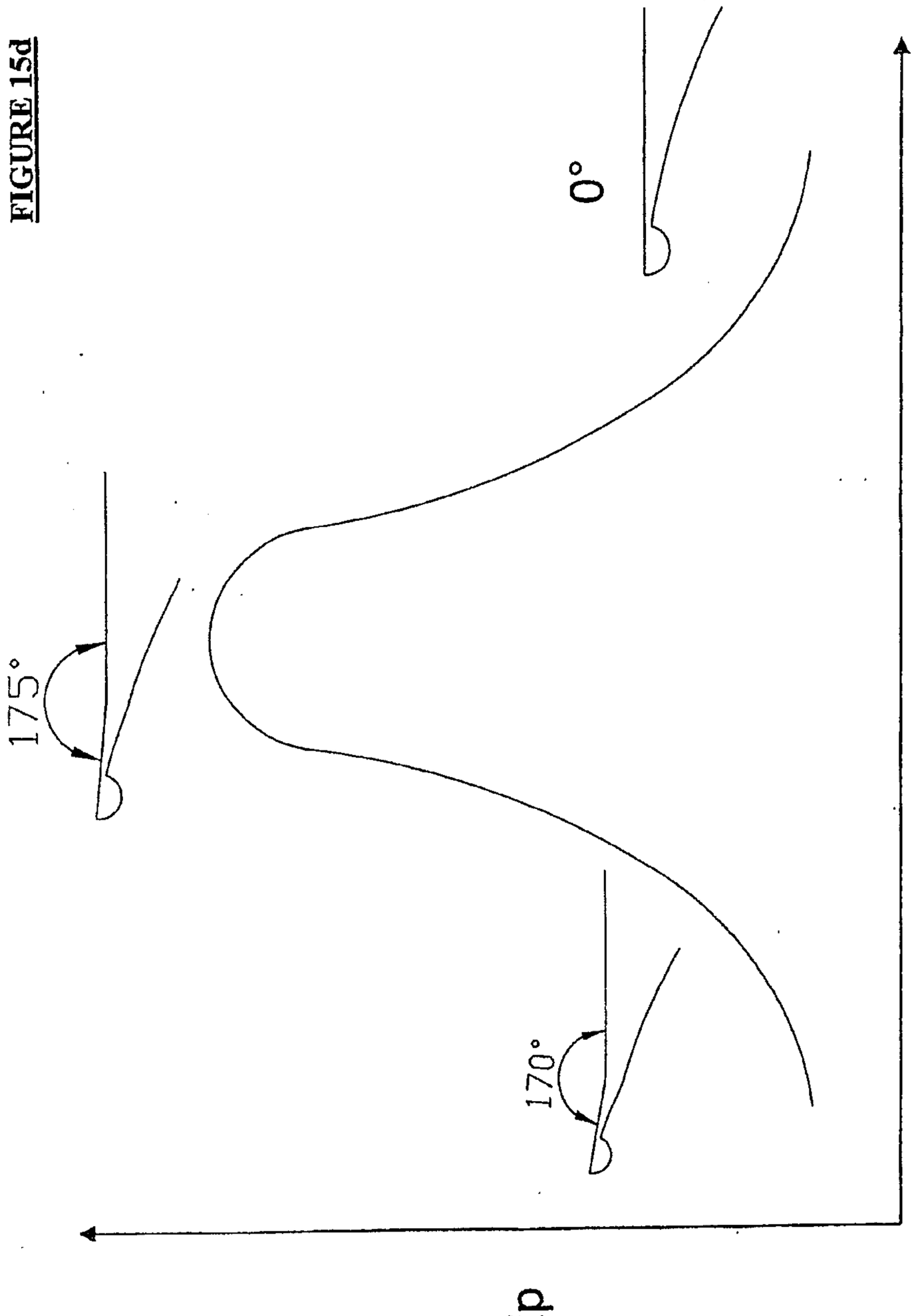

175°
0°
170°
Clip position
Potential energy stored as elastic deformation of clip material

FIGURE 15d

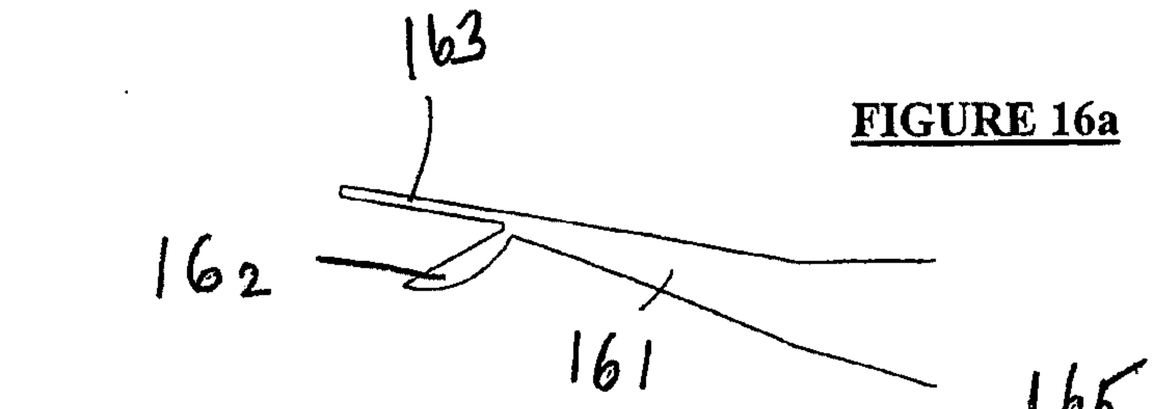


FIGURE 16a

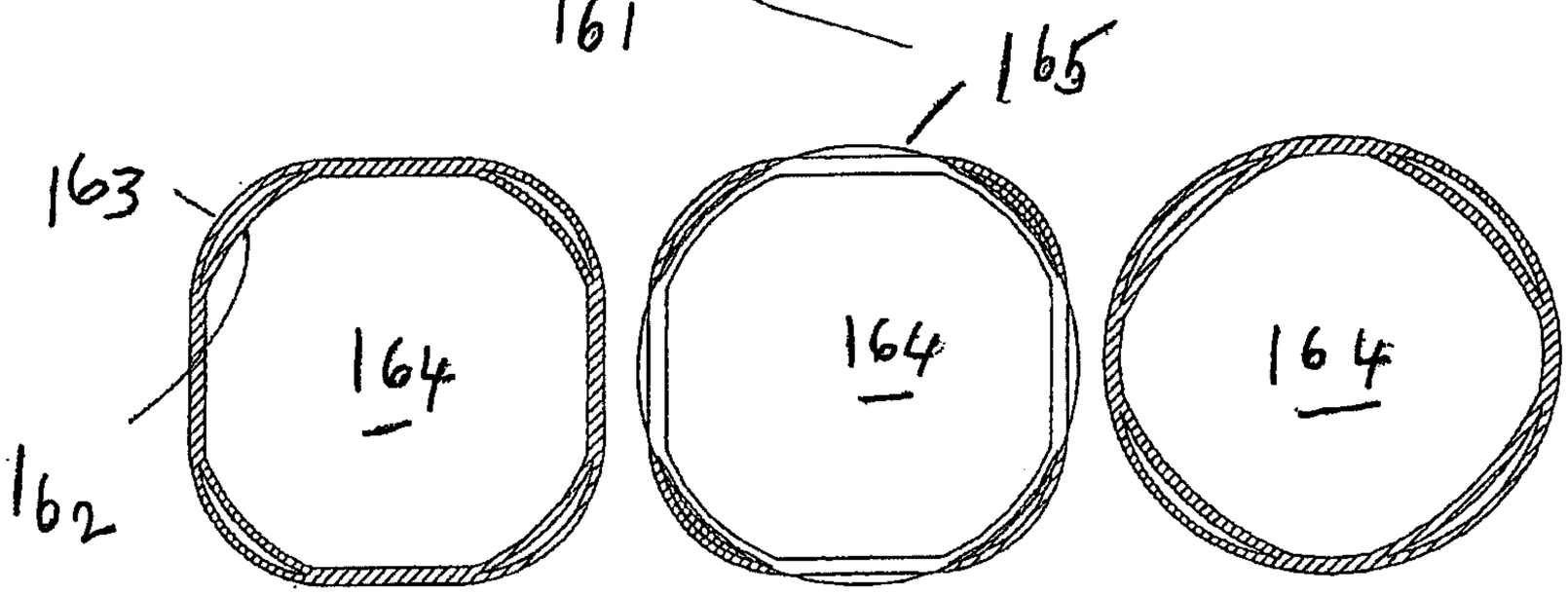


FIGURE 16b FIGURE 16d FIGURE 16c

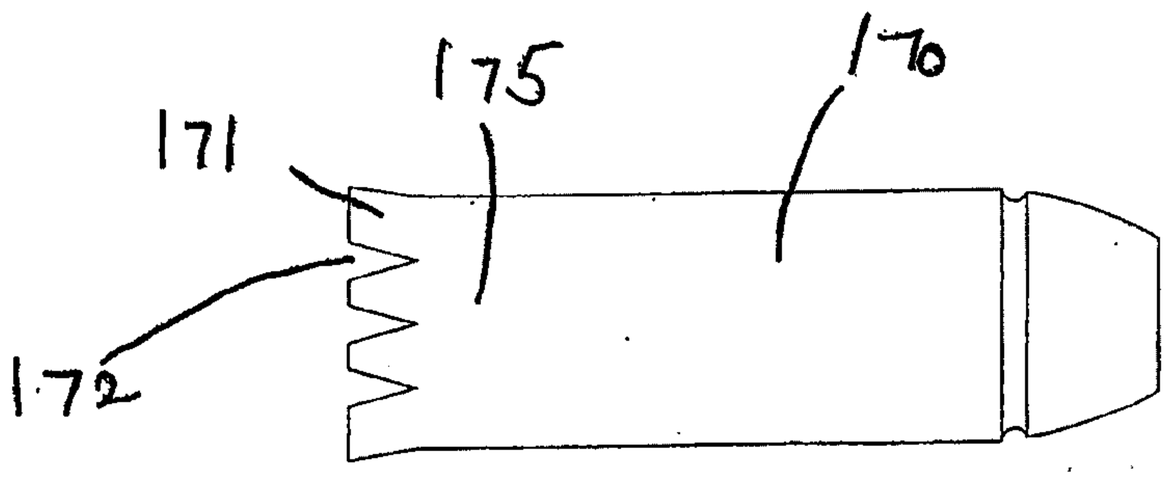


FIGURE 17a

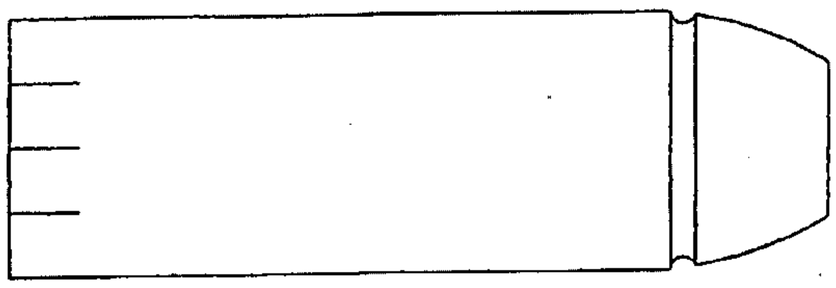


FIGURE 17b

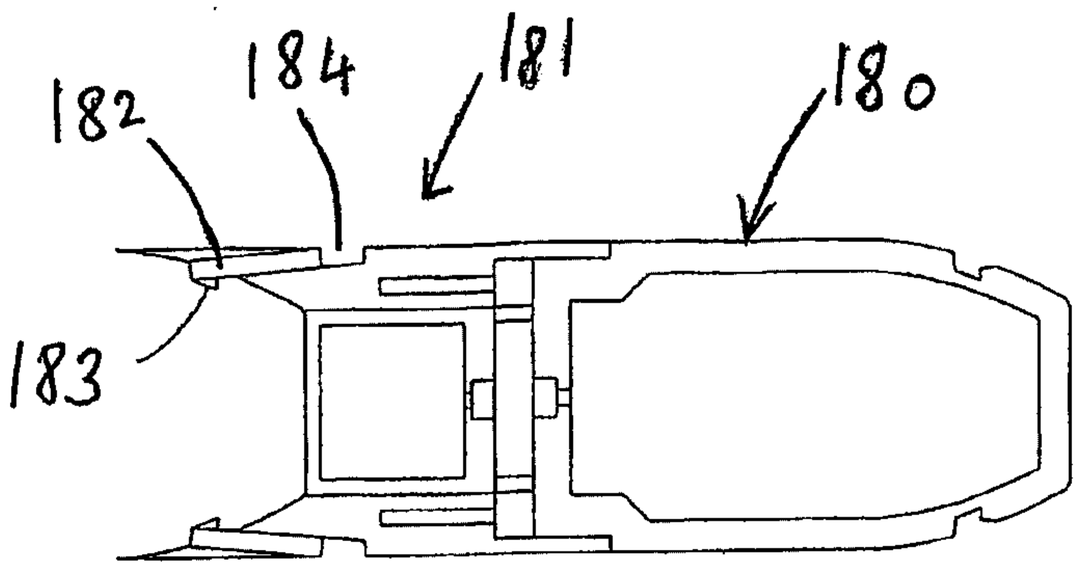


FIGURE 18a

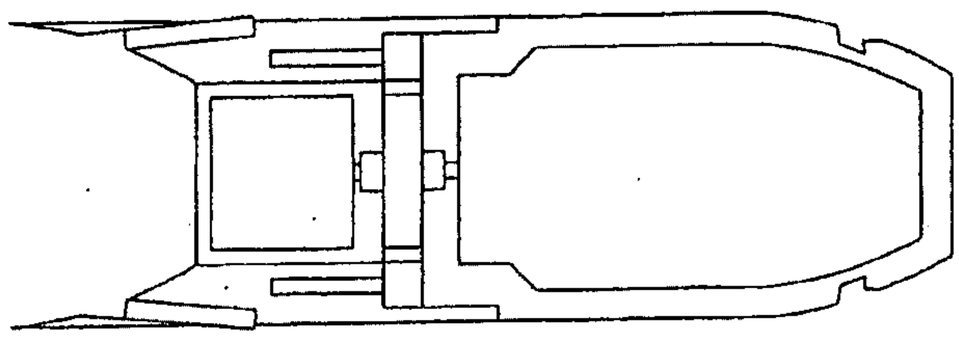


FIGURE 18b

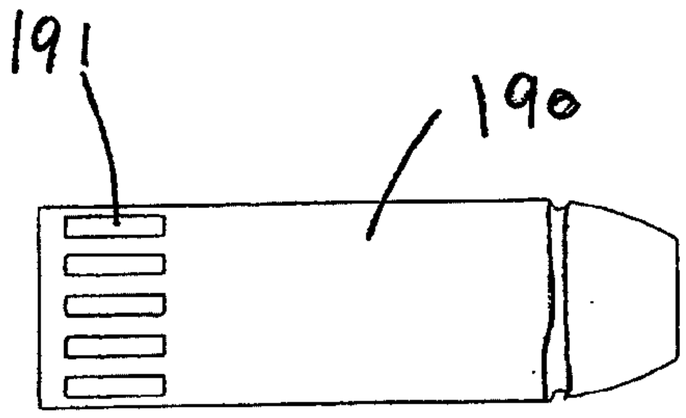


FIGURE 19a

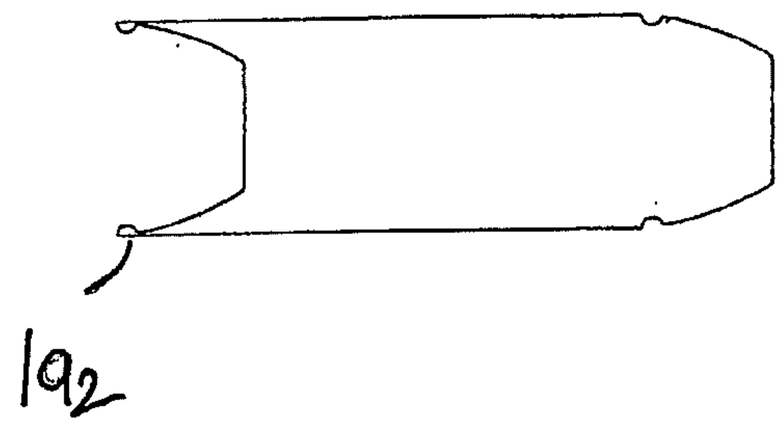


FIGURE 19b

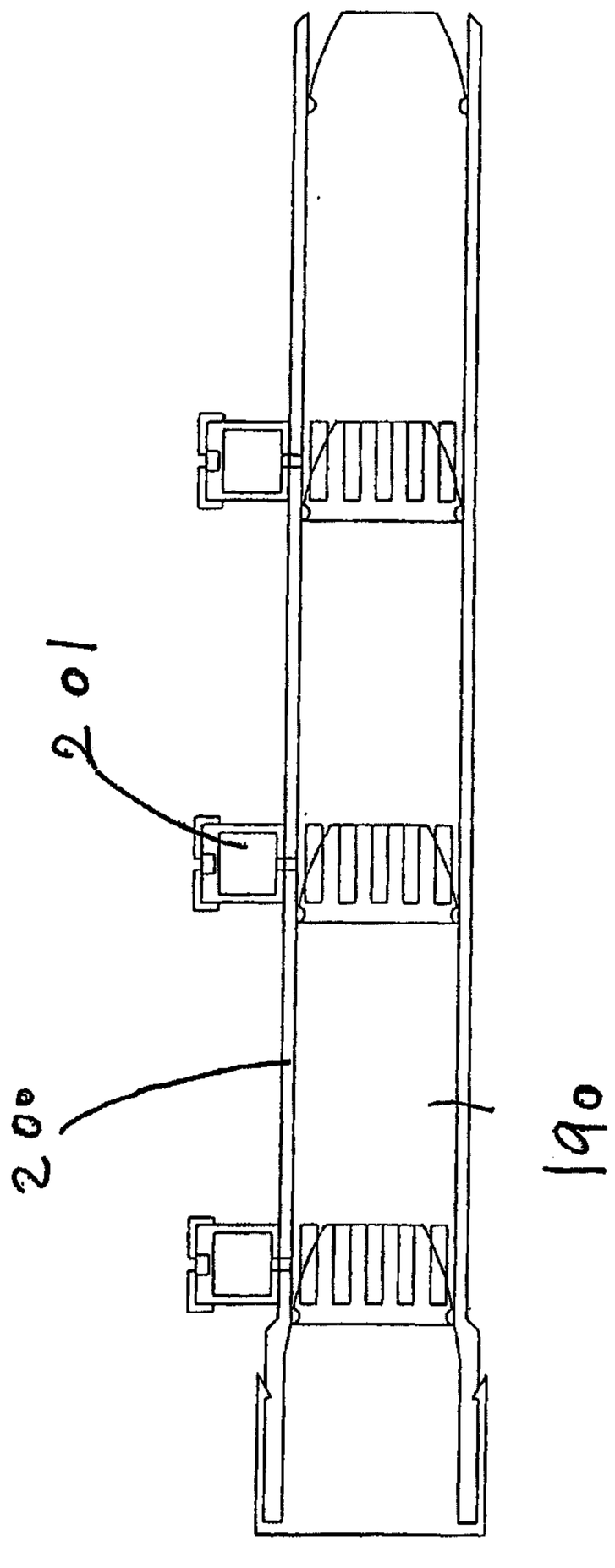


FIGURE 20

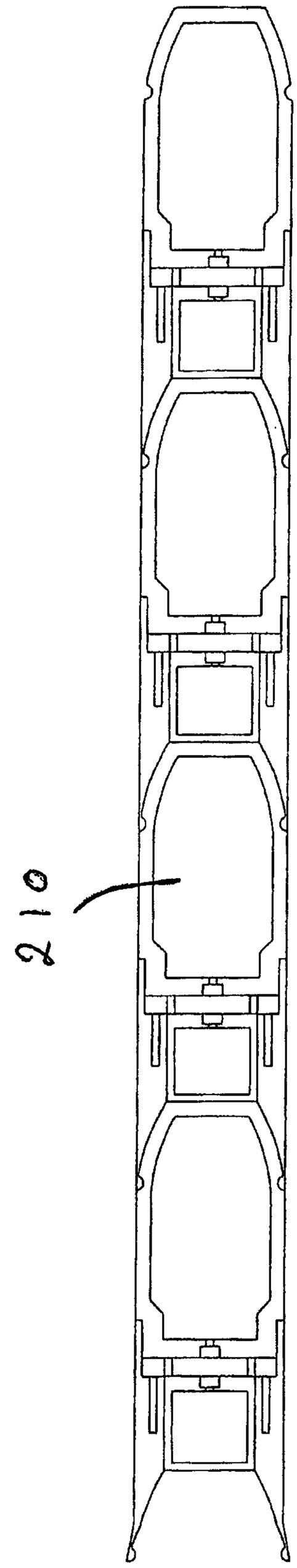
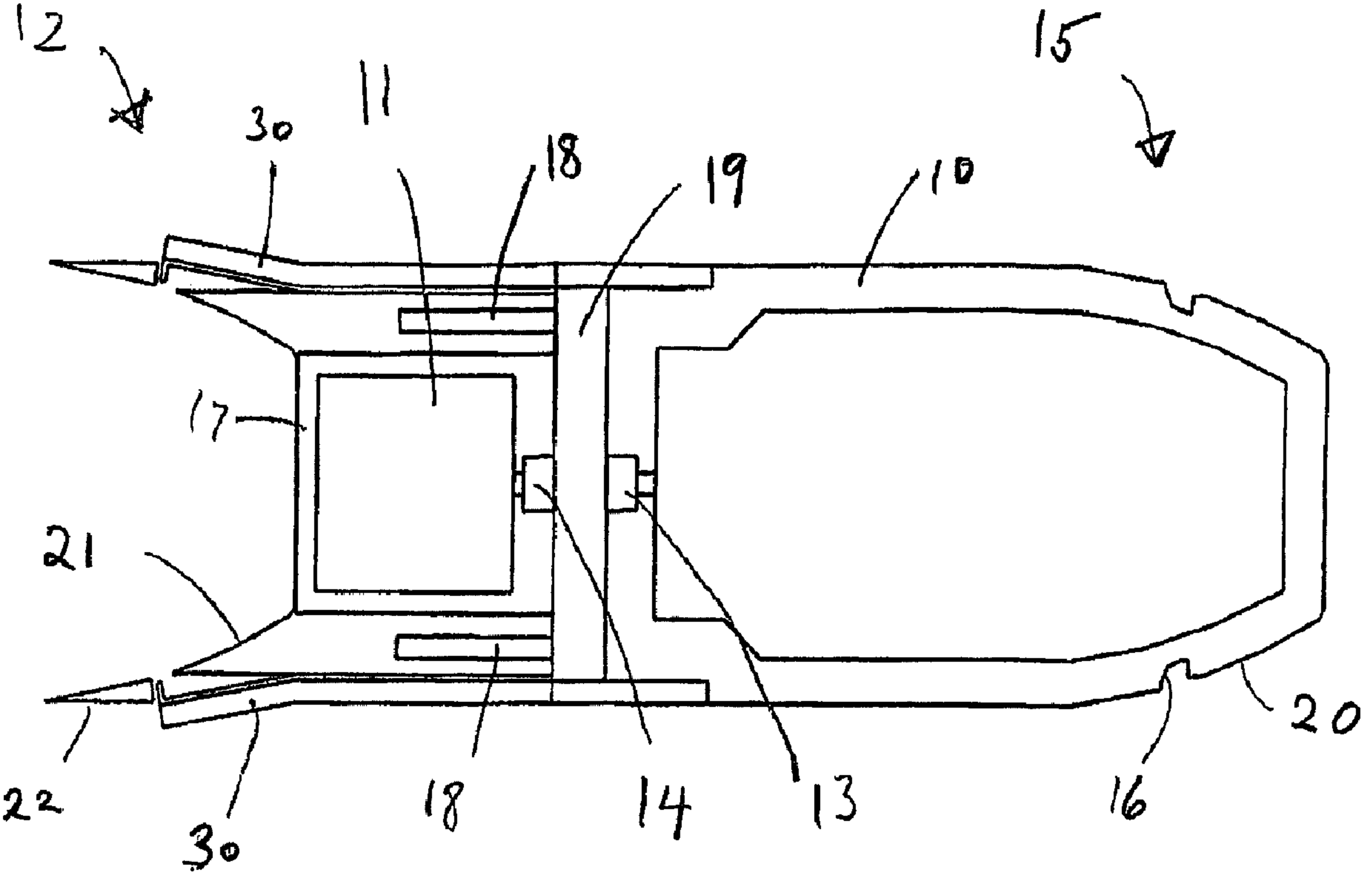


FIGURE 21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