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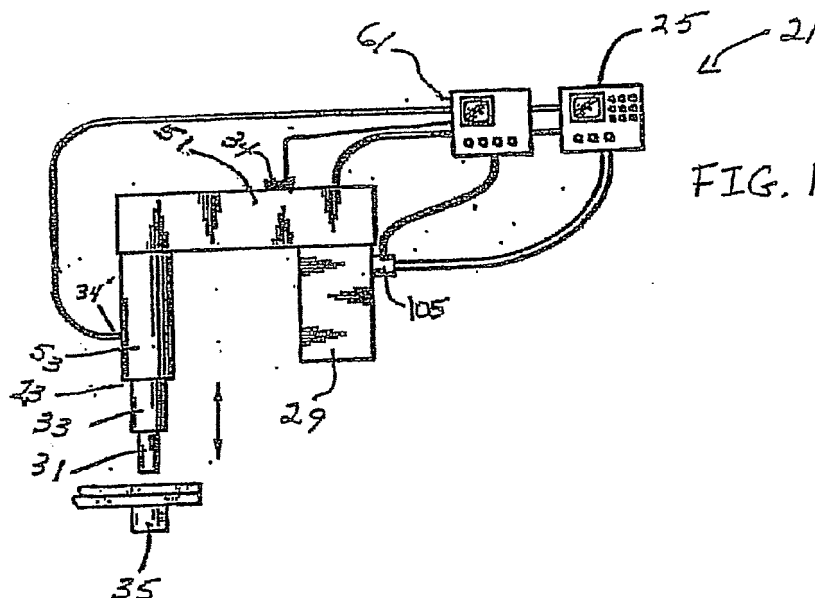
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(54) **Automated fastener setting tool**

(57) A fastener setting device includes a monitoring circuit having circuitry to receive a feed status signal from a first sensor within the feed system. The circuitry receives a robotic arm status signal from a second sensor

within the robotic arm and receives a rivet set status signal from a third sensor within the setting tool. The circuit determines if a fault condition occurs; and initiates a rivet clearing procedure if a fault condition is detected.



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## Description

### CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application claims the benefit of U.S. Provisional Application No. 61/615,562, filed on March 26, 2012. The entire disclosure of the above application is incorporated herein by reference.

### FIELD

**[0002]** The present disclosure relates to rivet setting devices and, more particularly, to a control system and method for a rivet setting device which will clear a fastener from a feed mechanism upon detection of a fault condition.

### BACKGROUND

**[0003]** The background description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

**[0004]** Fastener setting devices are often coupled to robotic arms and include mechanisms that apply forces to a fastener to plastically deform the fastener to couple two outputs together. Often, the fastener setting device has an associated fastener feeding device to feed fasteners into the device. The robotic arms can be configured to equally position the rivet setting device in specific locations along an assembly to couple various rivets onto a structure.

**[0005]** Unfortunately, failures in the robotic or the fastener feeding system can cause the system to stop unexpectedly. When this happens, undeformed or unset fasteners located within the feeding system or within the fastener setting machine must be removed before the fastener setting system can be restarted. To remove the fasteners, the feed system and setting tool must be disassembled, thus increasing costs and delaying production.

### SUMMARY

**[0006]** A system for setting a fastener includes a mode control module, a robot control module, and a fastener set module. The fastener set module selectively sets a fastener feed mode, a fastener set mode, and a fastener clear mode. In response to a fastener set error signal, the module transfers from one of the fastener set mode and fastener feed mode to the fastener clear mode.

**[0007]** The robot control module operates a fastener set clear mode during a fastener clear cycle. To accomplish this, the control module operates a mandrel clear

mode during a first robotic cycle, and operates a drive coupled to a mandrel actuator. The first robotic cycle moves the fastener set mechanism to a fastener feed discharge station a fixed distance from the workpiece. At the discharge station, the fastener is set into a dummy workpiece, thus clearing the feed mechanism.

**[0008]** A method for setting a fastener using a fastener setting device includes selectively moving from a status check mode for a fastener setting apparatus to one of a feeding mode, a setting mode, and a clearing mode. In response to an error signal from one of the feeding mode or the setting mode to the clearing mode, during a first system cycle operating a mandrel actuator in a fastener setting mode, and operating the robotic arm into a second system cycle.

**[0009]** A system for setting a self-piercing rivet is disclosed. The system has a self-piercing rivet setting tool. The tool includes a rivet engaging assembly, an axially movable piston assembly operatively coupled to said rivet for driving the rivet. The system includes a monitoring circuit, having circuitry to: receive a feed status signal from a first sensor within the feed system; receive a robotic arm status signal from a second sensor within the robotic arm; receive a rivet set status signal from a third sensor within the setting tool; determine if a fault condition occurs; and to initiate a rivet clearing procedure if a fault condition is detected.

**[0010]** The features of the system and of the methods mentioned above may be combined and/or exchanged with each other.

**[0011]** Preferred embodiments of the invention can be found in the subclaims.

**[0012]** Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

### DRAWINGS

**[0013]** The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

**[0014]** Figure 1 is a diagrammatic view showing a preferred embodiment of a riveting system according to the present teachings;

**[0015]** Figure 2 is a partially diagrammatic, partially elevational view according to the present teachings;

**[0016]** Figure 3 is a perspective view showing a riveting tool according to the present teachings;

**[0017]** Figure 4 is an exploded perspective view showing the nut and spindle mechanism, punch assembly, and clamp according to the present teachings;

**[0018]** Figure 5 is a cross sectional view, taken along line 5 of Figure 3, showing the riveting tool according to the present teachings;

**[0019]** Figure 6 is an exploded perspective view show-

ing a receiving head according to the present teachings;

**[0020]** Figure 7 is a cross sectional view showing the receiving head according to the present teachings;

**[0021]** Figure 8 is a partially fragmented perspective view showing a rivet feed tube according to the present teachings;

**[0022]** Figure 9 is an exploded perspective view showing a feeder according to the present teachings;

**[0023]** Figures 10a-10h are a series of cross sectional views, showing the self-piercing riveting sequence according to the present teachings;

**[0024]** Figures 11a-11e are a series of diagrammatic and enlarged views, similar to those of Figure 10, showing the self-piercing riveting sequence according to the present teachings;

**[0025]** Figure 12 is a diagrammatic view showing the control system according to the present teachings;

**[0026]** Figure 13 is a graph showing sense versus distance riveting characteristics according to the present teachings;

**[0027]** Figures 14a-14d are diagrams of example fastener setting systems according to the present disclosure in an example flowchart depicting an example method of controlling a fastener setting device for a transition from a fastener set mode to a fastener clearing set mode according to the present teachings;

**[0028]** Figure 15 is a partially diagrammatic, partially side elevational view showing another embodiment of a riveting system according to the present teachings; and

**[0029]** Figures 16a-16c represent a rivet clearing station and its interaction with the fastener setting tool according to the present teachings, where corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

## DETAILED DESCRIPTION

**[0030]** The following description of the preferred embodiments is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses. Generally speaking, the system sets a fastener for joining parts. The system is configured to confirm the quality of the setting process and of the resultant set as well as the status of the feed system. The system uses a rivet setting machine 23 having a first member configured to apply a setting force to a fastener to set the fastener. A coupling structure is provided which is configured to apply reaction forces to the first member in response to the setting force. Sensors of a plurality of sensors attached to the feed mechanism's structure individually sense changes in physical parameters within the feed system induced by a moving or stationary fastener.

**[0031]** A sensor 34 is configured to measure the presence of a fastener at a location which is a predetermined location within the feed system. As described below, the sensor 34 is located at a location on the feed tube which is susceptible to strains induced by moments caused by the movement of the fastener. Because of its location,

the sensor 34 is capable of being calibrated to indicate changes in physical parameters that can be displayed in comparative terms. Further, because of its location, sensor 34 need not be calibrated after routine maintenance such as the changing of dies or punch components. Optionally, the sensor 34 can be optical, magnetic, or magneto restrictive.

**[0032]** A first member or plunger 31 applies the setting force along an axis to a first side of the fastener and the setting force is resisted by a second member which applies a reaction force generally parallel to the setting force. This reaction force is caused by elastic deformation in the coupling structure. These forces can be used to detect the quality of a rivet set and can be used to set a default code. At this point, the system can determine if an additional fastener is located within the feed system that needs to be cleared.

**[0033]** Referring to Figures 1 and 2, a joining device for punch rivets, hereinafter known as a riveting system 21, includes a riveting machine or tool 23, a main electronic control unit 25, a plurality of feed sensors 34 and 34', a rivet feeder 27, and associated robotic movement mechanism and controls. Riveting tool 23 further has a drive mechanism which can be either hydraulic (not shown) or electric. The electric drive has an electric motor 29, a transmission unit, a plunger 31, a clamp 33, and a die or anvil 35. The hydraulic drive, when used, can utilize hydraulic fluid driven by a fluid initiated piston. The fluid initiated piston can be driven by either hydraulic or pneumatic fluid. While not needed for a blind fastener, the die 35 is preferably attached to a C-shaped frame 37 or the like. Frame 37 also couples the advancing portion of riveting tool 23 to a set of linear slides 39 which are, in turn, coupled to an articulated robot mounted to a factory floor. A linear slide control unit 41 and an electronic robot control unit 43 are electrically connected to linear slides 39 and main electronic control unit 25, respectively. The slides 39 are actuated by a pneumatic or hydraulic pressure source 45.

**[0034]** The transmission unit of riveting tool 23 can include a reduction gear unit 51 and a spindle drive mechanism 53. Plunger 31, also known as a punch assembly, includes a punch holder and punch, as will be described in further detail hereinafter. A data monitoring unit 61 may be part of the electronic control unit 25, as shown in Figure 2, or can be a separate microprocessing unit, as shown in Figure 1, to assist in monitoring signals from the various system monitoring sensors. As will be described in detail below, the system also utilizes feed sensors, force sensors, and strain sensors.

**[0035]** Referring to Figures 3, 5, and 6, the main electronic control unit 25 contains a microprocessor, a display screen, indicator lights, and input buttons. The main electronic control unit 25 is also electrically connected to the feed sensor 34 and other proximity switch sensors located in riveting tool 23. Electric motor 29 can be of a brushless, three-phase alternating current type. Energizing electric motor 29 serves to rotate an armature shaft

which, in turn, rotates an output gear 73. Electric motor 29 and output gear 73 are disposed within one or more cylindrical outer casings.

**[0036]** Reduction gear unit 51 includes gear housings 75 and 77 within which are disposed two different diameter spur gears 79 and 81. Various other ball bearings 83 and washers are located within housings 75 and 77. Additionally, removable plates 85 are bolted onto housing 75 to allow for lubrication. Spur gear 79 is coaxially aligned and driven by output gear 73, thus causing rotation of spur gear 81. Adapters 87 and 89 are also stationarily mounted to housing 77.

**[0037]** Referring to Figure 4 and again to Figures 1-3, when the system is associated with a self-piercing rivet, a nut housing 101 is directly connected to a central shaft of spur gear 79, therefore rotation of spur gear 79 causes a concurrent rotation of nut housing 101. Nut housing 101 is configured with a hollow and generally cylindrical proximal segment and a generally enlarged, cylindrical distal segment. A load cell 103 is concentrically positioned around a proximal segment of nut housing 101. Load cell 103 is electrically connected to a load cell interface 105 (see Figure 1) which, in turn, is electrically connected to monitoring unit 61. Load cell 103 preferably has a direct current bridge wherein the mechanical input force causes a change in resistance which generates a signal. Alternately, the load cell may be of a piezo-electric type.

**[0038]** A rotatable nut 111, also known as a ball, is directly received and coupled with a distal segment of nut housing 101 such that rotation of nut housing 101 causes a simultaneously corresponding rotation of nut 111. Ball bearing members 113 are disposed around nut housing 101. A spindle 115 has a set of external threads which are enmeshed with a set of internal threads of nut 111. Hence, rotation of nut 111 causes linear advancing and retracting movement of spindle 115 along a longitudinal axis. A proximal end of a rod-like punch holder 121 is bolted to an end of spindle 115 for corresponding linear translation along the longitudinal axis. A rod-like punch 123 is longitudinally and coaxially fastened to a distal end of punch holder 121 for simultaneous movement therewith.

**[0039]** An outwardly flanged section 125 of punch holder 121 abuts against a spring cup 127. This causes compression of a relatively soft compression spring 128 (approximately 100- 300 newtons of biasing force), which serves to drive a rivet out of the receiver and into an initial loaded position for engagement by a distal end of punch 123. A stronger compression spring 141 (approximately 8, 000- 15, 000 newtons of biasing force) is subsequently compressed by the advancing movement of punch holder 121. The biasing action of strong compression spring 141 serves to later retract a clamp 143 and nose piece back toward gear reduction unit 51 and away from the workpieces.

**[0040]** A main housing 145 has a proximal hollow and cylindrical segment for receiving the nut and spindle as-

sembly. Main housing 145 further has a pair of longitudinally elongated slots 147. A sleeve 149 is firmly secured to punch holder 121 and has transversely extending sets of rollers 151 or other such structures bolted thereto. Rollers 151 ride within slots 147 of main housing 145. Longitudinally elongated slots 153 of clamp 143 engage bushings 155 also bolted to sleeve 149. Thus, rollers 151 and slots 147 of main housing 145 serve to maintain the desired linear alignment of both punch holder 121 and clamp 143, as well as predominantly prevent rotation of these members. Additional external covers 157 are also provided. All of the moving parts are preferably made from steel.

**[0041]** Referring to Figures 3, 5, 8 and 12, one of the feed sensors 34 can be positioned either on the C-shaped support frame 37 or within the nose housing of the punch. A spindle position proximity switch sensor 201 is mounted within riveting tool 23. A spring-biased upper die and self-locking nut assembly 203 serve to actuate spindle position proximity switch sensor 201 upon the spindle assembly reaching a fully retracted, home position. A plate thickness proximity switch sensor 205 is also mounted within riveting tool 23. An upper die-type thickness measurement actuator and self-locking nut assembly 207 indicate the positioning of clamp 143 and thereby serve to actuate proximity switch sensor 205. Additional proximity switch sensors 34 and 34' are located in a feed tube for indicating the presence of a rivet therein in a position acceptable for subsequent insertion into the receiver of riveting tool 23. These proximity switch sensors 201, 205, 34 and 34' are all electrically connected to main electronic control unit 25 via a module 601. Furthermore, a resolver-type sensor 211 is connected to electric motor 29 or a member rotated therewith. Resolver sensor 211 serves to sense actuator torque, actuator speed, and/or transmission torque. The signal is then sent by the resolver to main electronic control unit 25. An additional sensor (not shown) connected to electric motor 29 is operable to sense and indicate power consumption or other electrical characteristics of the motor which indicate the performance characteristics of the motor; such a sensed reading is then sent to main electronic control unit 25.

**[0042]** Figures 6 and 7 best illustrate a receiver 241 attached to a distal end or head of riveting tool 23 adjacent punch 123. It is envisioned that the receiver 241 can incorporate a feed sensor, as previously described. An upper housing 243 is affixed to a lower housing 245 by way of a pair of quick disconnect fasteners 247. A clamp/nose piece portion 249 of the clamp assembly is screwed into lower housing 245 and serves to retain a slotted feed channel 251, compressibly held by an elastomeric O-ring 253. A pair of flexible fingers 255 pivot relative to housings 243 and 245 and act to temporarily locate a rivet 261 in a desired position aligned with punch 123 prior to insertion into the workpieces. Compression springs 262 serve to inwardly bias flexible fingers 255 toward the advancing axis of punch 123. Furthermore, a catch stop 263 is mounted to upper housing 243 by a pivot pin. Catch

stop 263 is downwardly biased from upper housing 243 by way of a compression spring 265.

**[0043]** Figures 7 and 8 illustrate a feed tube 271 having end connectors 273 and 275 and associated sensors 34 and 34'. End connector 273 is secured to receiver 241 (see Figure 8) and end connector 275 is secured to feeder 27 (see Figure 2). Feed tube 271 further includes a cylindrical outer protective tube 277 and an inner rivet carrying tube 279. Inner rivet carrying tube 279 has a T-shaped inside profile corresponding to an outside shape of the rivet fed therethrough. Feed tube 271 is semi-flexible. Entry and exit proximity switch sensors 36 and 36', respectively, monitor the passage of each rivet through feed tube 271 and individually send an indicating signal to main electronic control unit 25 (see Figures 2 and 15). The rivets are pneumatically supplied from feeder 27 to receiver 241 through feed tube 271.

**[0044]** Figure 9 shows the internal construction of the feeder 27. The feeder 27 can have a stamped metal casing 301, upper cover 303, and face plate 305. Feeder 27 is intended to be stationarily mounted to the factory floor. A storage bunker 307 is attached to an internal surface of face plate 305 and serves to retain the rivets prior to feeding. A rotary bowl or drum 309 is externally mounted to face plate 305. It is rotated by way of a rotary drive unit 311 and associated shafts. A pneumatic cylinder 313 actuates drive unit 311 and is controlled by a set of pneumatic valves 315 internally disposed within casing 301. An electrical connector 317 and associated wiring electrically connect feeder 27 to main electronic control unit 25 by way of module 601 (see Figures 2 and 12).

**[0045]** A pneumatically driven, sliding escapement mechanism 319 is also mounted to face plate 305 and is accessible to drum 309. A proximity switch sensor 34" is mounted to escapement mechanism 319 for indicating passage of each rivet from escapement mechanism 319. Proximity switch sensor 34" sends the appropriate signal to the main electronic control unit through module 601 (shown in Figure 12). Rotation of drum 309 causes rivets to pass through a slotted raceway 323 for feeding into escapement mechanism 319, which aligns the rivets and sends them into feed tube 271 (see Figure 8).

**[0046]** According to a preferred embodiment, Figures 10a- 10f and Figures 11a- 11e show the riveting process steps employing the system of the present invention. The preferred rivet employed is of a self-piercing and hollow type which does not fully pierce through the die-side workpiece. First, Figures 10a and 11a show the clamp/nose piece portion 249 and punch 123 starting from retracted positions relative to workpieces 50, 50' and moving thereto. Workpieces 50, 50' are preferably stamped sheet metal body panels of an automotive vehicle, such as will be found on a conventional pinch weld flange adjacent a door and window openings. The robot and linear slides will position the riveting tool adjacent the sheet metal flanges such that clamp/nose piece portion 249 and die 35 sandwich workpieces 50, 50' therebetween

at a target joint location. It is alternately envisioned that a manually (non-robotic) moved riveting tool or a stationary riveting tool can also be used with the present invention.

**[0047]** Figure 10b shows clamp/nose piece portion 249 clamping and compressing workpieces 50, 50' against die 35. Punch 123 has not yet begun to advance rivet 261 toward workpieces 50, 50'. At this point, the plate thickness proximity switch senses the thickness of the workpieces through location of the clamp assembly until the 4kn clamp spring is fully compressed; the plate thickness switch sends the appropriate signal to the main controller. Next, punch 123 advances rivet 261 to a point approximately 1 millimeter above the punch-side workpiece 50. This is shown in Figures 10c and 11 b. If the workpiece thickness dimension is determined to be within an acceptable range by the main electronic control unit, then the electric motor further advances punch 123 to insert rivet 261 into punch-side workpiece 50, as shown in Figure 11c, and then continuously advances the rivet into the die-side workpiece 50', as shown in Figures 10d and 11d. Die 35 serves to outwardly deform and diverge the distal end of rivet 261 opposite punch 123.

**[0048]** Figure 10e shows the system measuring the plate thickness of the workpieces 50, 50'. Finally, punch 123 and clamp/nose piece portion 249 are fully engaged to bring the fastener into engagement with the workpieces 50, 50'. This allows the system to measure the size of the fastener to determine if a fastener has been missed. Subsequently, the punch 123 and clamp/nose piece portion 249 are fully removed from the workpieces 50, 50' to be separated and removed from die 35 if an acceptable riveted joint is determined by the main electronic control unit based on sensed joint characteristics. As shown in Figure 11e, an acceptable riveted joint has an external head surface of rivet 261 positioned flush and co-planar with an exterior surface of punch-side workpiece 50'. Also, in an acceptable joint, the diverging distal end of rivet 261 has been sufficiently expanded to engage workpiece 50' without piercing completely through the exterior surface of die-side workpiece 50.

**[0049]** A simplified electrical diagram of a preferred embodiment riveting system is shown in Figure 12. Main electronic control unit 25, such as a high-speed industrial microprocessor computer, having a cycle time of about 0.02 milliseconds has been found to be satisfactory. A separate second microprocessor controller 61 is connected to main electronic control unit 25 by way of an analog input/output line 602 and an Encoder2 input 604 which measures the position of the spindle through a digital signal. Second microprocessor controller 61 receives an electric motor signal and a resolver signal. The load cell force signal is sent directly from the tool to the main electronic control unit 25 while the proximity switch signals (from the feeder, feed tube, and spindle home position sensors) are sent from the tool through an input/output delivery microprocessor module 601 and then to main electronic control unit 25. Input/output delivery mi-

croprocessor module 601 actuates error message indication lamps 603, receives a riveting start signal from an operator activatable switch 605, and relays control signals to feeder 27 from main electronic control unit 25. An IBS/CAN gateway transmits data from main electronic control unit 25 to a host system which displays and records trends in data such as joint quality, workpiece thickness, and the like.

**[0050]** Figure 13 is a feed/distance (displacement) graph showing a sequence of a single riveting operation or cycle and is directed with continuing reference to Figures 5-7 and 10a-10h. The first spiral spring distance range is indicative of the force and displacement of punch 123 due to light spring 128. The next displacement range entitled hold-down spring is indicative of the force and displacement generated by heavy spring 141, clamp 143, and the associated clamp/nose piece portion 249. As described above in the description of Figures 10a-10h, measurement of the sheet metal/workpiece thickness occurs at a predetermined point within this range by way of load cell 103 interacting with main electronic control unit 25. In the next rivet length range, the rivet length is sensed and determined through load cell 103 and main electronic control unit 25. In the distance range between 25 and 30mm, the middle line shown is the actual rivet signature sensed, while the upper line shown is the maximum tolerance band, and the lower line shown is the minimum tolerance band of an acceptable rivet length for use in the joining operation. If an out-of-tolerance rivet is received and indicated, the software will discontinue or "break off" the riveting process and send the appropriate error message.

**[0051]** The plunger, and optionally the clamp, can also be movable from a predeterminable rest position that can be changed through the computer software. The rest position of the plunger, and optionally of the clamp, is selected as a function of the design of the parts to be joined. If the parts to be joined are smooth metal plates, the distance between a riveting unit which comprises the plunger and the clamp and a die can be slightly greater than the thickness of the superimposed parts to be joined. If a part to be joined has a ridge, as viewed in the feed direction of the part to be joined, the rest position of the riveting unit is selected such that the ridge can be guided between the riveting unit and the die. Therefore, it is not necessary for the riveting unit always to be moved into its maximum possible end or home position.

**[0052]** A force or a characteristic corresponding to the force of the plunger, and optionally of the clamp, can be measured as a function of a change in strain within the rivet setting apparatus. This produces a measured level. This is compared with a desired level. If comparison shows that the measured level deviates from the desired level by a predetermined limit value in at least one predetermined range, a signal is triggered. This process control advantageously permits qualitative monitoring of the formation of a punch connection.

**[0053]** The feeder system includes the monitoring cir-

cuit configured to receive feed startup signals from a first sensor 34' in the feed system. The robot arm has a second sensor 42', while the setting tool has a third sensor 42'. The monitoring circuit is configured to monitor these sensors to determine if a fault condition is detected. Should a fault condition be detected, the monitoring system initiates a rivet clearing procedure.

**[0054]** The monitoring circuit can measure the feed of a fastener along an axial path of the feed tube 271. In this regard, the monitoring circuit measures the time between pulses and compares these pulses, as well as the timing of the pulses, to predetermined values. Should these values be out-of-tolerance, an error is issued and an improper feed signal can be provided. The signals can be compared to an associated test set of signals. This way, the monitoring circuit can determine if a fastener feed has been properly completed.

**[0055]** Figures 14a-14d show a flow chart of the computer software used in the main electronic control unit 25 for the preferred embodiment riveting system of the present invention. The beginning of the riveting cycle is started through an operator actuated switch, whereafter the system waits for the spindle to return to a home position. From a prestored memory location, a rivet joint number is read in order to determine the prestored characteristics for that specific joint in the automotive vehicle or other workpiece (e.g., joint number 16 out of 25 total). Thus, the workpiece thickness, rivet length, rivet quality, and force versus distance curves are recalled for comparison purposes for the joint to be riveted.

**[0056]** Next, the software determines if a rivet is present in the head based upon a proximity switch 34' signal. If not, the feeder 27 is energized to cause a rivet to be fed into the head. The spindle is then moved and the workpiece is clamped. The plate or workpiece thickness is then determined based on the load cell signals and compared against the recalled memory information setting forth the acceptable range. If the plate thickness is determined to be out of tolerance, then the riveting process is broken off or stopped. If the plate thickness is acceptable for that specific joint, then the rivet length is determined based on input signals from the load cell. If the punch force is too large, too soon in the stroke, then the rivet length is larger than an acceptable size, and vice versa for a small rivet. The riveting process is discontinued if the rivet length is out-of-tolerance. At any of these faults, the system will determine if a rivet is within the feed mechanism and initiate a clearing mode.

**[0057]** The spindle is then retracted after the joint is completed. As described below, the system will monitor the output of the feed sensor 34 to determine if a rivet set is acceptable. After the spindle is opened or retracted to the programmed home position, which may be different than the true and final home position, indicator signals are activated to indicate if the riveted joint setting is acceptable (if the riveting cycle is complete) and is ready for the next rivet setting cycle. It should also be appreciated that various resolver signals and motor power con-

sumption signals can also be used by second microprocessor 61 to indicate other quality characteristics of the joint, although they are not shown in these flow diagrams. However, such sensor readings would be compared against prestored memory values to determine whether to continue the riveting process or discontinue the riveting process and send an error signal. Motor sensor readings can also be used to store and display cycle-to-cycle trends in data to an output device such as a CRT screen or printout.

**[0058]** Shown is a separate software subroutine of error messages if the riveting process is broken off or discontinued. For example, if the plate thickness is unacceptable, then an error message will be sent, stating that the setting is not okay, with a specific error code. Similarly, if the rivet length was not acceptable, then a not okay setting signal will be sent with a specific error code. If another type of riveting fault has been determined, then another rivet setting not okay signal will be sent and a unique error code will be displayed. In this event, a rivet clearing routine is initiated.

**[0059]** Also represented are methodologies to determine if a rivet has been improperly set and if it has initiated the rivet clear module. The statistically significant feed and time or distance coordinates from these subsequent self-piercing rivet settings are monitored and collated. An exemplary set of data is formed from these feed versus time data. Tolerance bands are constructed based on the statistically significant sets of training data. There are various conditions that may exist in the setting of self-piercing rivets and these will be described separately.

**[0060]** To generate a baseline to compare the quality of rivets, a baseline rivet feed curve is generated. Figure 18a represents the system performance after a rivet clear mode has been initiated. Figures 14b-14d represent the detection of a plurality of rivets by comparing detected sensor signal curves to curves which are used to generate average feed or presence versus time curves to be used by the system. Specifically, the detection of a fastener having a length which is too long, too short, or not to spec. Optionally, statistical techniques can be employed related to strains in the rivet setting system to determine if a sample load versus time curve is close enough to the meeting curve to determine if the specific curve is usable in formulating the meeting curve. Once the baseline curve is developed a pulse curve (Figure 13), the system 21' tracks the feed or pressure versus time data of each rivet set to determine if the system has created a potentially defective set.

**[0061]** Should a defective set be detected, the system (see Figure 18a) issues a warning and initiates the fastener clearing module. In this case, the robotic arm is instructed to move the fastener setting mechanism to a clearing station (see Figures 16a-16c). At the clearing station, a plate having a dummy hole allows for the mechanism to set the fastener, thus clearing the feed mechanism. The system then checks to determine if a fault code still exists.

**[0062]** In this system, all portions of the medium curve have the specific fixed-size tolerance band defined around them. The system then tracks the feed timing or sensing versus time data or curve of an individual rivet set to determine whether it falls outside of the tolerance band. In case the rivet does fall outside of the specific tolerance band, an alarm or warning is presented to the line operator.

**[0063]** Figures 14b and 14c represent the feeding of an incorrect rivet. In this regard, the flow chart describes the detection of a fastener being too short or too long. Specifically, it should be noted that the varying tolerance heights depend on the portion of each curve. Should a defective set be detected, the system issues a warning and initiates the fastener clearing module (see Figure 14a). In this case, the robotic arm is instructed to move the fastener setting mechanism to the clearing station. At the clearing station, a plate having a dummy hole allows for the mechanism to set the fastener, thus clearing the feed mechanism. Optionally, the system monitors the feeding system and identifies the length of time T1 needed to feed the rivet. T1 is compared to an example Time Te to determine if an acceptable rivet set occurs.

**[0064]** The system for setting a fastener includes a mode control module, a robot control module, and a fastener set module. The fastener set module selectively sets a fastener feed mode, a fastener set mode, and a fastener clear mode. In response to the fastener set signal, the module transfers from one of the set mode and feed mode to the clear mode.

**[0065]** Optionally, as shown in Figure 14a, if a defect is detected the robot control module operates a fastener set mechanism clear mode during a fastener clear cycle. The system then operates a mandrel clear mode during a first robotic cycle and operates a drive coupled to a mandrel actuator. During the feeder clear operation, the fastener setting mechanism is moved by the robotic arm to the clearing station. The rivet is then fed into the setting mechanism which is actuated to set the fastener into a dummy location.

**[0066]** A method for clearing a fastener setting device according to the present teachings includes selectively setting a fastening mode for a fastener setting apparatus to one of a feeding mode, a setting mode, and a clearing mode. In response to one of the feeding mode or the setting mode, in the clearing mode during a first system cycle a mandrel actuator operates in a fastener setting mode.

**[0067]** The system has a monitoring circuit or module which has circuitry to receive a feed status signal from the sensor within the feed system. The system also is configured to receive a robotic arm status signal from a sensor within the robotic control system and a rivet set status signal from the sensor within the feed system. An example set of output/time signals is formed and used to initiate a rivet clearing procedure if the feed status signal is positive, and should a fault condition be detected. An operator is optionally prompted to initiate the clearing

procedure.

**[0068]** The monitoring circuit further includes circuitry to produce, from a series of feed status signals, a measured rivet set status dataset. The circuit scans the measured rivet set status dataset to determine a first last local feed value. The example rivet set status dataset is scanned to determine a second last local feed value. At this point, the system determines if the first last local feed value and the second local feed values are within one of a predetermined time tolerance band or within a predetermined feed size tolerance band. The feed sensor is configured to measure feed in an axial direction. Should a fault condition be detected, an operator is prompted to initiate the clearing procedure.

**[0069]** The system further includes an indicator operatively connected to the measurement circuit for signaling to an operator the acceptability of the set based on the comparison of the feed output/predetermined value pairs. The first transducer can be a micro-strain sensor, a metal detector, or an optical sensor.

**[0070]** Optionally, the method of producing a rivet set status dataset is based on a series of measured feed signals and scanning the feed- versus- time dataset to determine the point in time during the rivet setting process when the highest value of feed occurred. The method can include the steps of monitoring the axial feed of a fastener during a rivet setting process and producing a series of feed signals related thereto. Then, the system monitors the time of the rivet setting process and producing a series of time signals related thereto and identifies the occurrence during the rivet setting process of an improper feed or set. This information is used to identify the occurrence of the initiation of the rivet setting process and to determine if an improper feed occurred to identify a fault. Upon the detection of a fault, the system, upon clearance by an operator, initiates a rivet feed mode. This mode includes moving the fastener setting head to a location a distance away from the workpiece and setting the fastener into a "dummy" plate. The system will then again check the status of the feed sensors to determine if a fastener is within the feed system.

**[0071]** The system produces a rivet feed status waveform based on the series of feed signals and the series of time signals produced over the rivet setting process. The rivet feed status waveform is used to identify the location of a feed peak in the waveform; and the system uses the location of the feed peak to identify the total time of the rivet feed event. The system then compares the rivet set status waveform with an example rivet set status waveform to determine if the rivet set is acceptable.

**[0072]** It is envisioned (see Figure 15) that two separate rivet feeders 27 and 27' can be employed. Rivet feeders 27 and 27' are of the same general construction as that disclosed above; however, the rivet length employed in the feeders 27, 27' can vary. Each feeder 27 and 27' transmits the specific length rivets to a selector junction device 40 by way of separate input feed tubes 30 and 30'. Selector device 40 has a pneumatically actuated re-

ciprocating slide mechanism which is electrically controlled by a main electronic control unit 47. When main electronic control unit 47 recalls the specific joint to be worked on, it then sends a signal to selector device 40 as to which rivet length is needed. Selector device 40 subsequently mechanically feeds the correct rivet through a single exit feed tube 44 which is connected to a receiver 38 of riveting tool 23. It is envisioned sensors 36 and 34' can be used to monitor the feed system.

**[0073]** Thus, a single riveting tool can be used to rivet multiple joints having rivets of differing selected sizes or material characteristics without the need for complicated mechanical variations or multiple riveting tool set ups. The software program within main electronic control unit 47 can easily cause differing rivets to be sent to the single riveting tool 23, and changes can be easily made by re-programming the main electronic control unit. This saves space on the crowded assembly plant line, reduces mechanical complexity, and reduces potential failure modes.

**[0074]** Referring to Figures 16a-16c and again to Figure 3, a discharge station 815 is provided according to the present teachings. Discharge station 815 includes a dummy plate 816 and an associated collection container 817. Optionally, the discharge station 815 can provide plate 816 of a predetermined thickness having a hole defined therein. When the fastener setting mechanism 23 is moved to the discharge station, the feeder 27 is engaged to feed the fastener to the setting mechanism 23. A sensor 818 is disposed at the discharge station. Sensor 818 issues a signal when the fastener has left the upper housing 243 of receiver 241. The electronic control unit 25 upon receipt of the signal from sensor 818 actuates the fastener setting mechanism 23. After being positioned, the fastener is then set into the dummy plate 816. Optionally, the detection system will then re-check the feeder mechanism to determine if a second fastener has been fed. Electronic control unit 25 confirms if a second fastener is detected, the fastener setting mechanism 23 leaves the discharge station, and the feeder 27 will feed the second fastener to the fastener setting mechanism 23 for removal.

**[0075]** Figure 16c represents the retraction of the fastener setting tool 23 with the discharge station. It is envisioned the dummy plate can have an aperture which is oversized to facilitate the disposal of blind or self-piercing rivets. Optionally, the dummy plate can be indexable and capture the discarded fasteners therein.

**[0076]** The accuracy of riveting, as well as measurements in the preferred embodiment, is insured by use of the highly accurate electric servo motor and rotary-to-linear drive mechanism employed. For example, the rivet can be inserted into the workpieces with one tenth of a millimeter of accuracy. The control system of the present invention also provides a real time quality indication of the joint characteristics, rather than the traditional random sampling conducted after many hundreds of parts were improperly processed. Thus, the present invention



achieves higher quality, greater consistency, and lower cost riveted joints as compared to conventional constructions.

**[0077]** It should be noted that depending on the type of fastener or fastener setting equipment used, different shaped quality and feed curves are equally possible. As described below, while the time duration and magnitude of portions of these curves can vary by specific amounts, large deviations of these curves represent either a failure of the rivet set or a failure of the structure. As the system utilizes an average of "good" sets histories to set an acceptable median feed profile, the profile generated by the system is relatively independent of the orientation of the sensor 34 on feed system 27 or the specific manufacturing environment of the C-shaped frame 37. This is opposed to other systems which use load cell versus stroke length to perform an interpretation of an independent load stroke curve.

**[0078]** The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. For purposes of clarity, the same reference numbers will be used in the drawings to identify similar elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A or B or C), using a non-exclusive logical OR. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure.

**[0079]** Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

**[0080]** The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms "a," "an," and "the" may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms "comprises," "comprising," "including," and "having," are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or

groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

**[0081]** When an element or layer is referred to as being "on," "engaged to," "connected to," or "coupled to" another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being "directly on," "directly engaged to," "directly connected to," or "directly coupled to" another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., "between" versus "directly between," "adjacent" versus "directly adjacent," etc.). As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

**[0082]** Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as "first," "second," and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

**[0083]** Spatially relative terms, such as "inner," "outer," "beneath," "below," "lower," "above," "upper," and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the example term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

**[0084]** As used herein, the term module may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC); an electronic circuit; a combinational logic circuit; a field programmable gate array (FPGA); a processor (shared, dedicated, or group) that executes code; other suitable hardware components that provide the described functionality; or a combination of some or all of

the above, such as in a system-on-chip. The term module may include memory (shared, dedicated, or group) that stores code executed by the processor.

**[0085]** The term code, as used above, may include software, firmware, and/or microcode, and may refer to programs, routines, functions, classes, and/or objects. The term shared, as used above, means that some or all code from multiple modules may be executed using a single (shared) processor. In addition, some or all code from multiple modules may be stored by a single (shared) memory. The term group, as used above, means that some or all code from a single module may be executed using a group of processors. In addition, some or all code from a single module may be stored using a group of memories.

**[0086]** The apparatuses and methods described herein may be implemented by one or more computer programs executed by one or more processors. The computer programs include processor-executable instructions that are stored on a non-transitory tangible computer readable medium. The computer programs may also include stored data. Non-limiting examples of the non-transitory tangible computer readable medium are non-volatile memory, magnetic storage, and optical storage. The present application discloses in particular the aspects defined in the following clauses which form part of the present description, but are not claims:

(1). A system for setting a self-piercing rivet, said system comprising:

a self-piercing rivet setting tool, said tool including a rivet engaging assembly, an axially movable piston assembly operatively coupled to said rivet for driving said rivet, a housing annularly disposed about said piston;

a monitoring circuit, having circuitry to:

- (a) receive a feed status signal from a first sensor within the feed system;
- (b) receive a robotic arm status signal from a second sensor within the robotic arm;
- (c) receive a rivet set status signal from a third sensor within the setting tool;
- (d) determine if a fault condition is detected; and
- (e) initiate a rivet clearing procedure if a fault condition is detected.

(2). The system of Clause (1), wherein said monitoring circuit further includes circuitry to:

produce from a series of feed status signals and a measured rivet set status dataset;  
scan said measured rivet set status dataset to determine a first local feed value;  
scan an example rivet set status dataset to determine a second local feed value; and

determine if the first local feed value and the second local feed value are within one of a predetermined time tolerance band, or within a predetermined feed tolerance band.

(3). The system of Clause (1) or (2), wherein the first sensor is configured to measure feed of a fastener along an axial direction.

(4). The system of any of Clauses (1) to (3), further including an indicator operatively connected to said monitoring circuit for signaling to an operator the acceptability of a fastener feed based on said comparison of said feed output/ predetermined value pairs.

(5). The system of any of Clauses (1) to (4), wherein said first sensor is a micro-strain sensor.

(6). The system of any of Clauses (1) to (5), wherein the housing comprises a C-shaped structure.

(7). The system of any of Clauses (1) to (6), wherein the first sensor is positioned on an exterior surface of the feed system.

(8). The system of any of Clauses (1) to (7), wherein the body defines a sensor mounting location, said sensor mounting location being at a point on the feed system which experiences deformation during a rivet feed event.

(9). A method of setting a fastener with a setting tool having an axially movable piston assembly operatively coupled to an engaging assembly for driving said fastener in response to the application of pressurized hydraulic fluid to said piston assembly, said method being preferably adapted to be used on a system of any of Clauses (1) to (8), and including the steps of:

- (a) monitoring the feed status of a feed system during a rivet setting process and producing a series of measured feed/time signals related thereto;
- (b) defining an set of example feed/time signals;
- (c) aligning the measured feed/time signals to the example feed/time signals; and
- (d) identifying the occurrence of an improper feed during the rivet setting process from the feed/time signal based upon misalignment of signals.

(10). The method of Clause (9), further including the steps of:

producing a rivet set status dataset based on a series of measured force signal;  
scanning said force signal to determine the point

in time during the rivet setting process when the highest value of force occurs; and  
using said determined point to identify the rivet setpoint.

(11). A system for setting a self-piercing fastener and evaluating the acceptability of the set, said system being preferably combined with the system of any of Clauses (1) to (8) and/or being preferably adapted to conduct the method of Clause (9) or (10), and comprising:

a rivet setting tool, said tool including a C-shaped support body, a feed system, and a rivet engaging assembly configured to drive said fastener;  
a first transducer configured to measure a rivet feed within the feed system during a rivet setting process and producing feed status signal related thereto;  
a circuit, configured to:

- (a) receive a series of feed status signals and assign an associated time thereto during the rivet setting process;
- (b) identify the occurrence during the rivet setting process of the last local feed signal;
- (c) use the occurrence of the last local feed signal to identify the movement of the fastener;
- (d) determine the total time of said rivet feed process;
- (e) compare said total time with a predetermined desired value;
- and
- (f) compare said feed timing at the last local maximum with a predetermined value.

(12). A method of setting a self-piercing rivet with a setting tool having a support body and an axially movable piston assembly operative for driving said rivet, said method being preferably adapted to be used on a system of any of Clauses (1) to (8) or (11) and/or being preferably combined with the method of Clause (9) or (10), and including the steps of:

- (a) monitoring an axial fastener feed during a rivet setting process and producing a series of feed signals related thereto;
- (b) monitoring the time of said rivet setting process and producing a series of time signals related thereto;
- (c) identifying the occurrence during the rivet setting process of an improper feed;
- (d) using the occurrence of the improper feed to identify a fault; and
- (e) initiate a rivet cleaning process should the fault be detected.

(13). The method of Clause (12) further including the steps of:

- producing a rivet feed status waveform based on said series of feed signals and said series of time signals produced over a rivet feeding process;
- scanning said rivet feed status waveform to identify the location of a feed peak in said waveform; and
- using the location of the feed peak to identify the total time of the rivet feed event.

(14). The method of Clause (13) including comparing the rivet feed status waveform with an example rivet feed status waveform to determine if the rivet feed is acceptable.

(15). An electronic control system for use in a riveting process, particularly in a method of any of Clauses (9), (10), (12), (13) or (14), the system being preferably combined with the system of any of Clauses (1) to (8) or (11) and comprising:

- an electronic control unit;
- a drive connected to the electronic control unit;
- a feed sensor connected to the electronic control unit and the drive, the feed sensor being operable to indicate changes in feed status within the feed system during the rivet feeding process; and
- wherein the electronic control unit is configured to compare the changes in feed system with a predetermined value to determine if a rivet feed status is acceptable.

(16). The system of Clause (15) further comprising a rivet wherein the drive is a hydraulic drive.

(17). The system of Clause (15) or (16) further comprising:

- a rivet feeder having an actuator connected to the electronic control unit;
- and
- a feed tube sensor connected to the electronic control unit;
- wherein the electronic control unit operably controls feeding of the rivet by the feeder during the riveting process and the feed tube sensor sends a signal to the electronic control unit indicative of the presence of the rivet.

(18). The system of any of Clauses (15) to (17), further comprising a punch and a piston, the piston being operable to convert hydraulic pressure to linear motion driving the punch.

(19). The system of Clause (18) wherein the piston is operable to convert pneumatic pressure to linear motion.

(20). The system of any of Clauses (15) to (19), further comprising a second sensor being operable to measure one of: (a) torque of an electric motor, (b) speed of the drive, (c) a power characteristic of an electric motor, (d) a punch location, (e) rivet size.

(21). The system of any of Clauses (15) to (20), wherein the system comprises a second sensor configured to measure a workpiece thickness.

(22). The system of any of Clauses (15) to (21), wherein the second sensor is a load cell operably indicating a linearly moving member force.

## Claims

1. A system for setting a self-piercing rivet, said system comprising:

a self-piercing rivet setting tool, said tool including a rivet engaging assembly, an axially movable piston operatively coupled to said rivet for driving said rivet, a housing annularly disposed about said piston;

a feed system for feeding rivets to the tool;  
a robot system having a robotic arm; and  
a monitoring circuit, having circuitry to:

- (a) receive a feed status signal from a first sensor within the feed system;
- (b) receive a robotic arm status signal from a second sensor within the robotic arm;
- (c) receive a rivet set status signal from a third sensor within the setting tool;
- (d) determine if a fault condition is detected; and
- (e) initiate a rivet clearing procedure if a fault condition is detected.

2. The system of Claim 1 wherein said monitoring circuit further includes circuitry to:

produce from a series of feed status signals a measured rivet set status dataset;  
scan said measured rivet set status dataset to determine a first local feed value;  
scan an example rivet set status dataset to determine a second local feed value; and  
determine if the first local feed value and the second local feed value are within one of a predetermined time tolerance band, or within a predetermined feed tolerance band.

3. The system of Claim 1 or 2, wherein the first sensor is configured to measure feed of a rivet along an axial direction.

4. The system of any of Claims 1 to 3, further including an indicator operatively connected to said monitoring circuit for signaling to an operator the acceptability of a rivet feed, preferably based on said determination step of claim 2.

5. The system of any of Claims 1 to 4, wherein said first sensor is a micro-strain sensor.

6. The system of any of Claims 1 to 5, wherein the housing comprises a C-shaped structure.

7. The system of any of Claims 1 to 6, wherein the first sensor is positioned on an exterior surface of the feed system.

8. The system of any of Claims 1 to 7, wherein the housing defines a sensor mounting location, said sensor mounting location being at a point on the feed system which experiences deformation during a rivet feed event.

9. The system of any of Claims 1 to 8, wherein the monitoring circuit further includes circuitry to:

- (a) determine the total time of said rivet feed process;
- (b) compare said total time with a predetermined desired value;
- and
- (c) compare said feed timing at the last local maximum with a predetermined value.

10. The system of any of Claims 1 to 9, further comprising:

an electronic control unit;  
a drive connected to the electronic control unit;  
the feed sensor connected to the electronic control unit and the drive, the feed sensor being operable to indicate changes in feed status within the feed system during the rivet feeding process; and  
wherein the electronic control unit is configured to compare the changes in the feed system with a predetermined value to determine if a rivet feed status is acceptable.

11. The system of Claim 10, wherein the drive is a hydraulic drive.

12. The system of any of Claims 1 - 11, wherein the feed system comprises a rivet feeder having an actuator connected to an electronic control unit; and

the first sensor comprising a feed tube sensor which is connected to the electronic control unit; and the electronic control unit operably controls feeding of the rivet by the rivet feeder during the riveting process and the feed tube sensor sends a signal to the electronic control unit indicative of the presence of the rivet. 5

13. The system of any of Claims 1 to 12, further comprising a punch, the piston being operable to convert hydraulic pressure to linear motion driving the punch. 10

14. The system of any of Claims 1 to 12, wherein the piston is operable to convert pneumatic pressure to linear motion. 15

15. The system of any of Claims 1 to 14, further comprising a fourth sensor being operable to measure at least one of: (a) torque of an electric motor, (b) speed of the drive, (c) a power characteristic of an electric motor, (d) a punch location, (e) rivet size. 20

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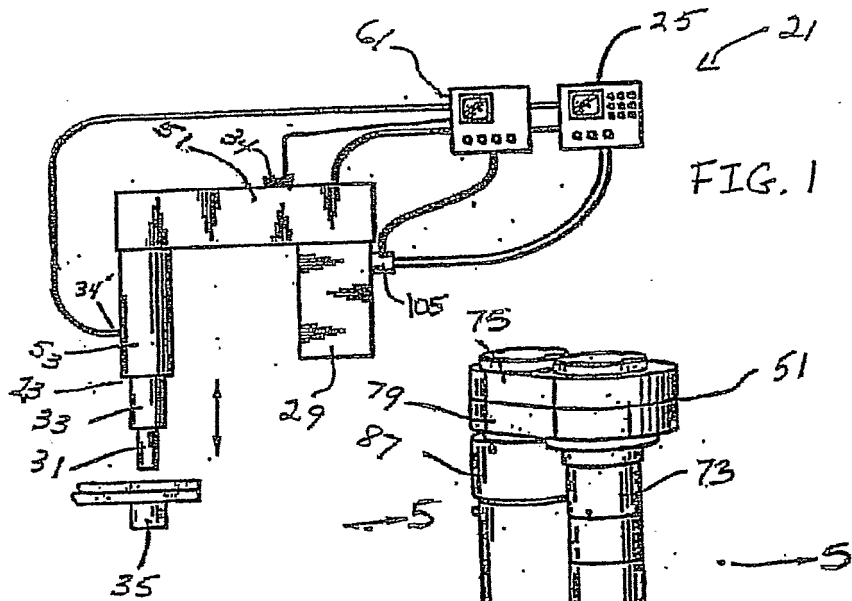
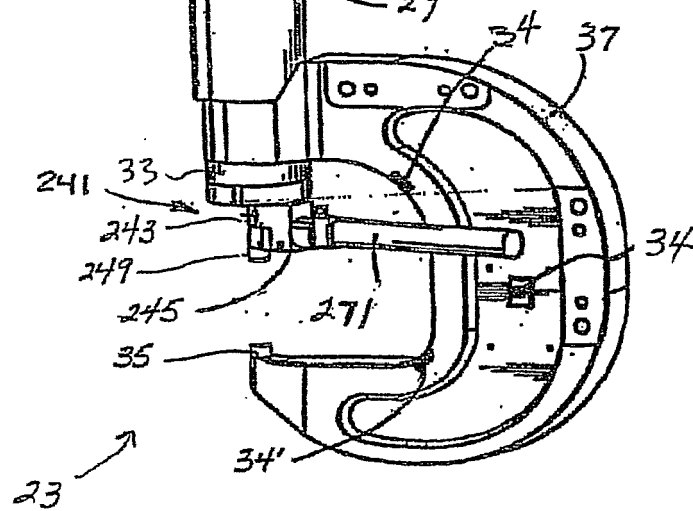


FIG. 3



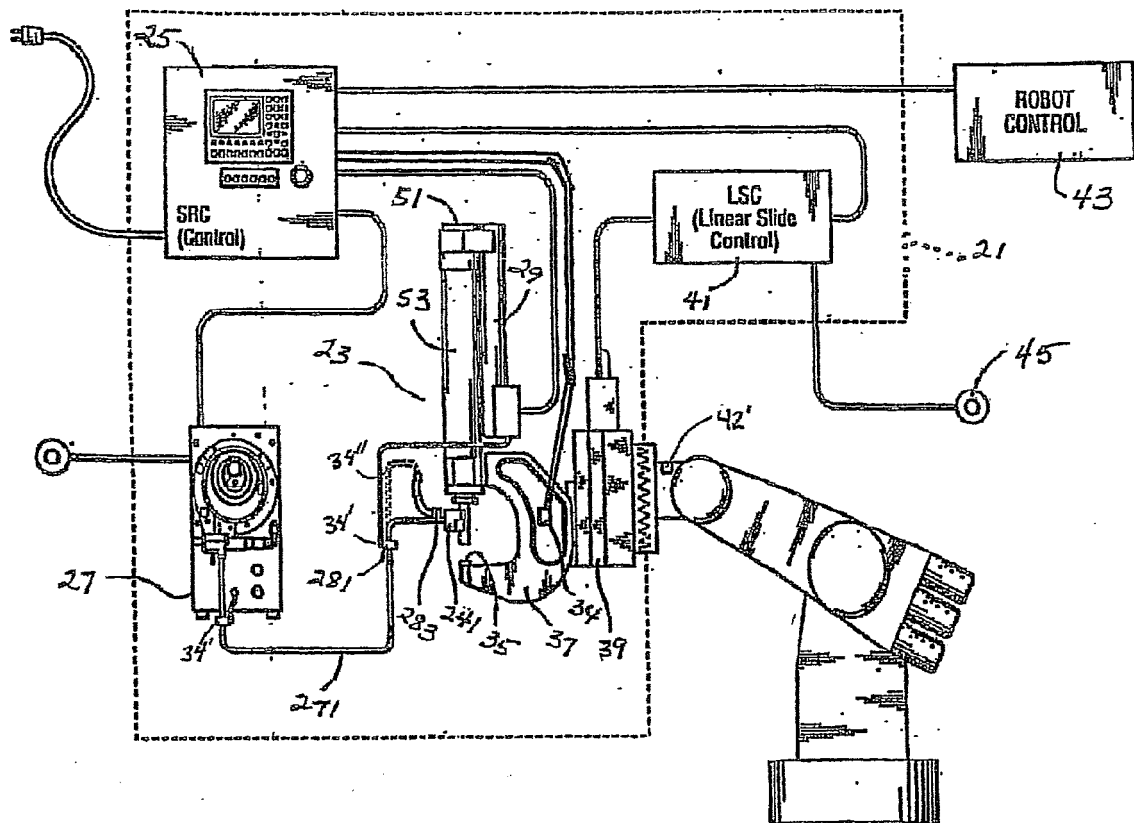
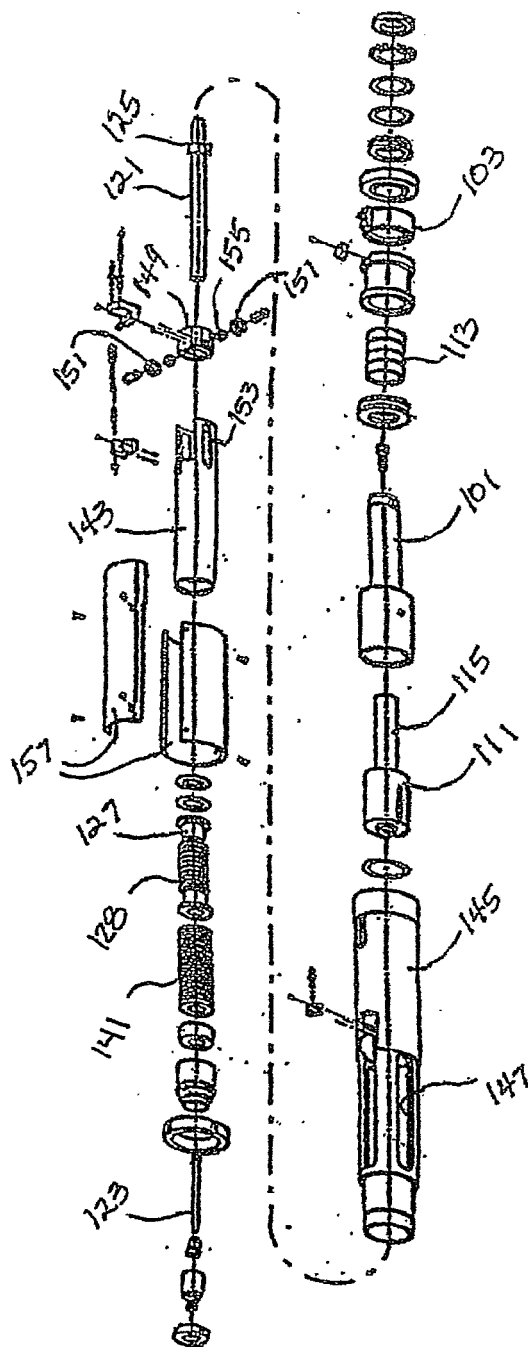


FIG. 2

FIG. 4





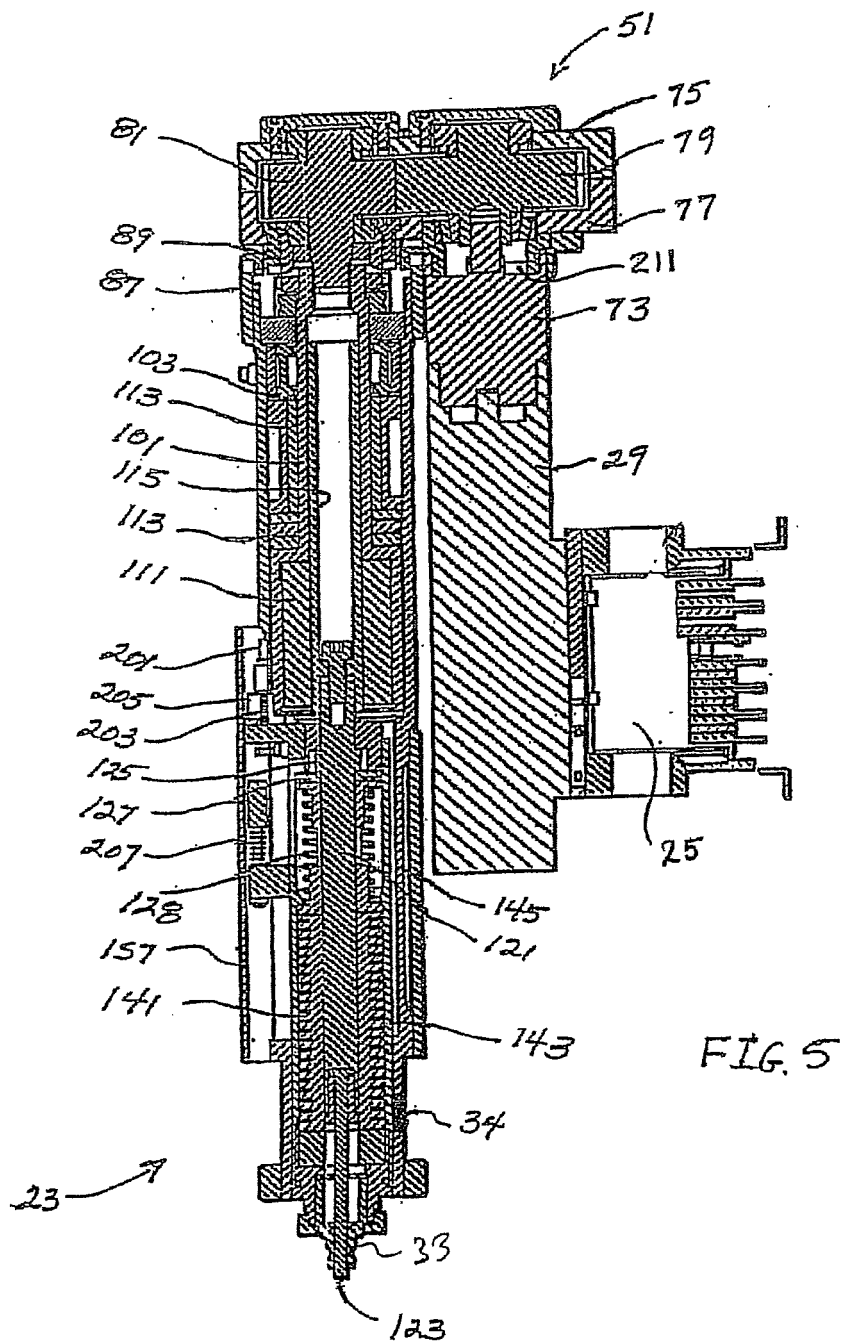


FIG. 6

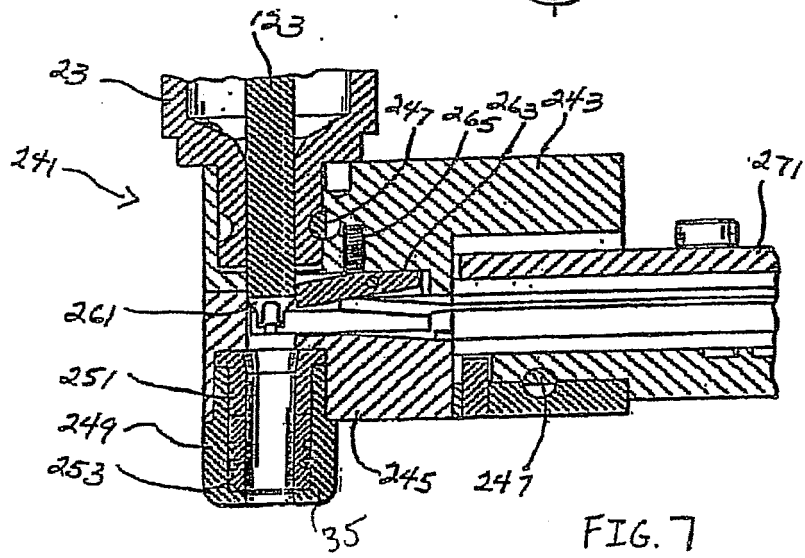
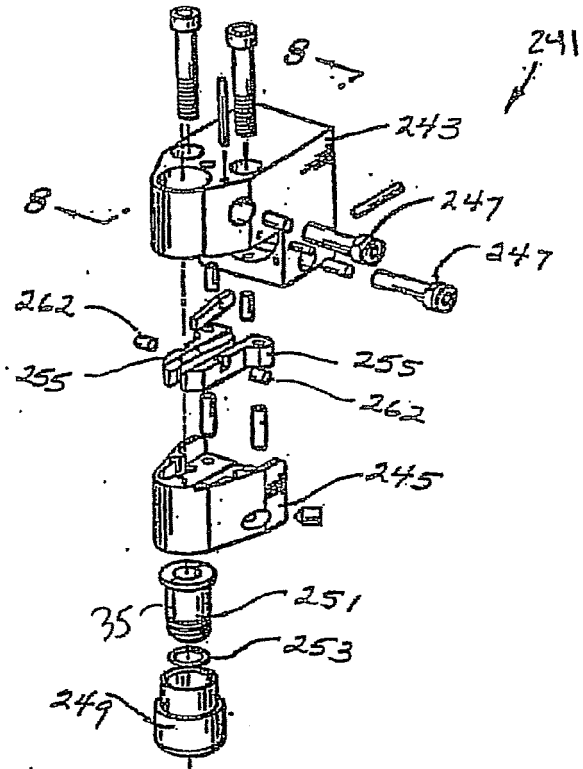
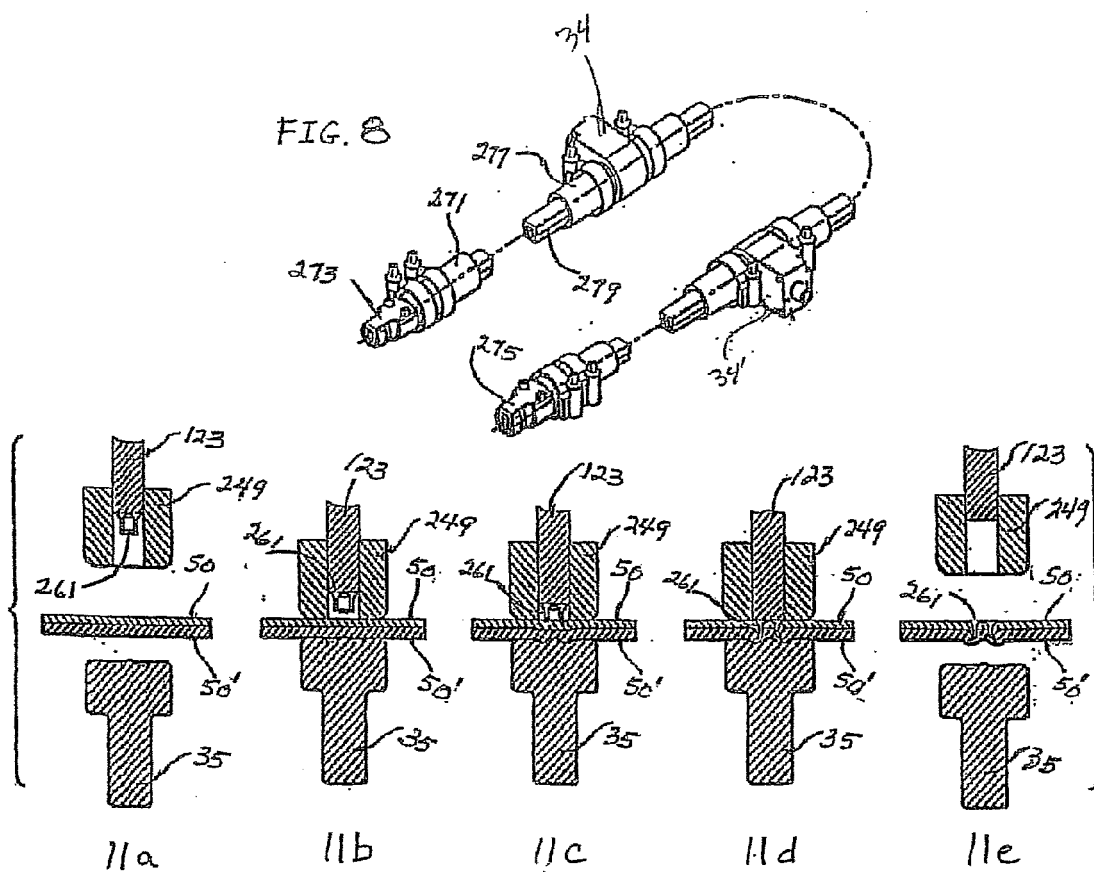
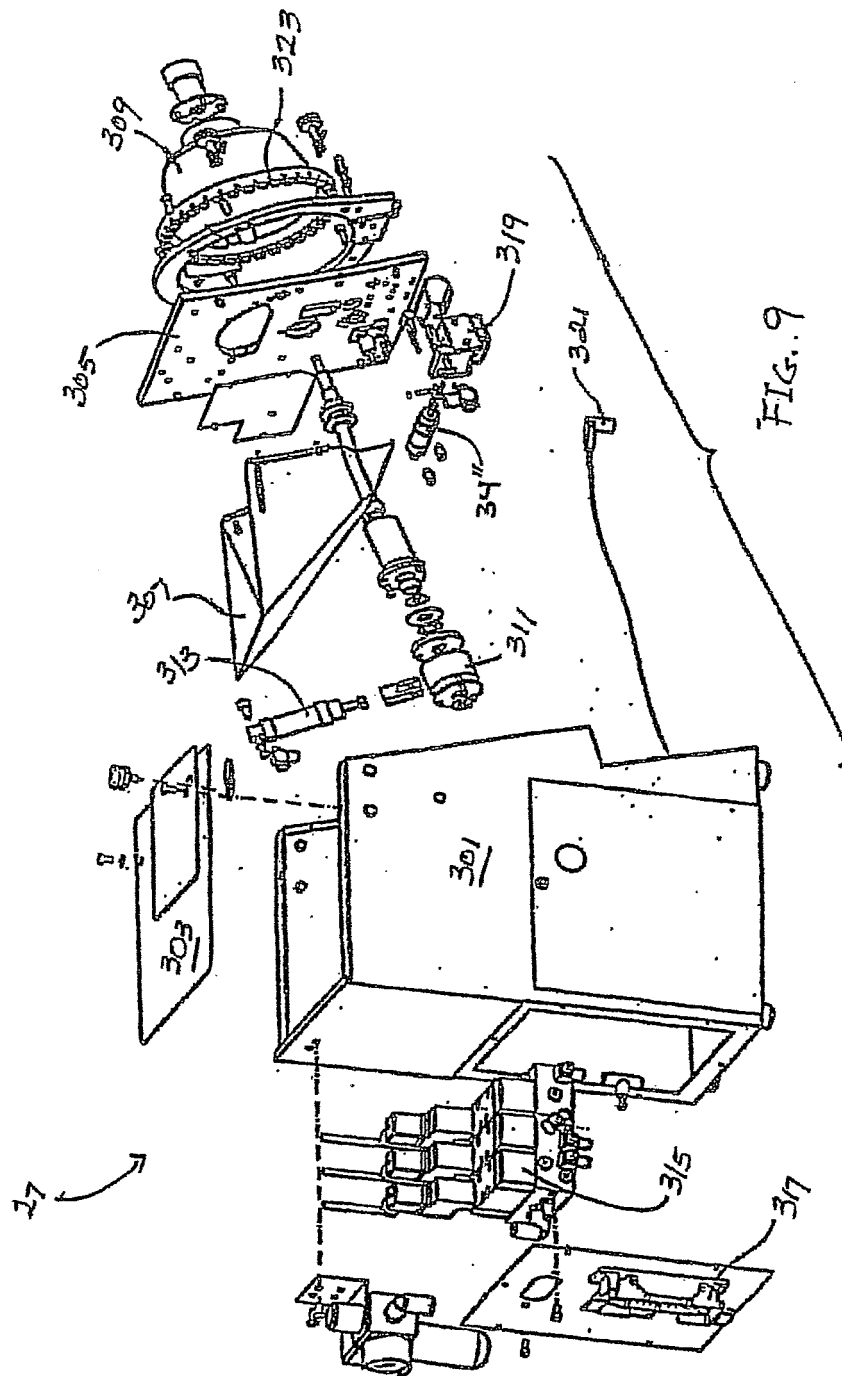


FIG. 7





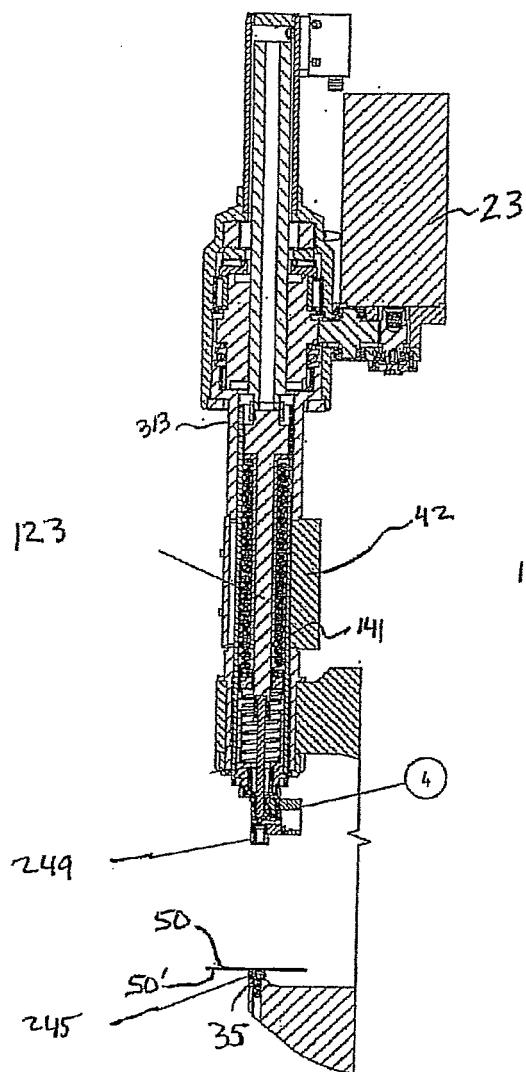


Fig 10A

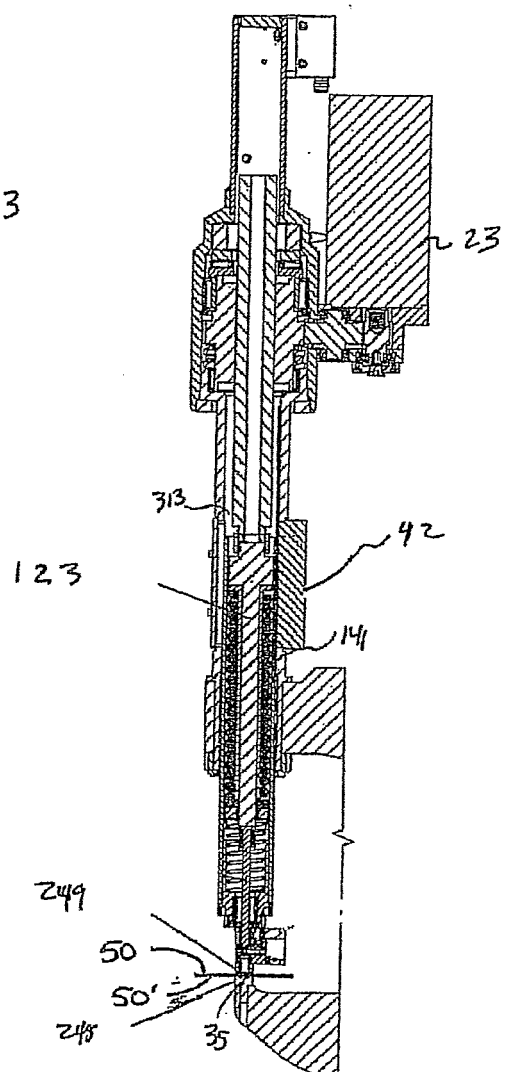
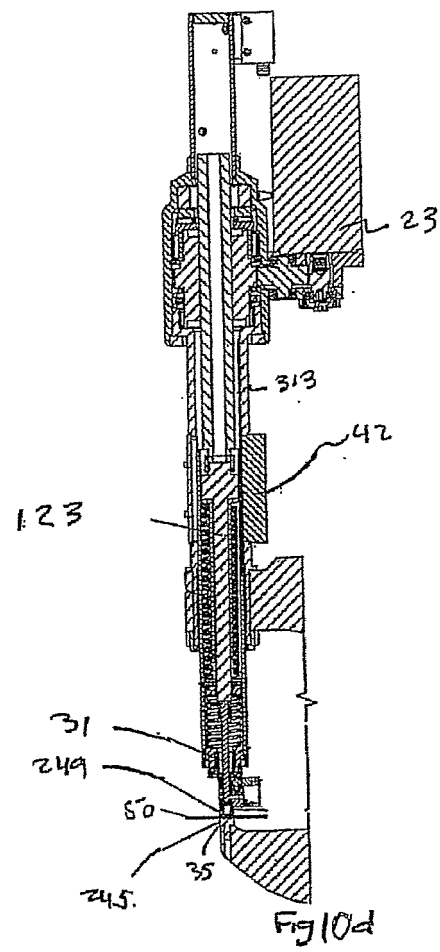
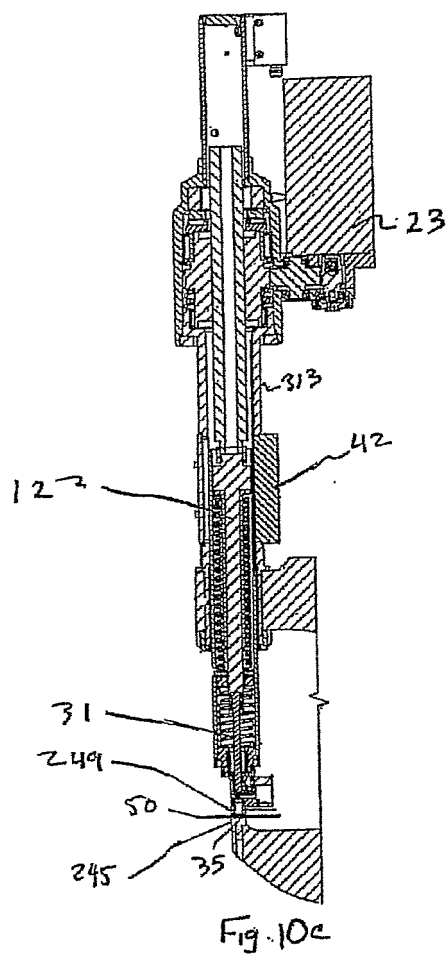
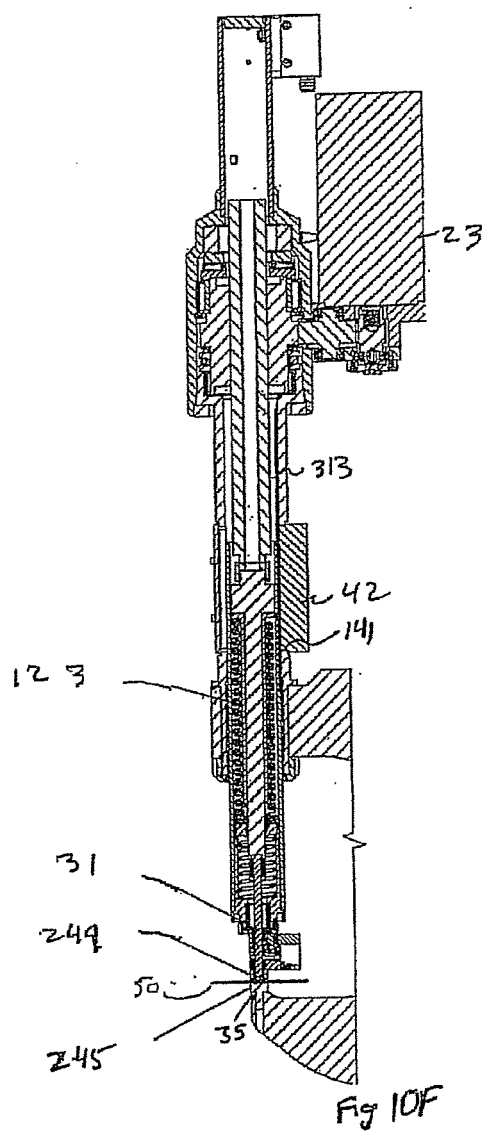
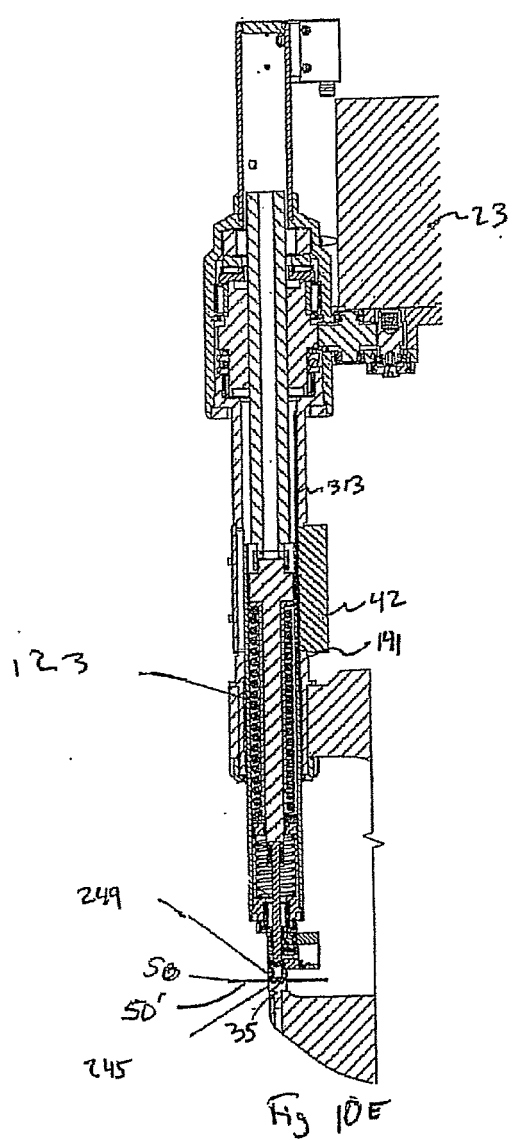
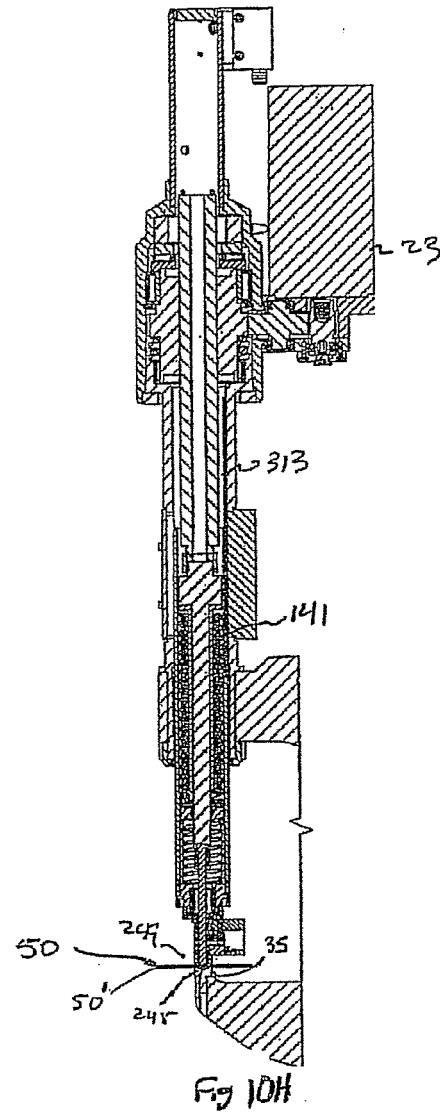
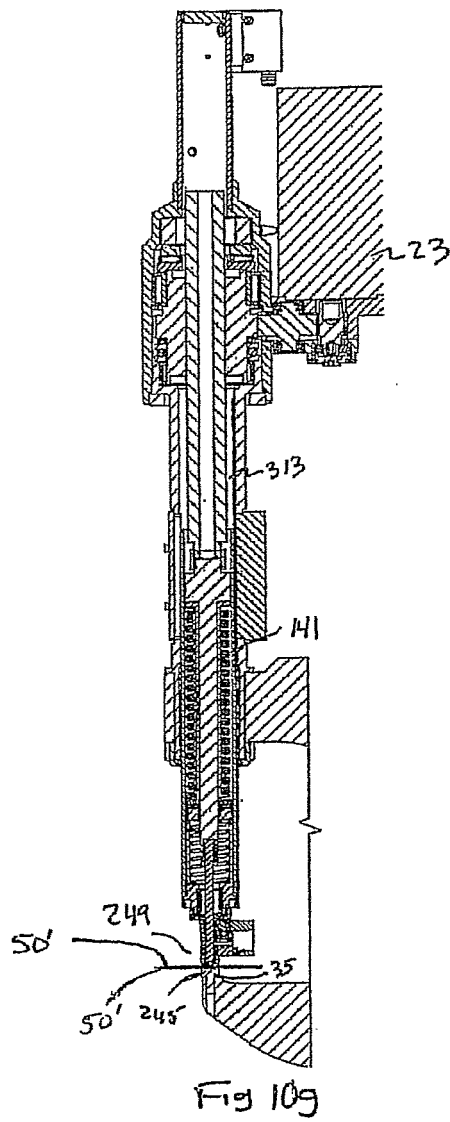


Fig 10b









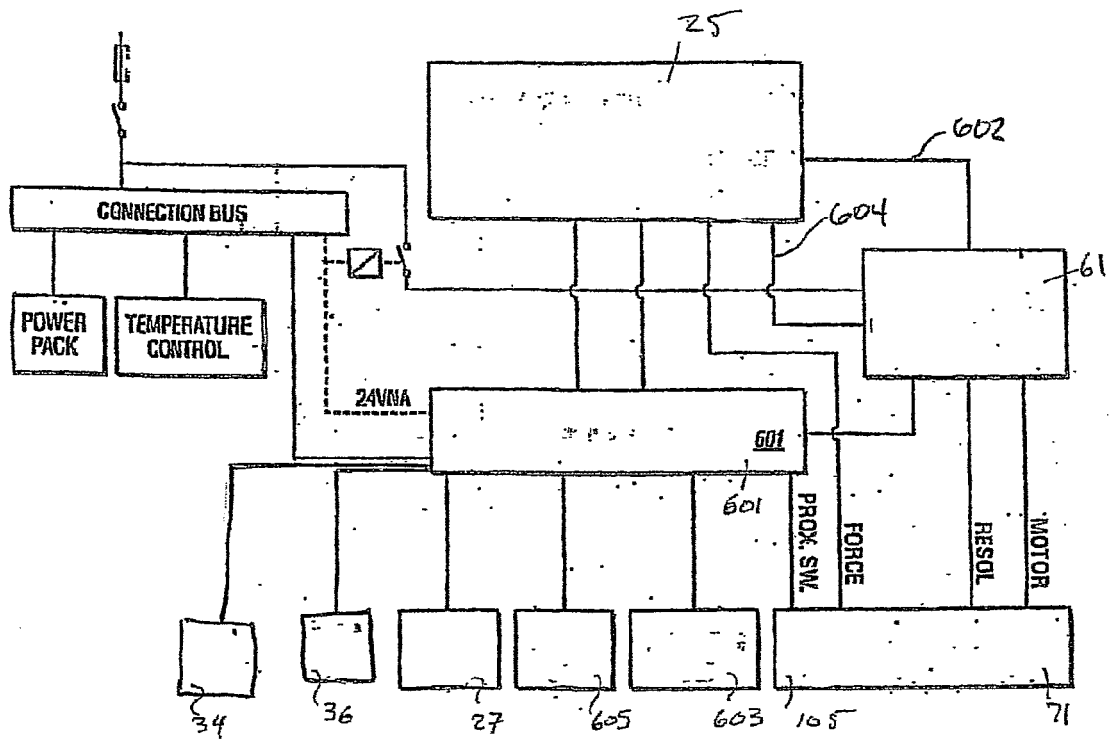


Fig. 12

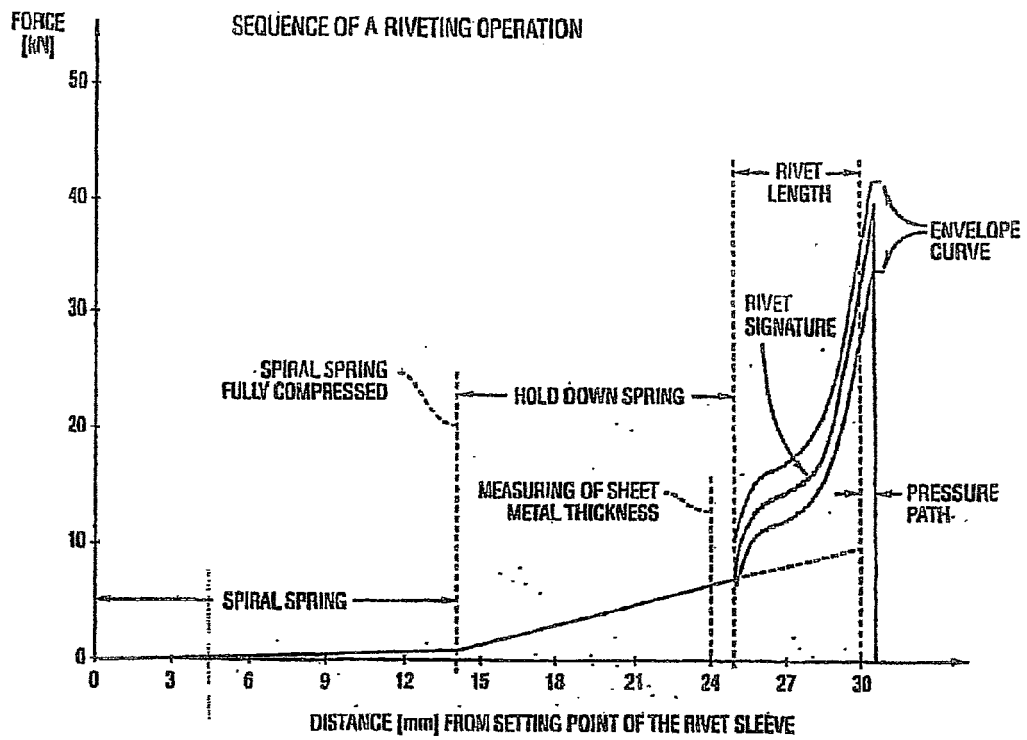


Fig. 13

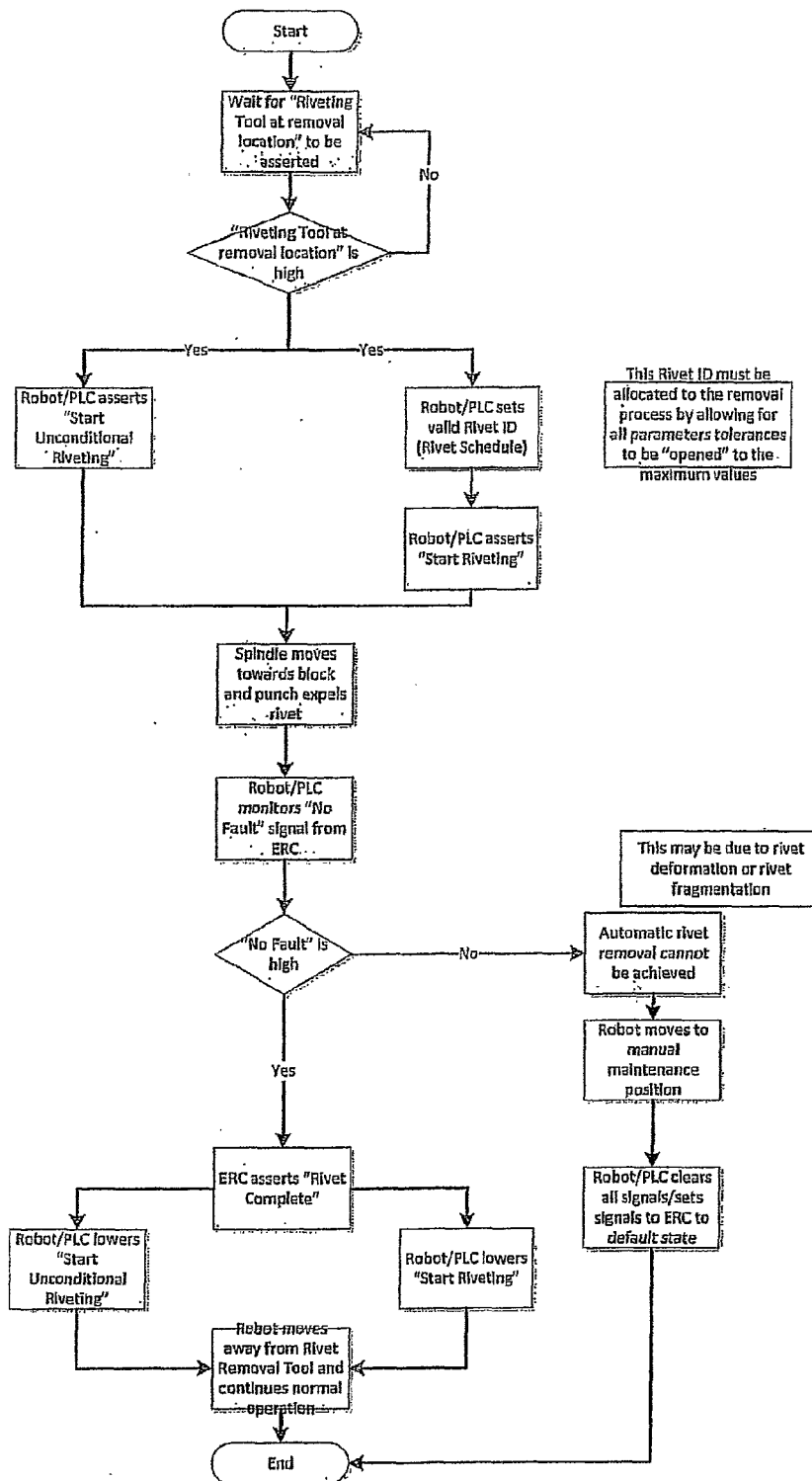


Figure 14a

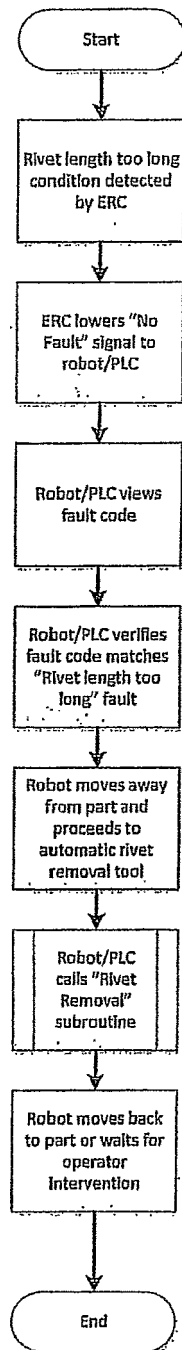


Figure 14b

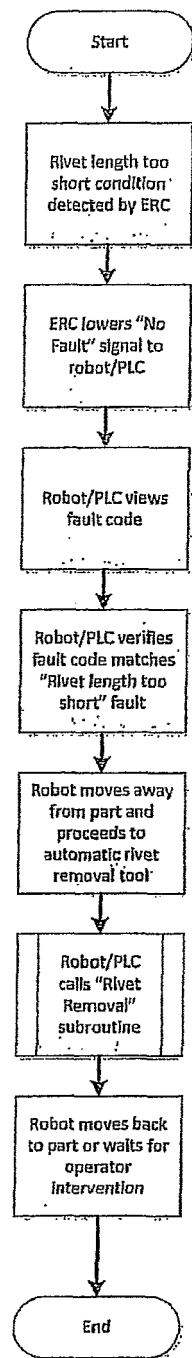


Figure 14c

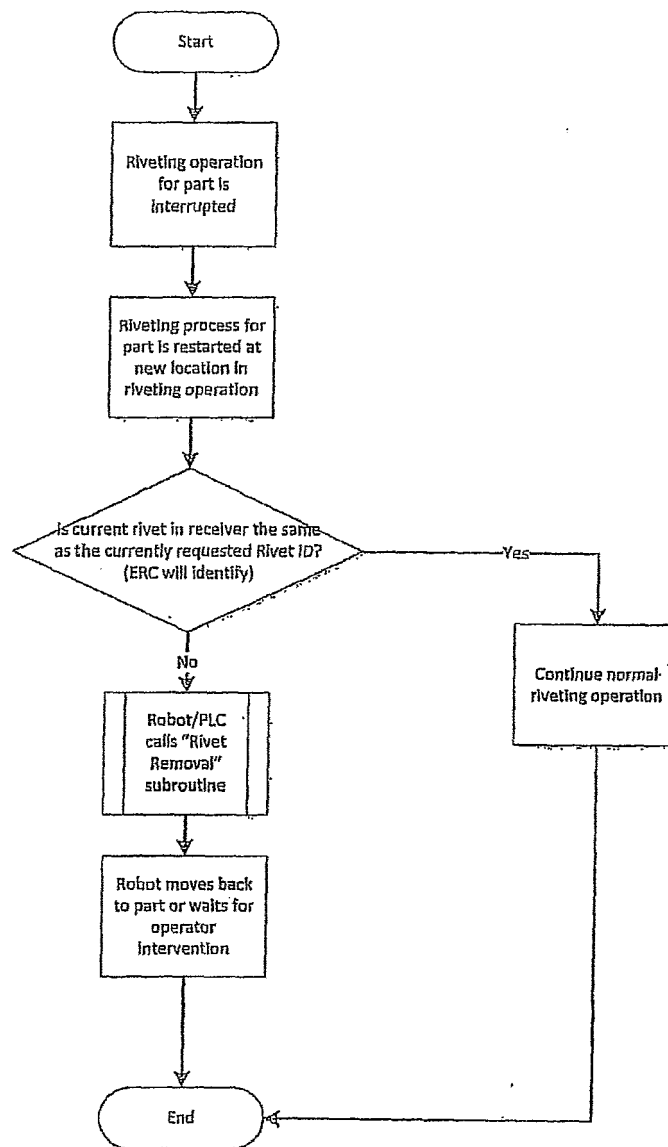


Figure 14d

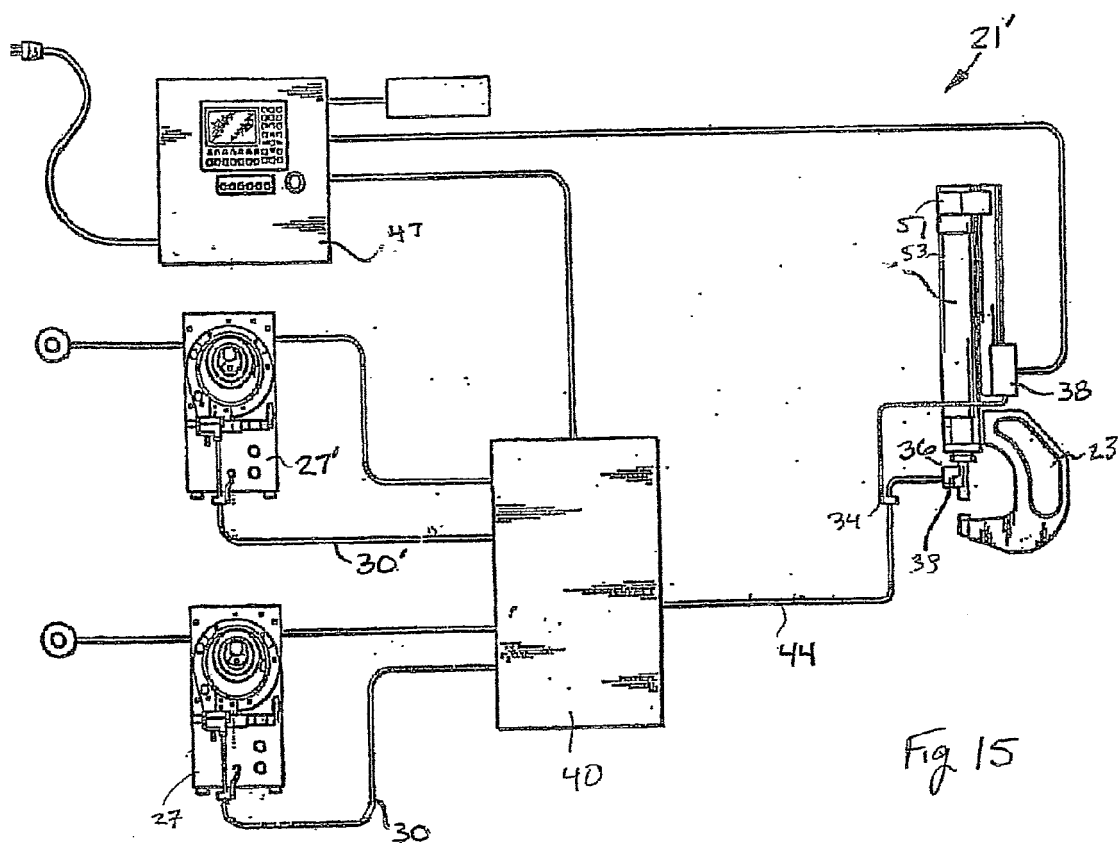
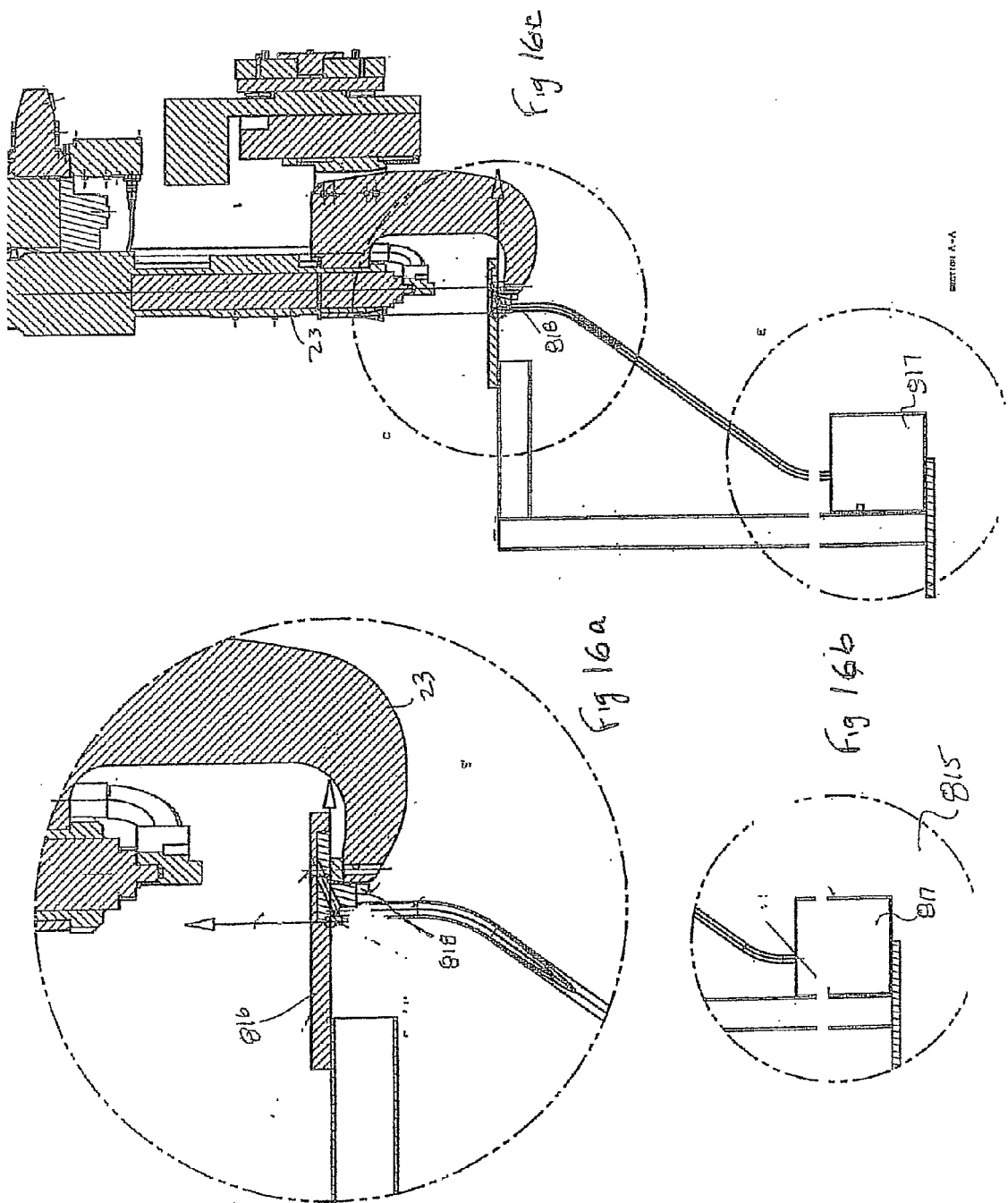


Fig 15





**REFERENCES CITED IN THE DESCRIPTION**

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**Patent documents cited in the description**

- US 61615562 A [0001]