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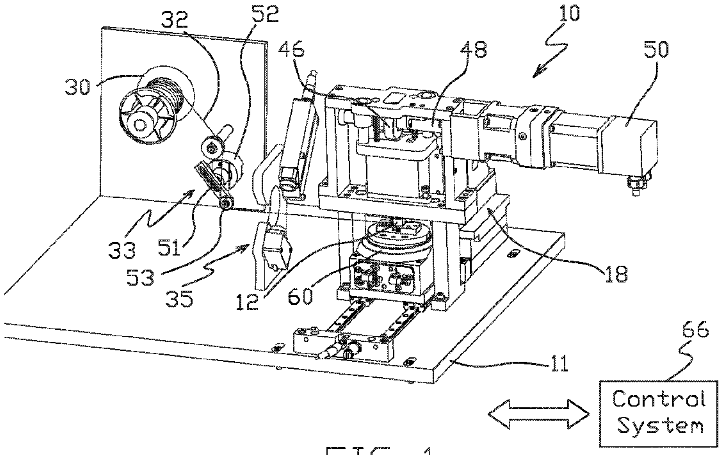

FIG 1

(57) Abstract: A wire feeding and bonding tool and method for attaching wires to a component having first and second spaced-apart wire attach structures. Wire from a supply is fed through a capillary having at least a linear end portion with a feed opening. The capillary is positioned with respect to the component to locate a first portion of the wire extending from the feed opening adjacent to the first wire attach structure, and the wire is attached to the first attach structure. The capillary is moved with respect to the component along a wire feed path to feed the wire from the first wire attach structure to the second wire attach structure and to locate a second portion of the wire extending from the feed opening adjacent to the second attach structure. The wire is attached to the second wire attach structure, and cut from the supply.

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WIRE FEEDING AND ATTACHING SYSTEM FOR CAMERA LENS SUSPENSIONS

FIELD OF THE INVENTION

[0001] The invention relates generally to wire bonding systems used to manufacture precision components. One embodiment of the invention is a wire feeding and attaching system used in the manufacture of camera lens suspensions such as those incorporated into mobile phones.

BACKGROUND

[0002] Small-scale, precision and other components sometimes include wires that are attached or bonded to portions of those components. Manufacturing tooling or systems, sometimes known as wire bond systems, can be used to attach the wires to the components.

[0003] By way of example, PCT International Application Publication No. WO 2014/083318 discloses a camera lens optical image stabilization (OIS) suspension system that has a moving assembly coupled to a stationary support assembly by four shape memory alloy (SMA) actuator wires. Each SMA actuator wire has one end attached to a crimp on the support assembly, and an opposite end attached to a crimp on the moving assembly. In view of factors such as the relatively small scale of the OIS suspension system, the precision by which the actuator wires need to be attached, and the relatively fragile or sensitive nature of wires, it can be difficult to efficiently manufacture suspension systems of these types.

[0004] There remains a continuing need for improved systems and method for manufacturing products having attached wires. In particular, there is a need for such systems and methods that are capable of accurately and reliably attaching wires in precision components. Systems and methods having these capabilities that enable efficient and high-volume manufacturing would be especially desirable.

SUMMARY

[0005] Embodiments of the invention include a wire feeding and bonding tool and method capable of accurately and reliably attaching wires to precision components of the type having first and second spaced-apart wire attach structures. An embodiment of the method includes feeding the wire through a capillary having an end portion with a feed opening and positioning the capillary to locate a first portion of the wire extending from the feed opening adjacent to the first wire attach structure. The first portion of the wire is attached to the first wire attach structure. The capillary is moved with respect to the component along a wire feed path to feed the wire from the first wire attach structure to the second wire attach structure and to position the capillary to locate a second portion of the wire extending from the feed opening adjacent to the second wire attach structure. The second portion of the wire is attached to the second wire attach structure. The wire can be cut from a supply after it is attached to the second wire attach structure.

[0006] In embodiments, the component wire attach structures can be crimps, and the wire can be attached by deforming the crimps. Other embodiments of the method include clamping and releasing the wire with respect to the capillary. Yet other embodiments of the method include tensioning the wire. In still other embodiments, the capillary has a linear end portion, and the capillary is moved while maintaining the linear end portion sufficiently coaxial with a wire axis extending between the first and second attach structures to reduce damage to the wire.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is an illustration of a wire bonding tool in accordance with embodiments of the invention.

[0008] FIG. 2 is a detailed illustration of the wire clamp assembly of the tool shown in FIG. 1

[0009] FIG. 3 is a detailed top side illustration of the pedestal shown in FIG. 1 with a component to which wires are to be attached claimed thereto.

[0010] FIG. 4 is a detailed illustration of crimping punches and a cutting tool of the wire bonding tool shown in FIG. 1.

[0011] FIG. 5 is a diagrammatic illustration of portions of a component that can have wires bonded thereto by the tool of FIG. 1, and a wire feed path used by the tool.

[0012] FIGs. 6a-6n are diagrammatic illustrations of portions of the tool shown in FIG. 1, illustrating a sequence of operations performed by the tool to bond wires to a component.

[0013] FIG. 7 is an illustration of a part clamp in accordance with embodiments of the invention.

[0014] FIG. 8 is a diagrammatic illustration of a capillary inspection system in accordance with embodiments of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0015] A wire feeding and bonding tool 10 in accordance with embodiments of the invention can be described generally with reference to FIGs. 1-3. As shown, tool 10 includes a base 11 and a support such as pedestal 12 for holding a component 14 (e.g., a camera lens optical image stabilization (OIS) assembly), to which one or more wires are to be bonded by the tool. A wire clamp assembly 16 is mounted to and driven with respect to the base 11 by an actuator such as stage 18. The wire clamp assembly 16 includes a base 20, and a clamp 22 for holding a capillary 24. The capillary 24 is a tubular structure that has an end portion 26 with a feed opening 28 at its distal end. In embodiments, including the embodiment shown in FIG. 2, the end portion 26 is linear. In other embodiments the end portion 26 is nonlinear (e.g., it can be curved). In the illustrated embodiment, the entire length of the capillary 24 is linear. The wire clamp assembly 16 also includes a ruby wire guide 34 and a wire clamp 36. Wire 32 to be attached to the component 14 is supplied from a supply 30 such as a spool. In embodiments, the supply 30 is driven by a motor (not shown in FIG. 1). From the supply 30, the wire 32 extends through a tensioning mechanism 33 and by an optical micrometer 35 to the wire clamp assembly 16. On the wire clamp assembly 16, the wire extends through the ruby wire guide 34 and clamp 36 before entering the proximal end of the capillary 24. The wire 32 extends through the capillary 24 and out the feed opening 28. Stage 18 moves the wire clamp assembly 16 with respect to the pedestal 12 about one or more axes to position the capillary and the wire 32 extending from the feed opening 28 with respect to structures on the component 14 to which the wire is to be bonded. In embodiments, stage 18 moves the capillary about x, y, z and θ axes (i.e., four degrees of freedom). The capillary clamp 22 allows the capillary 24 to be conveniently changed out in the event it is damaged. Wire clamp 36 includes a base member 37 and a moving member 39. An actuator (such as a solenoid, not shown) drives the moving member 39 with respect to the base member 37 between a release position that allows the wire 32 to be fed to the capillary 24, and a clamp position inhibiting movement of the wire with respect to the capillary.

[0016] Tool 10 also includes one or more attachment tools positioned with respect to the pedestal 12 for attaching the wire 32 to the component 14. In embodiments described in greater detail below, tool 10 is used to attach wire 32 to components 14 that have deformable crimp attach structures. Accordingly, and as shown in FIG. 4, embodiments of the invention include first and second crimping punches 40 and 41 that are actuated to deform the crimp attach structures so those structures engage the wire 32. Other embodiments of the invention (not shown) include other types of attachment tools, such as, e.g., soldering, welding and conductive adhesive dispensing tools for attaching the wires to the attach structures such as bonding areas on the component. Tool 10 also includes a cutting tool 44, such as a punch with a sharp edge (also shown in FIG. 4), positioned with respect to the pedestal 12 to cut the wire 32 (e.g., at a location between the feed opening 28 and the wire attach structures on the component 14). As shown in FIG. 1, in the illustrated embodiment of tool 10, the first and second crimping punches 40 and 41 and the cutting tool 44 are reciprocally driven or actuated by cams 46 mounted to a shaft 48 that is driven by a motor 50. In the illustrated embodiment, the pedestal 12 is mounted to an actuator 60 that moves the pedestal with respect to the base 11. In embodiments, the actuator 60 is a rotary index table to rotate the pedestal 12. In other embodiments (not shown) the actuator 60 can take other forms.

[0017] As shown in FIG. 7, embodiments of tool 10 also include a part clamp 100’ that is incorporated into a die set with the crimping punches 40, 41 and the cutting tool 44. In the illustrated embodiment, the clamp 100’ has four clamp pads 102’ that extend from a base 104’. Clamp pads 102’ are configured and positioned to engage a component 14 positioned on the pedestal 12. The part clamp 100’ is reciprocally driven or actuated by the cams 46 in embodiments.

[0018] A control system 66 illustrated generally in FIG.1 is coupled to the stage 18, wire supply motor, micrometer 35, wire clamp actuator, motor 50 and actuator 60. The control system 66 is a programmed controller in embodiments. As described in greater detail below, during operation of the tool 10, the control system 66: (1) actuates the stage 18 to position the capillary 24 with respect to portions of the wire 32 extending from the feed opening 28 presented at the wire attach structures on the component 14, (2) actuates the stage 18 to move the capillary 24 along a wire feed path between the attach structures on the component 14, (3) actuates the motor 50 to drive the punches 40 and 41, (4) actuates the motor 50 to drive the cutting tool 44, (5) actuates the wire supply motor to pay out or feed wire from the supply 30, and (6) actuate the wire clamp 36 to clamp the wire 32 with respect to the clamp assembly 16 (and therefore with respect to the capillary 24), and (7) actuates the motor 50 to drive the part clamp 100’ in embodiments.

[0019] In embodiments, the micrometer 35 provides information to the control system 66 regarding wire 32 fed past the micrometer, and the control system can use that information for active adjustment and control of the wire feed operations. For example, some embodiments of the invention can be used with coated wire having spaced-apart uncoated regions at locations where the wire is to be attached to the component 14. In such embodiments the micrometer 35 can be used to provide information representative of the locations of the uncoated wire regions. Other embodiments include other types of micrometers or other structures for providing information representative of the wire 32 fed from the supply 30. In embodiments, the wire supply motor can be a stepper motor with an encoder to provide information representative of the amount of actuation of the motor or supply 30 to the control system 66.

[0020] The tensioning mechanism 33 can include a weighted pendulum or dancer arm 51 and a rotary position sensor 52. Position sensor 52 is coupled to the control system 66 and provides information representative of the position of the dancer arm 51. A wire guide 53 is mounted to the end of the dancer arm 51 by a rotary bearing. As shown for example in FIG. 1, the wire 32 is routed between the supply 30 and the clamp assembly 16 by the wire guide 53, and the dancer arm 51 and wire guide are displaced off of the bottom dead center with respect to the rotational axis of the position sensor 52. The weight of the dancer arm 51 and wire guide 53 provides tension on the wire 32. The rotary position sensor 52 provides information to the control system 66 relating to the position of the dancer arm 51, enabling the control system to maintain the dancer arm at positions to provide desired amounts of tension on the wire 32 (e.g., maintaining the dancer arm position generally constant will provide a constant tension on the wire).

[0021] In embodiments, tool 10 is configured to attach shape memory alloy (e.g., nitinol) wire 32 to a component 14 in the form of an actuator of a camera lens optical image stabilization (OIS) system such as that described generally in PCT International Application Publication No. WO 2014/083318. As shown for example in FIG. 3, the actuator component 14 is a four-sided and generally square-shaped member having a first or stationary member 70 and a second or moving member 72. Each side of the component 14 includes a first wire attach structure in the form of a crimp 74 on the stationary member 70, and a second wire attach structure in the form of a crimp 76 on the moving member 72. Tool 10 attaches a section of wire 32 between the crimps 74 and 76 on each side of the component 14.

[0022] FIG. 5 is a diagrammatic illustration of portions of the stationary member 70 and crimp 74, and moving member 72 and crimp 76, on one side of the component 14. A wire axis 80 corresponding to the location of a section of wire 32 extending between and attached to the component 14 by the crimps 74 and 76 is illustrated. As described in greater detail below, during the attach process an end of the wire 32 (not shown in FIG. 5) extending from the feed opening 28 of the capillary 24 is presented and attached to a first attach structure such as crimp 76. The capillary 24 is then driven along a feed path 82 to feed the wire from crimp 76 to the second wire attach structure such as crimp 74. During this wire feed operation, the end portion 26 of the capillary 24 is maintained in an orientation that causes the wire 32 to emerge from the feed opening 28 sufficiently coaxial with the wire axis 80 to prevent, minimize or at least reduce the opportunity for damage to the wire 32. In the illustrated embodiment, for example, the linear end portion 26 of the capillary 24 (and the entire length of the capillary if it is linear) is maintained in an orientation that is sufficiently coaxial with the wire axis 80 to prevent, minimize or at least reduce the opportunity for damage to the wire 32. In embodiments (not illustrated in FIG. 5), the wire feed path can be coaxial with the wire axis 80. In other embodiments such as that illustrated in FIG. 5, the wire feed path 82 has at least portions that are not coaxial with the wire path 80. As shown, wire feed path 82 includes a first section 84 that feeds the wire 32 from the crimp 76 to a position opposite the crimp 74 from the crimp 76 and with the wire outside of the crimp 74, and a second section 86 that moves the wire into the crimp

74. First path section 84 is at an angle and direction with respect to the wire axis 80 to provide clearance between the capillary 24 (and optionally other components of the tool 10) and the crimp 74. In embodiments, the angle between the first section 84 of the feed path 82 and the wire path 80 is relatively small to prevent, minimize or at least reduce damage to the wire 32 during the feeding process. The second section 86 of the wire feed path 82 is relatively short with respect to the length of the first path section 84, and moves the wire 32 into the crimp 74 so it can be engaged by deformation of the crimp. In the illustrated embodiment, first path section 84 is linear, and second path section 86 is generally linear and perpendicular to the first path section. In the illustrated embodiment, the end portion 26 of the capillary 24 is oriented generally parallel to the wire axis 80 as the capillary is moved along the wire feed path 82. In other embodiments, the distal end portion 26 is oriented generally parallel to the first path section 84 as the capillary is driven along the first path section. Still other embodiments include other wire feed paths and orientations of the distal end portion 26 of the capillary 24, with the objective of preventing, minimizing or at least reducing damage to the wire 32 during the operation of tool 10. For example, in other embodiments (e.g., as illustrated in FIG. 6g), the second path section 86 is a looping path from a location outside of the crimp 74, over the top of the open crimp, and into the open crimp.

[0023] FIGs. 6a-6n illustrate embodiments of the operation of the tool 10. Pedestal 12 and actuator 60 are withdrawn from their operative positions with respect to other components of the tool 10 such as the clamp assembly 16 and the stage 18 to provide access to the pedestal. An unwired component 14 is located on and clamped to the pedestal 12 (e.g., by clamp 100 in the embodiment shown in FIGs. 6a-6n). The pedestal 12 and actuator 60 are then returned to the operative positions at which the sections of wire 32 are attached. During a set-up operation, the wire 32 is fed from the supply 30 to the capillary 24, and a defined amount of wire is exposed beyond the feed opening 28 of the capillary. In other embodiments having a part clamp 102’ such as that described in connection with FIG. 7, the pedestal 12 with the component 14 thereon is returned to the operative position in an unclamped state, and the motor 50 is actuated to cause the part clamp to move and engage the component, thereby securing the component onto the pedestal. In these embodiments the part clamp 102’ remains engaged with the component 14 throughout the wire feeding and attaching process described below, and following the completion of the process the motor 50 is actuated to retract the part clamp from the component before the pedestal and wired part are moved from the operative position to the withdrawn position.

[0024] FIG. 6a shows the pedestal 12 at a first position and orientation, with a first side of the component 14 having two unformed crimps 74 and 76, and the wire clamp assembly 16 at a first or home position with an end of the wire 32 extending from the feed opening 28 of the capillary 24 in a spaced-apart position from the crimps. With the wire 32 clamped with respect to the wire clamp assembly 16 by wire clamp 36, and as shown in FIGs. 6b and 6c, the wire clamp assembly 16 is driven with respect to the component 14 from the position shown in FIG. 6a to a position where the capillary 24 presents the end of the wire 32 within the crimp 76. In embodiments, the wire supply motor is actuated during this motion of the clamp assembly 16 to pay out wire from the source 30 while maintaining a desired tension on the wire 32 between the source and wire clamp 36. The first crimping punch 40 is then actuated to deform the crimp 76 and cause the crimp to engage and attach the wire 32 as shown in FIGs. 6d and 6e.

[0025] After the wire 32 is attached to the crimp 76, the wire clamp 36 is actuated to release the wire 32, and the wire clamp assembly 16 is driven with respect to the crimp 76 to expose the wire from the capillary 24 and to feed the wire along the wire feed path as shown in FIGs. 6f and 6g (e.g., such as path 82 shown in FIG. 5), and position the wire within the crimp 74. The amount of wire 32 exposed during this feed operation is determined by the spacing between crimps 74 and 76, and any amount of extra slack or “buckle” desired in the section of the wire between the crimps. The wire clamp 36 is then actuated to clamp the wire 32, and the wire clamp assembly 16 is actuated to move the capillary 24 back toward the crimp 76 to push the desired amount of slack into the wire between the crimps 76 and 74. During this operation, the engagement between the capillary 24 and wire 32 helps ensure that the desired slack is located between the crimps 76 and 74 (i.e., rather than being located between the wire clamp 36 and the proximal end of the capillary). After the wire 32 is properly located and tensioned in the open crimp 74 by the procedure described above, the second crimping punch 41 is actuated to deform the crimp 74 and cause the crimp 74 to engage and attach the wire 32 as shown in FIG. 6h.

[0026] With the wire attached to both crimps 76 and 74, the wire clamp 36 is actuated to release the wire 32. The wire clamp assembly 16 is then driven away from the crimp 74 by a distance that is sufficient to enable the wire 32 to be cut, and to pay out of the capillary 24 the desired length of wire to be located in the first crimp on the next side of the component 14. Wire clamp 36 is then actuated to clamp the wire 32 to the wire clamp assembly 16, followed by actuation of the cutting tool 44 to cut the wire between the crimp 74 and the feed opening 28 as shown in FIG. 6i. The appropriate amount of exposed wire for the next attaching sequence then extends from the feed opening 28. Punches 40 and 41 and cutting tool 44 are then retracted in the illustrated embodiment as shown in FIGs. 6j and 6k, and the wire clamp assembly 16 is actuated and returned to its home position shown in FIG. 6l. In other embodiments, a sufficient length of wire 32 to enable the wire to be cut is payed out or fed during the wire pay-out and feeding steps described in connection with FIGs. 6f and 6g. Steps including (1) actuating the wire clamp 36 to release the wire 32, (2) driving the wire clamp assembly 16 away from the crimp 74 to provide the additional and desired length wire to enable the cutting step, and (3) actuating the wire clamp to clamp the wire, as described above in connection with FIG. 6i, can be eliminated by this approach to improve the wiring assembly cycle time.

[0027] After the section of wire 32 is attached to the crimps 74 and 76 on a first side of the component 14, actuator 60 is actuated to rotate the pedestal 12 (e.g., 90°) and locate another (e.g., second) side of the component 14 having crimps 74 and 76 with respect to the wire clamp assembly 16 as indicated by FIGs. 6m and 6n. The process described and illustrated with respect to FIGs. 6a-6l is then repeated to attach a second section of wire 32 to the crimps 74 and 76 on the second side of the component 14. The process described and illustrated above is then repeated to attach sections of the wire 32 to the crimps 74 and 76 on the third and fourth sides of the component 14. The pedestal 12 and actuator 60 are withdrawn from their operative positions with respect to the clamping assembly 36 and stage 18, and the component 14 with the attached sections of wire 32 can be removed from the pedestal 12. The process described and illustrated above can then be repeated with another component 14.

[0028] FIG. 8 is an illustration of a capillary inspection system 150 that can be used with tool 10. As shown, inspection system 150 includes one or more imaging devices such as cameras 152 coupled to an image processor 154. Image processor 154 can be hardware and/or software based, and can be included in control system 66. Capillaries such as 24 can be delicate tooling components and may be damaged during operation of tool 10 (e.g., by operator handling). The capillaries 24 are also subject to manufacturing tolerances. Inspection system 150 can be used to identify damaged, misaligned or otherwise out-of-tolerance capillaries 24. During a tool set-up procedure, a rigid and precise fixture (not shown) that replicates the shape, tolerances and other characteristics and features of a desired capillary 24 is mounted to the wire clamp assembly 16. The capillary set-up fixture is imaged by the cameras 152, and the images are received by the image processor 154 and used by the image processor as a reference framework. After the reference framework is established, the capillary set-up fixture is removed and a capillary 24 is positioned in the wire clamp assembly 16. Prior to operation of the tool 10 following the installation of the capillary 24, and/or periodically during operation of the tool, images of the capillary (also produced by the cameras 152) are processed and evaluated by processor 154 (e.g., compared to the reference framework). If capillary variations of a type and/or degree within a predetermined threshold are identified (e.g., if the position of the feed opening 28 is slightly misaligned or misplaced from a desired position), control system 66 can compensate for the variations during the wire attaching process. If identified capillary variations are of a type and/or amount greater than a predetermined threshold, the image processor or control system 66 can issue an alert to an operator. The operator can then take appropriate action.

[0029] The wire bonding tool and associated method offer a number of important advantages. Wire such as the SMA wire attached to OIS components is relatively fragile and susceptible to damage (e.g., when bonding the wire onto the components). Supporting the wire in a capillary during bonding and other processes using the wire can prevent, minimize or at least reduce damage to the wire. By way of non-limiting example, in some embodiments nitinol wire 32 attached to OIS components such as 14 is about 27-29 μm in diameter (including an outer coating). In these embodiments the use of a capillary 24 of stainless steel and having an inner diameter of about 38 μm has been determined to provide advantages of the type described above. Other embodiments use capillaries and wire having other dimensions. The capillary 24 can also be formed from other materials, such as polymers. Dispensing wire from the capillary coaxially, or at a relatively small angle with respect to coaxially, reduces damage to the wire while allowing the wire to be manipulated. In addition to enhancing the efficiency of the wire attach process, the tool enables the speed and therefore volume of the attach process to be increased.

[0030] Although the invention has been described with reference to preferred embodiments, those skilled in the art will recognize that changes can be made in form and detail without departing from the spirit and scope of the invention.

[0031] For example, in other embodiments, one or more wire sections can be attached to the component by different wiring/assembly tools (e.g., at different stations, as an alternative to rotating the component with respect to a single attachment tool). Each such wiring/assembly tool can be dedicated to attaching a wire section to one side of the component, and the component can be transported between the tools. The methods by which the wire sections are attached at such different tools can be the same or similar to the methods described above.

[0032] Different wire feeding, clamping and/or tensioning structures can be implemented. For example, clamp 36 can be actuated by piezo electric or micro-motor actuators for enhanced speed. In embodiments described in connection with FIG. 1, the wire tension provided by the tensioning mechanism is maintained primarily and throughout the wiring process with respect to portions of the wire that are secured or fixed by a clamp assembly, crimp or other attachment structure. The securing or fixation function is periodically switched between the clamp assembly and the crimp. During situations when the wire is not sufficiently retained by a crimp and the clamp opens, the wire tension can cause the wire to unthread through and from the capillary (i.e., in a direction opposite and away from the feed opening). "Dropped wire" events of this type can cause tool downtime while the wire is re-threaded into the capillary and associated set-up procedures are completed. Embodiments of the invention incorporate wire retention mechanisms that reduce the opportunities for such dropped wire events. For example, embodiments include slip clutch, rollers and/or other mechanisms that do not completely release the wire. One such mechanism can allow the wire to slip in one direction (i.e., the feed direction), but not the other, by closely controlling slip tension thresholds. Another mechanism uses roller contacts to retain the wire, and targeted slip clutch settings to selectively control wire slip. Embodiments using driven rollers (e.g., with motors coupled to the control system) to pay out the wire would have certain advantages. The same rollers can be used to simplify the initial set-up by automating the capillary threading process, purging any potentially damaged wire and synchronizing positions of uncoated wire regions. Certain steps in the wire attach process may be more efficiently performed by paying out additional wire instead of the unclamp/translate/reclamp/translate process of embodiments described in connection with FIG. 1.

[0033] Wire feeding by the embodiments described in connection with FIG. 1 is done by moving the clamp assembly (and capillary) about x, y, z and θ axes (e.g., four degrees of freedom) with respect to a relatively fixed component (other than rotation of the component by the actuated pedestal to present different sides of the component). The same or similar relative wire feeding (e.g., wire feed paths) can be achieved by providing some or all of the degrees of freedom movement through movement of the component. For example, in embodiments, the tool is configured with a clamp assembly that translates about x and y axes, and a pedestal that this driven by an actuator in z and θ axes. Wire feeding paths such as those described above can be achieved by different combinations of motion of the clamp assembly and component (e.g., the pedestal, instead of the clamp assembly, can be driven through relatively small ranges of motion about the z and θ axes).

CLAIMS

1. A wire feeding and bonding tool, including:

a support to hold a component to which a wire is to be attached, wherein the component has at least first and second spaced-apart wire attach structures to which a wire can be attached, and wherein a first wire axis extends between the first and second wire attach structures;

a wire feed system including:

a capillary having an end portion with a feed opening, wherein a wire to be attached to the wire attach structures can be fed through the capillary and extend from the feed opening;

a stage for moving the capillary with respect to the support about one or more axes to position the capillary and a wire extending from the feed opening;

an attachment tool positioned with respect to the support to attach the wire to the attach structures;

a cutting tool positioned with respect to the support to cut the wire; and

a control system coupled to the stage, the attachment tool and the cutting tool, wherein the control system:

actuates the stage to position the capillary with portions of the wire extending from the feed opening presented at the first and second wire attach structures;

actuates the stage to move the capillary along a wire feed path and feed the wire from the first wire attach structure to the second wire attach structure with the wire emerging from the feed opening sufficiently coaxial with the wire axis to reduce damage to the wire;

actuates the attachment tool to attach the wire to the first and second attach structures; and

actuates the cutting tool to cut the wire.

2. The wire feeding and bonding tool of claim 1 wherein:

the capillary includes a linear end portion; and

the control system actuates the stage to move the capillary with the linear end portion sufficiently coaxial with the wire axis to reduce damage to the wire.

3. The wire feeding and bonding tool of claim 2 wherein all or substantially all of the capillary is linear.

4. The wire feeding and bonding tool of claim 1 and further including a capillary clamp mounted to the stage, to releasably hold the capillary.

5. The wire feeding and bonding tool of claim 1 wherein the component has crimp wire attach structures, and further wherein:

the control system actuates the stage to position the capillary with portions of the wire extending from the feed opening extending into the crimps; and

the attachment tool comprises at least one punch to deform the crimps so the crimps engage the portions of the wire therein.

6. The wire feeding and bonding tool of claim 1 and further including a tensioning apparatus to apply tension to the wire.

7. The wire feeding and bonding tool of claim 1 wherein:

the control system actuates the stage to move the capillary away from the first wire attach structure along a first portion of the wire feed path that is generally linear; and

the control system actuates the stage to move the capillary during a second portion of the wire feed path that is generally perpendicular to the first portion of the wire feed path, and wherein the second portion of the wire feed path is shorter than the first portion of the wire feed path.

8. The wire feeding and bonding tool of claim 7 wherein the control system actuates the stage to move the capillary through a looping path during the second portion of the wire feed path.

9. The wire feeding and bonding tool of claim 1, wherein the control system:

actuates the stage to position the capillary with an end of the wire extending from the feed opening adjacent to the first wire attach structure;

actuates the attachment tool to attach the end of the wire adjacent to the first wire attach structure to the first wire attach structure;

actuates the stage to move the capillary along the wire feed path after the wire is attached to the first attach structure, and to position a portion of the wire extending from the capillary adjacent to the second wire attach structure;

actuates the attachment tool to attach the portion of the wire adjacent to the second wire attach structure to the second wire attach structure; and

actuates the cutting tool to cut the portion of the wire attached to the second attach structure from a portion extending from the feed opening.

10. The wire feeding and bonding tool of claim 9 wherein the component has first and second crimp wire attach structures, and further wherein:

the control system actuates the stage to position the capillary with the wire extending from the feed opening into the crimps; and

the attachment tool comprises at least one punch to deform the crimps so the crimps engage the portions of the wires therein.

11. The wire feeding and bonding tool of claim 10 wherein:

the attachment tool comprises first and second punches;

the control system actuates the first punch to deform the first crimp; and

the control system actuates the second punch to deform the second crimp.

12. The wire feeding and bonding tool of claim 11 wherein:

the control system actuates the stage to move the capillary away from the first crimp along a first portion of the wire feed path that is generally linear; and

the control system actuates the stage to move the capillary during a second portion of the wire feed path that is generally perpendicular to the first portion of the wire feed path to position the wire within the second crimp, and wherein the second portion of the wire feed path is shorter than the first portion of the wire feed path.

13. The wire feeding and bonding tool of claim 12 wherein the control system actuates the stage to move the capillary through a looping path during the second portion of the wire feed path.

14. The wire feeding and bonding tool of claim 11 wherein the component has at least third and fourth crimp wire attach structures, and wherein a second wire attach axis that is non-

collinear with the first wire attach axis extends between the third and fourth crimps, and further wherein:

the tool further includes a support actuator coupled to the control system to rotate the support with respect to the wire feed system; and

the control system:

actuates the support actuator to rotate the support and component held thereon;

actuates the stage to position the capillary with an end of the wire extending from the feed opening into to the third crimp;

actuates the first punch to deform the third crimp and attach the wire to the third crimp;

actuates the stage to move the capillary along the wire feed path after the wire is attached to the third crimp, and to position a portion of the wire extending from the capillary into the fourth crimp;

actuates the second punch to deform the fourth crimp and attach the wire to the fourth crimp; and

actuates the cutting tool to cut the portion of the wire attached to the fourth crimp from a portion extending from the feed opening.

15. The wire feeding and bonding tool of claim 14 wherein the control system actuates the support actuator to rotate the support and component held thereon about ninety degrees.

16. The wire feeding and bonding tool of claim 9 and further including a tensioning apparatus to tension the wire.

17. The wire feeding and bonding tool of claim 9 wherein

the capillary includes a linear end portion; and

the control system actuates the stage to move the capillary with the linear end portion sufficiently coaxial with the wire axis to reduce damage to the wire.

18. The wire feeding and bonding tool of claim 1 wherein the component has at least third and fourth wire attach structures, and wherein a second wire attach axis that is non-collinear with the first wire attach axis extends between the third and fourth wire attach structures, and further wherein:

the tool further includes a support actuator coupled to the control system to move the support with respect to the wire feed system; and

the control system:

actuates the support actuator to move the support and component held thereon;

actuates the stage to position the capillary with an end of the wire extending from the feed opening adjacent to the third wire attach structure;

actuates the attachment tool to attach the wire to the third wire attach structure;

actuates the stage to move the capillary along the wire feed path after the wire is attached to the third wire attach structure, and to position a portion of the wire extending from the capillary adjacent to the fourth wire attach structure;

actuates the attachment tool to attach the wire to the fourth wire attach structure; and

actuates the cutting tool to cut the portion of the wire attached to the fourth wire attach structure from a portion extending from the feed opening.

19. The wire feeding and bonding tool of claim 18 wherein:

the control system actuates the stage to move the capillary away from the first wire attach structure along a first portion of the wire feed path that is generally linear;

the control system actuates the stage to move the capillary during a second portion of the wire feed path that is generally perpendicular to the first portion of the wire feed path to position the wire adjacent to the second wire attach structure, and wherein the second portion of the wire feed path is shorter than the first portion of the wire feed path;

the control system actuates the stage to move the capillary away from the third wire attach structure along a first portion of the wire feed path that is generally linear;

the control system actuates the stage to move the capillary during a second portion of the wire feed path that is generally perpendicular to the first portion of the wire feed path to position the wire adjacent to the fourth wire attach structure, and wherein the second portion of the wire feed path is shorter than the first portion of the wire feed path.

20. A method for attaching wires to a component having first and second spaced-apart wire attach structures defining a first wire axis extending between the first and second wire attach structures, including:

feeding the wire through a capillary having a feed opening;

positioning the capillary to locate a first portion of the wire extending from the feed opening adjacent to the first wire attach structure;

attaching the first portion of the wire to the first wire attach structure;

moving the capillary with respect to the component along a wire feed path to feed the wire from the first wire attach structure to the second wire attach structure and positioning the capillary to locate a second portion of the wire extending from the feed opening adjacent to the second wire attach structure with the wire emerging from the feed opening sufficiently coaxial with the wire axis to reduce damage to the wire; and

attaching the second portion of the wire to the second wire attach structure.

21. The method of claim 20 wherein the capillary has a linear end portion and moving the capillary includes maintaining the linear end portion of the capillary sufficiently coaxial with the wire axis to reduce damage to the wire.

22. The method of claim 20 wherein moving the capillary includes:

moving the capillary away from the first attachment structure along a first and generally linear portion of the wire feed path; and

moving the capillary along a second portion of the wire feed path after moving the capillary along the first portion of the wire feed path to locate the second portion of the wire adjacent to the second wire attach structure, wherein the second portion of the wire feed path is generally perpendicular to the first portion of the wire feed path.

23. The method of claim 22 wherein the capillary has a linear end portion and moving the capillary includes maintaining the linear end portion of the capillary sufficiently coaxial with the wire axis to reduce damage to the wire.

24. The method of claim 23 wherein the second portion of the wire feed path is shorter than the first portion of the wire feed path.

25. The method of claim 24 wherein moving the capillary along the second portion of the wire feed path includes moving the capillary along a looping path.

26. The method of claim 25 wherein:

moving the capillary along the second portion of the wire feed path includes moving the wire into an opening of a crimp attach structure; and

attaching the second portion of the wire to the second wire attach structure includes deforming the crimp attach structure to engage the wire.

27. The method of claim 26 and further including clamping and releasing the wire with respect to the capillary.

28. The method of claim 22 and further including tensioning the wire.

29. The method of claim 24 and further including clamping and releasing the wire with respect to the capillary.

30. The method of claim 29 and further including tensioning the wire.

31. The method of claim 20 and further including clamping and releasing the wire with respect to the capillary.

32. The method of claim 31 wherein the capillary has a linear end portion and moving the capillary includes maintaining the linear end portion of the capillary sufficiently coaxial with the wire axis to reduce damage to the wire.

33. The method of claim 32 and further including tensioning the wire.

34. The method of claim 20 and further including tensioning the wire.

35. The method of claim 34 wherein the capillary has a linear end portion and moving the capillary includes maintaining the linear end portion of the capillary sufficiently coaxial with the wire axis to reduce damage to the wire.

36. The method of claim 20 and further including cutting the wire between the second attach structure and the capillary after attaching the second portion of the wire to the second attach structure.

37. The method of claim 20 wherein:

moving the capillary includes:

moving the capillary away from the first attachment structure toward the second attachment structure while feeding wire from the capillary;

clamping the wire with respect to the capillary after moving the capillary away from the first attachment structure;

moving the capillary with the clamped wire toward the first attachment structure to push slack into the wire between the first and second attachment structures; and

attaching the second portion of the wire to the second wire attach structure includes attaching the wire to the second wire attach structure after moving the capillary to push slack into the wire.

38. The method of claim 20 and further including:

monitoring the wire to identify locations of uncoated regions on the wire; and

adjusting the position of the wire with respect to the capillary as a function of the identified locations of the uncoated regions on the wire.

39. The wire feeding and bonding tool of claim 1 wherein:

the tool further includes a clamp coupled to the control system to releasably fix the position of the wire with respect to the capillary; and

the control system:

actuates the stage to position the capillary with an end of the wire extending from the feed opening adjacent to the first wire attach structure;

actuates the attachment tool to attach the end of the wire adjacent to the first wire attach structure to the first wire attach structure;

actuates the stage to move the capillary after the wire is attached to the first attach structure, to feed wire from the capillary and to position a portion of the wire extending from the capillary adjacent to the second wire attach structure;

actuates the clamp to fix the wire with respect to the capillary after the portion of the wire is positioned adjacent to the second wire attach structure;

actuates the stage to move the capillary with the fixed wire toward the second attachment structure to push slack into the wire between the first and second attachment structures; and actuates the attachment tool to attach the wire to the second wire attach structure.

40. The wire feeding and bonding tool of claim 1 wherein:

the tool further includes a monitor to identify locations of uncoated regions on the wire; and

the control system is coupled to the monitor and causes the location of the wire with respect to the capillary to be adjusted as a function of the identified locations of the uncoated regions of the wire.

41. A wire feeding and bonding tool, including:

a support to hold a component to which a wire is to be attached, wherein the component has at least first and second spaced-apart wire attach structures to which a wire can be attached;

a wire feed system including:

a capillary having an end portion with a feed opening, wherein a wire to be attached to the wire attach structures can be fed through the capillary and extend from the feed opening;

an actuator for moving the capillary and support with respect to one another to position the capillary and a wire extending from the feed opening with respect to the component;

an attachment tool positioned with respect to the support to attach the wire to the attach structures; and

a control system coupled to the actuator and the attachment tool, wherein the control system:

actuates the actuator to position the capillary with portions of the wire extending from the feed opening presented at the first and second wire attach structures;

actuates the actuator to move the capillary along a wire feed path and feed the wire from the first wire attach structure to the second wire attach structure; and

actuates the attachment tool to attach the wire to the first and second attach structures.

42. The tool of claim 41 wherein the actuator includes a stage coupled to the capillary.

43. The tool of claim 42 wherein:

the actuator further includes a support actuator coupled to the support; and

the control system is coupled to the support actuator and actuates the stage and the support actuator to move the capillary along the wire feed path.

44. The tool of claim 41 wherein:

the tool further includes a clamp coupled to the control system to releasably fix the position of the wire with respect to the capillary; and

the control system actuates the actuator, attachment tool and clamp to:

position the capillary with an end of the wire extending from the feed opening adjacent to the first wire attach structure;

attach the end of the wire adjacent to the first wire attach structure to the first wire attach structure;

move the capillary after the wire is attached to the first attach structure, to feed wire from the capillary and to position a portion of the wire extending from the capillary adjacent to the second wire attach structure;

fix the wire with respect to the capillary after the portion of the wire is positioned adjacent to the second wire attach structure;

move the capillary with the fixed wire toward the second attachment structure to push slack into the wire between the first and second attachment structures; and

attach the portion of the wire adjacent to the second wire attach structure to the second wire attach structure.

45. The wire feeding and bonding tool of claim 41 wherein:

the tool further includes a monitor to identify location of uncoated regions on the wire; and

the control system is coupled to the monitor and causes the position of the wire with respect to the capillary to be adjusted as a function of the identified locations of the uncoated regions of the wire.

46. The tool of claim 41 wherein the control system actuates the actuator to move the capillary along a wire feed path and to feed the wire from the first wire attach structure to the

second wire attach structure with the wire emerging from the feed opening sufficiently coaxial with the capillary to reduce damage to the wire.

47. A method for attaching wires to a component having first and second spaced-apart wire attach structures, including:

feeding the wire through a capillary having a feed opening;

positioning the capillary with respect to the component to locate a first portion of the wire extending from the feed opening adjacent to the first wire attach structure;

attaching the first portion of the wire to the first wire attach structure;

moving the capillary with respect to the component along a wire feed path to feed the wire from the first wire attach structure to the second wire attach structure and locating a second portion of the wire extending from the feed opening adjacent to the second wire attach structure; and

attaching the second portion of the wire to the second wire attach structure.

48. The method of claim 47 wherein moving the capillary with respect to the component includes moving the capillary and the component.

49. The method of claim 47 wherein:

moving the capillary includes:

moving the capillary away from the first attachment structure toward the second attachment structure while feeding wire from the capillary;

clamping the wire with respect to the capillary after moving the capillary away from the first attachment structure;

moving the capillary with the clamped wire toward the first attachment structure to push slack into the wire between the first and second attachment structures; and

attaching the second portion of the wire to the second wire attach structure includes attaching the wire to the second wire attach structure after moving the capillary to push slack into the wire.

50. The method of claim 47 and further including:

monitoring the wire to identify locations of uncoated regions on the wire; and

adjusting the position of the wire with respect to the capillary as a function of the identified locations of the uncoated regions on the wire.

51. The method of claim 47 wherein moving the capillary includes moving the capillary with the wire emerging from the feed opening sufficiently coaxial with the wire axis to reduce damage to the wire.

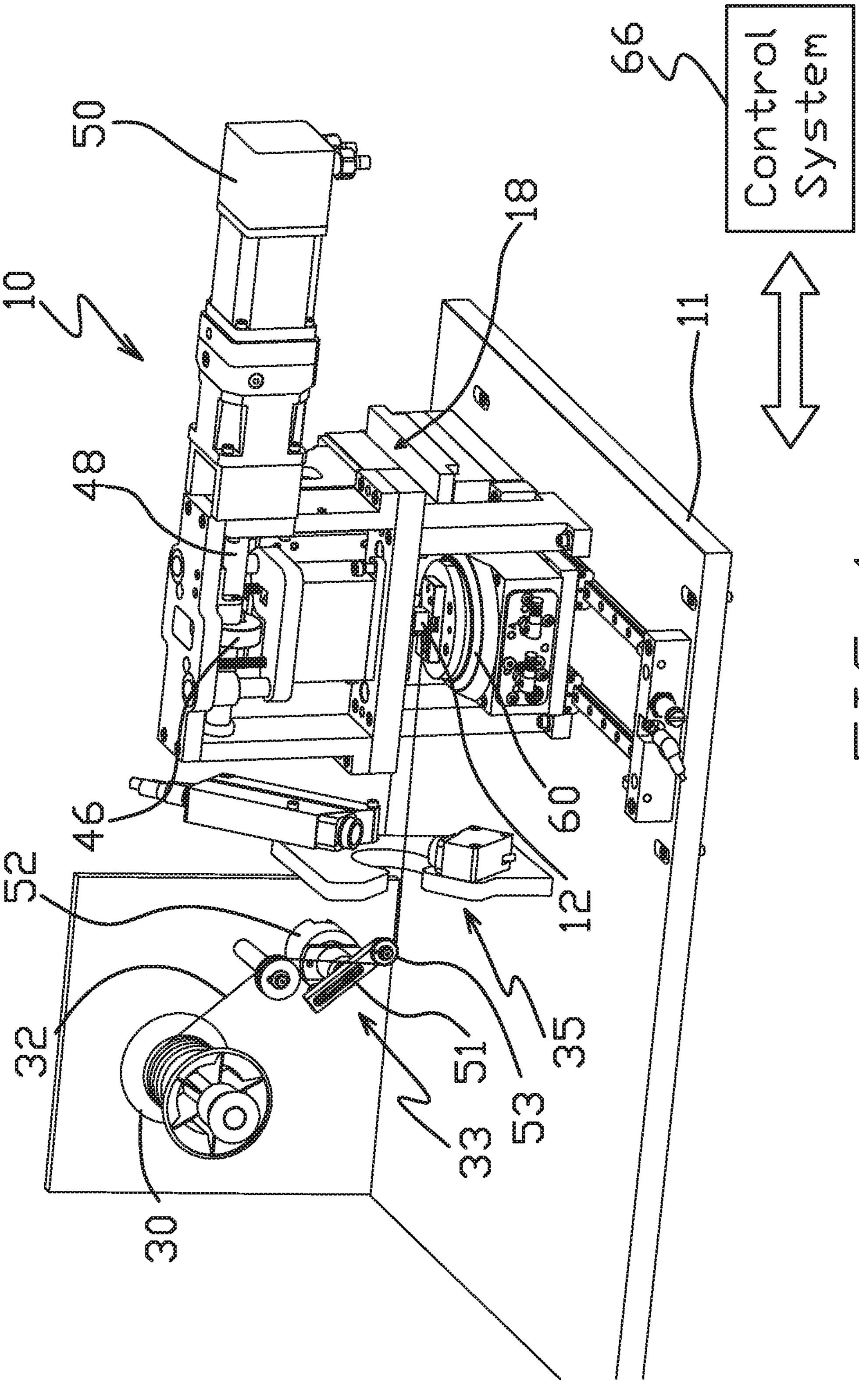

FIG 1

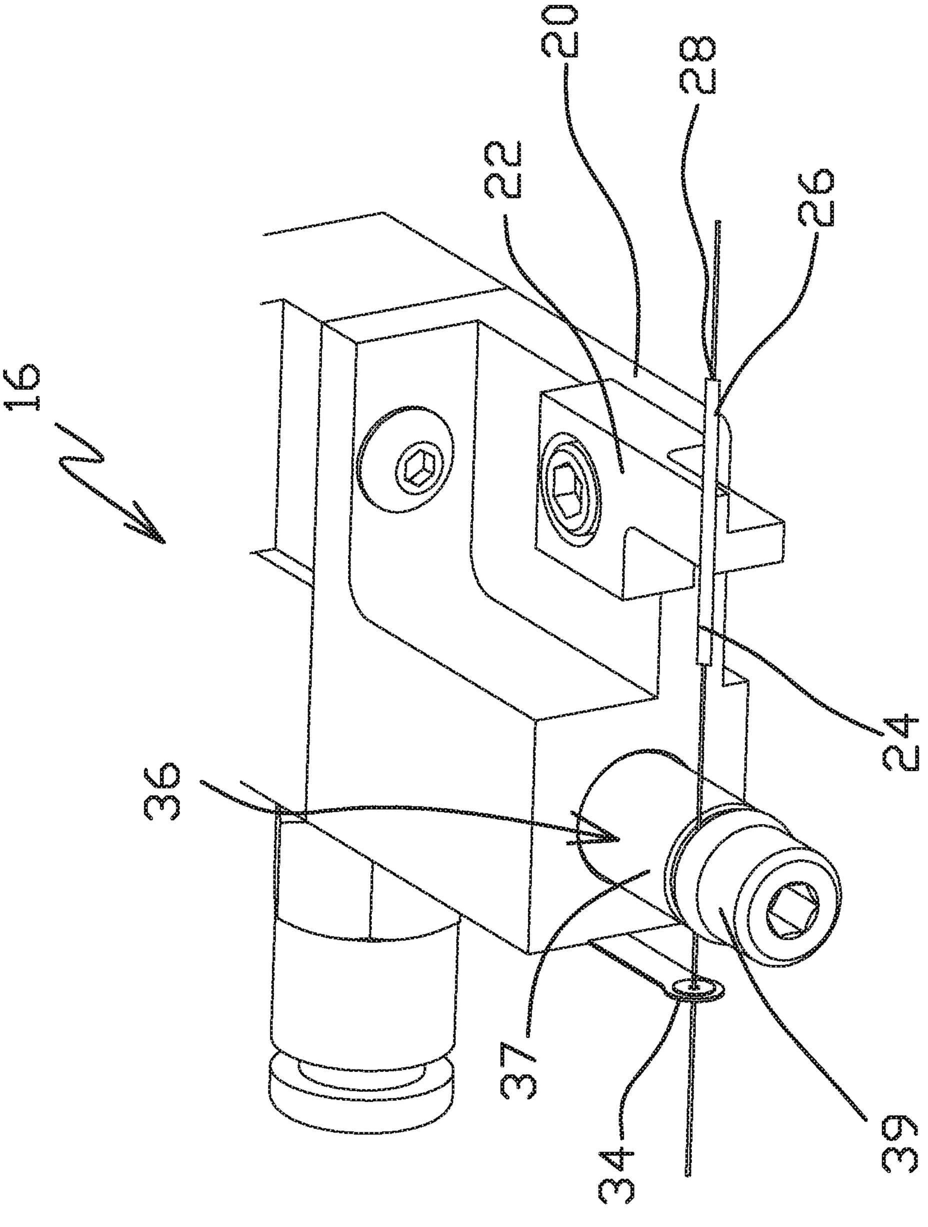

FIG 2

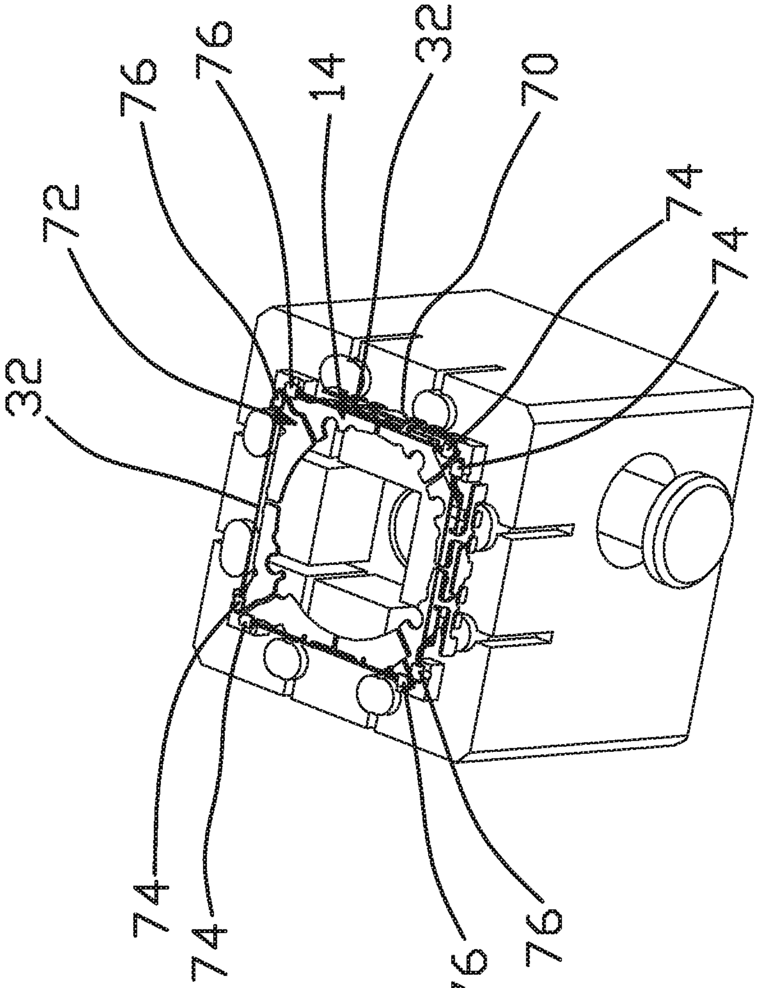

FIG 3

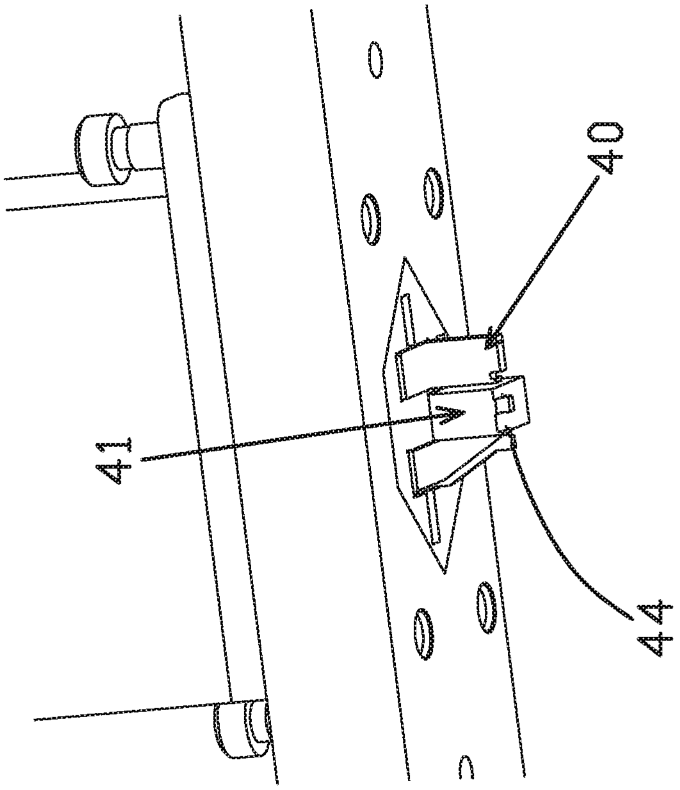

FIG 4

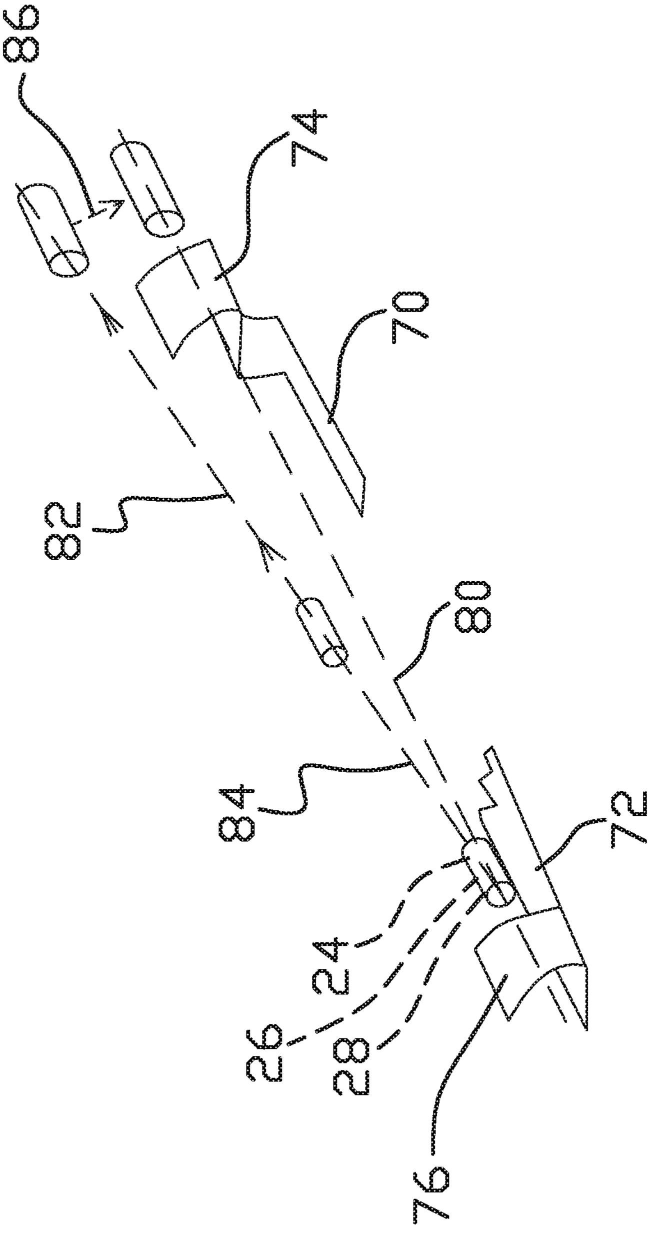

FIG 5

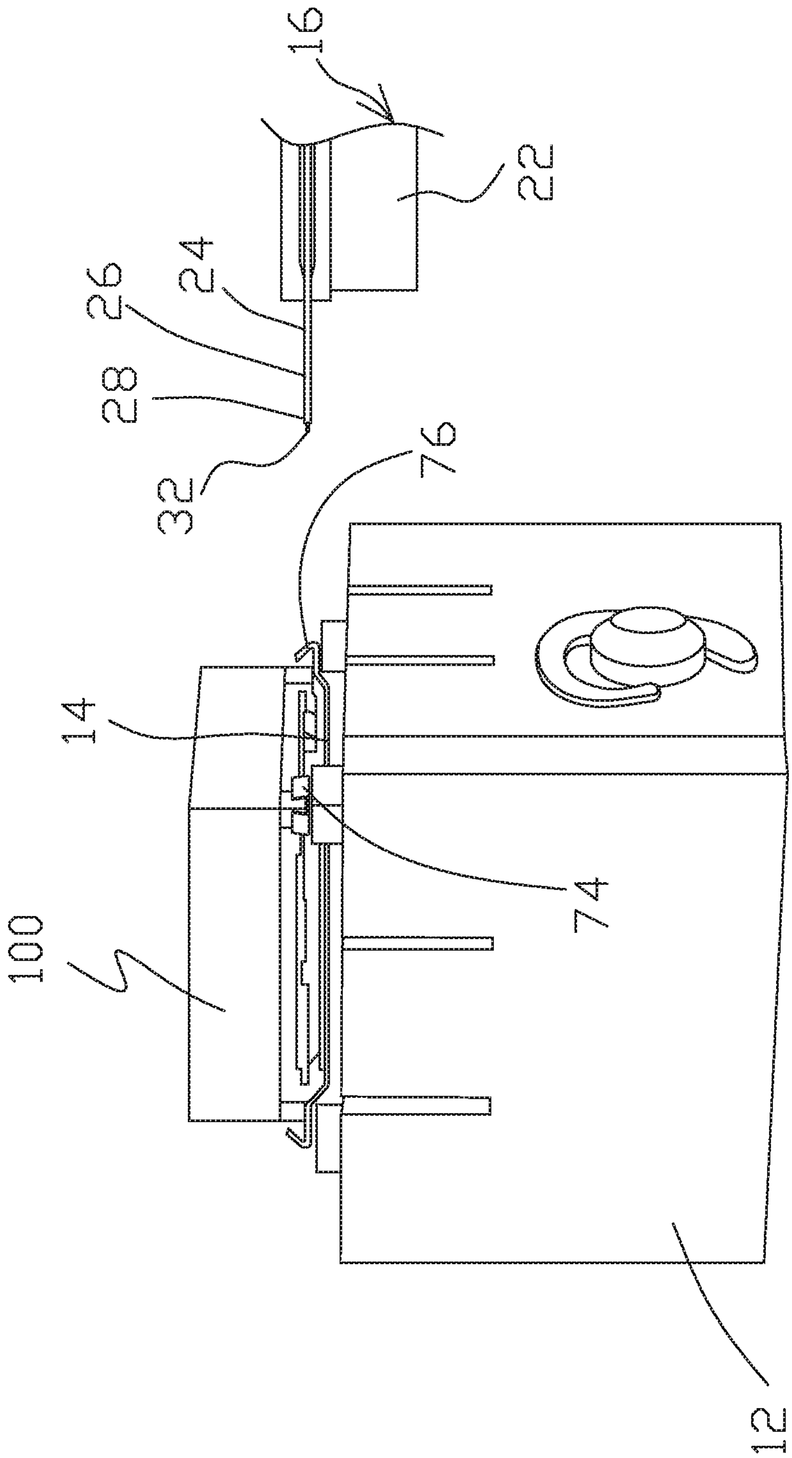

FIG 6a

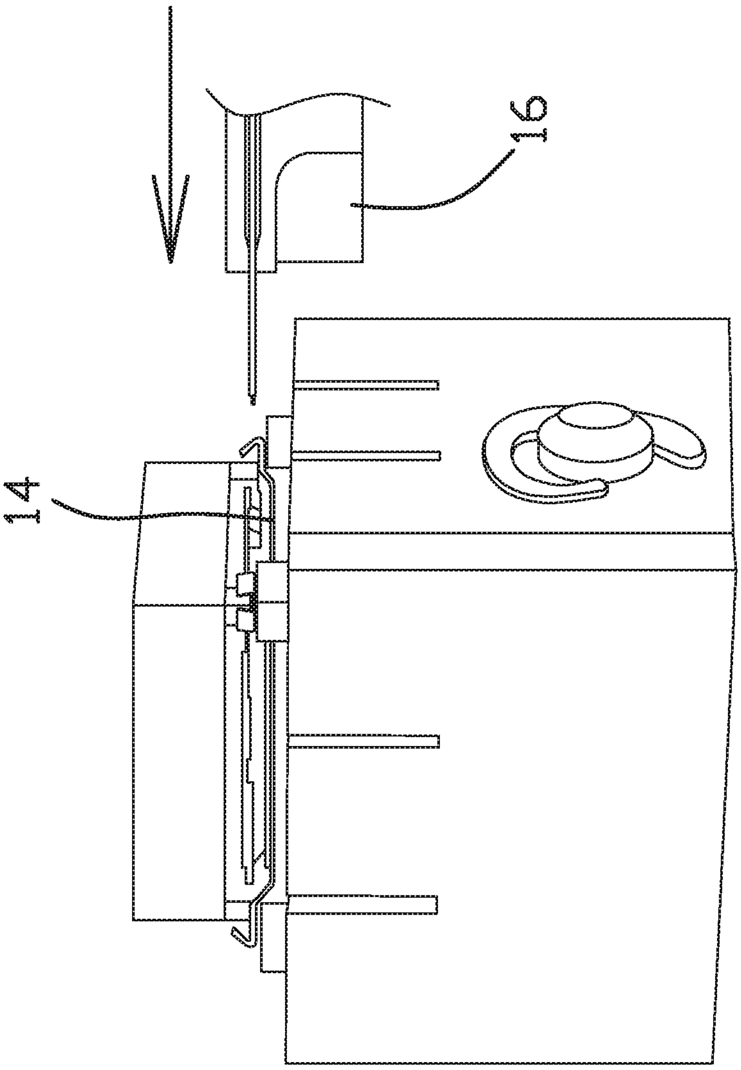

FIG 6b

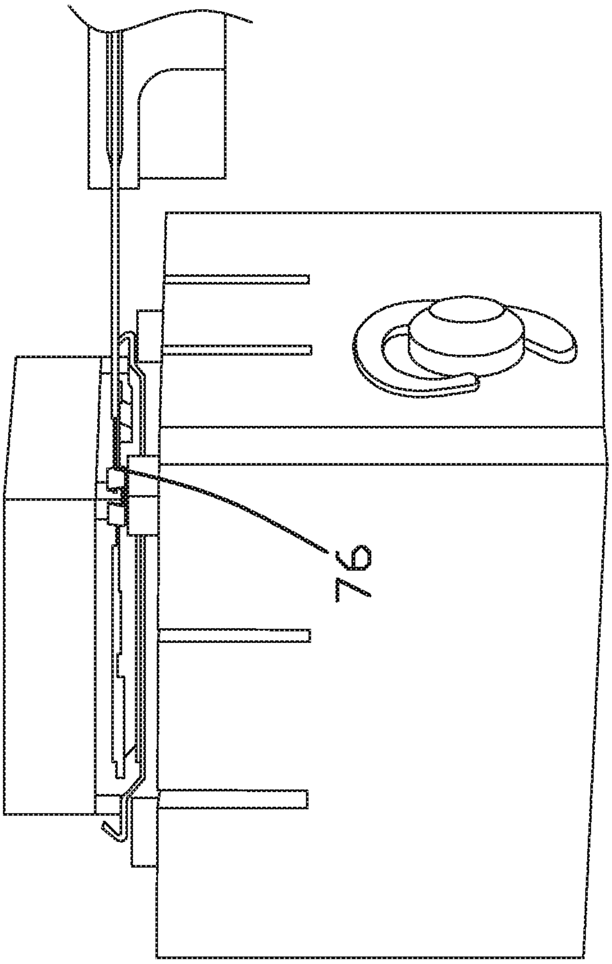

FIG 6C

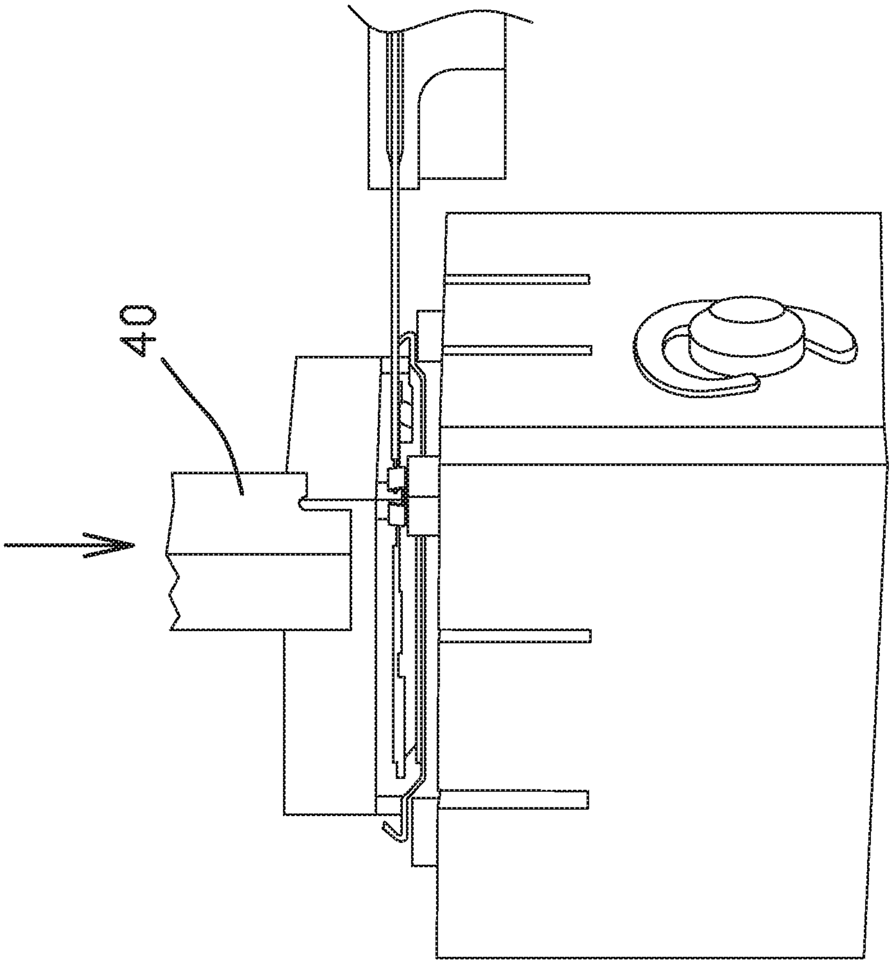

FIG 6d

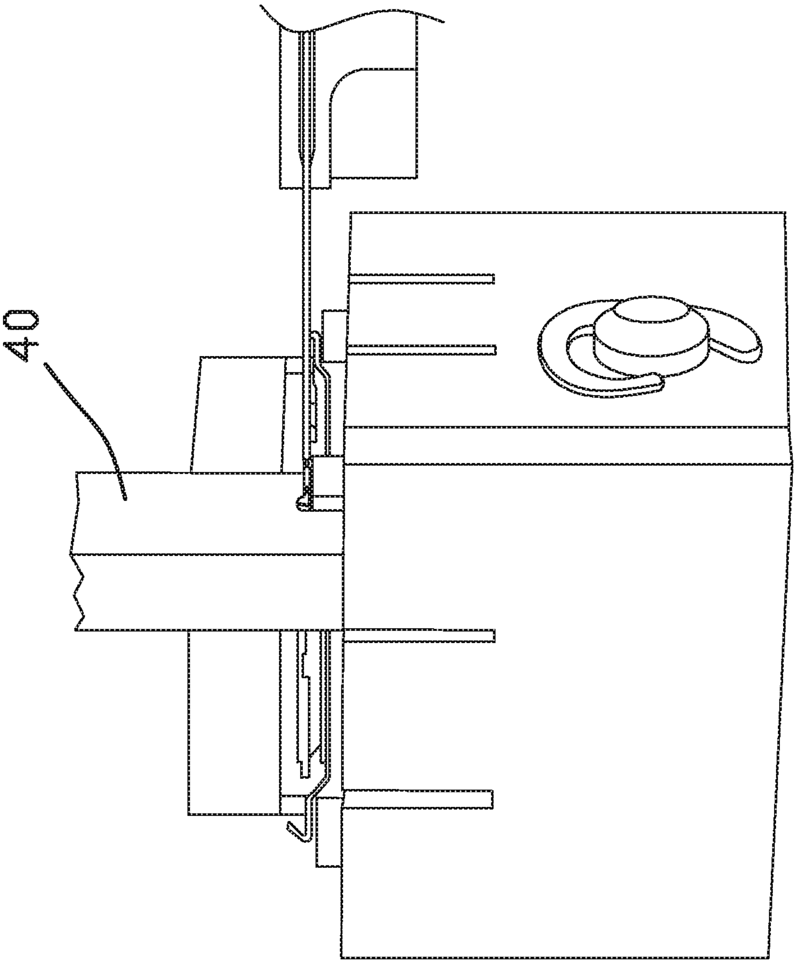

FIG 6e

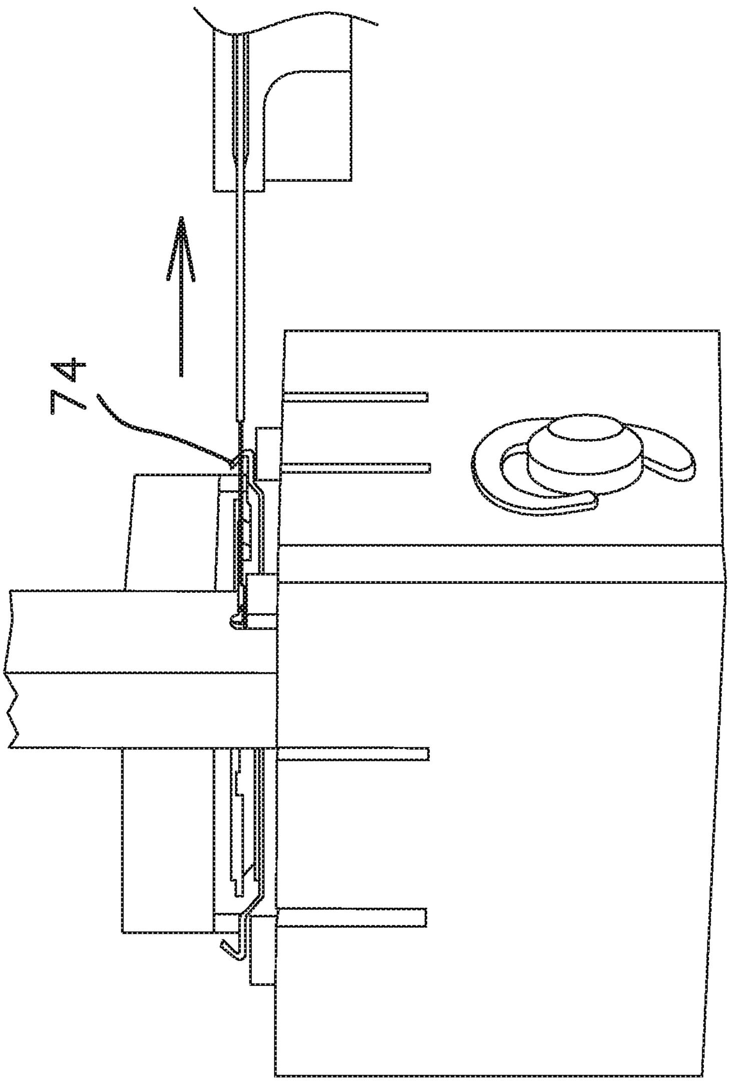

FIG 6f

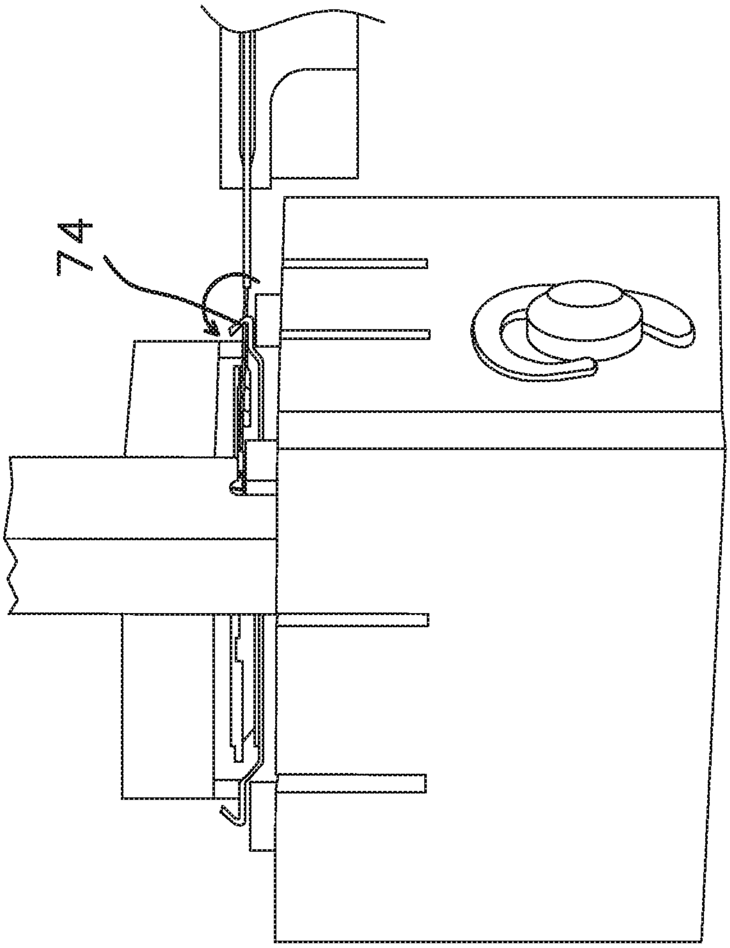

FIG 6g

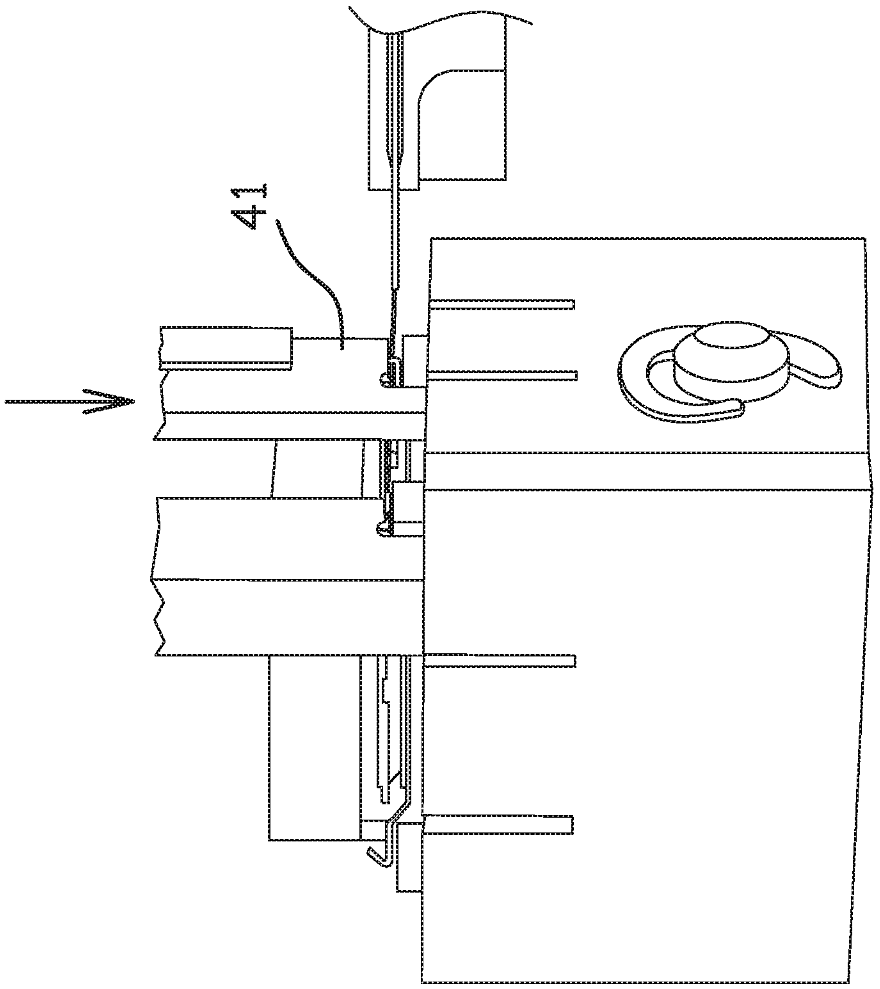

FIG 6h

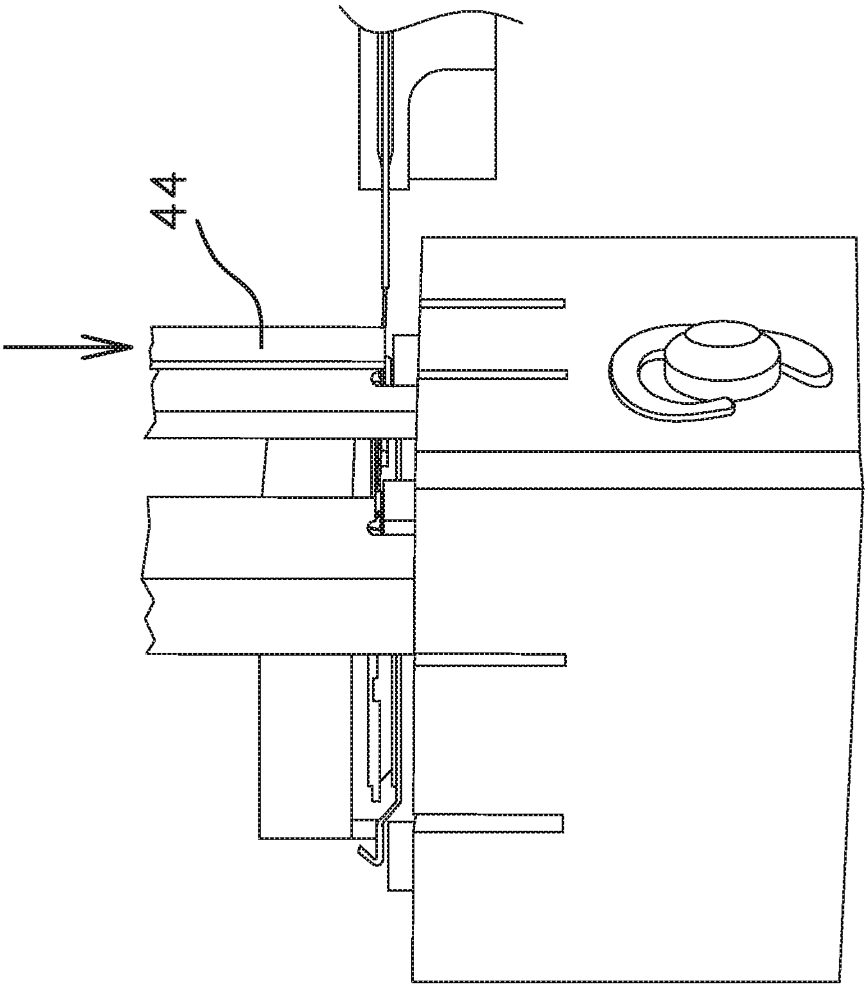

FIG 6i

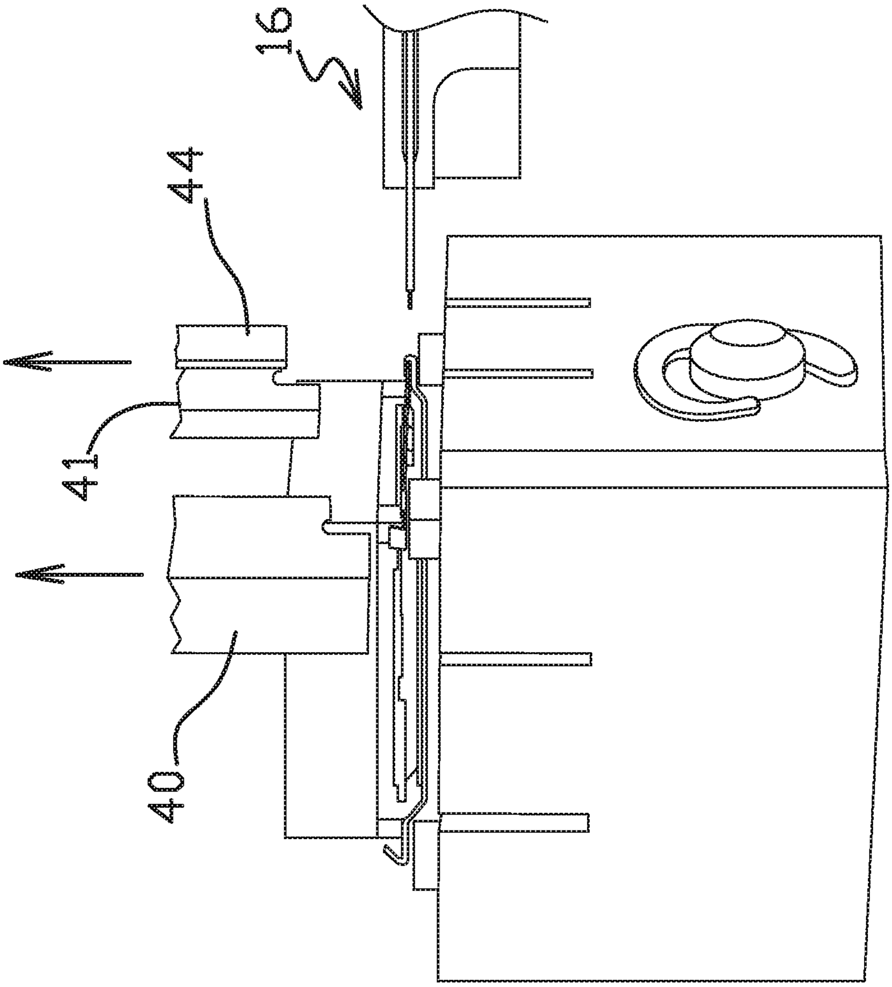

FIG 6J

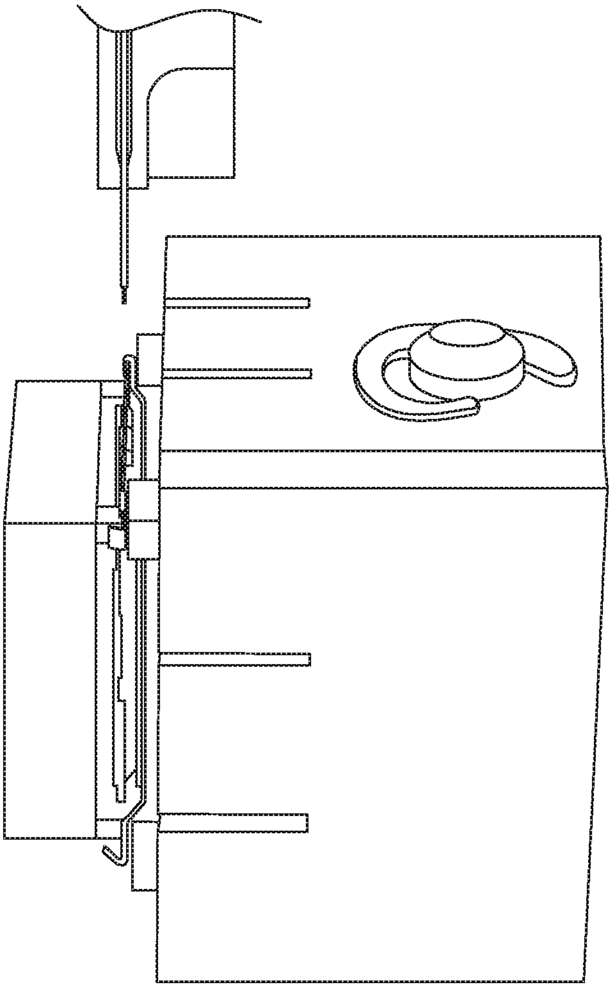

FIG 6K

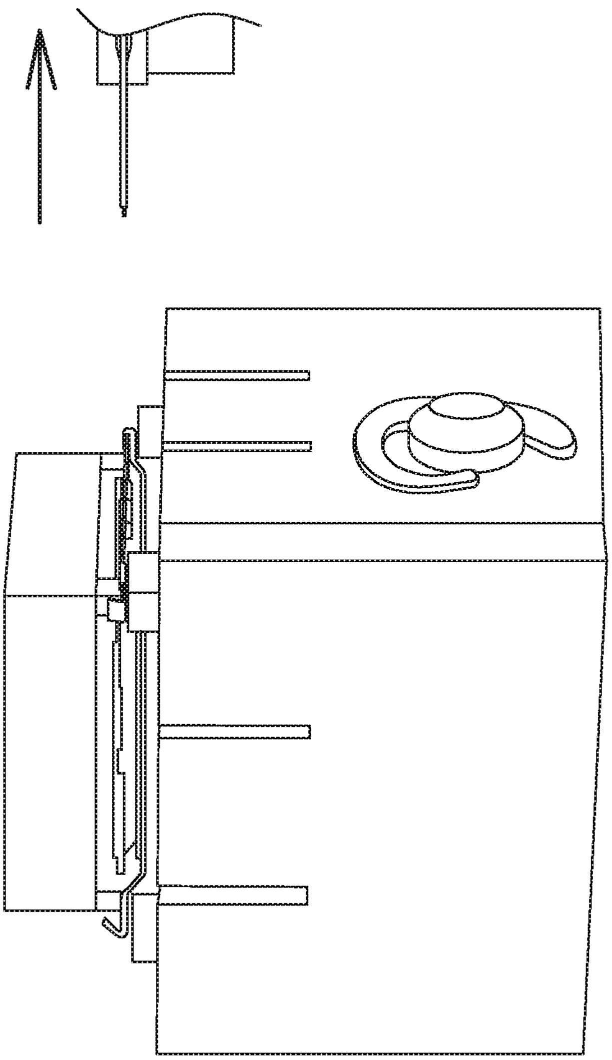

FIG 6L

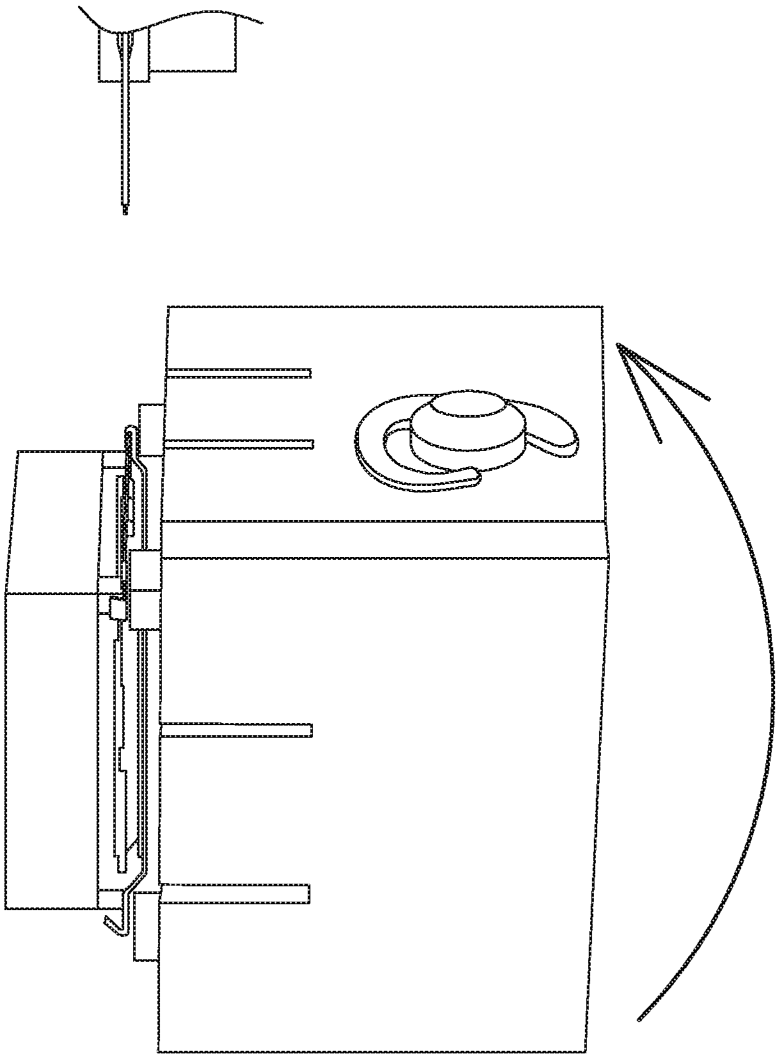

FIG 6m

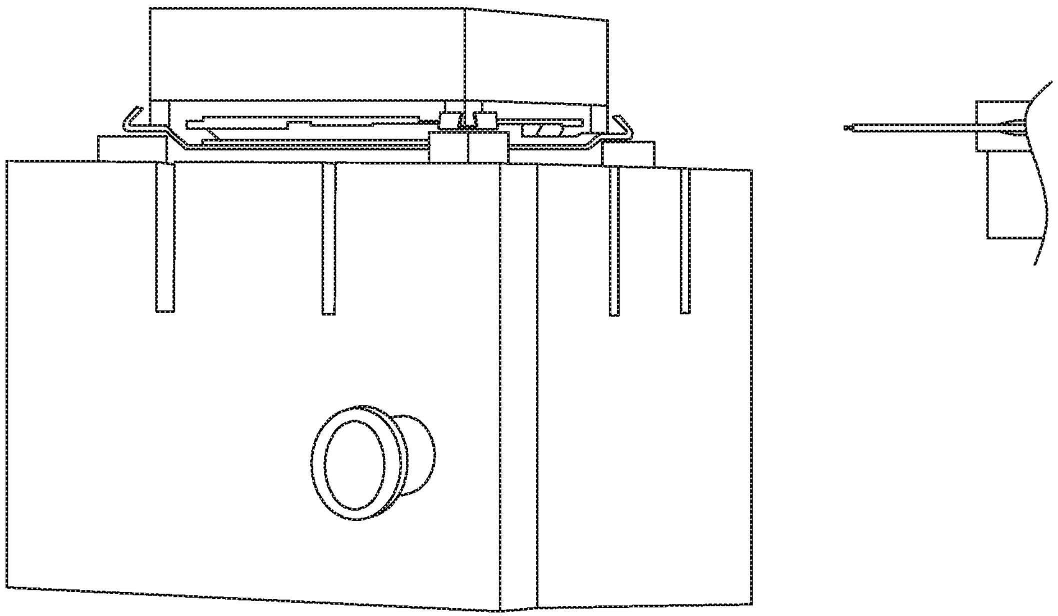

FIG 6n

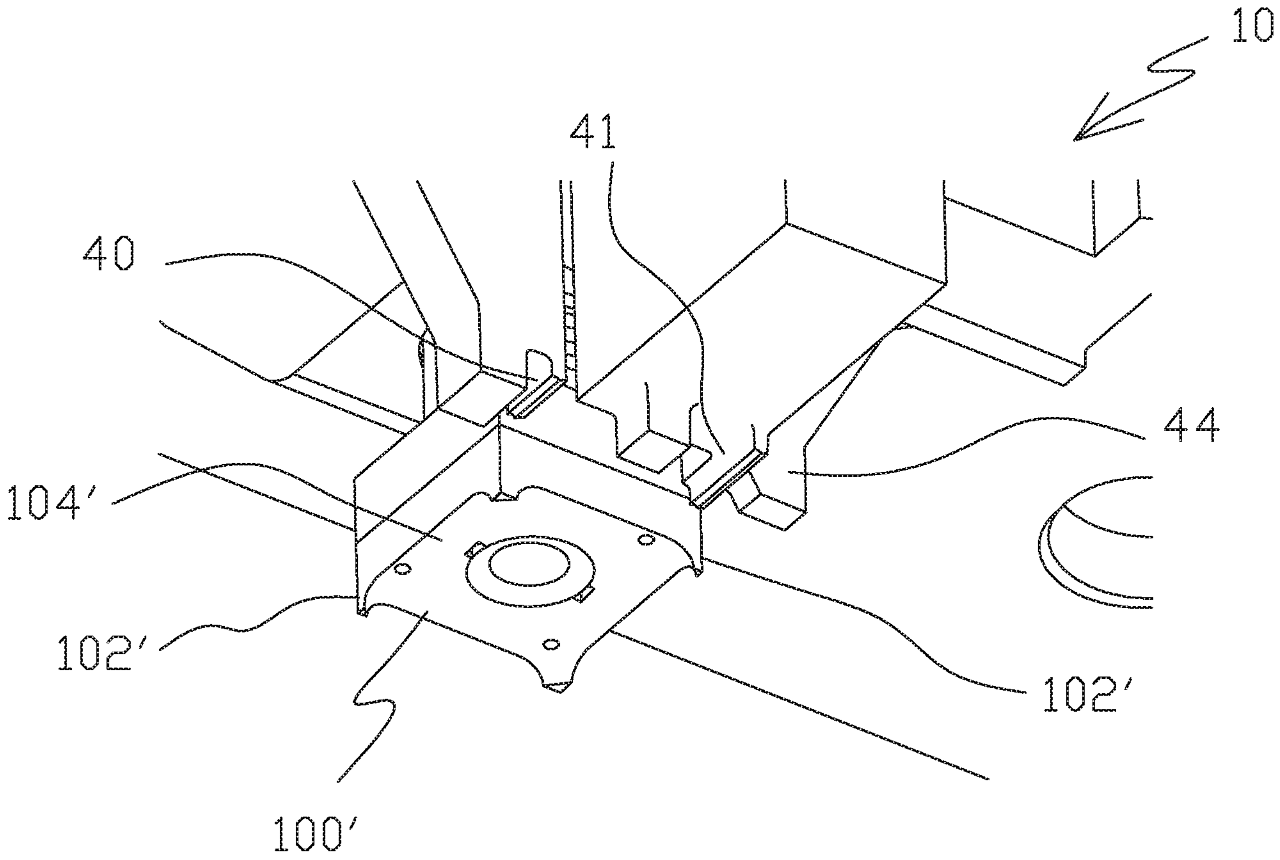

FIG 7

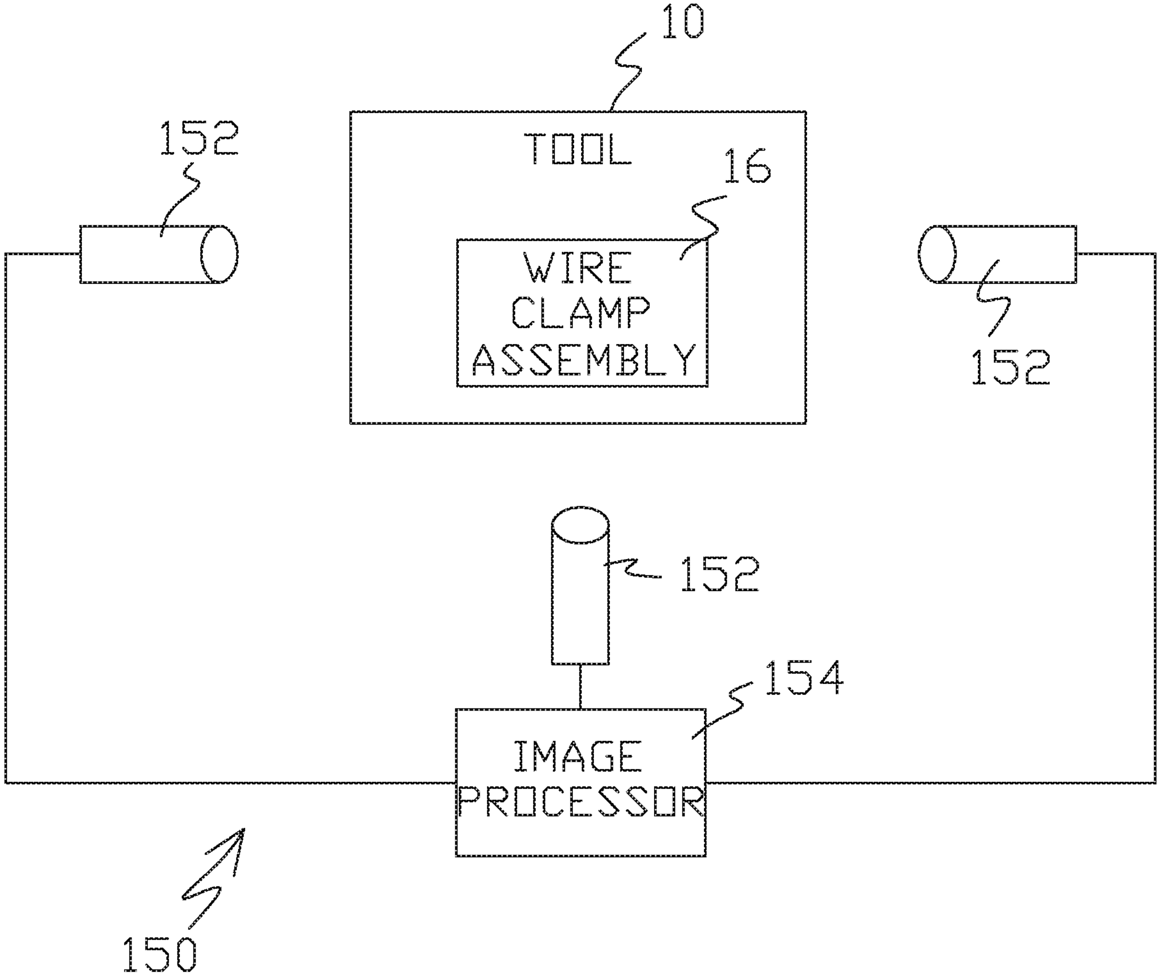
10
152
TOOL
16
WIRE
CLAMP
ASSEMBLY
152
152
154
IMAGE
PROCESSOR
150

FIG 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US16/25194

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H01L 21/60; H01L 24/43; H01L 24/78; H01R 43/052; H01R 43/28 (2016.01)
CPC - H01L 21/67138; H01L 24/43; H01L 24/85; H01R 43/052; H01R 43/28
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: H01R 43/052, 43/28; H01L 21/60, 24/43, 24/78, 24/85; H02G 1/14 (2016.01)
CPC: H01R 43/052, 43/28; H01L 21/60, 21/67138, 2224/7855, 2224/786, 24/43, 24/78, 24/85; H02G 1/14; G05B 2219/45033

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 228/4.5, 5.1, 49.5, 160, 180.4, 904; 29/748

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatSeer (US, EP, WO, JP, DE, GB, CN, FR, KR, ES, AU, IN, CA, INPADOC Data); Google; Google Scholar; EBSCO; Search Terms: wire, lead, filament, feed, supply, dispense, bond, attach, crimp, solder, weld, join, capillary, tube, chuck, stage, table, platform, X-Y, axis, translate, linear, cut, sever, shear, controller, computer, processor, monitor, detect, coat, uncoated, insulated, crimp, punch, press

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US 4,437,603 A (KOBAYASHI, M. et al.) 20 March 1984; figures 1-5, 7, 16, 17; column 1, lines 25-35; column 2, lines 50-55; column 4, lines 1-5, 15-25; column 5, lines 45-50; column 8, lines 1-10, 35-40; column 9, lines 20-25, 40-45; column 10, lines 45-50, 60-65; column 11, lines 5-10	41-43, 46 ------------ 1-4, 6, 9, 16-18, 20, 21, 31-37, 39, 44, 47-49, 51
Y	US 4,781,319 A (DEUBZER, W. et al.) 01 November 1988; figures 1, 4; column 3, lines 40-45	1-4, 6, 9, 16-18, 20, 21, 31-37, 39, 47-49, 51
Y	US 4,140,265 A (MORINO, R.) 20 February 1979; figures 9-12; column 2, lines 20-35; column 11, lines 45-55; column 12, lines 1-25; column 14, lines 5-10	37, 39, 44, 49
Y	US 2013/0221071 A1 (KIM, Y. et al.) 29 August 2013; figure 1; paragraph [0046]	4
Y	US 3,734,386 A (HAZEL, H.) 22 May 1973; figure 1; column 2, lines 40-50; column 3, lines 55-60; column 5, lines 1-20, 55-65	18
A	US 3,776,447 A (SIMMONS, M. et al.) 04 December 1973; entire document	1-51
A	US 6,279,215 B1 (NOMOTO, Y.) 28 August 2001; entire document	1-51
A	US 5,477,463 A (TAMURA, Y.) 19 December 1995; entire document	1-51
A	US 4,824,005 A (SMITH, H.) 25 April 1989; entire document	1-51

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier application or patent but published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 04 June 2016 (04.06.2016)	Date of mailing of the international search report 30 JUN 2016
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Shane Thomas PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774