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Bond

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(54) **SYSTEM AND METHOD FOR AUTOMATED PRECISION CONTROL OF A COMPUTER NUMERICAL CONTROL (CNC) MACHINE**

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G05B 19/25 (2006.01)

(52) **U.S. Cl.**
CPC ***G05B 19/4145*** (2013.01); ***G05B 19/253*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,080,855	B2	7/2015	Nahum et al.	
9,158,298	B2	10/2015	Gronbach	
10,067,495	B2	9/2018	Rivers et al.	
10,078,320	B2	9/2018	Rivers et al.	
10,095,216	B2	10/2018	Hietmann	
10,556,356	B2	2/2020	Rivers et al.	
10,778,804	B2	9/2020	Rivers et al.	
11,262,725	B2	3/2022	Frick et al.	
11,267,153	B2	3/2022	Rivers et al.	
2020/0261992	A1 *	8/2020	Frank	B25F 5/00
2021/0021972	A1	1/2021	Belt et al.	
2021/0252733	A1 *	8/2021	Kübeler	B23D 59/002

* cited by examiner

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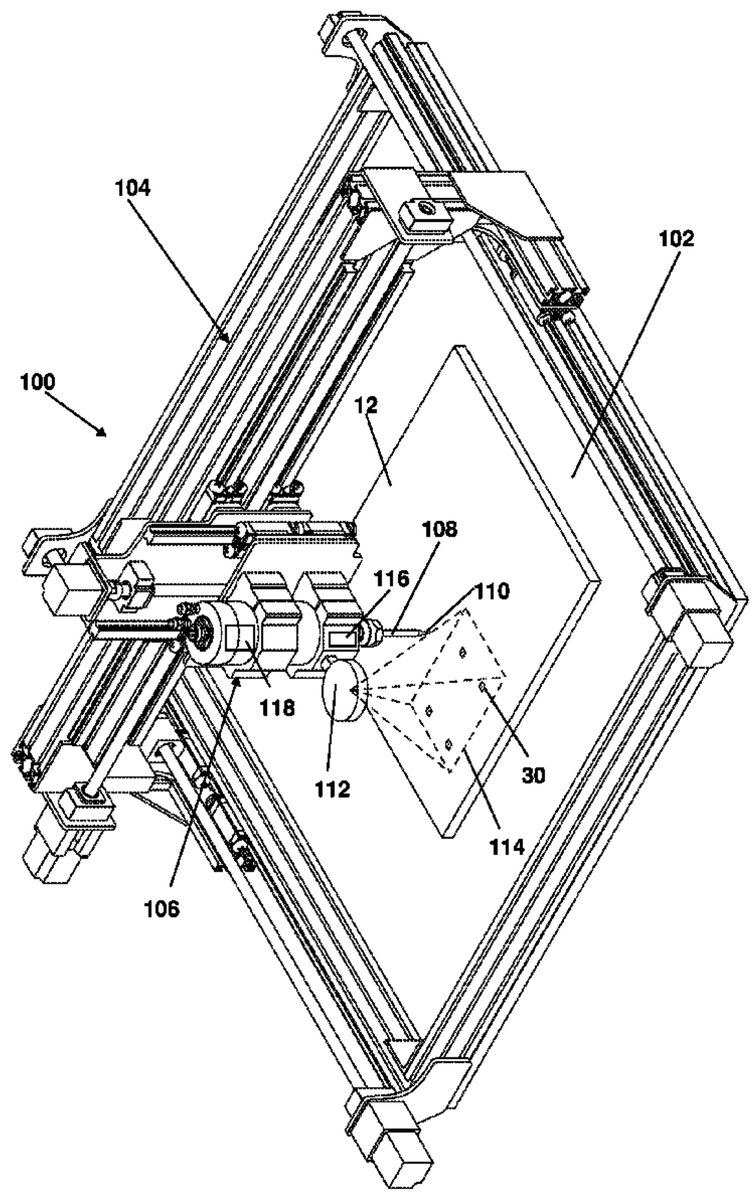
(57) **ABSTRACT**

A system, method, and device for automated precision control of a computer numerical control (CNC) machine to a workpiece. The system receives via at least one visual input device at least one detectable marking on a workpiece. The system decodes the at least one detectable marking and determines a stored and pre-defined movement routine of a cutting element attached to the CNC machine relative to the workpiece based on the at least one marking. The system then determines, using the at least one visual input device and/or another visual input device, a current position of a working end of the cutting element relative to the at least one marking. Finally, the system performs the pre-defined movement routine including cutting into the workpiece with the cutting element.

12 Claims, 13 Drawing Sheets



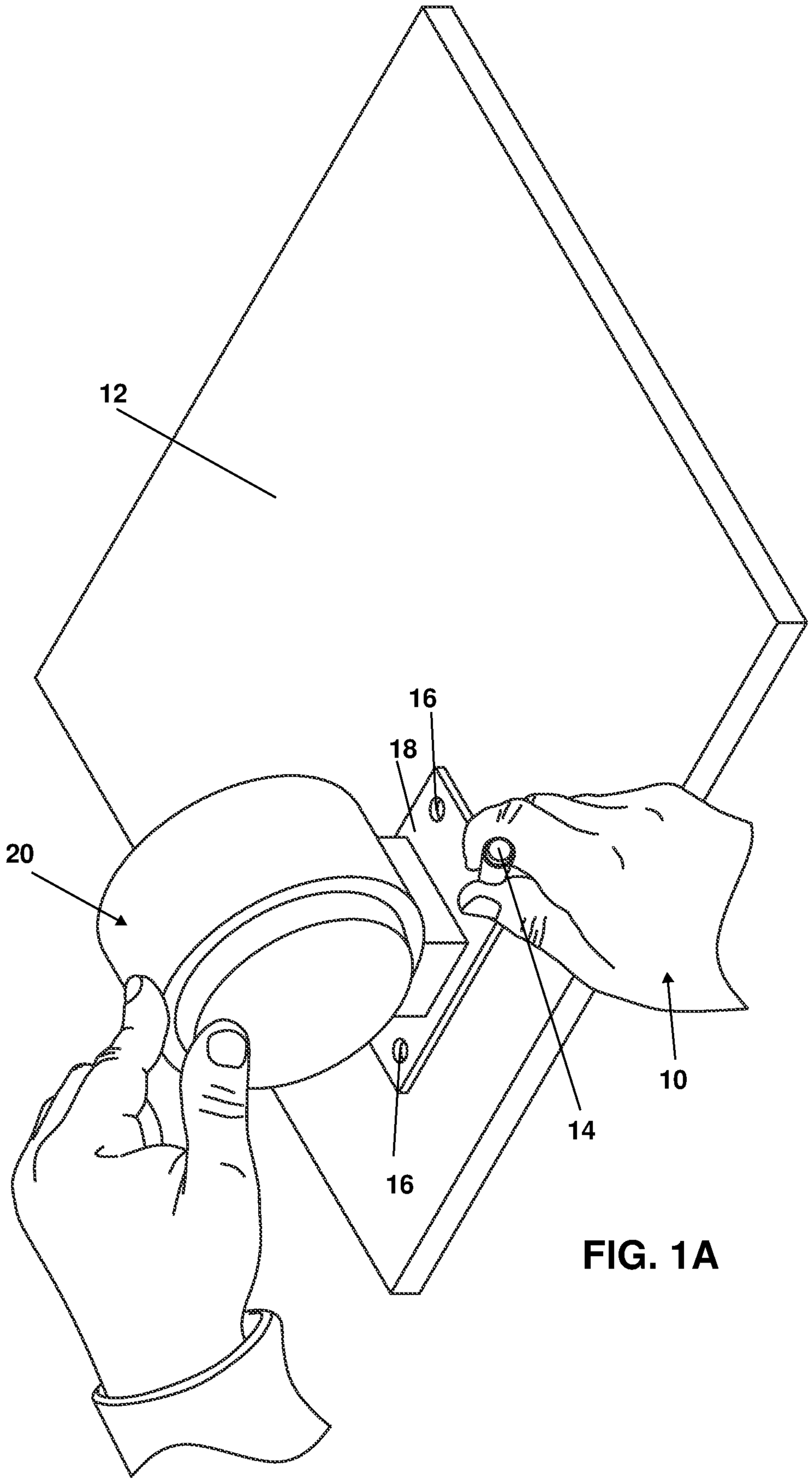


FIG. 1A

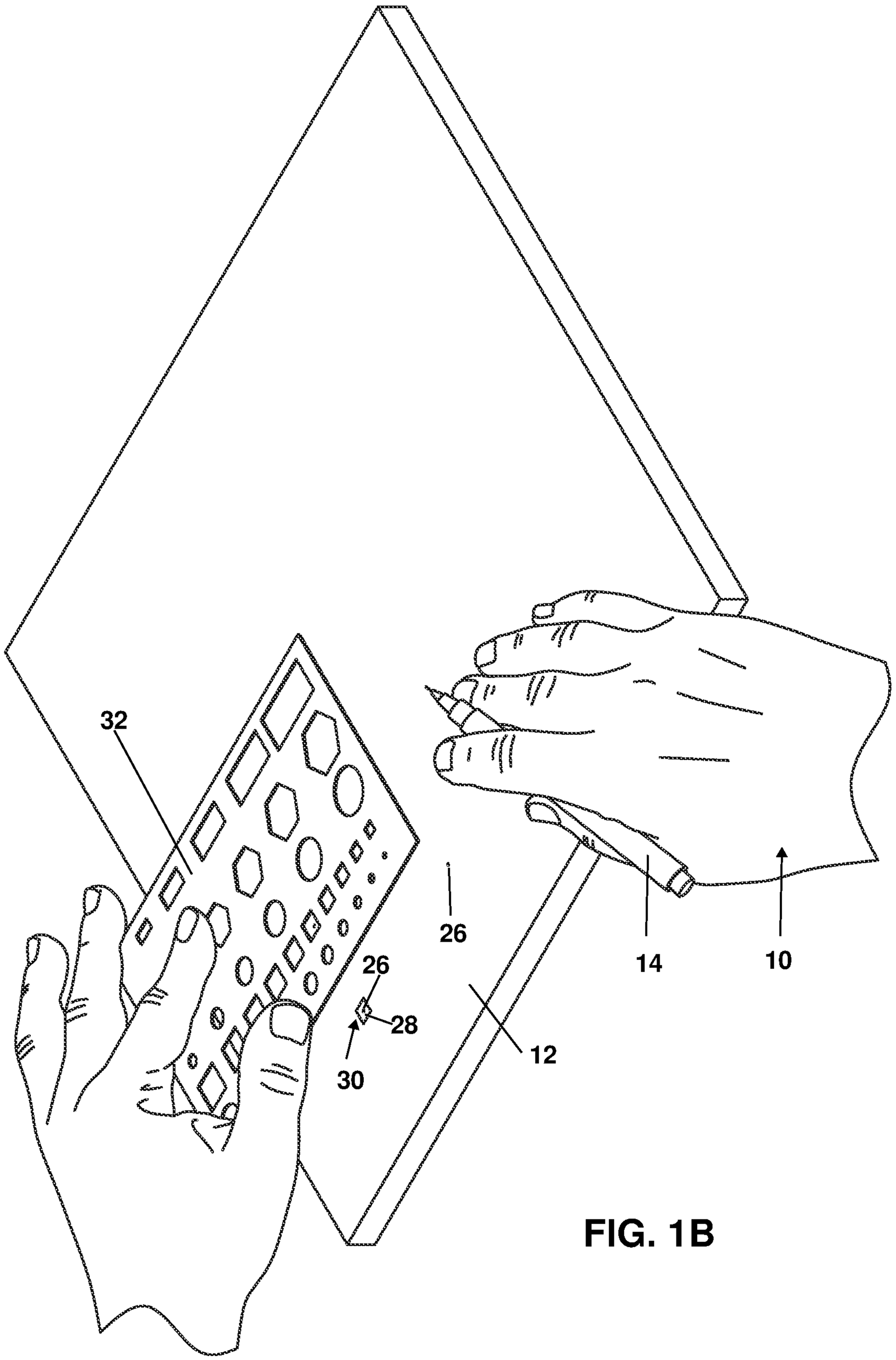


FIG. 1B

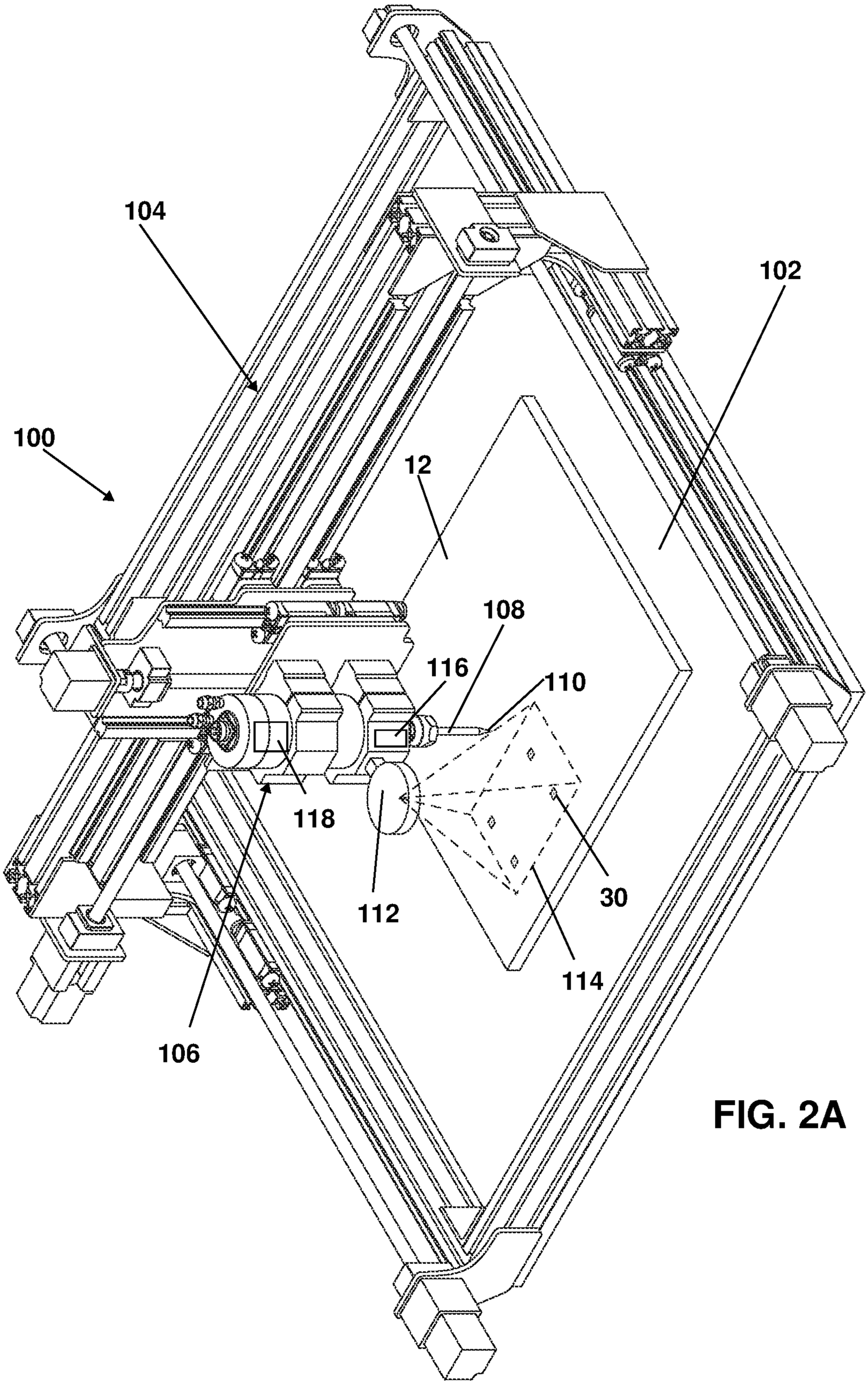


FIG. 2A

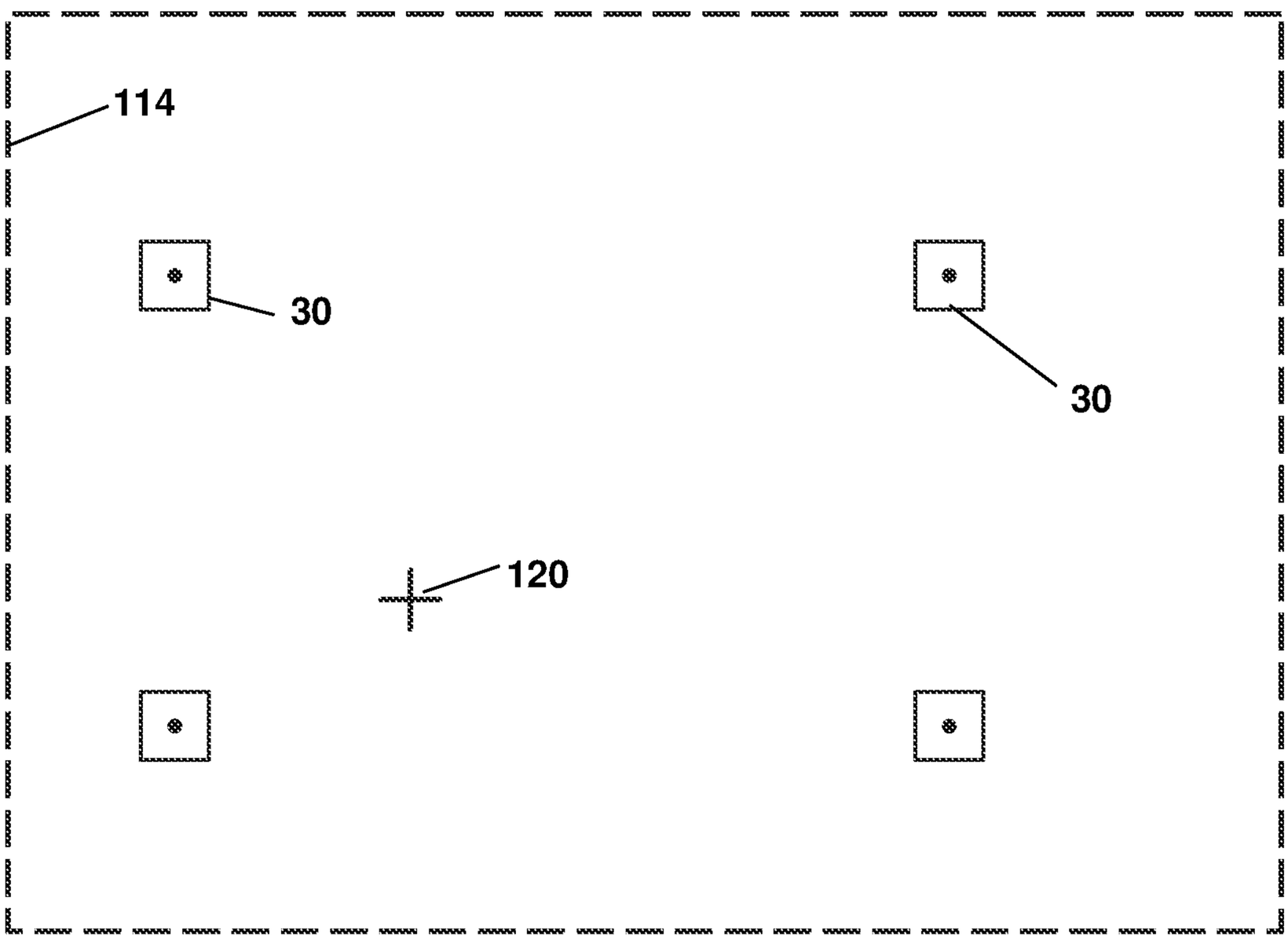


FIG. 2B

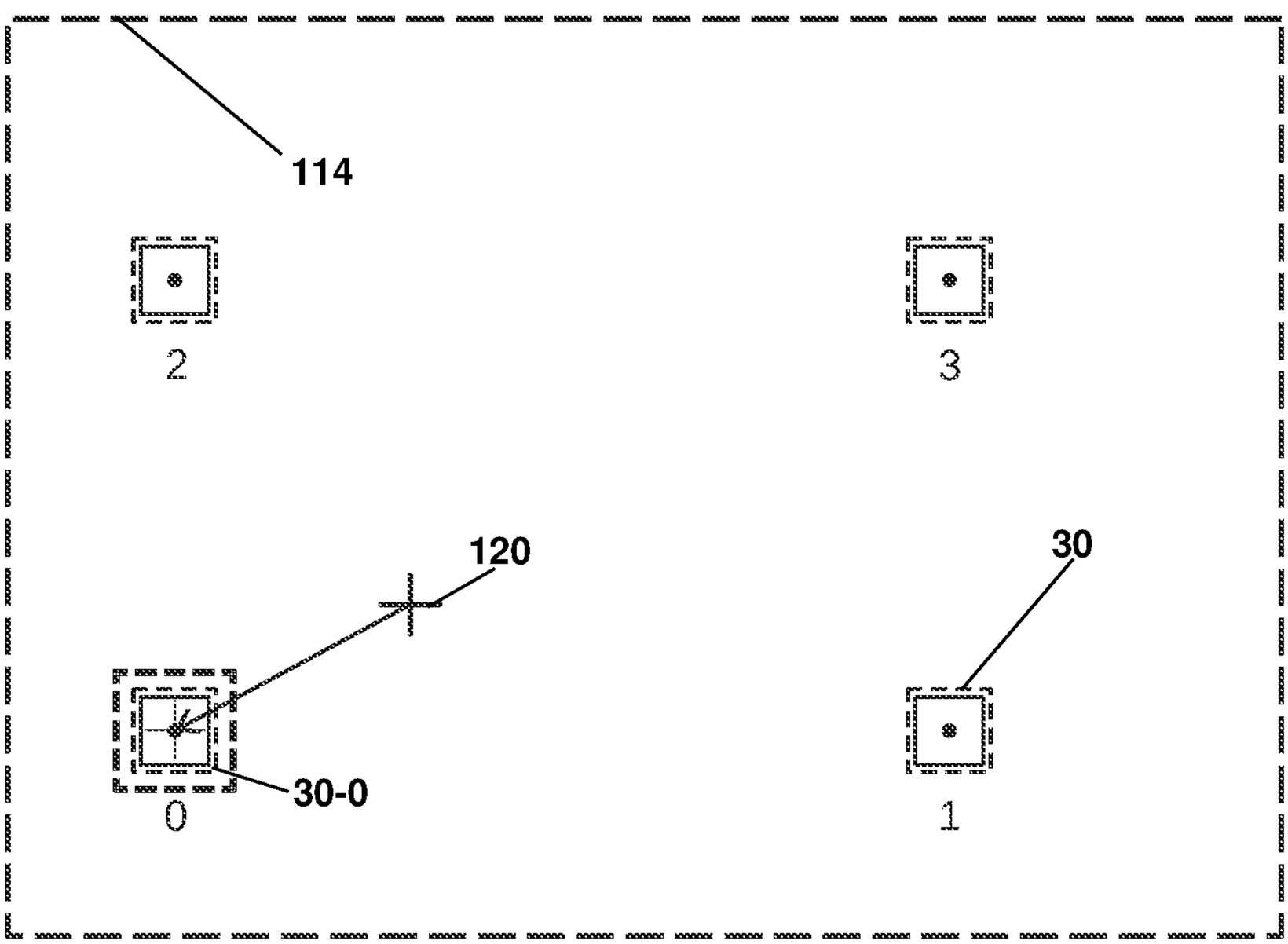


FIG. 2C

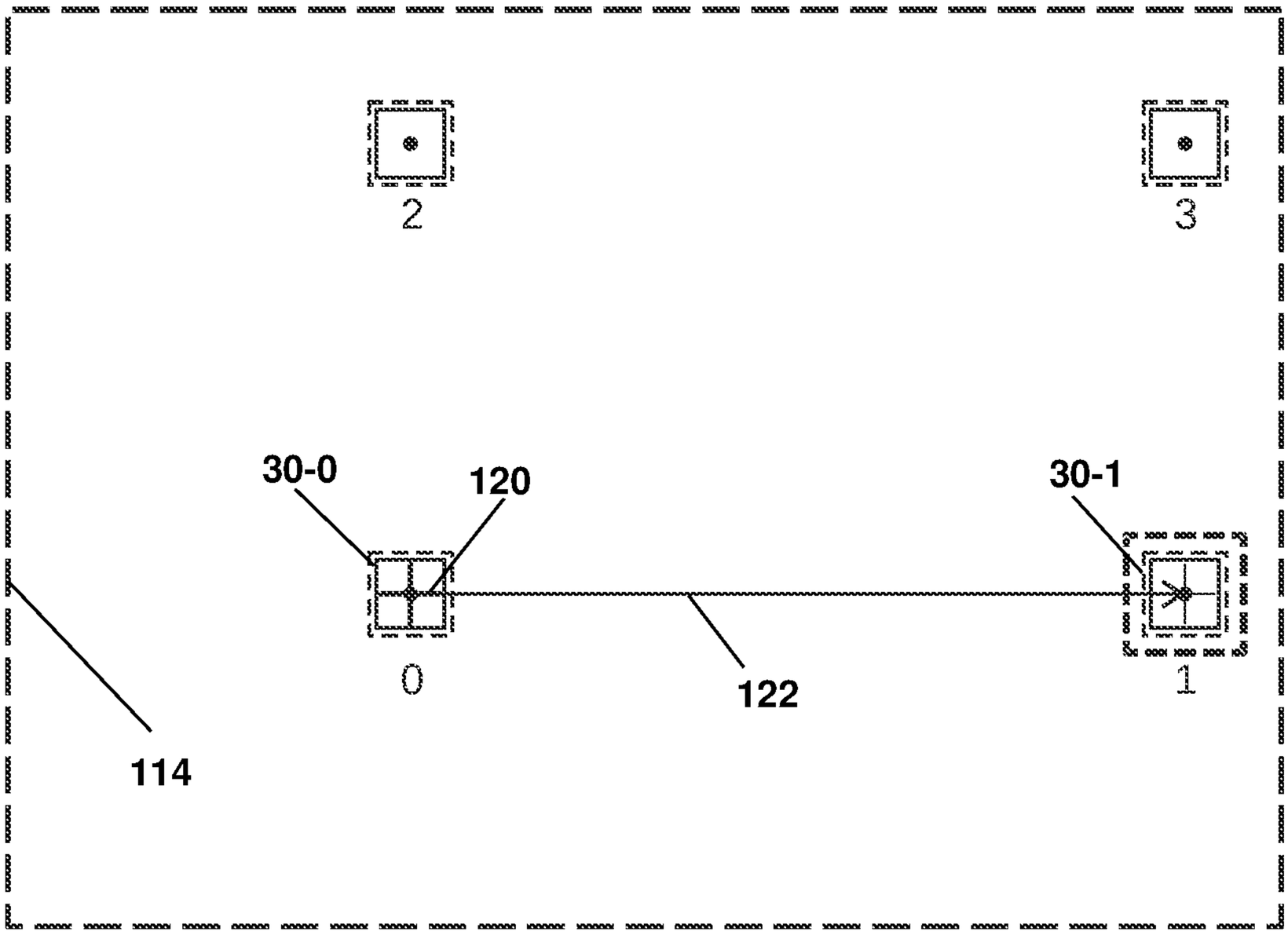


FIG. 2D

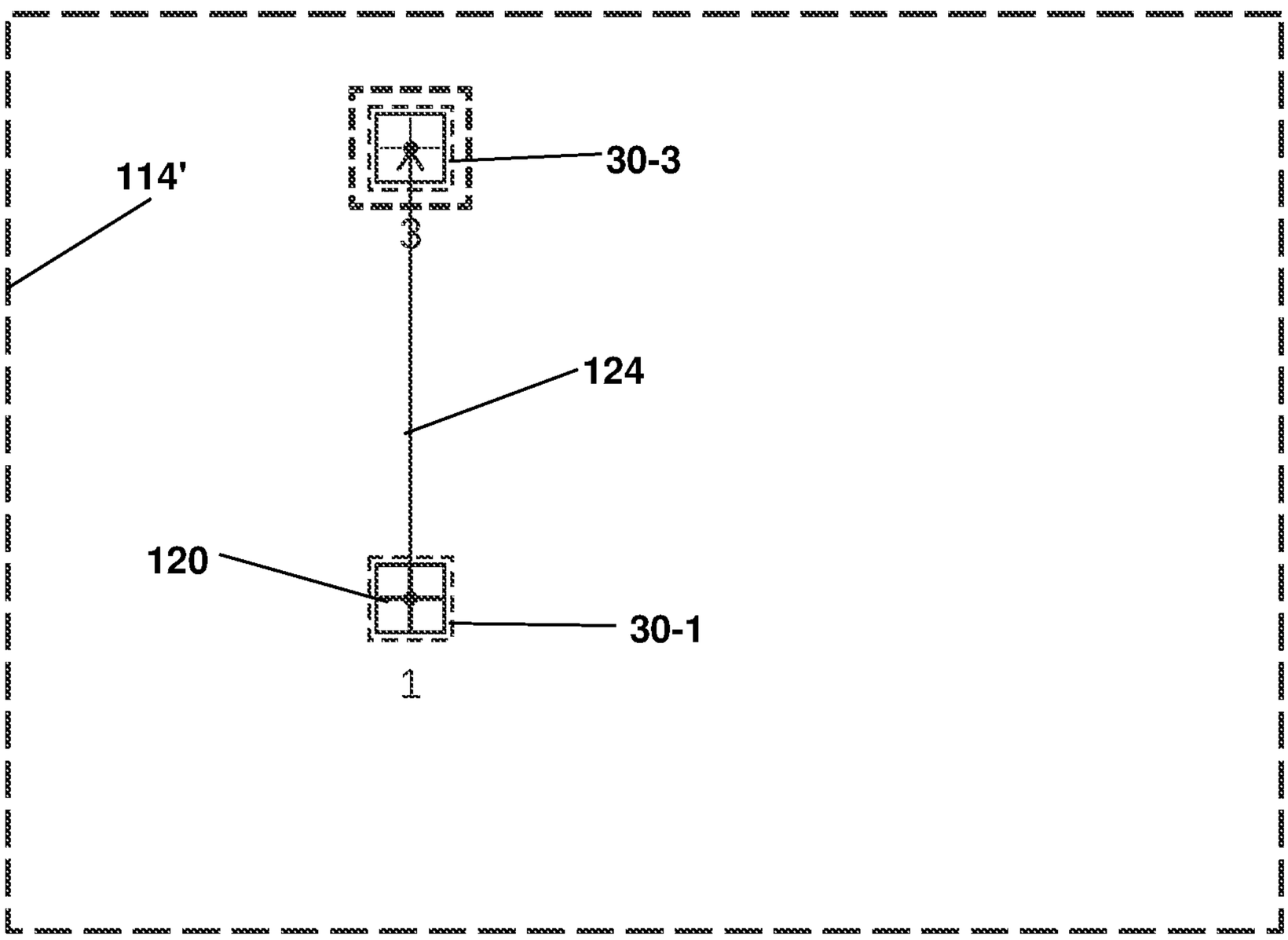


FIG. 2E

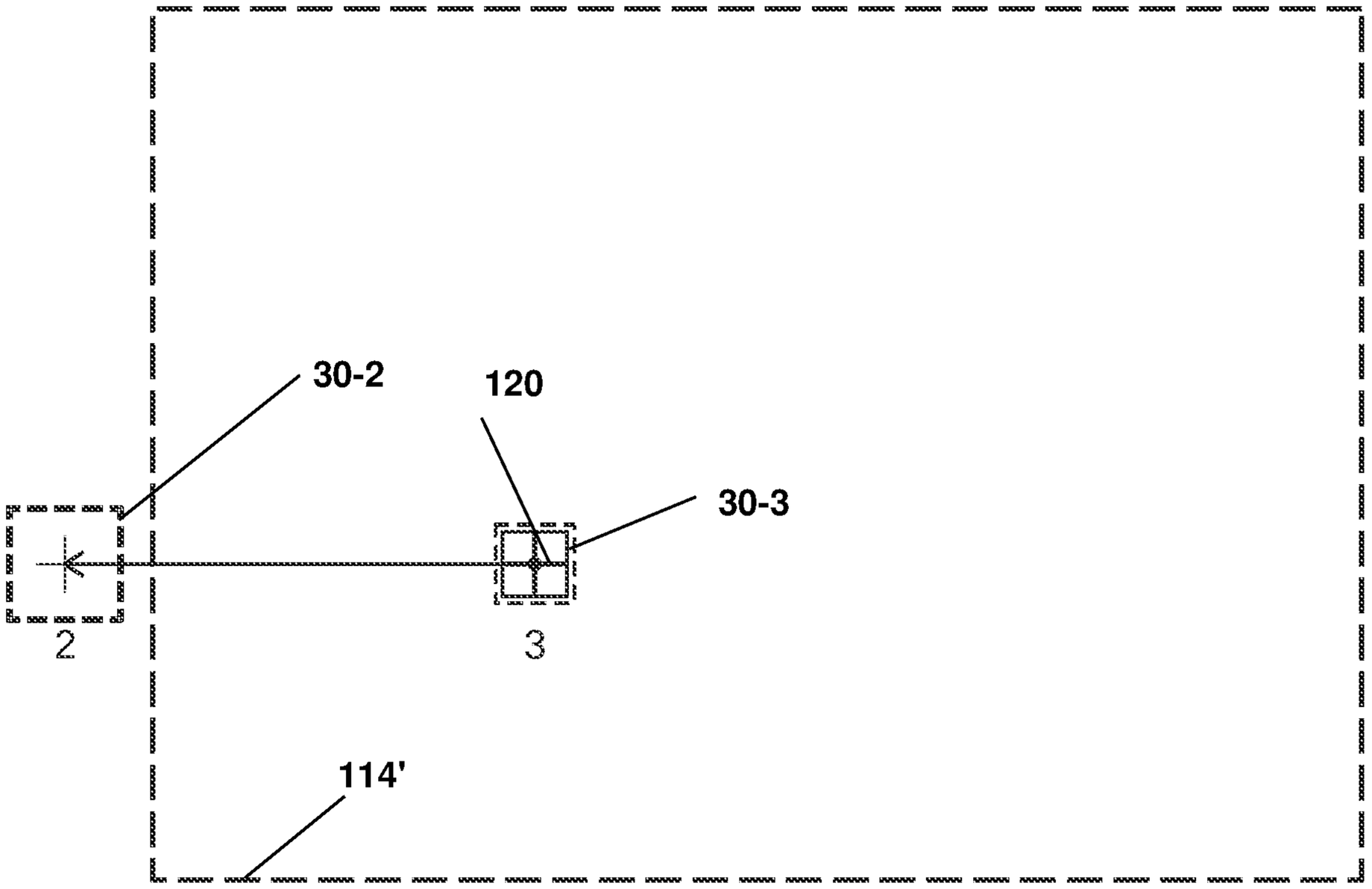


FIG. 2F

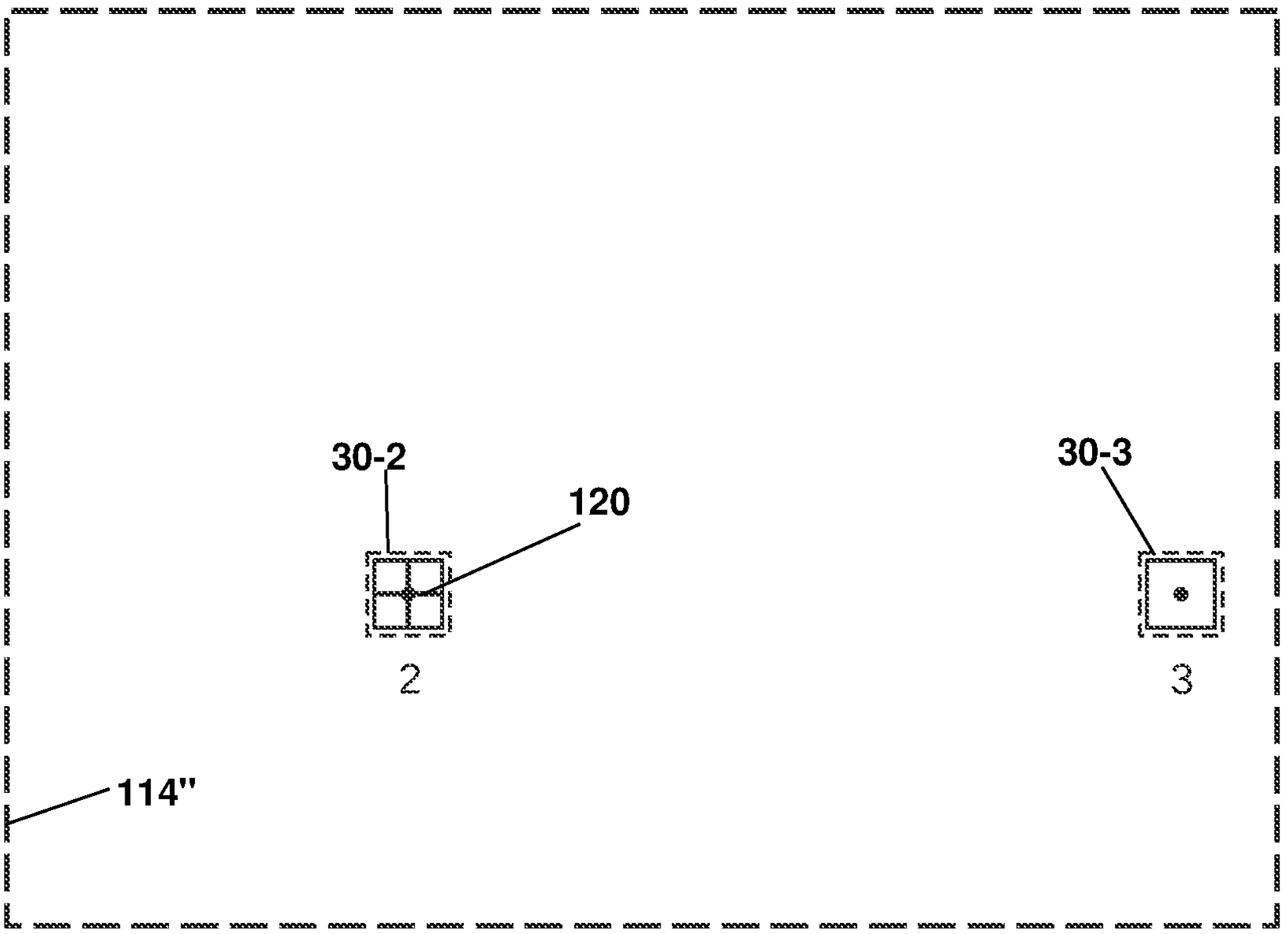


FIG. 2G

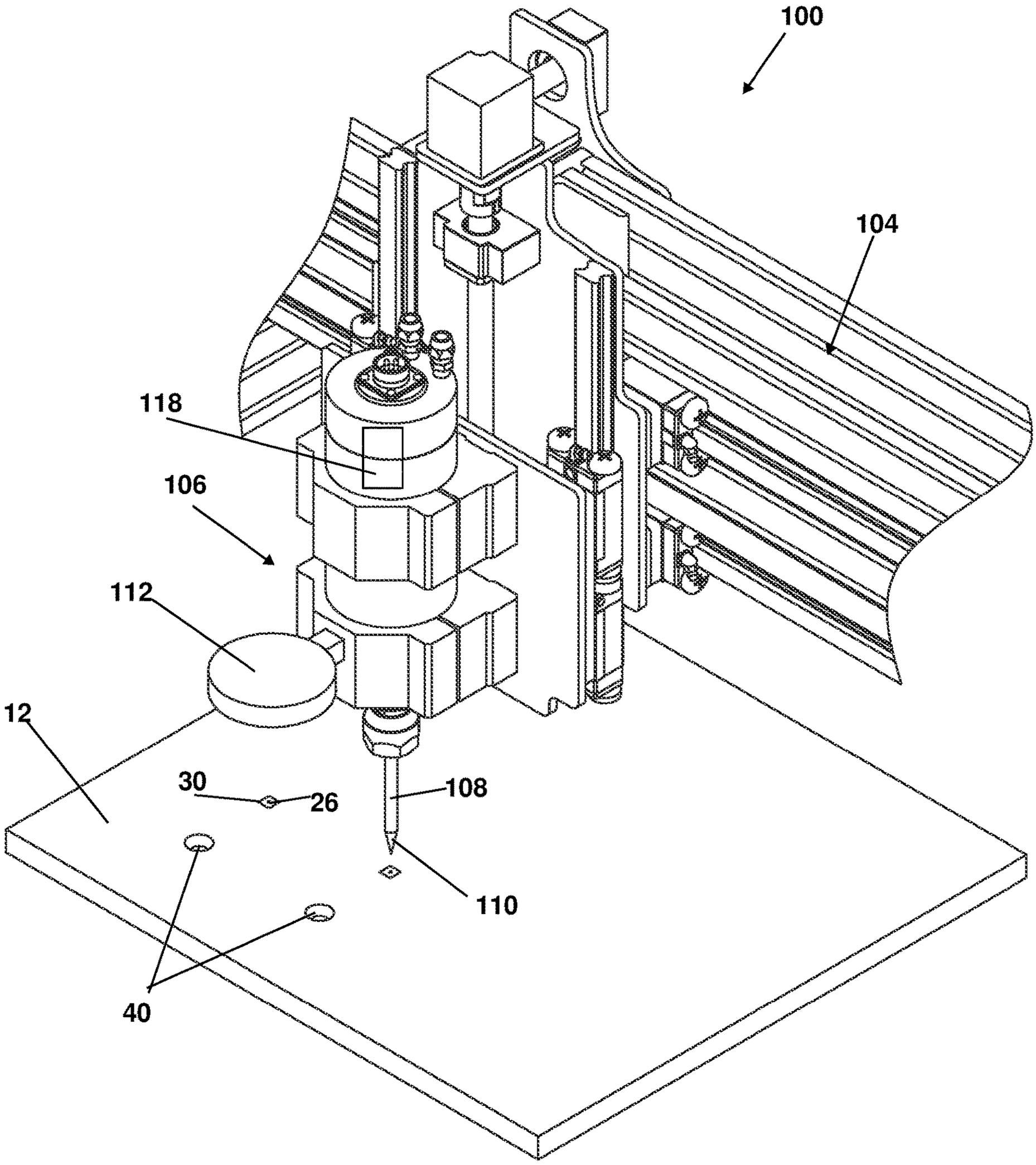


FIG. 3

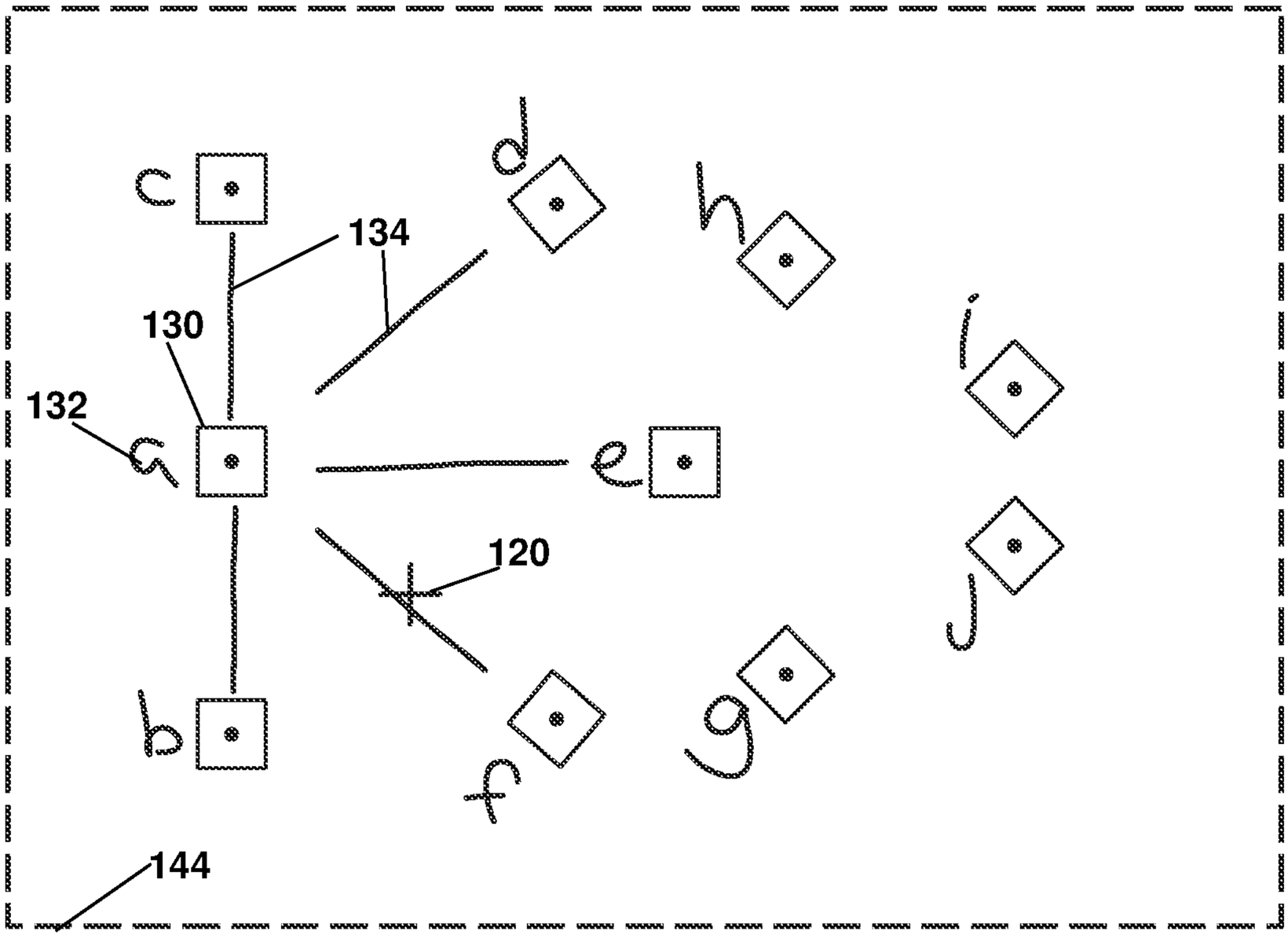


FIG. 4A

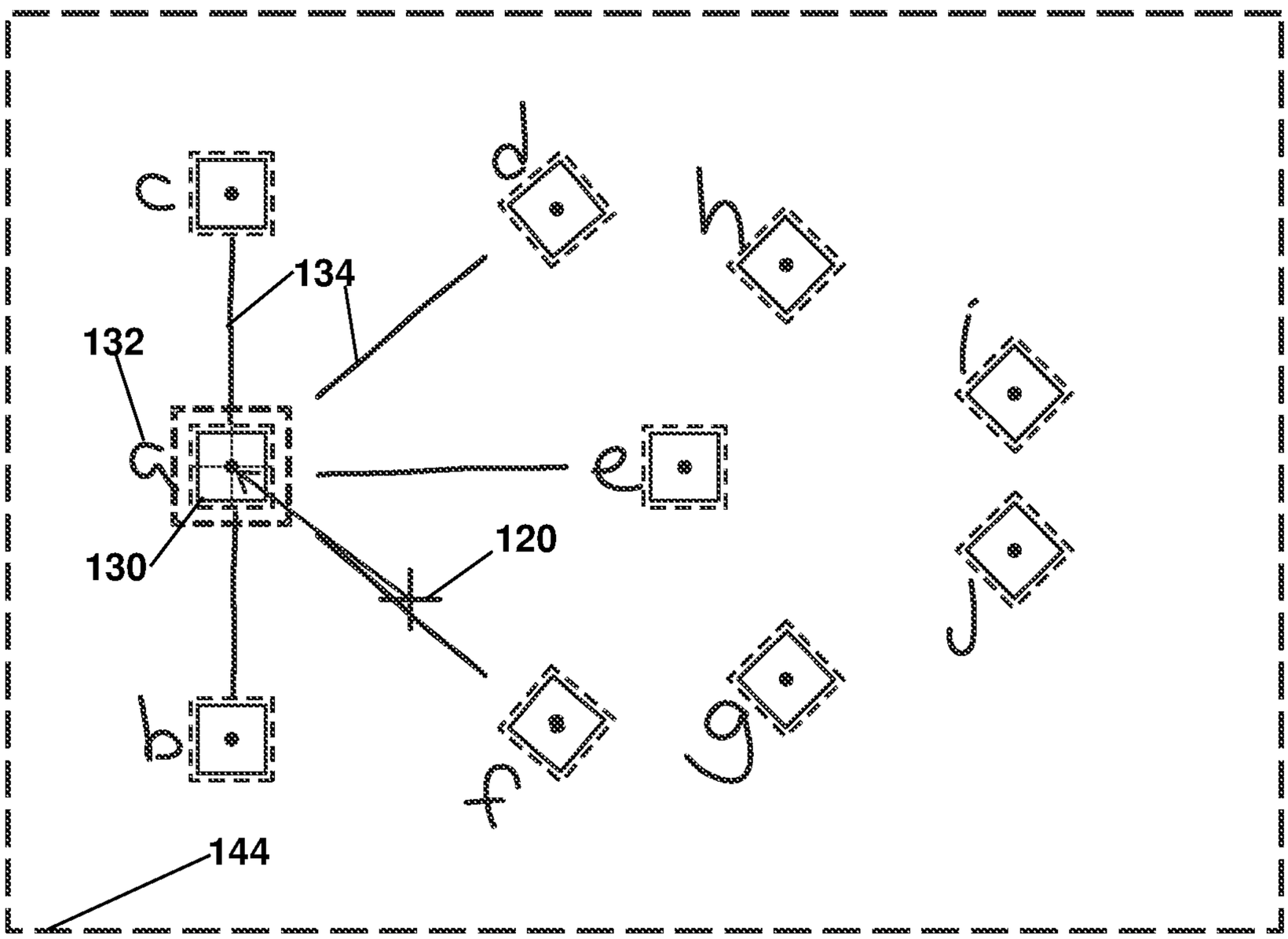


FIG. 4B

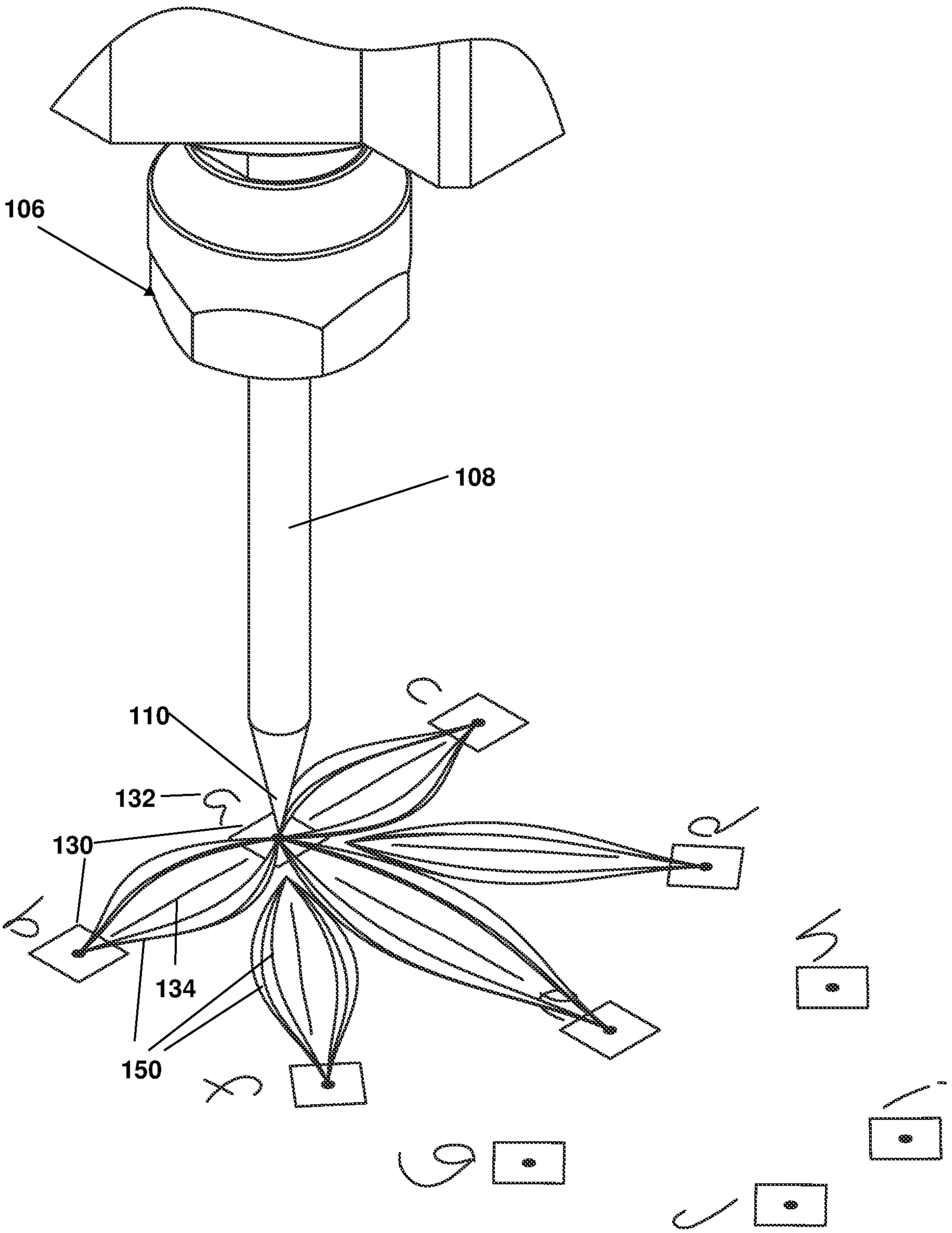


FIG. 5

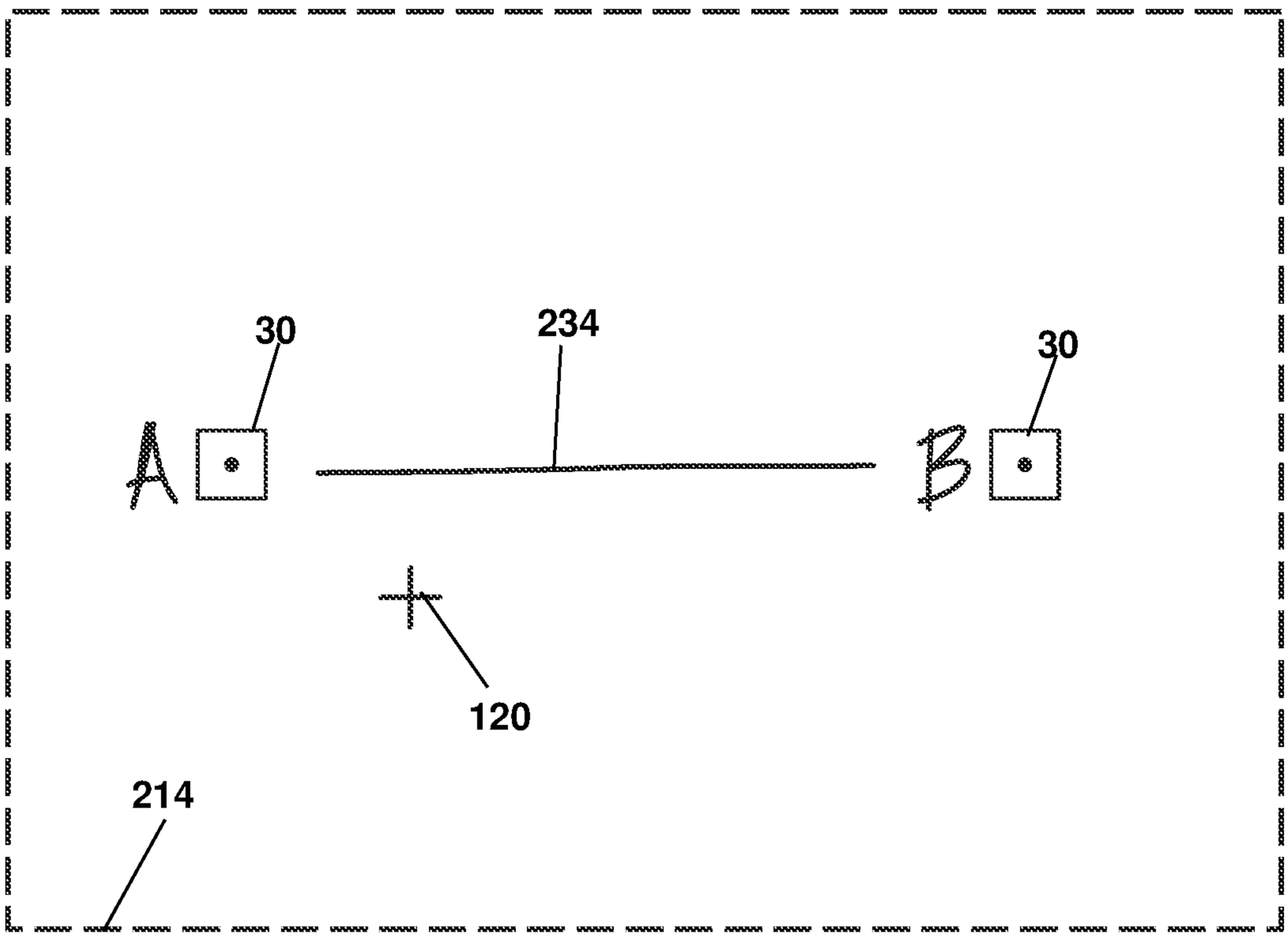


FIG. 6A

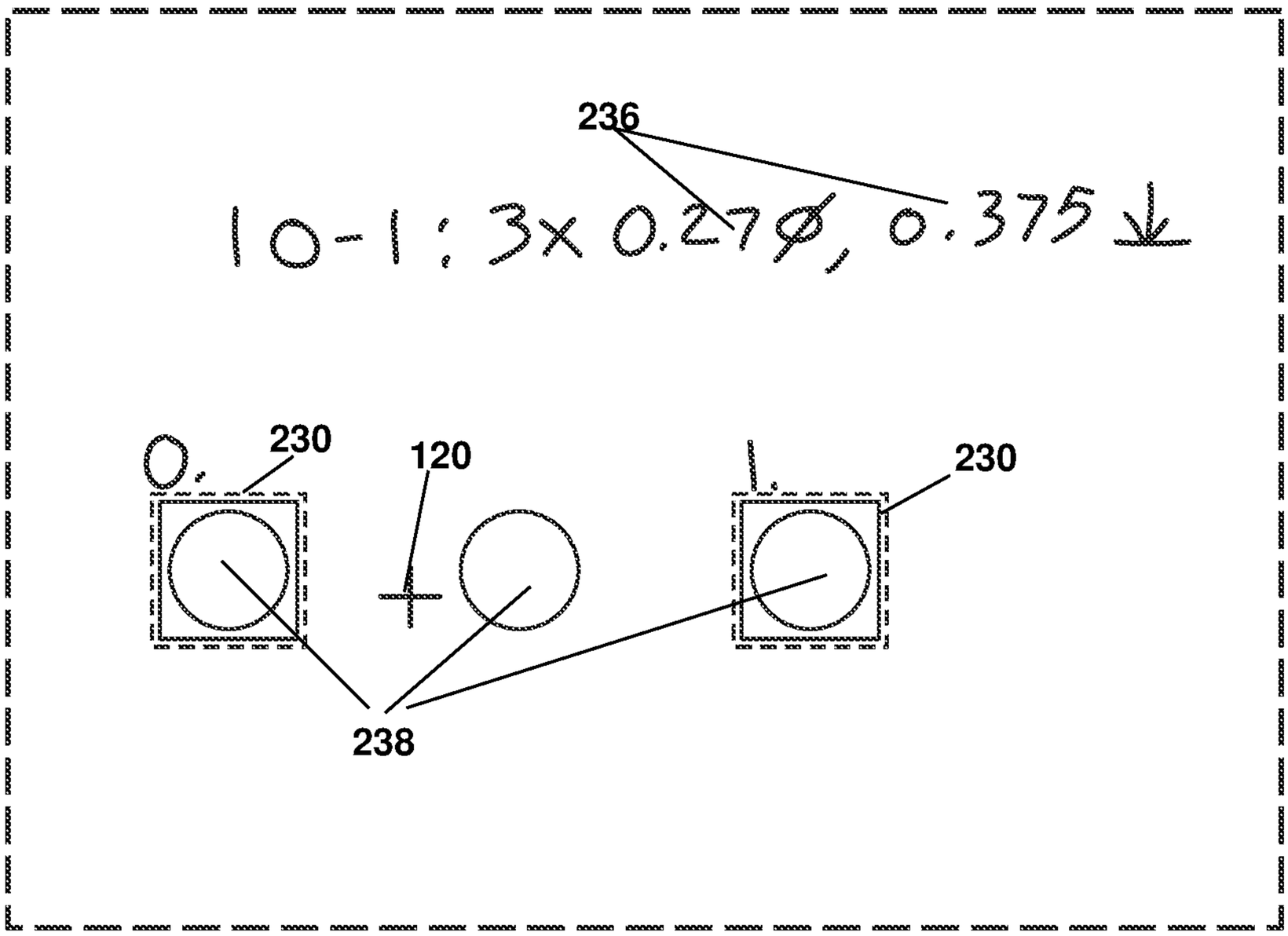


FIG. 6B

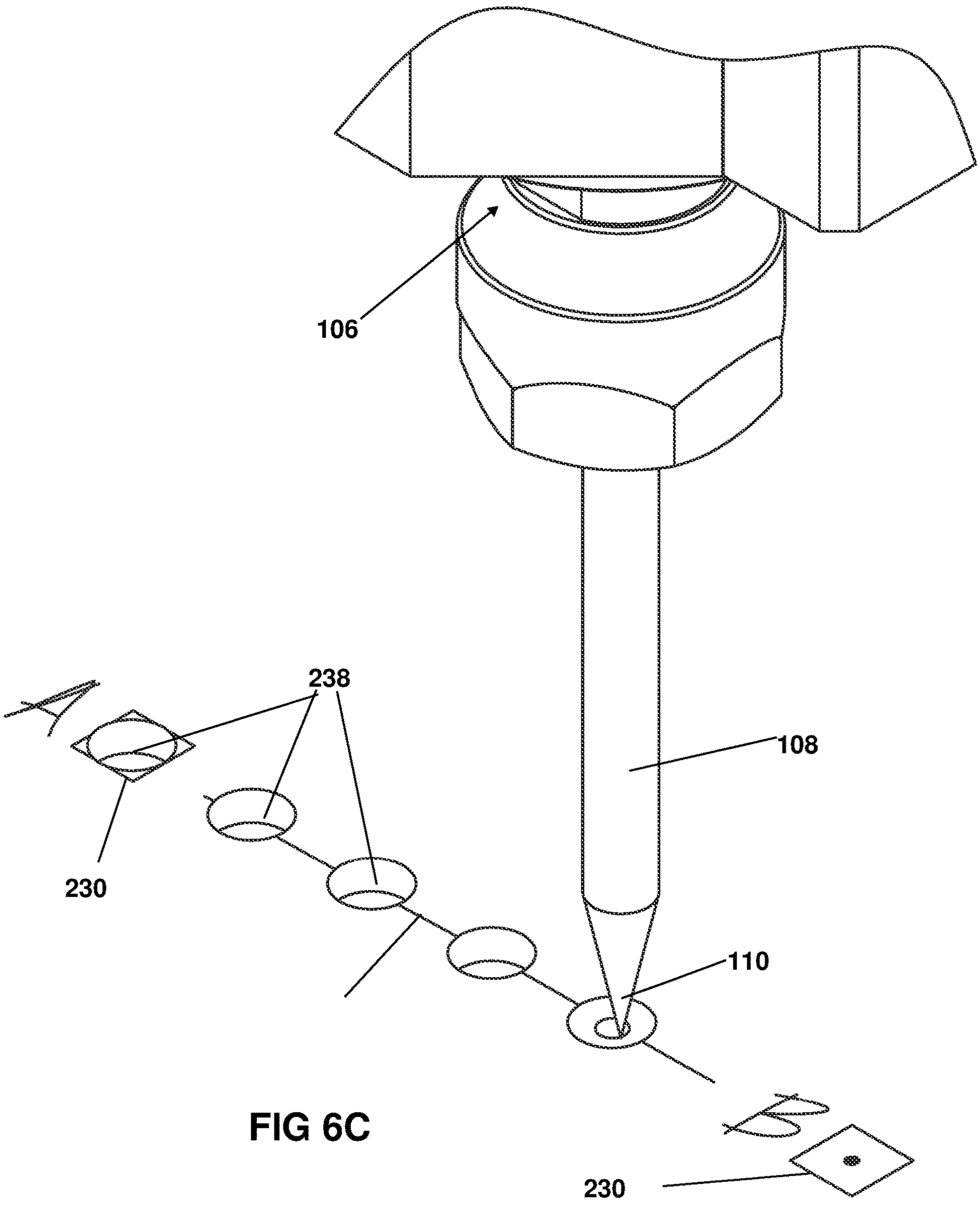


FIG 6C

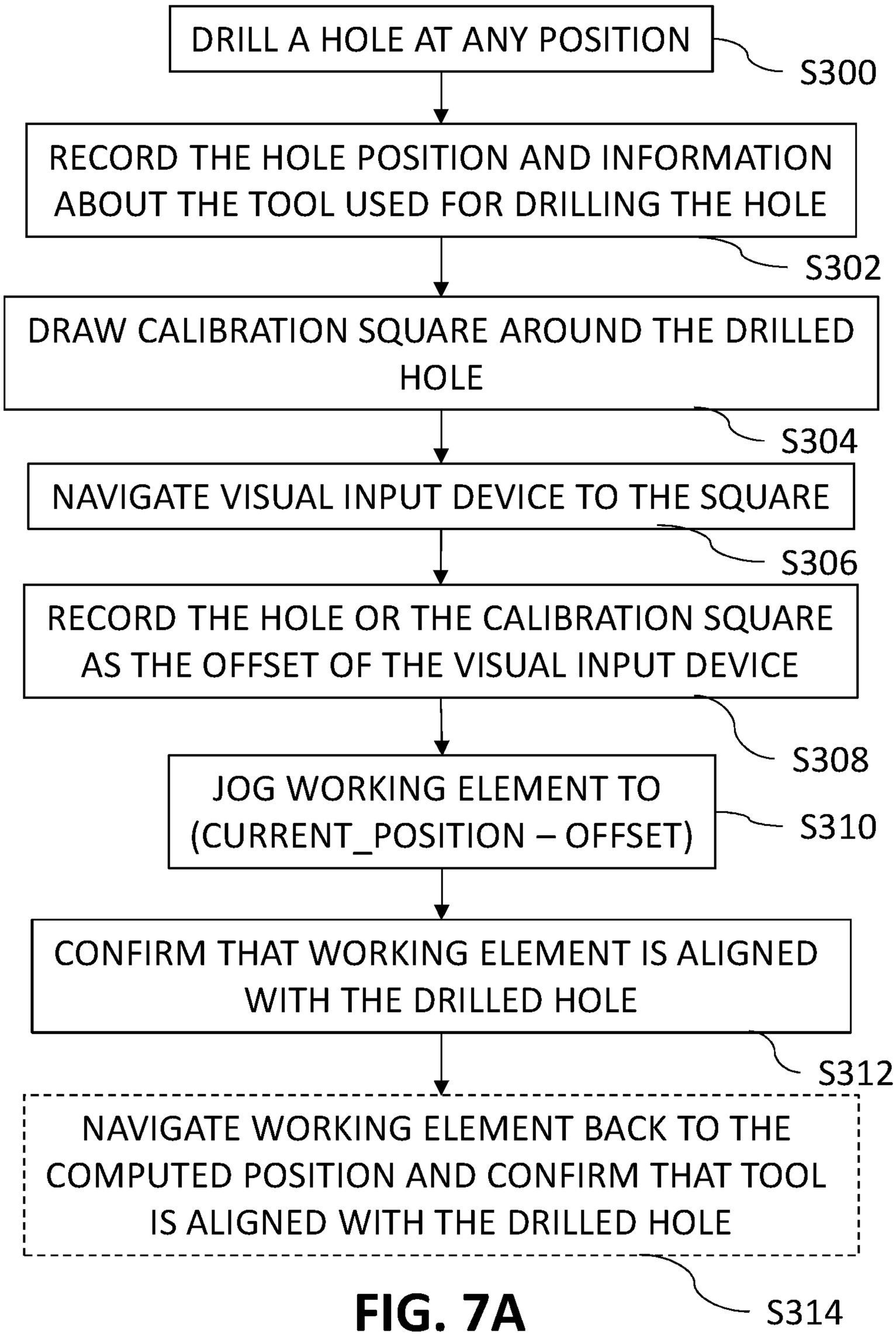

DRILL A HOLE AT ANY POSITION
S300
RECORD THE HOLE POSITION AND INFORMATION ABOUT THE TOOL USED FOR DRILLING THE HOLE
S302
DRAW CALIBRATION SQUARE AROUND THE DRILLED HOLE
S304
NAVIGATE VISUAL INPUT DEVICE TO THE SQUARE
S306
RECORD THE HOLE OR THE CALIBRATION SQUARE AS THE OFFSET OF THE VISUAL INPUT DEVICE
S308
JOG WORKING ELEMENT TO (CURRENT_POSITION – OFFSET)
S310
CONFIRM THAT WORKING ELEMENT IS ALIGNED WITH THE DRILLED HOLE
S312
NAVIGATE WORKING ELEMENT BACK TO THE COMPUTED POSITION AND CONFIRM THAT TOOL IS ALIGNED WITH THE DRILLED HOLE
S314

FIG. 7A

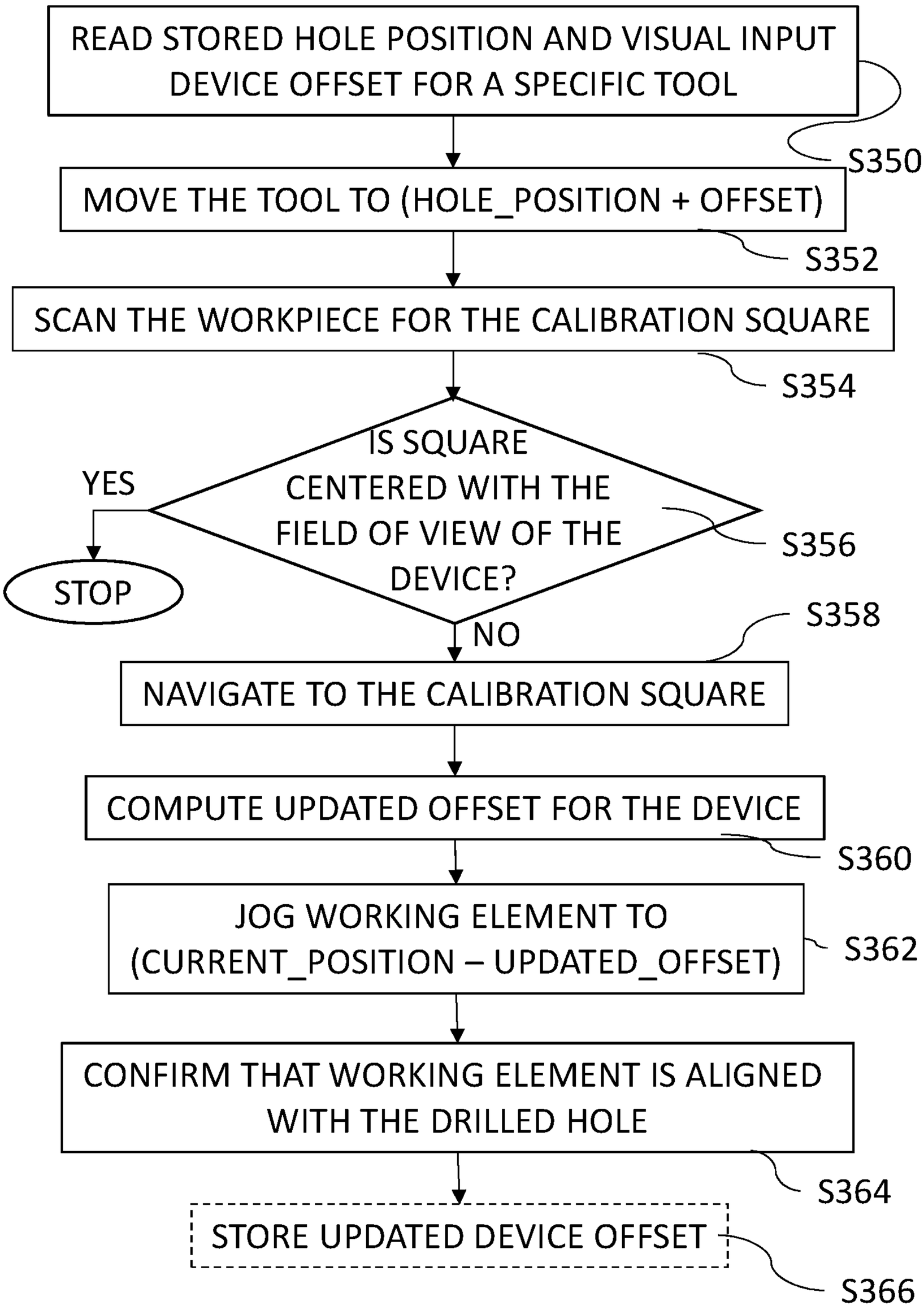

READ STORED HOLE POSITION AND VISUAL INPUT DEVICE OFFSET FOR A SPECIFIC TOOL
S350
MOVE THE TOOL TO (HOLE_POSITION + OFFSET)
S352
SCAN THE WORKPIECE FOR THE CALIBRATION SQUARE
S354
IS SQUARE CENTERED WITH THE FIELD OF VIEW OF THE DEVICE?
S356
YES
STOP
NO
S358
NAVIGATE TO THE CALIBRATION SQUARE
COMPUTE UPDATED OFFSET FOR THE DEVICE
S360
JOG WORKING ELEMENT TO (CURRENT_POSITION – UPDATED_OFFSET)
S362
CONFIRM THAT WORKING ELEMENT IS ALIGNED WITH THE DRILLED HOLE
S364
STORE UPDATED DEVICE OFFSET
S366

FIG. 7B

SYSTEM AND METHOD FOR AUTOMATED PRECISION CONTROL OF A COMPUTER NUMERICAL CONTROL (CNC) MACHINE

FIELD OF THE DISCLOSED TECHNOLOGY

The disclosed technology relates generally to methods of creating a precise workpiece, and, more specifically, to a method and a system for automated precision control of a computer numerical control (CNC) machine to create a precise workpiece, using visual indicia.

BACKGROUND OF THE DISCLOSED TECHNOLOGY

Computer numerical control (CNC) machines are precision machines capable of accurately manipulating (e.g. cutting, bending, etching, 3d printing) a workpiece, based on specifications and parameters provided to a machine via a computer.

In the prior art, in order to achieve accurate, repeatable CNC-machined parts that comply with design tolerances, it is commonly necessary to specify a large number of parameters for each machining operation, typically using Computer Aided Manufacturing (CAM) software. These parameters may include the material's physical position relative to a work coordinate system offset defined in the machine's control software, such as "G54," the default work coordinate offset commonly used in G-Code-based systems. The complete set of required parameters supplied to the CAM software, can then be used to generate CNC machine control commands, for example G-Code.

At the CNC machine, the machinist positions and fixes the material to the worktable and sets the coordinates, telling the CNC machine where to start a cut. The position of the material on the worktable, if needed, is then compensated for in the CNC controller's software, such as by modifying the coordinates of the work offset. In practice, alignment and fixturing of the workpiece often involves several time-consuming corrective steps, particularly for novice CNC machinists. Often, modifications to the CAD model, the CAM toolpath, the output G-Code, the CNC controller work offsets, the material itself, and possibly all of the above, are made before activating the machine to produce an intolerance part.

In addition to workpiece positional parameters and their adjustment, many other parameters must often be modified and refined to obtain acceptable CNC performance. Adjustment of such parameters requires skilled operator time, often consume extra material for test passes, can result in damage to parts, damage to tools, and occasionally damage to the CNC equipment itself.

Furthermore, machining large pieces of material can generate additional complexity. For example, a linear piece of material may be placed on a diagonal of the worktable rather than aligned to the worktable's X or Y axes. Such cases require adjustment of machining parameters in CAD, CAM or even the CNC control software to allow for diagonal material cutting. These require significant operator skill in measurement and material placement, such as carefully measuring with an angle measurement tool, and skillfully aligning then fixturing the part to produce in-tolerance results. This precise material positioning requires additional skill and time, can often lead to mistakes, and/or wasted material both from requiring multiple test runs, and from

performing machining operations such as drills, slots or cuts on a larger piece of material stock to account for reduced predictability of the cut path.

It is common practice among carpenters and various material workers to mark indicia on a material to be cut or worked. Simple material marks, such as scoring material with tools such as scribes, punches or even just pen marking, make it possible to accurately measure and mark important positions relative to previously-faced and squared precision edges, corners and surfaces, either provided by the stock material or from a prior machining operation. For instance, to define the point where a hole is to be drilled, a machinist may typically measure with a ruler, caliper or micrometer, scribe a line parallel to a precisely machined material edge, then measure and punch a hole location along the marked line. This small indication on the material can provide a starting point for a drilling or milling operation both by its visual location and as a physical indentation to guide the drill. Prior to the advent of CNC tooling, and even to the present day this is common practice.

Indicia such as dots, crosses (exes), or lines drawn on material, on paper or on computer drawings may be used to define a set of indication primitives intended to guide the machinist on how to fabricate a part within the allowable deviations of the designer. Informally, any indicia that allows a machinist to repeatably produce in-tolerance results are acceptable. More formally, a symbolic language known as Geometric Dimensioning and Tolerancing (GD&T), as defined under several international standards such as ASME Y14.5 or ISO Geometrical Product Specifications consists of a rich set of visual indicia. Such indication primitives are commonly used in modern CAD software as the basis for sketching dimensioned drawings, which can be built upon to create 3-dimensional models. As is commonplace in manual operations, indications on a material workpiece can provide tightly-toleranced and detailed engineering specifications directly on the material prior to performing a variety of machining operations using manual machines such as manual mills, lathes, drill presses, saws, sheet metal tools such as brakes and sheers, and other common machine shop equipment.

Furthermore, those same indication primitives have been used and improved by carpenters, metal workers and builders for centuries. As metrology and marking tools and techniques advance, so too has precision increased in machining operations. For precision machining these markings are typically called out relative to a starting reference surface, commonly a finely ground flat stone such as a surface plate from which all other measurements are taken.

The centuries-old process of measuring from a reference surface, then marking, and cutting has languished in the modern CNC workshop. The skillset specialization required has created a rift between the industrial designer, mechanical engineer, CNC part programmer and CNC machine operator, though it is widely acknowledged that rapid part iteration allows engineers and machinists alike to experiment and improve designs, adjusting dimensions and refining parts as needed. A rapid and easy process to work in this iterative methodology has been hampered due to the complexity of the software and of operating CNC equipment. CNC machines are more capable than ever, but are also more time consuming, costly, difficult and often frustrating to use, so much so that skilled machinists can often manually machine a wide range of parts in less time and more efficiently than working with CNC machines.

Despite the increasingly wide availability of CNC machinery, in both amateur and professional workshops a

wide range of electrical, pneumatic and hydraulic or otherwise powered tooling may be found in use today. Many of these tools duplicate functionality that can be performed by a single CNC machine. As such, the complexity of use of CNC machines results in duplication of workshop functionality, having a high price-tag.

To focus on a single operation such as drilling, a drill press, a milling machine and a lathe may all be employed in the drilling or boring of holes in wide range of materials. These manual machines are often preferred for simple boring operations whereby the machinist measures and marks their material, fixes it in the machine and performs the operation on the spot. Equivalent operations could be performed on a CNC mill, router, plasma cutter, punch or laser, but would typically first require modeling the material and the hole positions, then using CAM software to generate the appropriate tool paths, entering **115** material heights including material base, retract height, and clearance height, selecting the tool to bore the holes, defining the material location on the machine, creating a CNC setup, setting feeds and speeds, outputting G-Code, then at the machine reading the G-Code into the CNC control software, fixturing the material precisely to match the coordinate axes specified in CAM, navigating **120** the CNC tool head to a corner of the material, zeroing the work coordinates on that position, performing an "air cut" wherein the tool path is executed by the CNC machine above the workpiece to confirm it does not collide with anything, and finally executing the G-Code and monitoring the machine as it performs the drilling operations.

For simple operations such as drilling a few holes, it is impractical or inefficient to use CNC equipment unless the same or similar operations are frequently repeated.

As mentioned, the set of parameters that frequently require skillful adjustment are large and complex, and relate to many aspects of the material, the worktable, the planned machining process, and the machining tool. CAM software available on the market such as Vectric's Aspire, Inventable's Easel, and others, offer reduction in number of input parameters by providing templates, defaults, packaged tool paths, and other simplifications. However, since these software products have no awareness of workpiece position in the physical world, some of the most tedious and difficult parts of CNC machine operation remain. The further simplification of CAD and CAM tools, often causes the operator to have less control over relevant parameters.

At the other end of the complexity and cost spectrum, high-end CAM software such as Hexagon's Esprit offers detailed physical simulation of the operating characteristics of thousands of particular makes and models of CNC machinery, so toolpaths can be planned by a CNC programmer at a desk rather than an operator at the machine. Some CAM software packages such as Mazak's Smooth AI Spindle offer real-time measurement and compensation during cutting operations such as chatter control whereby speeds and/or feed rates are adjusted in real-time if chatter is detected. These are welcome advances in the part fabrication industry, however none of these remedy the core dilemma of locating material and cut locations.

There is thus a need in the art for a method and a system simplifying the setup and calibration of CNC machines, particularly with respect to the location of the material relative to the workspace and tooling, in order to quickly produce high-precision parts.

SUMMARY OF THE DISCLOSED TECHNOLOGY

The disclosed technology provides a method and a system for automated precision control of a computer numerical control (CNC) machine to create a precise workpiece, using visual indicia.

There is provided, in accordance with an embodiment of the disclosed technology, a system for automated precision control of a computer numerical control (CNC) machine to a workpiece. The system receives via at least one visual input device at least one detectable marking on a workpiece. The system decodes the at least one detectable marking and determines a stored and predefined movement routine of a cutting element attached to the CNC machine relative to the workpiece based on the at least one marking. The system then determines, using the at least one visual input device and/or another visual input device, a current position of a working end of the cutting element relative to the at least one marking. Finally, the system performs the pre-defined movement routine including cutting into the workpiece with the cutting element.

In some embodiments, the at least one visual input device and a holder for the cutting element are fixedly mounted to, and move together, relative to a position of the workpiece.

In some embodiments, the cutting element holder is adapted to removably hold the cutting element and the mount for the workpiece is adapted to removably hold the workpiece.

In some embodiments, the at least one visual input device includes a plurality of visual input devices which are used to determine at least a two-dimensional location in a three-dimensional space of the workpiece.

In some embodiments, the at least one visual input device is used to determine a scale of the pre-defined movement routine and to apply a magnification level of the pre-defined movement routine to the workpiece.

In some embodiments, the at least one marking is hand-written and determined, in the step of decoding, to be a square, and a starting position of the cutting is at the center of the square. In some embodiments, in the step of decoding, decoding a marking of two lines is insufficient to cause the step of performing to be carried out until the two lines are inscribed within a larger proximate shape.

In some embodiments, the pre-defined movement routine is parameterized by one or more variables, and the at least one marking includes a marking representative of a constant value used in place of each of the one or more variables when performing the pre-defined movement routine.

In some embodiments, the at least one marking includes a first marking and a second marking. The first marking corresponds to a first reference point of the pre-defined movement routine, and the second marking corresponds to a second reference point on the workpiece cut during the pre-defined movement routine. In some embodiments, the pre-defined movement routine is at least one of translated, rotated and scaled based on a position of the second marking compared to a position of the first marking.

There is provided, in accordance with an embodiment of the disclosed technology, a method of modifying a workpiece including steps of securing the workpiece to a fixed location, and marking a surface of the workpiece with human readable indicia using a handheld writing apparatus (or paper cutout with indicia) placing markings at a specific location on the workpiece causing a cutting tool to move in at least three axes to a coordinate of the marking. The human

readable indicia is associated with a predefined series of movements which begin relative to a position of a detected marking on a surface.

In some embodiments, the human readable indicia include a first indicium at a first coordinate on the workpiece and a second indicium at a second coordinate on the workpiece and the predefined series of movements is at least one of translated, rotated and scaled based on positions of the first indicium and the second indicium such that the cutting tool cuts relative to the first indicium and the second indicium.

In some embodiments, the human readable indicia include at least one indicium indicating a location to be cut by the cutting tool, one indicium associated with, and causing, a selection of one of the pre-defined series of movements, and one indicium indicating a variation to the predefined series of movements. In some embodiments, the one indicium indicating of a variation includes a real number and the variation includes carrying out a trigonometric modifying function on the predefined series of movements before the cutting tool cuts.

In some embodiments, the pre-defined series of movements includes a graphic which, when the cutting tool cuts, is at an orientation relative to placement of the first indicium and the second indicium.

There is provided, in accordance with another embodiment of the disclosed technology, a device including a computer numerical control (CNC) machine with a movable housing having a cutting element therein, and a spatial recognition system further including at least one visual input device mounted to the movable housing. The device further includes a control mechanism with an input from the spatial recognition system and an output which controls placement of the movable housing. Based on the input from the spatial recognition system, upon the control mechanism detecting printed indicia on a surface of a workpiece, the movable housing is moved into position such that rotation of the bit cuts into the printed indicia and the workpiece.

"Substantially" and "substantially shown," for purposes of this **235** specification, are defined as "at least 90%," or as otherwise indicated. "Identical" or "exactly," for purposes of this specification, is defined as "within an acceptable tolerance level known in the art." Any device may "comprise," or "consist of," the devices mentioned there-in, as limited by the claims. Any element described may be one of "exactly" or "substantially," as described.

For the purposes of the present application, "control of a CNC machine" is considered to include navigation of a working tool, operation of the working tool, and activating or deactivating an electric motor, a coolant supply or pump, a vacuum device, and the like.

For the purposes of the present application, the terms "marking" or "markings" and "indicium" or "indicia" are used interchangeably, and are defined as one or more symbols formed on a workpiece or on a worktable, which are observable by a visual input device. The symbols may be made in any suitable way, such as using ink, tape, stickers, localized etching, and the like.

It should be understood that the use of "and/or" is defined inclusively, such that the term "a and/or b" should be read to include the sets: "a and b," "a or b," "a," or "b."

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A and **1**B show marking steps of a method for modifying a workpiece using a CNC machine according to an embodiment of the disclosed technology.

FIGS. **2**A, **2**B, **2**C, **2**D, **2**E, **2**F, and **2**G illustrate scanning steps of a method for modifying a workpiece using a CNC machine according to an **265** embodiment of the disclosed technology.

FIG. **3** shows a cutting step of a method for modifying a workpiece using a CNC machine according to an embodiment of the disclosed technology, the cutting being based on the markings of FIGS. **1**A and **1**B and the **270** scanning of FIGS. **2**A to **2**G.

FIGS. **4**A and **4**B illustrate marking and scanning steps of a method for modifying a workpiece using a CNC machine according to another embodiment of the disclosed technology.

FIG. **5** shows an etching step of a method for modifying a workpiece using a CNC machine according to another embodiment of the disclosed technology, the cutting being based on the marking and calibration of FIGS. **4**A and **4**B.

FIGS. **6**A, **6**B, and **6**C illustrate marking and scanning steps of a method for modifying a workpiece using a CNC machine according to another embodiment of the disclosed technology, where the modification is formed between two reference points and/or using variables.

FIGS. **7**A and **7**B are flowcharts of a method for initial calibration of a CNC system according to the disclosed technology.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE DISCLOSED TECHNOLOGY

A system for automated precision control of a computer numerical control (CNC) machine operating on a workpiece includes receiving, via at least one visual input device, at least one detectable marking on a workpiece. The at least one detectable marking would typically have been placed on the workpiece by an operator of the system, or of the machine. The at least one detectable marking is decoded to determine a stored and pre-defined movement routine of a cutting element attached to said CNC machine relative to said workpiece based on the at least one marking. Using the one or more visual input devices and/or other visual input devices, a current position of a working end of said cutting element relative to the at least one marking is determined. Subsequently, the pre-defined movement routine, which includes cutting into the workpiece with the cutting element, is performed.

A method of modifying a workpiece includes the steps of securing the workpiece to a fixed location, and marking a surface of said workpiece with human readable indicia using a handheld writing apparatus, to cause a cutting tool to move in at least three axes to a coordinate of the marking. The human readable indicia is associated with a predefined series of movements which begin at a position of a detected marking on a surface. As an example, a marking might be "Bore(A, diam=2.0, d=0.25)" which instructs the cutting of a circle that is 2" in diameter and 0.25" deep.

A device includes a computer numerical control (CNC) machine with a movable housing having a cutting element therein. The device further includes a spatial recognition system, which includes at least one visual input device mounted to the movable housing. The device also includes control mechanism receives input from said spatial recognition system and provides output which controls placement of said movable housing. Based on the input from the spatial recognition system, upon the control mechanism detecting printed indicia on a surface of a workpiece, the control mechanism causes motion of the movable housing into position such that rotation of the cutting element cuts into

the printed indicia and said workpiece. The spacial recognition system can include depth sensors, time-of-flight determinations, stereo camera, and two-dimensional cameras.

Embodiments of the disclosed technology will become clearer in view of the forthcoming description of the figures.

FIGS. **1**A and **1**B show marking steps of a method for modifying a workpiece using a CNC machine according to an embodiment of the disclosed technology. As seen in FIG. **1**A, a user **10** manually marks a workpiece **12**, using a writing implement **14**, such as a pen or pencil, with locations **16** to be **330** modified by the CNC machine, such as locations to be cut. In the illustrated embodiment, the user marks four locations **16**, corresponding to bores in a base **18** of a device **20** that the user wishes to mount onto workpiece **12**. However, any suitable number of markings, for any purpose, may be marked by the user at this step.

Turning to FIG. **1**B, it is seen that the user initially marked workpiece **12** with dots **26**, representing the four locations **16**. Subsequently, user **10** uses writing implement **14** to expand the marking including the dot **26**. In the illustrated embodiment, the user draws a square **28** around each dot **26**, such that the dot is at the center of the square, to form a marking **30**. However, in other embodiments, different markings may be used, such as an x shape having the dot at its center, a cross having the dot at its center, a circumscribing circle, and the like. In some embodiments, the user may use a stencil **32** to ensure that all the markings are equally sized, consistent, and/or accurate.

Reference is now made to FIGS. **2**A, **2**B, **2**C, **2**D, **2**E, **2**F, and **2**G, which illustrate scanning steps of a method for modifying a workpiece using a CNC machine according to an embodiment of the disclosed technology. The scanning steps are used for identifying and/or calibrating positional parameters of a CNC machine, relative to workpiece **12**, using markings **30** applied in the marking steps of FIGS. **1**A and **1**B.

As seen in FIG. **2**A, a CNC machine **100** includes a base surface **102**, onto which is placed a workpiece, such as workpiece **12**. A mobilizing assembly **104** is adapted to mobilize a movable housing, or working head, **106** in at least three dimensions relative to base surface **102** and to workpiece **12**. In some embodiments, mobilizing assembly **104** is adapted to mobilize working head **106** along more than **3** degrees of freedom or axes, such, such as along six degrees of freedom or axes. Working head **106** includes a working element **108** terminating in a working end **110**. One or more visual input devices **112**, are disposed on working head **106**, to capture an image of a field of view **114**, the **360** field of view including a position of working end **110**. Device(s) **112** are adapted to move together with the working element **108**.

In the illustrated embodiment, the working element **108** comprises a cutting element, such as a cutting bit, terminating in a cutting end. However, in some embodiments, the working element may be any suitable working element, such as a router, a mill, a lathe, a laser, a water jet, a three-dimensional printing element (e.g. a material depositing element used for three-dimensional printing), a vinyl cutter, and a wire bender.

Visual input device(s) **112** may include any suitable type of device. For example, a device **112** may be a depth sensor, a camera, a stereo camera, or a depth finder using time of flight to determine depth. Device(s) **112** being able to identify depth may be particularly advantageous in determining a starting Z-value for working end **110** of the working element, relative to workpiece **12**. Device(s) **112** being able to identify depth may also be advantageous in providing compensation during a cutting routine cutting into workpiece **12**, for example for projecting cutting tool paths onto the surface of a workpiece having variable heights. Such identification of depth can also be used for purposes of collision avoidance with items or the surface of the workpiece.

Visual input device(s) **112** is functionally associated with a spatial recognition system **116**, which provides input to a controller **118** forming part of the CNC machine. Specifically, device(s) **112** may be one or more cameras, which capture an image of the field of view **114**, and provide the image to controller **118**. Controller **118** is adapted to receive the input from spatial recognition system, and to detect a two-dimensional location of printed markings in the image, such as detecting markings **30** within the field of view **114**. Controller **118** is then adapted to move the working head into a suitable place, such that when the working head is operated, the operation is at the detected markings. As shown and described hereinbelow, the operation maybe cutting into workpiece **12**, at the location of markings **30**.

FIGS. **2**B to **2**G show the steps of CNC machine **100** scanning markings **30** within field of view **114**. In FIG. **2**B, a marker **120** indicates a location detected by controller **118**, within the image of field of view **114** captured by camera **112**. In FIG. **2**B, marker **120** is disposed at some location within the field of view. In FIG. **2**C, controller **118** identifies a first of markings **30-0** at position **0**, and begins moving marker **120** to align with marking **30-0**.

In FIG. **2**D, controller **118** identifies a second of the markings **30-1**, at position **1**, and identifies that the marking **30-1** is located at a straight line **122** from marking **30-0**. Controller **118** moves marker **120** to align with marking **30-1**.

As seen in FIG. **2**E, motion of marking **120** to align with marking **30-1** also moves the field of view, such that field of view **114'** includes markings **30-1** and **30-3**, but does not include marking **30-0** (FIG. **2**D). In FIG. **2**E, controller **118** identifies a third of the markings **30-3**, at position **3**, and identifies that the marking **30-3** is located at a straight line **124** from marking **30-1**. Controller **118** moves marker **120** to align with marking **30-3**.

As seen in FIG. **2**F, the last of the four markings **30-2** is outside of field of view **114'**. However, controller **118** may have previously identified the existence of marking **30-2** (for example when scanning for marking **30-0** in FIG. **2**B) of may anticipate the existence of such a marking to form a closed rectangular structure. As such, in FIG. **2**G, controller **118** moves the marker **120** to align with marking **30-2**, thus returning also moving the field of view to the left, resulting in a third field of view **114"**.

Following completion of the scanning process of FIGS. **2**B to **2**G, controller **118** has identified each of markings **30**, and has aligned the marker **120** therewith accurately. The controller **118**, and CNC machine **100**, are now aware of the spatial relationship of working element **108** relative to workpiece **12**, and are set to initiate work on the workpiece.

It is to be appreciated that in some embodiments, following scanning or decoding of the markings **30**, the movement therebetween may be in accordance with a pre-defined, and previously stored, movement routine. In some embodiments, the movement routine may be defined in a calibration phase occurring prior to the scanning phase. An exemplary calibration phase is described hereinbelow with respect to FIGS. **7**A and **7**B. In other embodiments, the movement routing may be defined by the scanning or decoding operations, and then may be stored for use when cutting, or otherwise operating on, workpiece **12**.

FIG. **3** shows a cutting step of a method for modifying a workpiece using a CNC machine according to an embodiment of the disclosed technology, the cutting being based on markings **30** of FIGS. **1**A and **1**B and the scanning of the markings in FIGS. **2**A to **2**G.

As seen in FIG. **3**, following scanning of markings **30**, controller **118** brings working element **108** to each of the markings in turn, to modify workpiece **12** at the location of each of the markings. In the illustrated embodiment, working element **108** is a cutting element, and controller **118** causes the working end **110** of cutting element **108** to cut or drill a hole **40** at each of markings **30**. Typically, the starting position of the cutting element **108** is at point **26**, within each of markings **30**. As such, at least some of the markings on workpiece **12**, namely markings **30**, are associated with a predefined series of movements (e.g. drilling a hole and/or moving to the next marking) which begin at a position of a detected marking **30** on the surface of workpiece **12**.

In some embodiments, the depth of the hole may be provided to controller **118** separately, such as a parameter provided in a code file, or may be a default depth. In some embodiments, the depth of the hole may be provided to the controller as visual input via device(s) **112**, as explained hereinbelow with respect to FIGS. **6**A to **6**C.

FIGS. **4**A and **4**B illustrate marking and scanning steps of a method for modifying a workpiece using a CNC machine, such as CNC machine **100** of FIG. **2**A, according to another embodiment of the disclosed technology.

As seen in FIGS. **4**A and **4**B, in addition to placement of markings **130** on a workpiece, similar to marking **30** of FIGS. **1**A and **1**B, the user has also labeled the markings **130** with letters a, b, . . . J, indicated by reference numeral **132**. The user can use further added lines **134** extending between some of the markings, or some of the letters.

In the embodiment of FIGS. **4**A and **4**B, spatial recognition system **116** and/or controller **118** includes a character recognition functionality, such as a suitable software component, such that when scanning the input received from device(s) **112**, controller **118** can identify the characters **132**, and use the sequence of the characters **132** to determine the sequence of scanning of the markings **130** and/or of moving between the markings or working on each of the markings.

As seen, in FIG. **4**A, marker **120** is placed in a random location in a field of view **144**. In FIG. **4**B, marker **120** is being moved toward marking **130** at location a, which is the first marking within the field of view.

Furthermore, controller is adapted to identify the placement of lines **134**, and to use the placement of the lines as guidance for operating on the workpiece. For example, the instructions for how to treat a line may be provided in a separate instruction file or instruction code provided to controller **118**, or may be provided to the controller using parameters set into variables, as explained in further detail hereinbelow with respect to FIGS. **6**A to **6**C.

Turning to FIG. **5**, it is seen that controller **118** has caused motion of the working head **106** of CNC machine **100**, such that the working end **110** of cutting element **108** has etched multiple lines **150** in the workpiece **12**. The **475** lines **150** extend between markings **130** which have lines **134** therebetween, to form the appearance of leaves. The exact placement of the etched curves **150** is defined relative to lines **134** and relative to markings **130**, and is in accordance with instructions provided to controller **118** via any suitable method, such as in instruction code, or using variables, as explained herein.

As seen from FIGS. **4**A, **4**B, and **5**, inclusion of additional indicators on workpiece **12**, in addition to markings **30** or **130**, enables CNC machine **100** to perform complex operations, such as etching of a pattern, while keeping much of the transfer of information from the operator to the CNC machine via perceivable markings on the workpiece. As such, at least some of the markings on workpiece **12**, namely lines **134** (or lines defined by two squares), are associated with a predefined series of movements which begin at a position of a detected marking **130** on the surface of workpiece **12**.

In a similar manner, indicators on workpiece **12** may include letters to be etched over by CNC machine **100**.

FIGS. **6**A, **6**B, and **6**C illustrate marking and scanning steps of a method for modifying a workpiece using a CNC machine according to another embodiment of the disclosed technology, where the modification is formed between two reference points and/or using variables.

As seen in FIG. **6**A, two markings **230**, labeled with A and B, are provided on the surface of a workpiece, within a field of view **214** of the CNC machine. In some embodiments a line **234** may be drawn between the two markings. The two markings **230** define two reference points, which may be associated with a movement routine. The use of two reference points, enables the movement routine to be translated, rotated, and/or scaled, based on a position of the second marking relative to a position of the first marking. As a result, the working element **108** engages the workpiece at locations relative to the first and second markings, and not in absolute locations.

For example, if the two markings are close to each other, a smaller number of holes may be drilled between the two markings, than if the two markings are further from each other. Alternately, if three holes are to be drilled at equal distances between the two markings, the distance between each two holes will be greater when the distance between the reference points is greater, and will be smaller when the distance between the reference points is smaller.

Turning to FIG. **6**B, it is seen that two reference markings, as described with respect to FIG. **6**A, can be used in combination with variables to define a movement routine for the working element **108** of the CNC machine. For example, in FIG. **6**B, two markings **230** are labeled 0 and 1. Values **236**, associated with various variables related to cutting of workpiece **12**, are marked onto the workpiece. In the illustrated embodiment, the variables define that, between points 0 and 1, the CNC machine should cut three holes having a diameter of 0.27 in and a depth of 0.375 in. As seen, the result is three bores **238**, two of which are on points 0 and 1, and the last of which is spaced equally between the two.

Further, a user can write code on the material such as by way of a programming language known in the art and/or call a class and/or function pre-set within the CNC machine (e.g. "class Bore"). For example, "Bore(Rect(A,B), diam=0.25, d=0.5)" might make a 0.25" diameter, 0.5" deep hole at the corners of the rectangle defined by the two diagonal points A and B.

In a similar manner, any number of parameters, or any information, may be provided, in writing, on the surface of the workpiece, to be scanned by the CNC machine. For example, the markings may include symbols, such as letters, digits, or marks, to be etched by the CNC machine, a specification of a font and/or text size to be used for etching text, a depth of etching or drilling, and the like. As another example, the markings or variable provided on the surface of the workpiece may define parameters of a tool to be used, such as a type of tool, or properties of the tool, e.g. its diameter or its height. QR codes may be associated with pre-defined such parameters and be placed on the tool's

storage container or nearby and used to indicate via visual input device to a CNC machine which tool is in use on the CNC machine.

FIG. **6**C shows the markings **230** labeled as reference points A and B, having five bores drilled therebetween. The variation in the number of bores may be defined by a marking or by indicia, which may be provided on the surface of workpiece **12**, in a similar manner to that shown in FIG. **6**B. For example, the marking on workpiece **12** may indicate a fixed distance between every two bores along the line A-B, such that the number of bores depends on the distance between the two reference points. As another example, the marking on workpiece **12** may provide a function, defining a variation on the sequence of movements that CNC machine **100** is programmed to do when identifying two reference points. For example, the function may be a trigonometric modifying function, including the drawing of sin or tan curves, drawing a similar triangle, changing a size, angle, or the like of a shape compared to a saved parametric shape. As another example, the marking may provide a specific number of bores to be made between reference points A and B, such that the distance between each two bores is dependent on the distance between reference points A and B.

FIG. **7**A is a series of flowcharts of a method for initial calibration of a CNC system according to the disclosed technology which determines the spatial offset of the visual input device from the central axis of the working element.

As seen in FIG. **7**A, initially a hole is drilled at any position on a calibration workpiece at step S**300** provided that the position is within the center of a field of view of visual input device (**112**, FIG. **2**A), such as a camera. The hole position and tool number used for drilling the hole are recorded, for example to a preferences file, at step S**302**. For example, the record may indicate that a ¼" end mill tool T1 was used to drill a ¼" diameter hole having a depth of ½" at position X=10.0" and Y=10.0". Typically a Z-axis position of the visual input device is set to a minimal value, such as ½", which brings the camera close to the calibration workpiece.

At step S**304**, a calibration square is drawn around the drilled hole, such that the drilled hole is at the center of the calibration square. In order to ensure that the hole is indeed centered in the square, supporting tools may be used, such as a jig allowing centering of a square stencil on the hole.

At step S**306**, the controller (**118**, FIG. **2**A) navigates the visual input device to the square, and the position of the calibration square, and therefore of the hole drilled at step S**300**, is recorded as a new offset for the visual input device at step S**308**. Continuing the example brought hereinabove with respect to step S**302**, at step S**306** the visual input device may be navigated to the square, resulting in a position reading of X=15.0" and Y=15.0". Thus, the new offset recorded at step S**308** would be (5.0", 5.0") ($X_{offset}=X_{camera}-X_{drilled}=15.0-10.0=5.0$, same for Y_{offset}).

At step S**310**, working element (**108**, FIG. **2**A) of the CNC machine is navigated to (current_position−new_offset), and at step S**312** the user confirms that the working element is aligned with the hole drilled at step S**300**.

In some embodiments, the method of calibration may further include an optional step S**314**, in which the controller navigates the working element back to the computed position, and the user confirms that the tool is aligned with the previously drilled hole.

FIG. **7**B is a flowchart of a method for confirmation of calibration, or recalibration, of a CNC system according to the disclosed technology.

At an initial step S**350**, a stored hole position, and a visual input device offset for a specific tool, are read from a preferences file, where they were previously stored. At step S**352**, the controller moves the tool to a location at (hole_position+visual_input_device_offset), and scans the workpiece for the calibration square at step S**354**.

At step S**356**, the operator, or the controller, evaluates whether the square is precisely centered within the field of view of the visual input device. If the square is precisely centered, the recalibration process is complete. Otherwise, if the square is not precisely centered, at step S**358** the controller causes the visual input device to navigate to the square, and computes a new device offset by subtracting the newly acquired calibration square position from the saved hole position, at step S**360**. At step S**362**, the working element is jogged to (current_position−updated_offset), and at step S**364** the user confirms that the working element is aligned with the hole drilled at step S**300**. The user may then be prompted to update the stored camera offset, at step S**366**.

While the disclosed technology has been taught with specific reference to the above embodiments, a person having ordinary skill in the art will recognize that changes can be made in form and detail without departing from the spirit and the scope of the disclosed technology. The described embodiments are to be considered in all respects only as illustrative and not restrictive. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope. Combinations of any of the methods, systems, and devices described herein-above are also contemplated and within the scope of the disclosed technology.

I claim:

1. A method for automated precision control of a computer numerical control (CNC) machine to a workpiece comprising:

receiving via at least one visual input device at least one detectable marking on a workpiece;

decoding said at least one detectable marking and determining a stored and pre-defined movement routine of a cutting element attached to said CNC machine relative to said workpiece based on said at least one marking;

determining, using said at least one visual input device and/or another visual input device, a current position of a working end of said cutting element relative to said at least one marking; and

performing said pre-defined movement routine comprising cutting into said workpiece with said cutting element

wherein said at least one visual input device and a holder for said cutting element are fixedly mounted to a movable housing, and move together, relative to a position of said workpiece

wherein said at least one visual input device comprises a plurality of visual input devices which are used to determine at least a two-dimensional location in a three-dimensional space of said workpiece

wherein said at least one visual input device is used to determine a scale of said pre-defined movement routine and to apply a magnification level of said pre-defined movement routine to said workpiece.

2. The method of claim **1**, wherein said cutting element holder is adapted to removably hold said cutting element and a mount for said workpiece is adapted to removably hold said workpiece.

3. The method of claim **1**, wherein said pre-defined movement routine is parameterized by one or more variables; and

said at least one marking comprises a marking representative of a constant value used in place of each of said one or more variables when performing said pre-defined movement routine.

4. The method of claim **1**, wherein said at least one marking comprises a first marking and a second marking;

said first marking corresponds to a first reference point of said pre-defined movement routine; and

said second marking corresponds to a second reference point on said workpiece cut during said pre-defined movement routine.

5. The method of claim **4**, wherein said pre-defined movement routine is at least one of translated, rotated and scaled based on a position of said second marking compared to a position of said first marking.

6. A method for automated precision control of a computer numerical control (CNC) machine to a workpiece comprising:

receiving via at least one visual input device at least one detectable marking on a workpiece;

decoding said at least one detectable marking and determining a stored and pre-defined movement routine of a cutting element attached to said CNC machine relative to said workpiece based on said at least one marking;

determining, using said at least one visual input device and/or another visual input device, a current position of a working end of said cutting element relative to said at least one marking; and

performing said pre-defined movement routine comprising cutting into said workpiece with said cutting element,

wherein said at least one marking is handwritten and determined, in said step of decoding, to be a square; and

a starting position of said cutting is at the center of said square.

7. The method of claim **6**, wherein in said step of decoding, decoding a marking of two lines is insufficient to cause said step of performing to be carried out until said two lines are inscribed within a larger proximate shape.

8. A method of modifying a workpiece comprising steps of:

securing said workpiece to a fixed location;

marking a surface of said workpiece with human readable indicia using a handheld writing apparatus to cause a cutting tool to move in at least three axes to a coordinate of said marking;

wherein said human readable indicia is associated with a predefined series of movements which begin at a position of a detected marking on a surface; and

wherein said human readable indicia is used to determine a scale of said pre-defined series of movements and to apply a magnification level of said pre-defined movements to said workpiece.

9. The method of claim **8**, wherein:

said human readable indicia comprise a first indicium at a first coordinate on said workpiece and a second indicium at a second coordinate on said workpiece and said predefined series of movements is at least one of translated, rotated and scaled based on positions of said first indicium and said second indicium such that said cutting tool cuts relative to said first indicium and said second indicium.

10. The method of claim **9**, wherein said pre-defined series of movements comprises a graphic which, when said cutting tool cuts, is at an orientation relative to placement of said first indicium and said second indicium.

11. The method of claim **8**, wherein said human readable indicia comprise at least:

one indicium indicating a location to be cut by said cutting tool;

one indicium associated with, and causing, a selection of one of said pre- defined series of movements; and

one indicium indicating a variation to said predefined series of movements.

12. The method of claim **11**, wherein said one indicium indicating of a variation comprises a real number and said variation comprises carrying out a trigonometric modifying function on said predefined series of movements before said cutting tool cuts.

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