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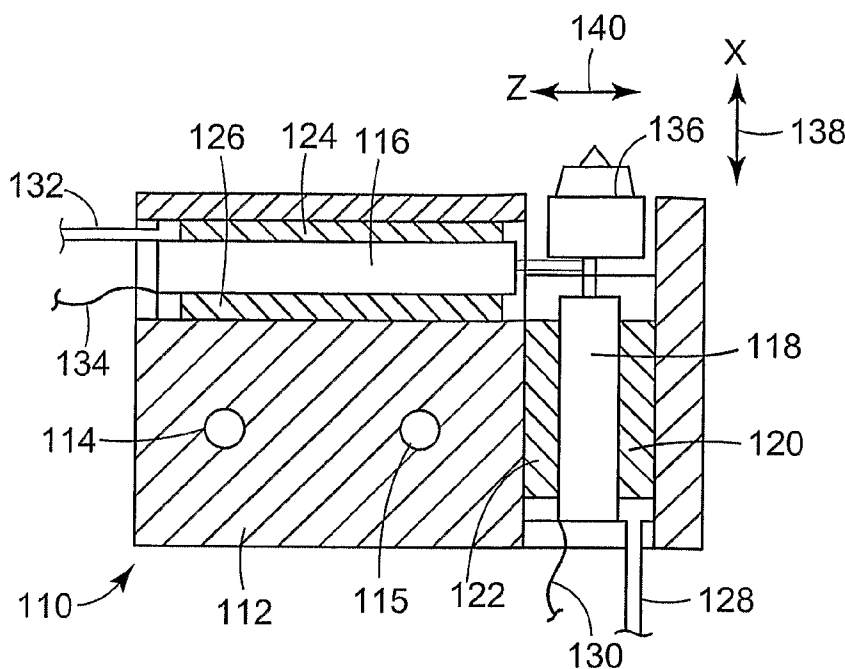
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[Continued on next page]

(54) Title: CUTTING TOOL HAVING VARIABLE AND INDEPENDENT MOVEMENT IN AN X-DIRECTION AND A Z-DIRECTION INTO AND Laterally ALONG A WORK PIECE FOR MAKING MICROSTRUCTURES



(57) Abstract: A cutting tool assembly having a tool post capable of lateral movement along a work piece to be cut and an actuator with a tool tip. The actuator provides for independent and variable control of the movement of the tool tip in an x-direction into the work piece and in a z-direction laterally along the work piece for use in making microstructures in the work piece.

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**CUTTING TOOL HAVING VARIABLE AND INDEPENDENT MOVEMENT IN
AN X-DIRECTION AND A Z-DIRECTION INTO AND Laterally ALONG A
WORK PIECE FOR MAKING MICROSTRUCTURES**

REFERENCE TO RELATED APPLICATIONS

The present application is related to the following applications : U.S. patent application of Alan Campbell, Dale Ehnes, and Daniel Wertz, entitled "Cutting Tool Having Variable Movement at Two Simultaneously Independent Speeds in an X-Direction Into a Work Piece for Making Microstructures"; U.S. patent application of Dale Ehnes, Alan Campbell, and Daniel Wertz, entitled "Cutting Tool Having Variable Movement in a Z-Direction Laterally Along a Work Piece for Making Microstructures"; and U.S. patent application of Dale Ehnes, Alan Campbell, and Daniel Wertz, entitled "Cutting Tool Having Variable Rotation About a Y-Direction Transversely Across a Work Piece for Making Microstructures"; all filed November 15, 2005.

FIELD OF INVENTION

The present invention relates to diamond machining of microreplication tools used in creating microreplicated structures.

BACKGROUND

Machining techniques can be used to create a wide variety of work pieces such as microreplication tools. Microreplication tools are commonly used for extrusion processes, injection molding processes, embossing processes, casting processes, or the like, to create microreplicated structures. The microreplicated structures may comprise optical films, abrasive films, adhesive films, mechanical fasteners having self-mating profiles, or any molded or extruded parts having microreplicated features of relatively small dimensions, such as dimensions less than approximately 1000 microns.

The microstructures can also be made by various other methods. For example, the structure of the master tool can be transferred on other media, such as to a belt or web of polymeric material, by a cast and cure process from the master tool to form a production

tool; this production tool is then used to make the microreplicated structure. Other methods such as electroforming can be used to copy the master tool. Another alternate method to make a light directing film is to directly cut or machine a transparent material to form the appropriate structures.

5 Other techniques include chemical etching, bead blasting, or other stochastic surface modification techniques. However, those techniques are typically not capable of forming the sharp, precise microstructures, and the breadth of features, desired to obtain the appropriate light diffusion characteristic achieved with a cutting tool using the methods of the present invention. In particular, these methods are not capable of producing highly
10 accurate, repeating structures because of the inherent impreciseness and unrepeatability associated with chemical etching, bead blasting, and other stochastic surface modification techniques.

SUMMARY OF INVENTION

15 A first cutting tool assembly includes a tool post and an actuator configured for attachment to the tool post and for electrical communication with a controller. A tool tip attached to the actuator is mounted for movement with respect to a work piece to be cut. The actuator provides for independent and variable control of the movement of the tool tip in an x-direction into the work piece and a z-direction laterally along the work piece for
20 use in selectively cutting the work piece.

A second cutting tool assembly includes a tool post capable of lateral movement along a work piece to be cut and an actuator configured for attachment to the tool post and for electrical communication with a controller, the actuator including a piezoelectric stack. A tool tip attached to the piezoelectric stack is mounted for movement with respect to the
25 work piece to be cut. The actuator provides for independent and variable control of the movement of the tool tip in an x-direction into the work piece and a z-direction laterally along the work piece for use in selectively cutting the work piece in order to make microstructures in the work piece.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are incorporated in and constitute a part of this specification and, together with the description, explain the advantages and principles of the invention. In the drawings,

5 FIG. 1 is a diagram of a cutting tool system for making microstructures in a work piece;

FIG. 2 is a diagram illustrating a coordinate system for a cutting tool;

FIG. 3 is a diagram of an exemplary PZT stack for use in a cutting tool;

FIG. 4A is a perspective view of a tool tip carrier;

10 FIG. 4B is a front view of a tool tip carrier for holding a tool tip;

FIG. 4C is a side view of a tool tip carrier;

FIG. 4D is a top view of a tool tip carrier;

FIG. 5A is a perspective view of a tool tip;

FIG. 5B is a front view of a tool tip;

15 FIG. 5C is a bottom view of a tool tip;

FIG. 5D is a side view of a tool tip;

FIG. 6A is a top sectional view of an X-Z actuator for use in a cutting tool;

FIG. 6B is a side sectional view illustrating placement of a PZT stack in an X-Z actuator;

20 FIG. 6C is a front view of an X-Z actuator;

FIG. 6D is a back view of an X-Z actuator;

FIG. 6E is a top view of an X-Z actuator;

FIGS. 6F and 6G are side views of an X-Z actuator;

FIG. 6H is a perspective view of an X-Z actuator; and

25 FIG 7A is a perspective view of a paddle for mounting two PZT stacks for an X-Z actuator;

FIG 7B is a top view of a paddle for mounting two PZT stacks for an X-Z actuator;

FIG 7C is a front view of a paddle for mounting two PZT stacks for an X-Z actuator;

30 FIG 7D is a side view of a paddle for mounting two PZT stacks for an X-Z actuator;

FIG. 7E is a perspective view illustrating mounting of two PZT stacks to a paddle for an X-Z actuator; and

FIG. 8 is a diagram conceptually illustrating microstructures that can be made using the cutting tool system having an X-Z actuator.

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DETAILED DESCRIPTION

Cutting Tool System

General diamond turning techniques are described in PCT Published Application WO 00/48037. The apparatus used in methods and for making optical films or other films can include a fast servo tool. As disclosed in WO 00/48037, a fast tool servo (FTS) is a solid state piezoelectric (PZT) device, referred to as a PZT stack, which rapidly adjusts the position of a cutting tool attached to the PZT stack. The FTS allows for highly precise and high speed movement of the cutting tool in directions within a coordinate system as further described below.

FIG. 1 is a diagram of a cutting tool system 10 for making microstructures in a work piece. Microstructures can include any type, shape, and dimension of structures on, indenting into, or protruding from the surface of an article. For example, microstructures created using the actuators and system described in the present specification can have a 1000 micron pitch, 100 micron pitch, 1 micron pitch, or even a sub- optical wavelength pitch around 200 nanometers (nm). These dimensions are provided for illustrative purposes only, and microstructures made using the actuators and system described in the present specification can have any dimension within the range capable of being tooled using the system.

System 10 is controlled by a computer 12. Computer 12 has, for example, the following components: a memory 14 storing one or more applications 16; a secondary storage 18 providing for non-volatile storage of information; an input device 20 for receiving information or commands; a processor 22 for executing applications stored in memory 16 or secondary storage 18, or received from another source; a display device 24 for outputting a visual display of information; and an output device 26 for outputting information in other forms such as speakers for audio information or a printer for a hardcopy of information.

The cutting of a work piece 54 is performed by a tool tip 44. An actuator 38 controls movement of tool tip 44 as work piece 54 is rotated by a drive unit and encoder 56, such as an electric motor controlled by computer 12. In this example, work piece 54 is shown in roll form such as a hard copper roll; however, it can be implemented in planar form and make use of other materials for machining. For example, the work piece can be alternatively implemented with aluminum, nickel, steel, or plastics (e.g., acrylics). The particular material to be used may depend, for example, upon a particular desired application such as various films made using the machined work piece. Actuator 38, and the actuators described below, can be implemented with stainless steel, for example, or other materials.

Actuator 38 is removably connected to a tool post 36, which is in turn located on a track 32. The tool post 36 and actuator 38 are configured on track 32 to move in both an x-direction and a z-direction as shown by arrows 40 and 42. Computer 12 is in electrical connection with tool post 36 and actuator 38 via one or more amplifiers 30. When functioning as a controller, computer 12 controls movement of tool post 36 along track 32 and movement of tool tip 44 via actuator 38 for machining work piece 54. If an actuator has multiple PZT stacks, it can use separate amplifiers to independently control each PZT stack for use in independently controlling movement of a tool tip attached to the stacks. Computer 12 can make use of a function generator 28 in order to provide waveforms to actuator 38 in order to machine various microstructures in work piece 54, as further explained below.

The machining of work piece 54 is accomplished by coordinated movements of various components. In particular, the system, under control of computer 12, can coordinate and control movement of actuator 38, via movement of tool post 36, along with movement of the work piece in the c-direction and movement of tool tip 44 in one or more of the x-direction, y-direction, and z-direction, those coordinates being explained below. The system typically moves tool post 36 at a constant speed in the z-direction, although a varying speed may be used. The movements of tool post 36 and tool tip 44 are typically synchronized with the movement of work piece 54 in the c-direction (rotational movement as represented by line 53). All of these movements can be controlled using, for example,

numerical control techniques or a numerical controller (NC) implemented in software, firmware, or a combination in computer 12.

Work piece 54, after having been machined, can be used to make films having the corresponding microstructures for use in a variety of applications. Examples of those films include optical films, friction control films, and micro-fasteners or other mechanical microstructured components. The films are typically made using a coating process in which a material in a viscous state is applied to the work piece, allowed to at least partially cure, and then removed. The film composed of the cured material will have substantially the opposite structures than those in the work piece. For example, an indentation in the work piece results in a protrusion in the resulting film.

Cooling fluid 46 is used to control the temperature of tool post 36 and actuator 38 via lines 48 and 50. A temperature control unit 52 can maintain a substantially constant temperature of the cooling fluid as it is circulated through tool post 36 and actuator 38. Temperature control unit 52 can be implemented with any device for providing temperature control of a fluid. The cooling fluid can be implemented with an oil product, for example a low viscosity oil. The temperature control unit 52 and reservoir for cooling fluid 46 can include pumps to circulate the fluid through tool post 36 and actuator 38, and they also typically include a refrigeration system to remove heat from the fluid in order to maintain it at a substantially constant temperature. Refrigeration and pump systems to circulate and provide temperature control of a fluid are known in the art. In certain embodiments, the cooling fluid can also be applied to work piece 54 in order to maintain a substantially constant surface temperature of the material to be machined in the work piece.

FIG. 2 is a diagram illustrating a coordinate system for a cutting tool such as system 10. The coordinate system is shown as movement of a tool tip 62 with respect to a work piece 64. Tool tip 62 may correspond with tool tip 44 and is typically attached to a carrier 60, which is attached to an actuator. The coordinate system, in this exemplary embodiment, includes an x-direction 66, a y-direction 68, and a z-direction 70. The x-direction 66 refers to movement in a direction substantially perpendicular to work piece 64. The y-direction 68 refers to movement in a direction transversely across work piece 64 such as in a direction substantially parallel to a plane of rotation of work piece 64. The z-

direction 70 refers to movement in a direction laterally along work piece 64 such as in a direction substantially perpendicular to a plane of rotation of work piece 64. The rotation of the work piece is referred to as the c-direction, as also shown in FIG. 1. If the work piece is implemented in planar form, as opposed to roll form, then the y-direction and z-direction refer to movement in mutually orthogonal directions across the work piece in directions substantially perpendicular to the x-direction.

The system 10 can be used for high precision, high speed machining. This type of machining must account for a variety of parameters, such as the coordinated speeds of the components and the work piece material. It typically must take into consideration the specific energy for a given volume of metal to be machined, for example, along with the thermal stability and properties of the work piece material. Cutting parameters relating to machining are described in the following references: Machining Data Handbook, Library of Congress Catalog Card No. 66-60051, Second Edition (1972); Edward Trent and Paul Wright, Metal Cutting, Fourth Edition, Butterworth-Heinemann, ISBN 0-7506-7069-X (2000); Zhang Jin-Hua, Theory and Technique of Precision Cutting, Pergamon Press, ISBN 0-08-035891-8 (1991); and M. K. Krueger et al., New Technology in Metalworking Fluids and Grinding Wheels Achieves Tenfold Improvement in Grinding Performance, Coolant/Lubricants for Metal Cutting and Grinding Conference, Chicago, Illinois, U.S.A., June 7, 2000.

PZT Stack, Tool Tip Carrier, and Tool Tip

FIG. 3 is a diagram of an exemplary PZT stack 72 for use in a cutting tool. A PZT stack is used to provide movement of a tool tip connected to it and operates according to the PZT effect, which is known in the art. According to the PZT effect, an electric field applied to certain types of materials causes expansion of them along one axis and contraction along another axis. A PZT stack typically includes a plurality of materials 74, 76, and 78 enclosed within a casing 84 and mounted on a base plate 86. The materials in this exemplary embodiment are implemented with a ceramic material subject to the PZT effect. Three disks 74, 76, and 78 are shown for exemplary purposes only and any number of disks or other materials, and any type of shapes of them, can be used based upon, for example, requirements of particular embodiments. A post 88 is adhered to the disks and

protrudes from casing 84. The disks can be implemented with any PZT material such as for example, a barium titanate, lead zirconate, or lead titanate material mixed, pressed, based, and sintered. One such PZT material is available from Kinetic Ceramics, Inc., 26240 Industrial Blvd., Hayward, CA 94545, U.S.A. The disks can also be implemented with a magnetostrictive material, for example.

Electrical connections to the disks 74, 76, and 78, as represented by lines 80 and 82, provide electrical fields to them in order to provide for movement of post 88. Due to the PZT effect and based upon the type of electric field applied, precise and small movement of post 88, such as movement within several microns, can be accomplished.

Also, the end of PZT stack 72 having post 88 can be mounted against one or more Belleville washers, which provides for preloading of the PZT stack. The Belleville washers have some flexibility to permit movement of post 88 and a tool tip attached to it. Each PZT stack in the actuators described below can also incorporate Belleville washers for preloading or, alternatively, any device mounted against each PZT stack for preloading of it.

FIGS. 4A-4D are views of an exemplary tool tip carrier 90, which would be mounted to post 88 of the PZT stack for control by an actuator, as explained below. FIG. 4A is a perspective view of tool tip carrier 90. FIG. 4B is a front view of tool tip carrier 90. FIG. 4C is a side view of tool tip carrier 90. FIG. 4D is a top view of tool tip carrier 90.

As shown in FIGS. 4A-4D, tool tip carrier 90 includes a planar back surface 92, a tapered front surface 94, and a protruding surface 98 with angled or tapered sides. An aperture 96 provides for mounting of tool tip carrier 90 onto a post of a PZT stack. Tapered surface 98 would be used for mounting of a tool tip for machining of a work piece. In this exemplary embodiment, tool tip carrier 90 includes a planar surface to enhance stability of mounting it by providing for more surface area contact when mounted to a PZT stack, and it includes the tapered front surfaces to reduce the mass of it. Tool tip carrier 90 would be mounted to post 88 of the PZT stack by use of an adhesive, brazing, soldering, a fastener such as a bolt, or in other ways.

Other configurations of tool tip carriers are possible based, for example, upon requirements of particular embodiment. The term "tool tip carrier" is intended to include

any type of structure for use in holding a tool tip for machining a work piece. Tool tip carrier 90 can be implemented with, for example, one or more of the following materials: sintered carbide, silicon nitride, silicon carbide, steel, or titanium. The material for tool tip carrier 90 preferably is stiff and has a low mass.

FIGS. 5A-5D are views of an exemplary tool tip 100, which would be secured to surface 98 of tool tip carrier 90 such as by use of an adhesive, brazing, soldering, or in other ways. FIG. 5A is a perspective view of tool tip 100. FIG. 5B is a front view of tool tip 100. FIG. 5C is a bottom view of tool tip 100. FIG. 5D is a side view of tool tip 100. As shown in FIGS. 5A-5D, tool tip 100 includes sides 104, tapered and angled front surfaces 106, and a bottom surface 102 for securing it to surface 98 of tool tip carrier 90. The front portion 105 of tool tip 100 is used for machining of a work piece under control of an actuator. Tool tip 90 can be implemented with, for example, a diamond slab.

X-Z Actuator

FIGS. 6A-6H are views of an exemplary X-Z actuator 110. The term "X-Z actuator" refers to any type of actuator or other device that provides for movement of a tool tip in substantially both an x-direction and a z-direction for use in machining a work piece. FIG. 6A is a top sectional view of X-Z actuator 110. FIG. 6B is a side sectional view illustrating placement of a PZT stack in X-Z actuator 110. FIG. 6C is a front view of X-Z actuator 110. FIG. 6D is a back view of X-Z actuator 110. FIG. 6E is a top view of X-Z actuator 110. FIGS. 6F and 6G are side views of X-Z actuator 110. FIG. 6H is a perspective view of X-Z actuator 110. Some details of X-Z actuator 110 in FIGS. 6C-6H have been removed for clarity.

As shown in FIGS. 6A-6H, X-Z actuator 110 includes a main body 112 capable holding an x-direction PZT stack 118 and a z-direction PZT stack 116. PZT stacks 118 and 116 are attached to a tool tip carrier having a tool tip 136 for using in moving the tool tip in an x-direction and z-direction, respectively, as shown by arrows 138 and 140. PZT stacks 118 and 116 can be implemented with the exemplary PZT stack 72 shown in FIG. 3. The tool tip on a carrier 136 can be implemented with the tool tip carrier shown in FIGS. 4A-4D and the tool tip shown in FIGS. 5A-5D. Main body 112 also includes two

apertures 114 and 115 for use in mounting it to tool post 36, such as via bolts, for machining work piece 54 under control of computer 12.

PZT stacks 118 and 116 are securely mounted in main body 112 for the stability required for precise controlled movement of tool tip 136. PZT stack 118 is secured in
5 main body 112 by rails such as rails 120 and 122, and PZT stack 116 is secured in main body 112 by rails such as rails 124 and 126. The PZT stacks 118 and 116 can preferably be removed from main body 112 by sliding them along the rails and can be secured in place in main body 112 by bolts or other fasteners. PZT stacks 118 and 116 include electrical connections 130 and 134, respectively, for receiving signals from computer 12.

10 The end caps of PZT stacks 118 and 116 include ports 128 and 132, respectively, for receiving cooling fluid such as oil from reservoir 46, circulating it around the PZT stacks, and delivering the oil back to reservoir 46 for maintaining temperature control of it. Main body 112 can include appropriate channels for directing the cooling fluid around PZT stacks 118 and 116, and the cooling fluid can be circulated by a pump or other device in
15 temperature control unit 52.

FIG. 6B is a side sectional view illustrating placement of PZT stack 118 in main body 112 with the end cap of PZT stack 118 not shown. Main body 112 can include a plurality of rails in each aperture for the PZT stacks to hold them securely in place. For example, PZT stack 118 is surrounded by rails 120, 122, 142, and 144 in order to hold it
20 securely in place when mounted in main body 112. The end cap attached to PZT stack 118 can accommodate bolts or other fasteners to secure PZT stack to one or more of the rails 120, 122, 142, and 144, and the end cap can also provide for sealing PZT stack 118 in main body 112 for use in circulating the cooling fluid around it. PZT stack 116 can be mounted in a similar manner. Both PZT stacks 116 and 118 can include one or more
25 Belleville washers positioned between the stacks and the tool tip carrier 136 for preloading of them.

FIGS. 7A-7D illustrate a paddle 150 for use in securing actuators 116 and 118 to tool tip carrier 136. FIG 7A is a perspective view of paddle 150. FIG 7B is a top view of paddle 150. FIG 7C is a front view of paddle 150. FIG 7D is a side view of paddle 150.
30 FIG. 7E is a perspective view illustrating mounting of two PZT stacks to paddle 150. As shown in FIGS. 7A-7D, paddle 150 includes a ring portion 156 having a surface for being

secured to PZT stack 116 for z-direction control, and a ring portion 152 having a surface for being secured to PZT stack 118 for x-direction control. In this embodiment, ring portions 152 and 156 have apertures 154 and 158, respectively. Aperture 154 can be used to secure paddle 150 to both PZT stack 118 and tool tip carrier 136 using, for example, a fastener. Paddle 150 is preferably made from titanium, and it can alternatively be made from other materials. For example, paddle 150 can alternatively be implemented with aluminum. A factor for a material to implement paddle 150 can include, for example, a strength to weight ratio of the material. Actuators 116 and 118 can be secured to paddle 150, as shown in FIG. 7E, by use of an adhesive, brazing, soldering, or in other ways.

FIG. 8 is a diagram conceptually illustrating microstructures that can be made using the cutting tool system having an X-Z actuator. As shown in FIG. 8, an article 160 includes a top surface 162 and a bottom surface 164. Top surface 162 includes microstructures as represented by lines 166, and those microstructures can be made using the actuators described above to machine a work piece and then using that work piece to make a film or article using a coating technique.

While the present invention has been described in connection with an exemplary embodiment, it will be understood that many modifications will be readily apparent to those skilled in the art, and this application is intended to cover any adaptations or variations thereof. For example, various types of materials for the tool post, actuator, and tool tip, and configurations of those components, may be used without departing from the scope of the invention. This invention should be limited only by the claims and equivalents thereof.

CLAIMS:

1. A cutting tool assembly, comprising:
a tool post;
5 an actuator configured for attachment to the tool post and for electrical communication with a controller; and
a tool tip attached to the actuator and mounted for movement with respect to a work piece to be cut, wherein the actuator provides for independent and variable control of the movement of the tool tip in an x-direction into the work piece and a z-direction
10 laterally along the work piece for use in selectively cutting the work piece.
2. The cutting tool assembly of claim 1, wherein the actuator includes a pair of piezoelectric stacks connected to the tool tip, and for electrical connection with the controller, for controlling the movement of the tool tip.
15
3. The cutting tool assembly of claim 2, further including a paddle for connecting the pair of piezoelectric stacks to the tool tip.
4. The cutting tool assembly of claim 3, wherein the paddle is composed of a titanium
20 material.
5. The cutting tool assembly of claim 1, wherein the actuator includes ports for transmission of a fluid through the actuator for cooling of the actuator.
- 25 6. The cutting tool assembly of claim 1, wherein the actuator includes a first amplifier for controlling the movement of the tool tip in the x-direction and a second amplifier for controlling the movement of the tool tip in the z-direction.
7. The cutting tool assembly of claim 2, further comprising washers connected to the
30 piezoelectric stacks for use in preloading the piezoelectric stacks.

8. The cutting tool assembly of claim 1, wherein the tool post is configured to move the actuator in the z-direction along the work piece at a substantially constant speed.
9. The cutting tool assembly of claim 1, wherein the actuator is configured for
5 removable attachment to a post on the tool post.
10. A method for cutting a work piece, comprising:
providing a tool post;
providing an actuator configured for attachment to the tool post and for electrical
10 communication with a controller;
situating a tool tip in the actuator for movement with respect to the work piece to be cut; and
configuring the actuator for providing independent and variable control of the
movement of the tool tip in an x-direction into the work piece and a z-direction laterally
15 along the work piece for use in selectively cutting the work piece.
11. The method of claim 10, wherein the configuring step includes controlling the movement of the tool tip using a pair of piezoelectric stacks.
12. The method of claim 11, further including connecting the pair of piezoelectric
20 stacks to the tool tip using a paddle.
13. The method of claim 10, further including cooling of the actuator using a fluid.
14. The method of claim 10, wherein the configuring step includes using a first
25 amplifier for controlling the movement of the tool tip in the x-direction and using a second amplifier for controlling the movement of the tool tip in the z-direction.
15. The method of claim 11, further comprising preloading the piezoelectric stacks
30 using washers.

16. The method of claim 10, wherein the providing the tool post step includes moving the actuator in the z-direction along the work piece at a substantially constant speed.

17. The method of claim 10, further including removably attaching the actuator to a post on the tool post.

18. A cutting tool assembly, comprising:

a tool post capable of lateral movement along a work piece to be cut;

an actuator configured for attachment to the tool post and for electrical

communication with a controller, the actuator including a piezoelectric stack; and

a tool tip attached to the piezoelectric stack in the actuator and mounted for movement with respect to the work piece to be cut, wherein the actuator provides for independent and variable control of the movement of the tool tip in an x-direction into the work piece and a z-direction laterally along the work piece for use in selectively cutting the work piece in order to make microstructures in the work piece.

19. The cutting tool assembly of claim 18, wherein the actuator includes ports for transmission of a fluid through the actuator for cooling of the actuator.

20. The cutting tool assembly of claim 18, wherein the actuator is configured for removable attachment to a post on the tool post.

21. A method for making a microstructured article, comprising:

making a machined work piece, comprising

providing a tool post;

providing an actuator configured for attachment to the tool post and for electrical communication with a controller;

situating a tool tip in the actuator for movement with respect to the work piece to be cut; and

configuring the actuator for providing independent and variable control of the movement of the tool tip in an x-direction into the work piece and a z-direction

laterally along the work piece for use in selectively cutting the work piece to create the machined work piece;

applying a material to the machined work piece such that the material substantially conforms to surface of the machined work piece; and

5 removing the material from the machined work piece.

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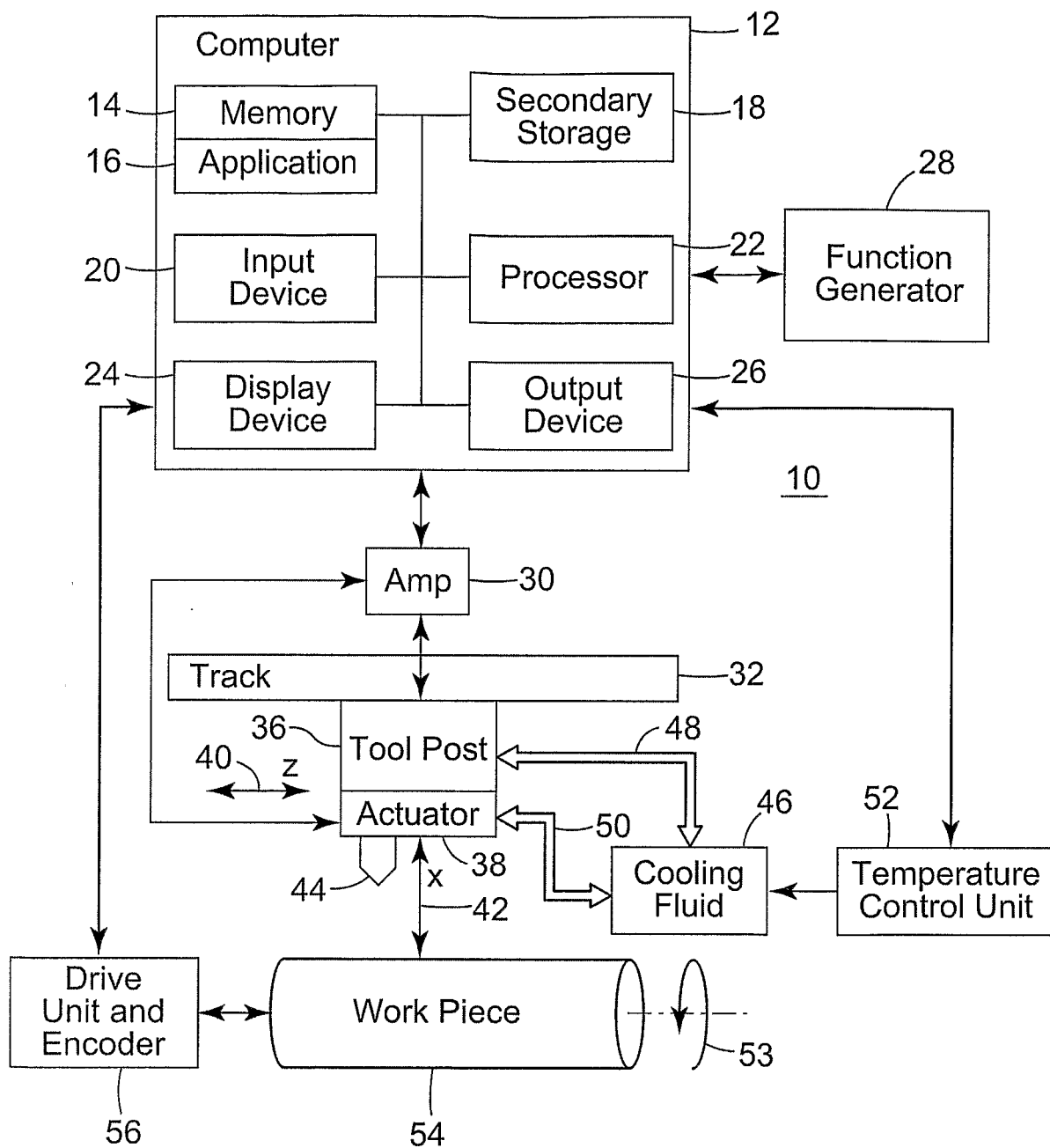


FIG. 1

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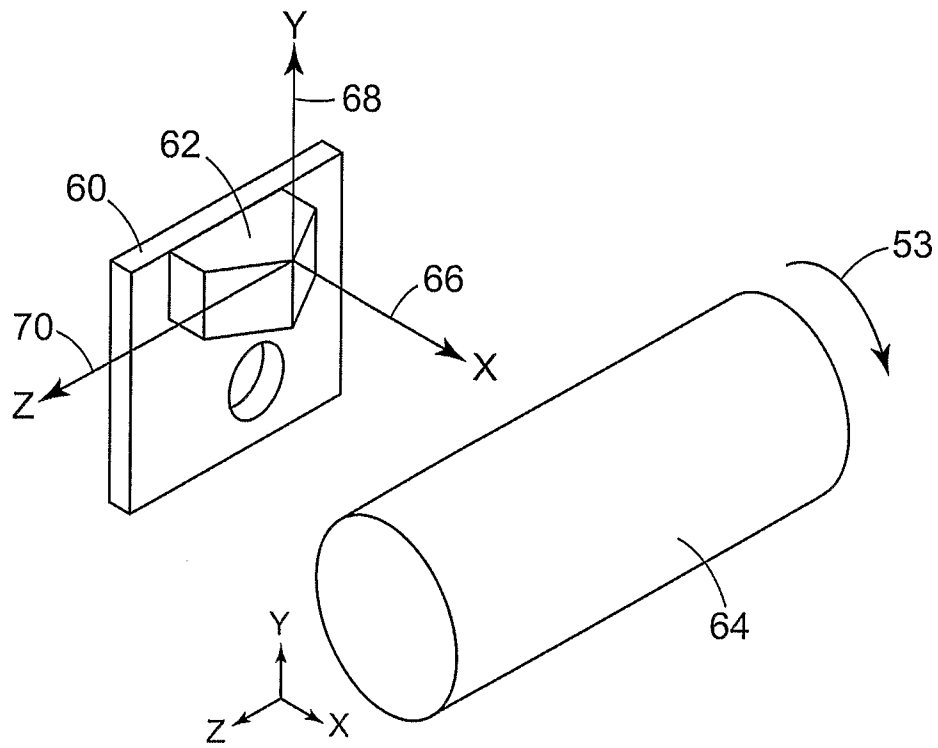


FIG. 2

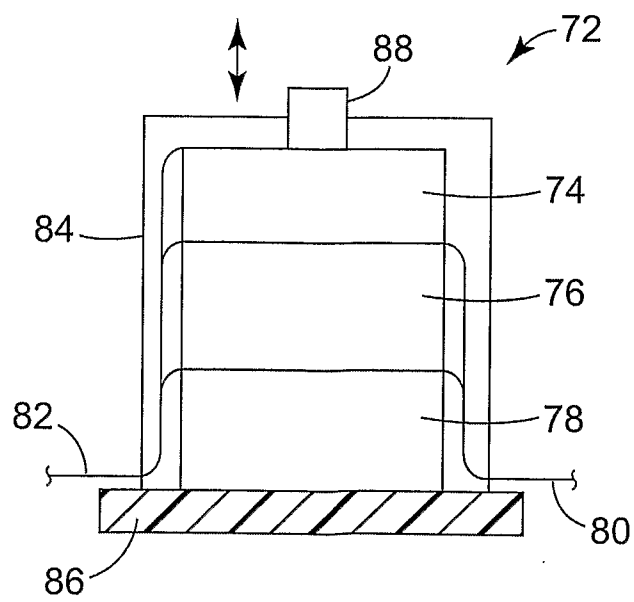


FIG. 3

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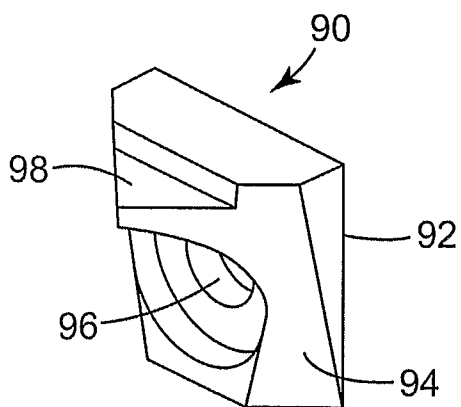


FIG. 4A

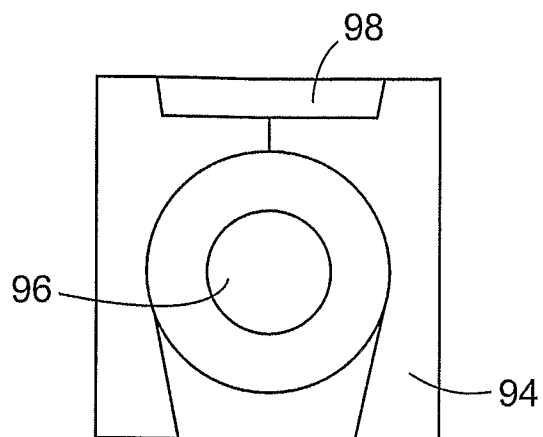


FIG. 4B

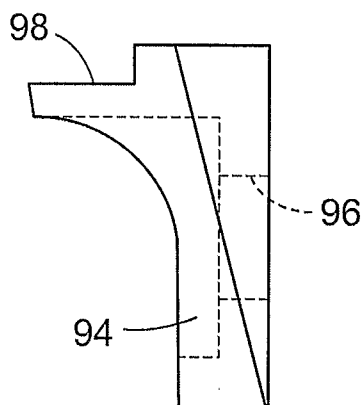


FIG. 4C

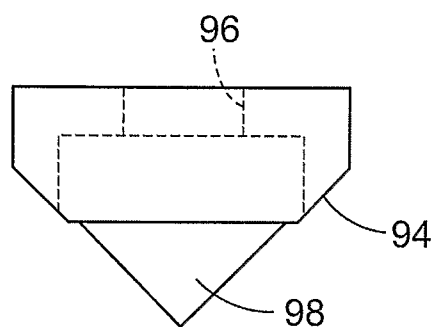


FIG. 4D

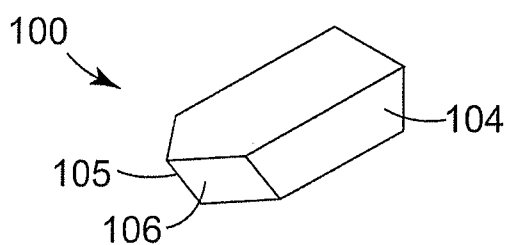


FIG. 5A

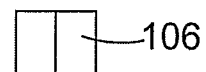


FIG. 5B

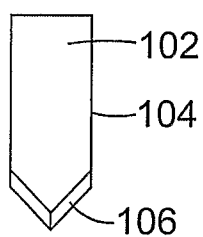


FIG. 5C

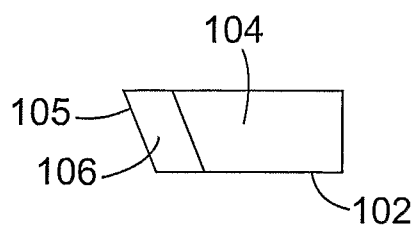


FIG. 5D

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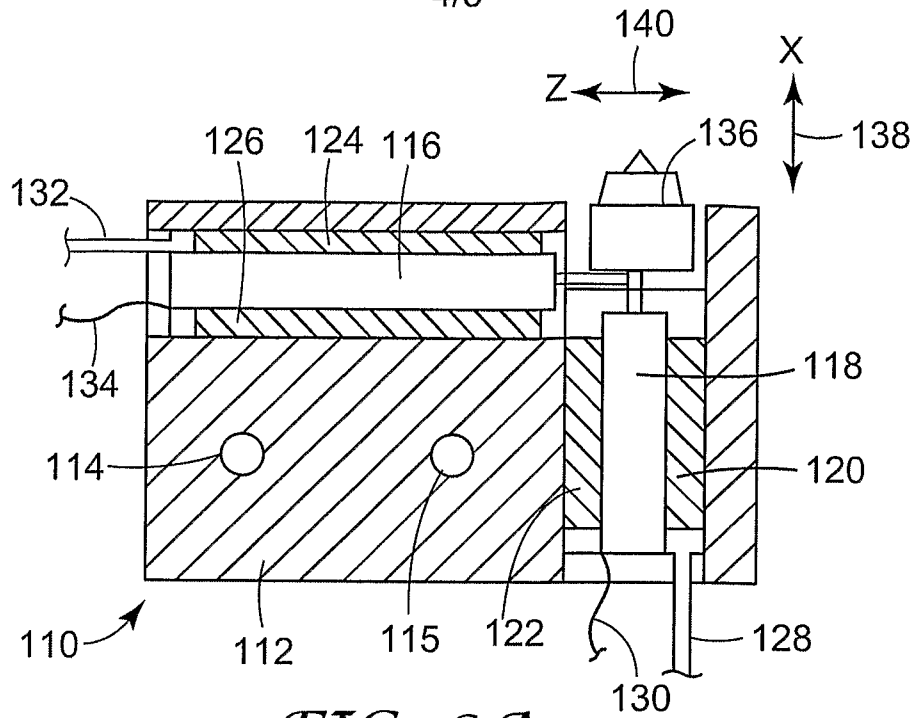


FIG. 6A

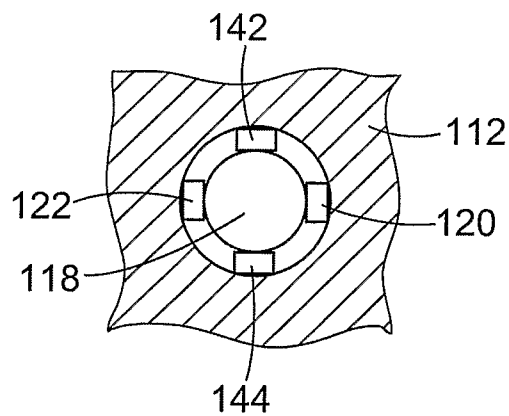


FIG. 6B

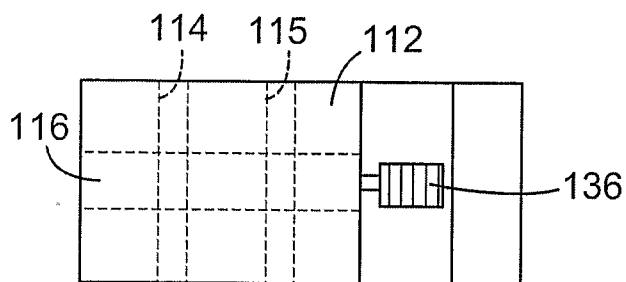


FIG. 6C

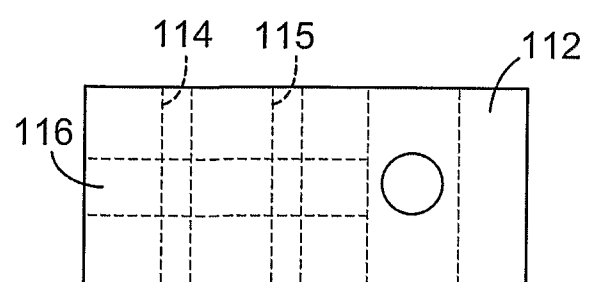


FIG. 6D

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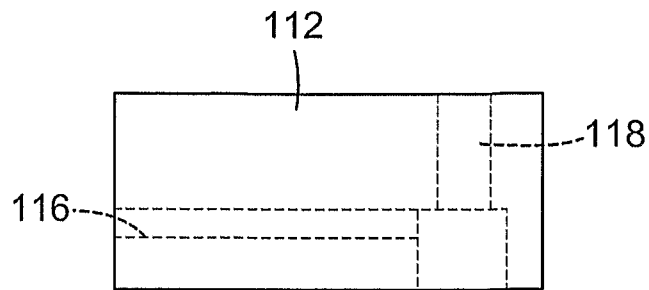


FIG. 6E

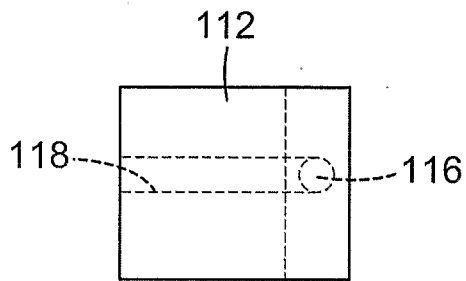


FIG. 6F

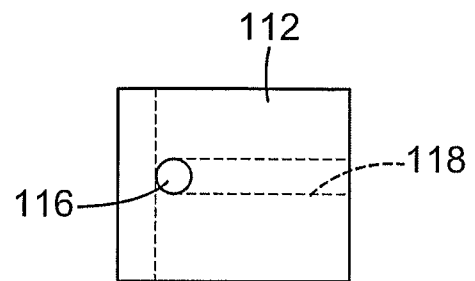


FIG. 6G

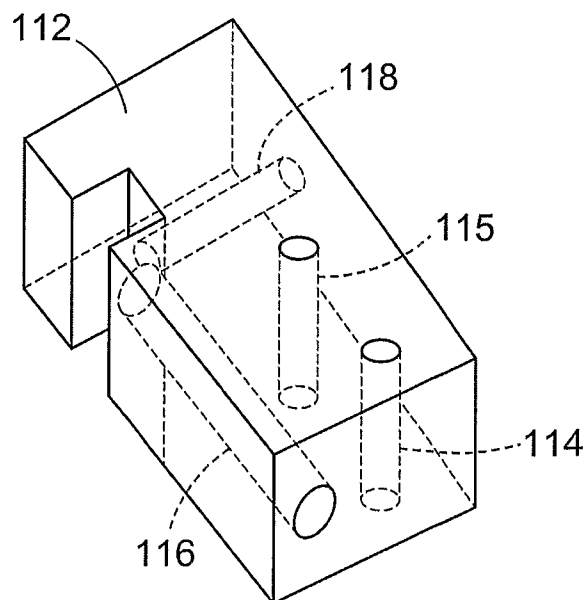


FIG. 6H

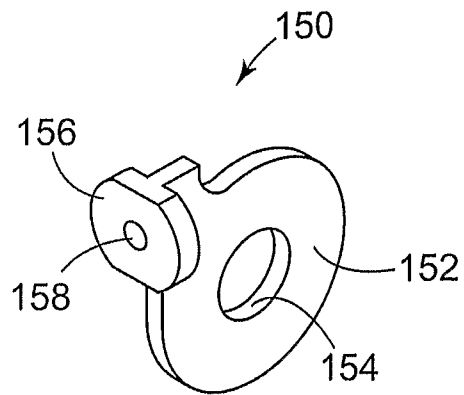


FIG. 7A

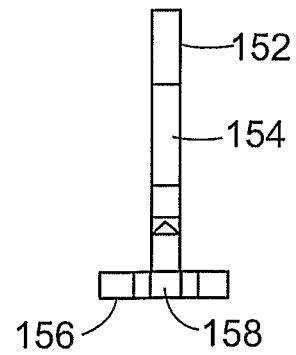


FIG. 7B

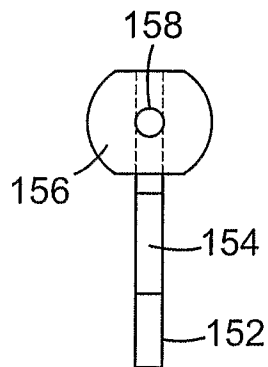


FIG. 7C

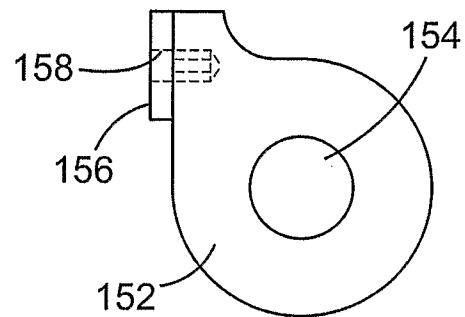


FIG. 7D

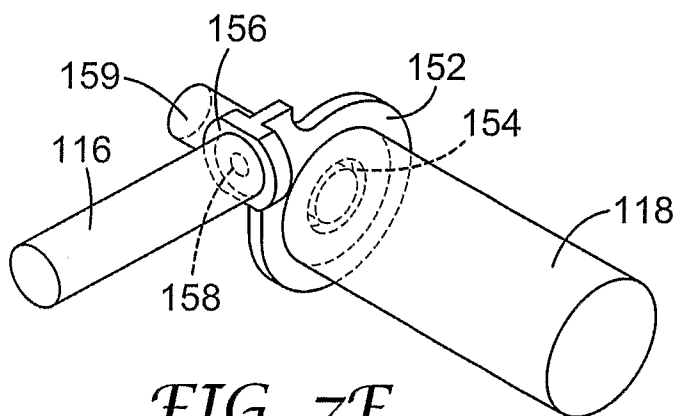


FIG. 7E

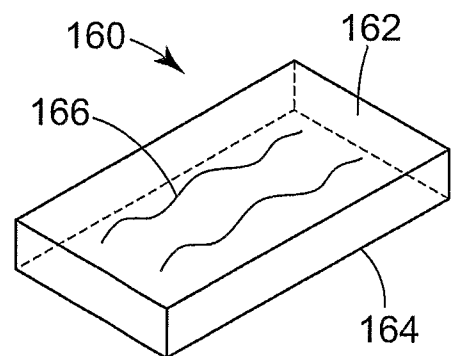


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2006/042171**A. CLASSIFICATION OF SUBJECT MATTER*****B23Q 15/013(2006.01)i, B23Q 15/14(2006.01)i, B23Q 16/00(2006.01)i***

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 8 : B23Q 15/00, 15/02, 15/013

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKIPASS (KIPO internal) & Keywords: "actuator", "tool", "cut", "piezoelectric"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	JP 2005-014169 A (CANON INC.) 20 January 2005 See paragraphs [0022]-[0028] and figures 1-3.	1, 6, 8, 10, 14, 16 2, 3, 11, 12, 18 4,5,7,9,13,15,17,19-21
Y A	JP 10-118811 A (MATSUSHITA ELECTRIC IND. CO., LTD.) 12 May 1998 See paragraphs [0007], [0020]-[0024], [0033], [0034] and figures 1, 4, 7.	2, 3, 11, 12, 18 1, 4-10, 13-17, 19-21
A	JP 01-281848 A (KOBE STEEL LTD.) 13 November 1989 See pages 2-3 and figures 1, 2.	1-20
A	JP 63-306854 A (HITACHI LTD.) 14 December 1988 See pages 2-3 and figures 1, 2.	1-20

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

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Date of the actual completion of the international search

30 MARCH 2007 (30.03.2007)

Date of mailing of the international search report

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Telephone No. 82-42-481-8417



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2006/042171

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2005-014169 A	20.01.2005	NONE	
JP 10-118811 A	12.05.1998	NONE	
JP 01-281848 A	13.11.1989	NONE	
JP 63-306854 A	14.12.1988	NONE	