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Ghalambor

(54) METHODS AND SYSTEMS FOR SENSOR-BASED DEBURRING

(76) Inventor: **Hamid R. Ghalambor**, Irvine, CA (US)

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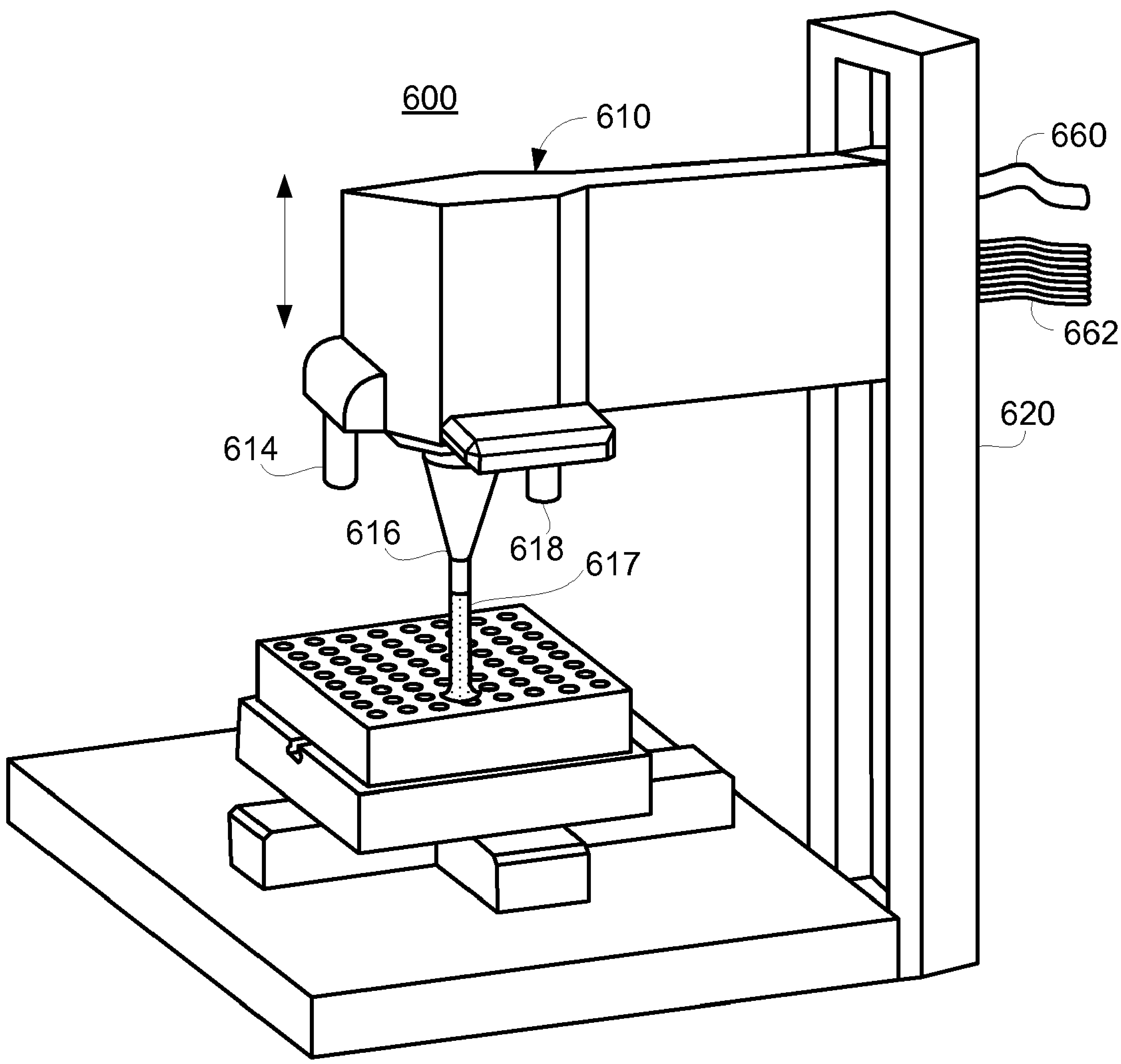
USPC **451/2**

(57) **ABSTRACT**

A sensor may be used to determine the presence of burrs on a workpiece, and a blasting media may be applied to the workpiece to lessen or eliminate burrs. The blasting media may be applied to the workpiece using a nozzle. The sensor may be scanned over the workpiece, and one or more burr metrics may be determined to qualify or quantify the presence of burrs. Based on the one or more burr metrics, a blasting schedule may be determined and performed. One or more characteristics of the workpiece may be checked after deburring to determine the extent of alteration, if any, of the workpiece caused by deburring.



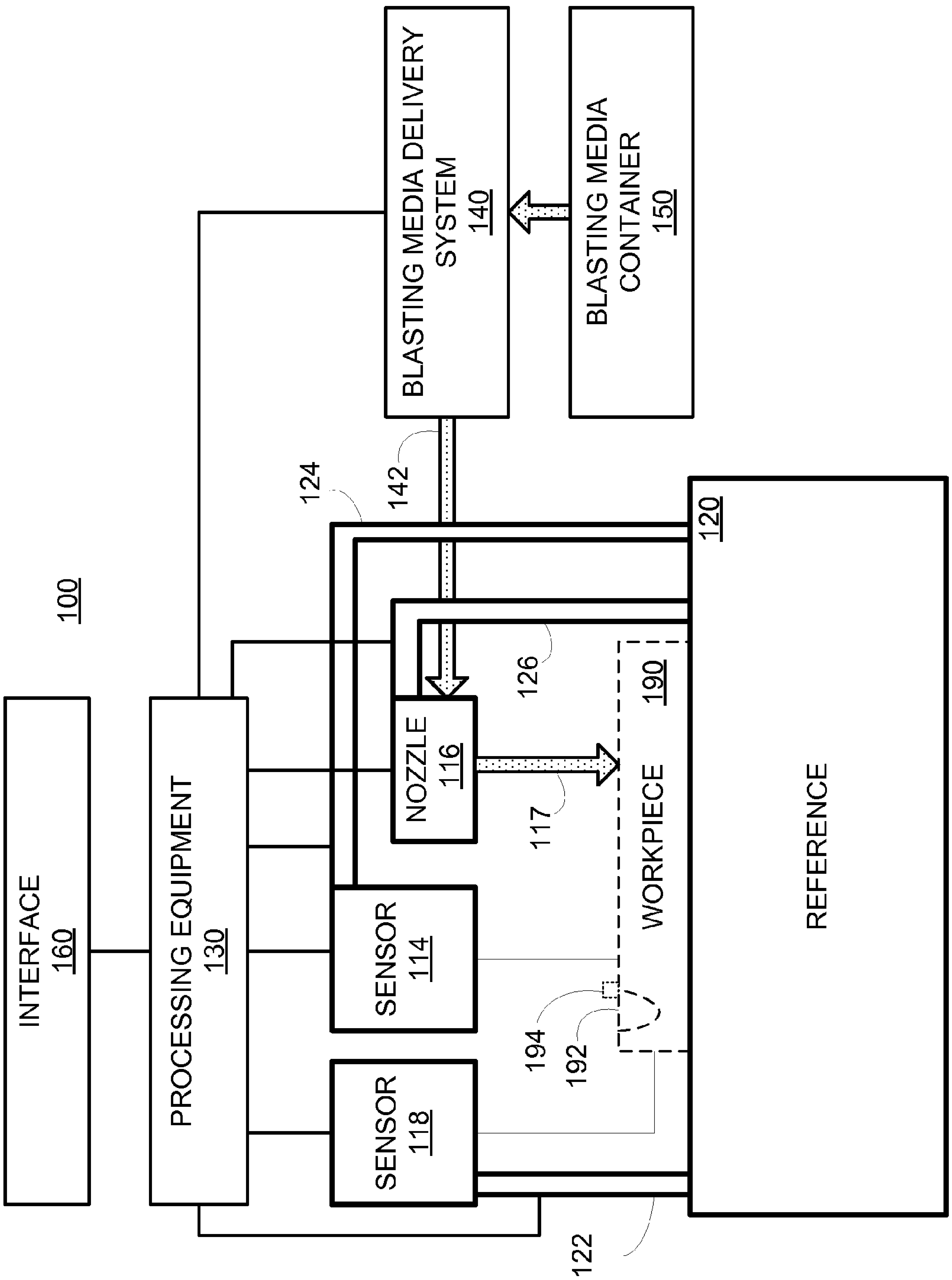

100
INTERFACE
160
PROCESSING EQUIPMENT
130
SENSOR
114
SENSOR
118
NOZZLE
116
BLASTING MEDIA DELIVERY
SYSTEM
140
BLASTING MEDIA
CONTAINER
150
WORKPIECE
190
REFERENCE
120
122
124
126
142
117
192
194

FIG. 1

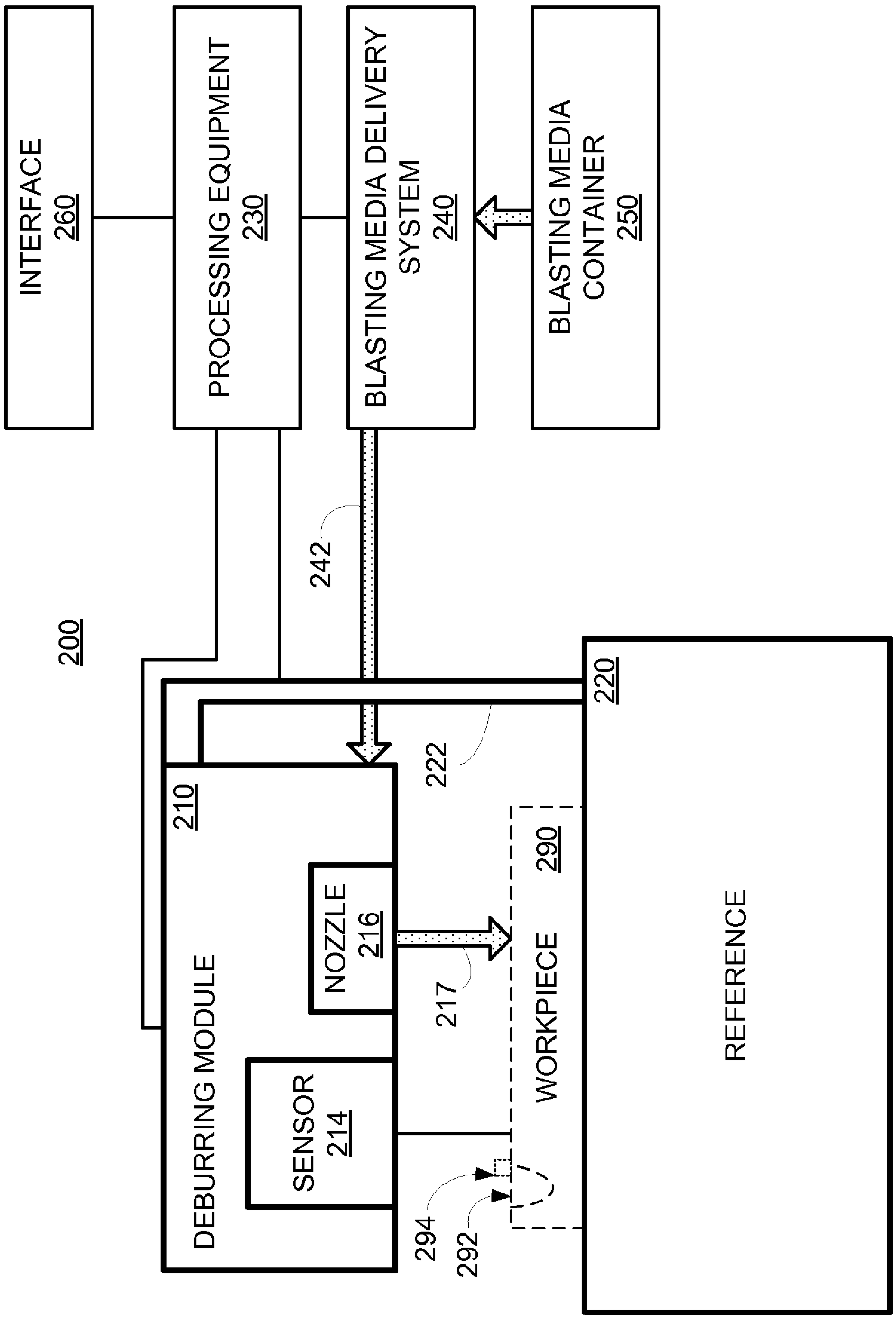

INTERFACE
260
PROCESSING EQUIPMENT
230
BLASTING MEDIA DELIVERY SYSTEM
240
BLASTING MEDIA CONTAINER
250
200
242
220
222
210
NOZZLE
216
290
DEBURRING MODULE
SENSOR
214
217
WORKPIECE
REFERENCE
294
292

FIG. 2

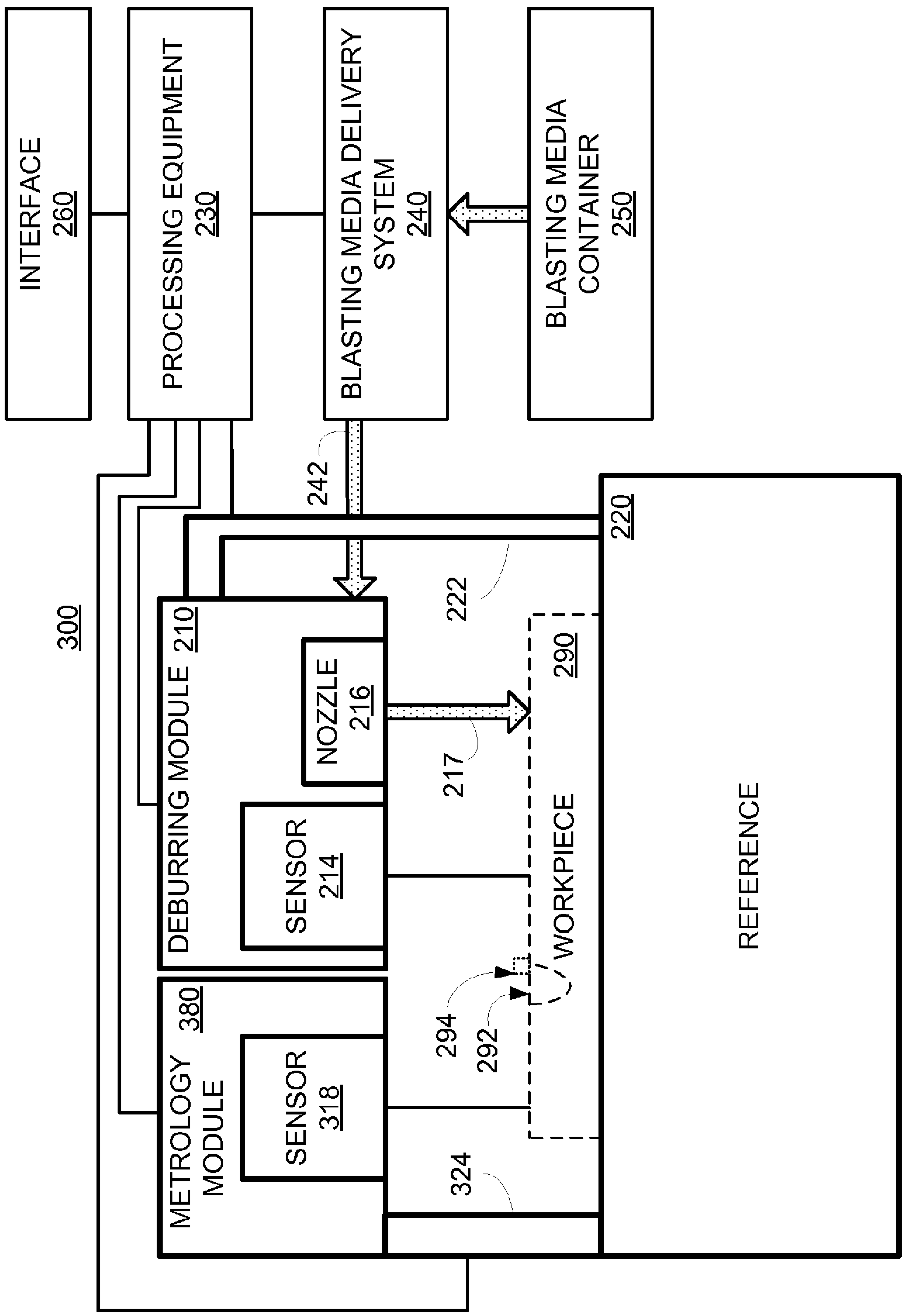

INTERFACE 260
PROCESSING EQUIPMENT 230
BLASTING MEDIA DELIVERY SYSTEM 240
BLASTING MEDIA CONTAINER 250
242
220
222
300
DEBURRING MODULE 210
NOZZLE 216
290
217
SENSOR 214
WORKPIECE
REFERENCE
294
292
METROLOGY MODULE 380
SENSOR 318
324

FIG. 3

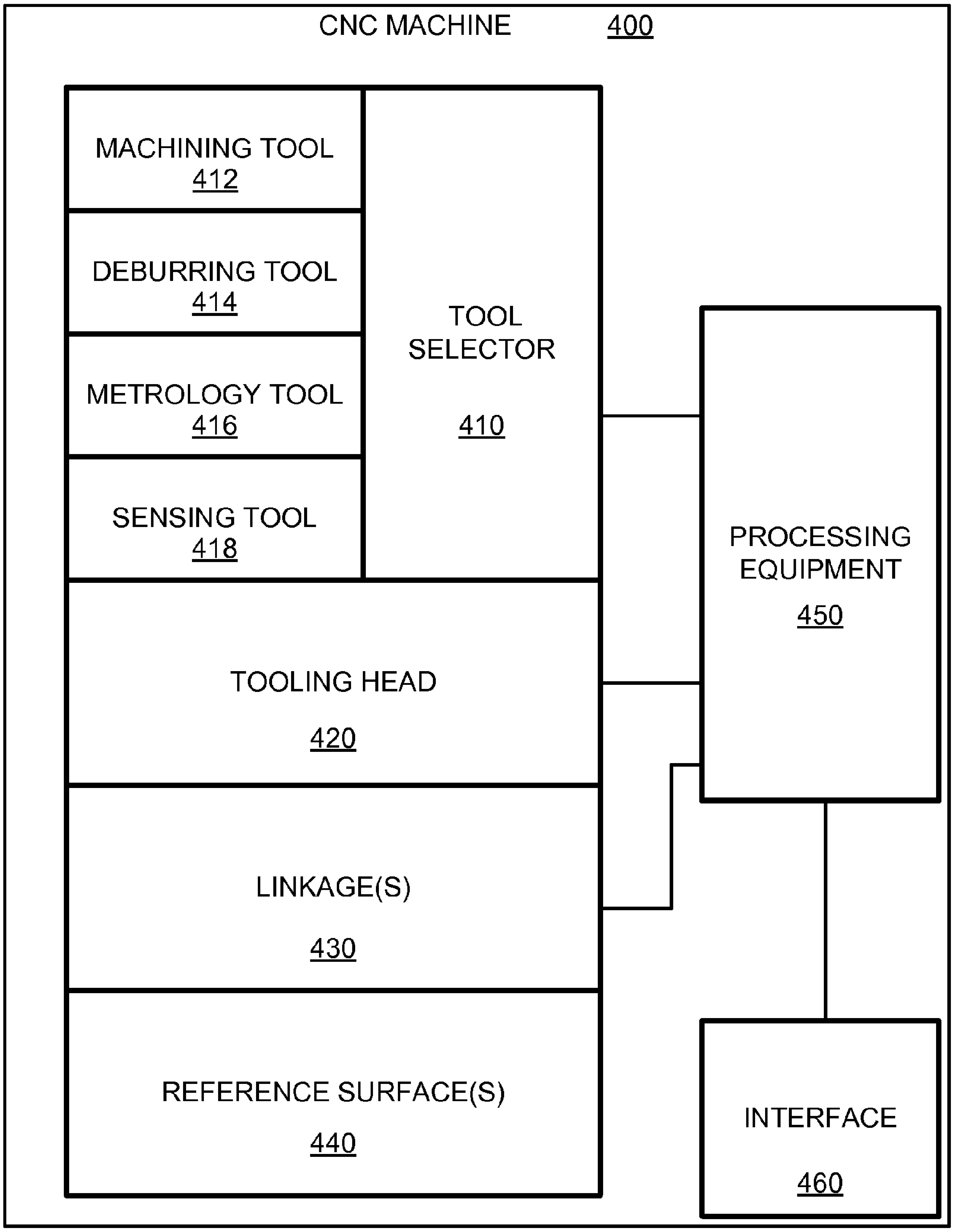

CNC MACHINE 400
MACHINING TOOL 412
DEBURRING TOOL 414
METROLOGY TOOL 416
SENSING TOOL 418
TOOL SELECTOR 410
TOOLING HEAD 420
LINKAGE(S) 430
REFERENCE SURFACE(S) 440
PROCESSING EQUIPMENT 450
INTERFACE 460

FIG. 4

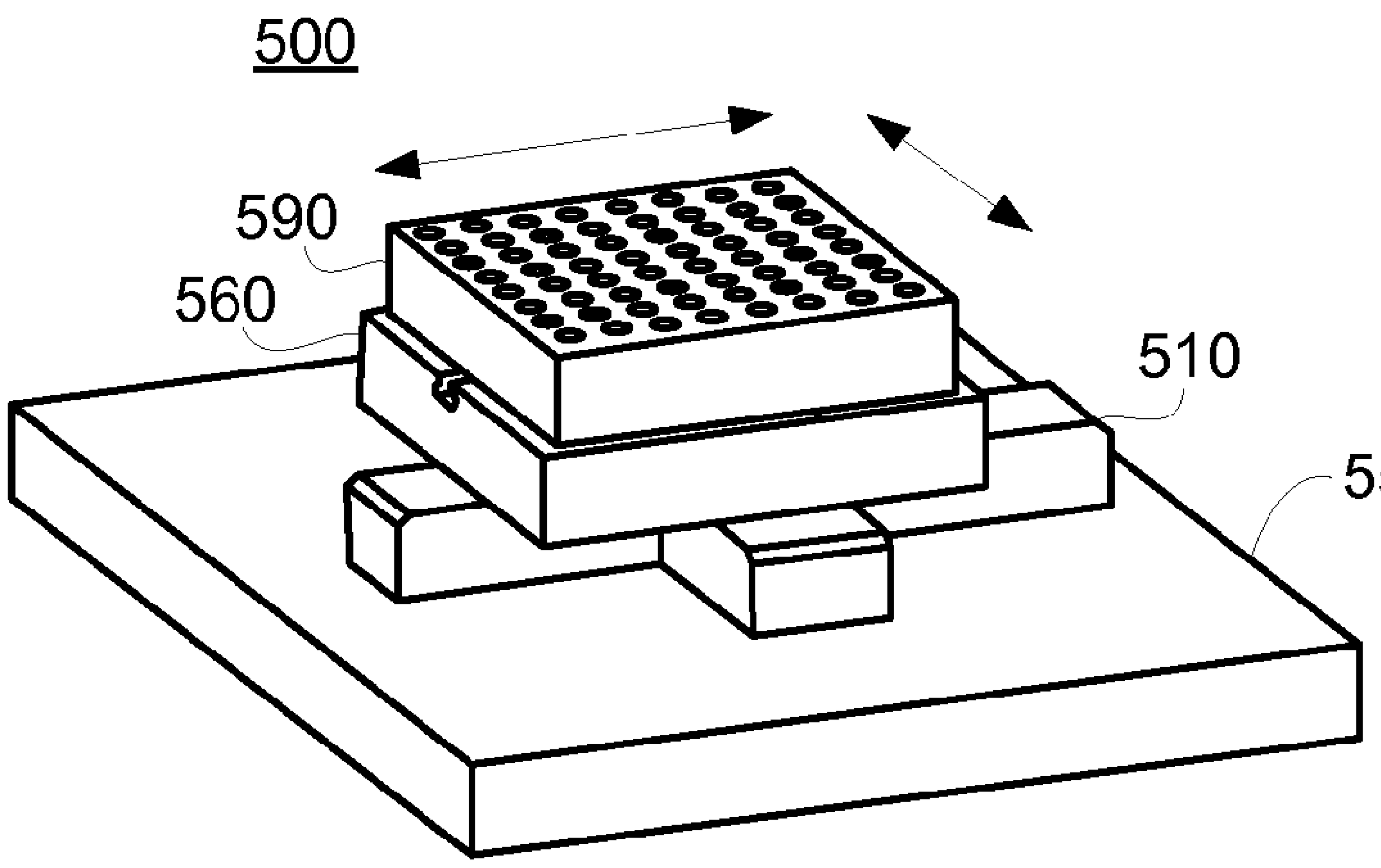


FIG. 5

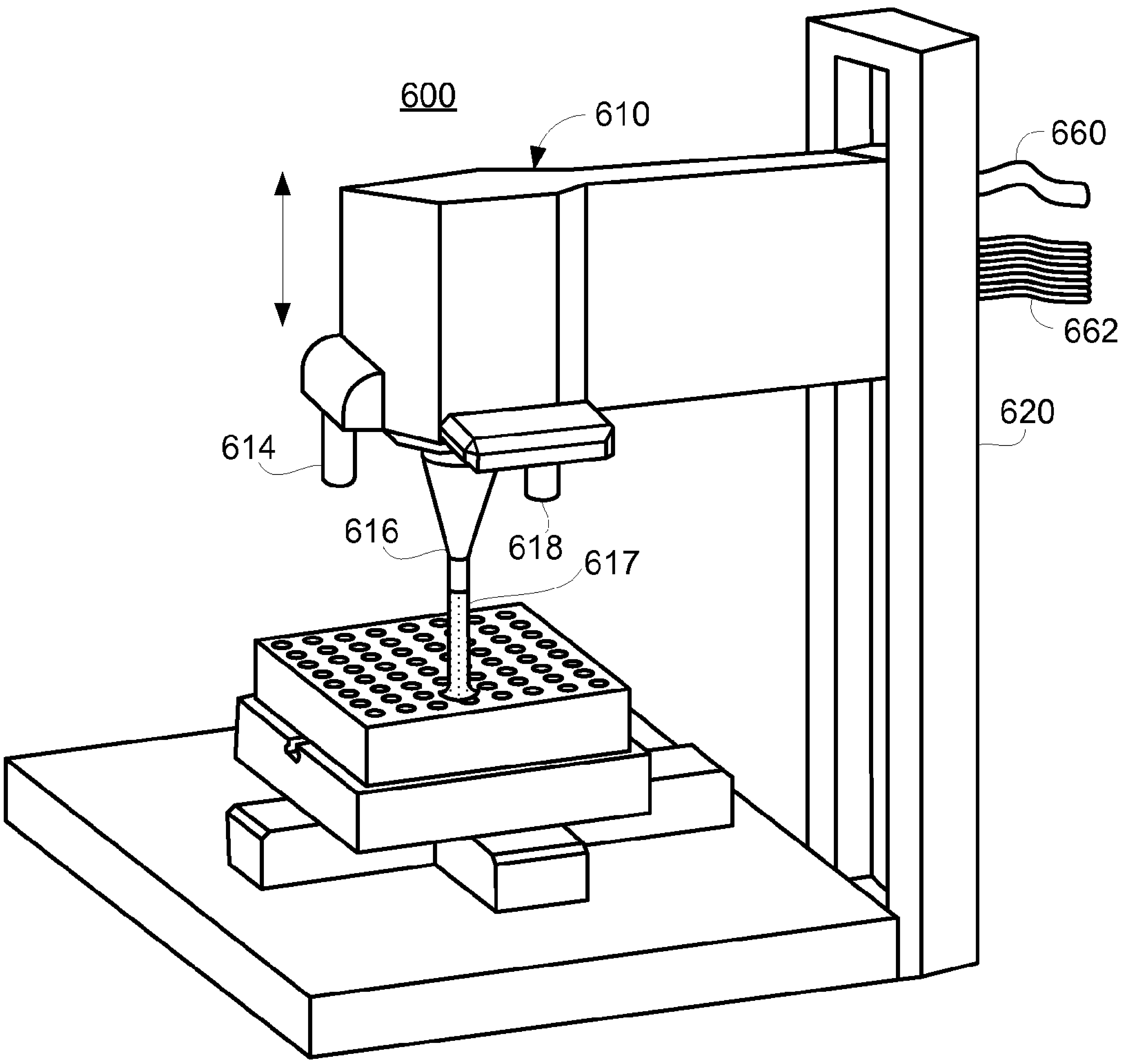


FIG. 6

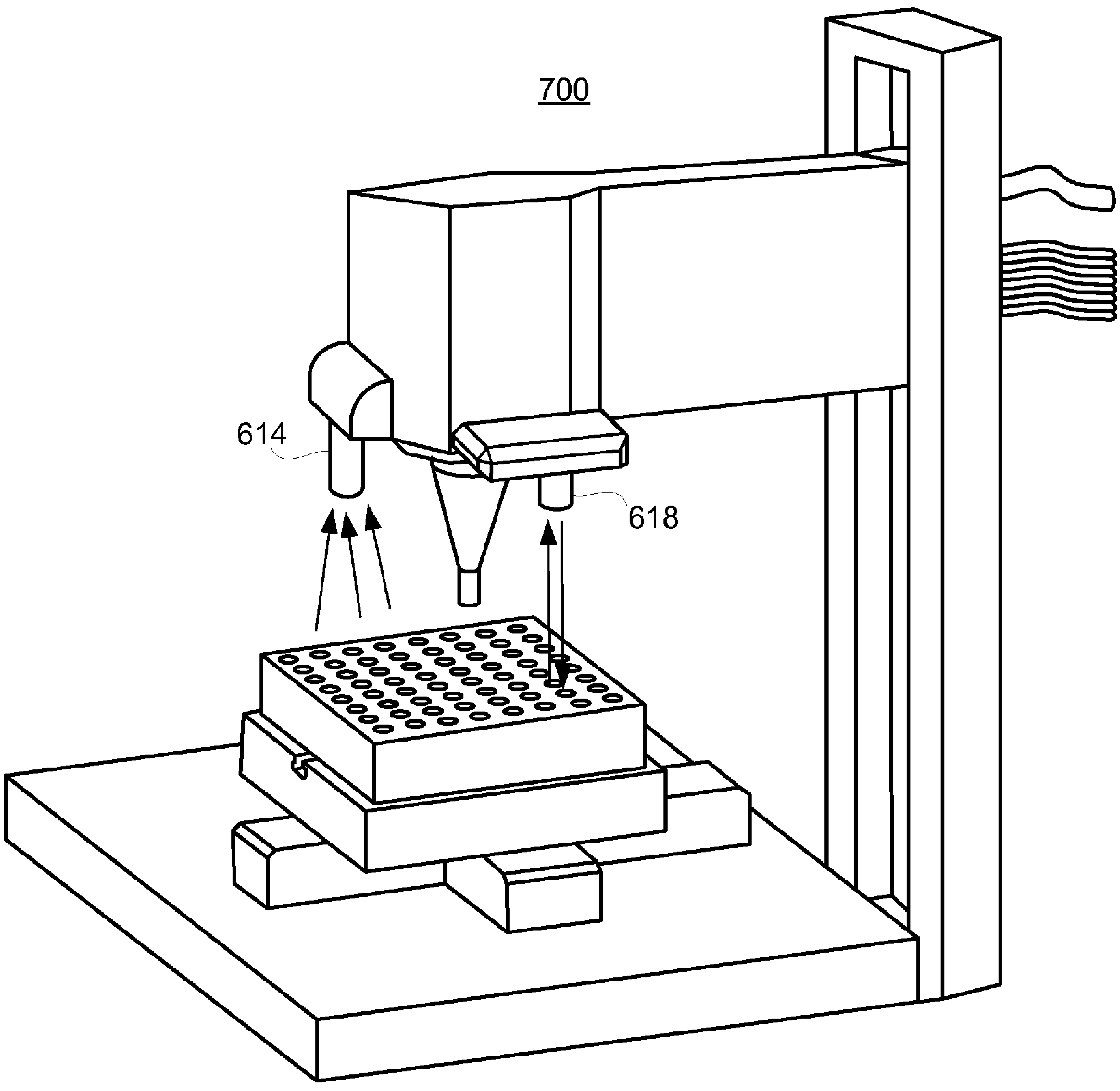


FIG. 7

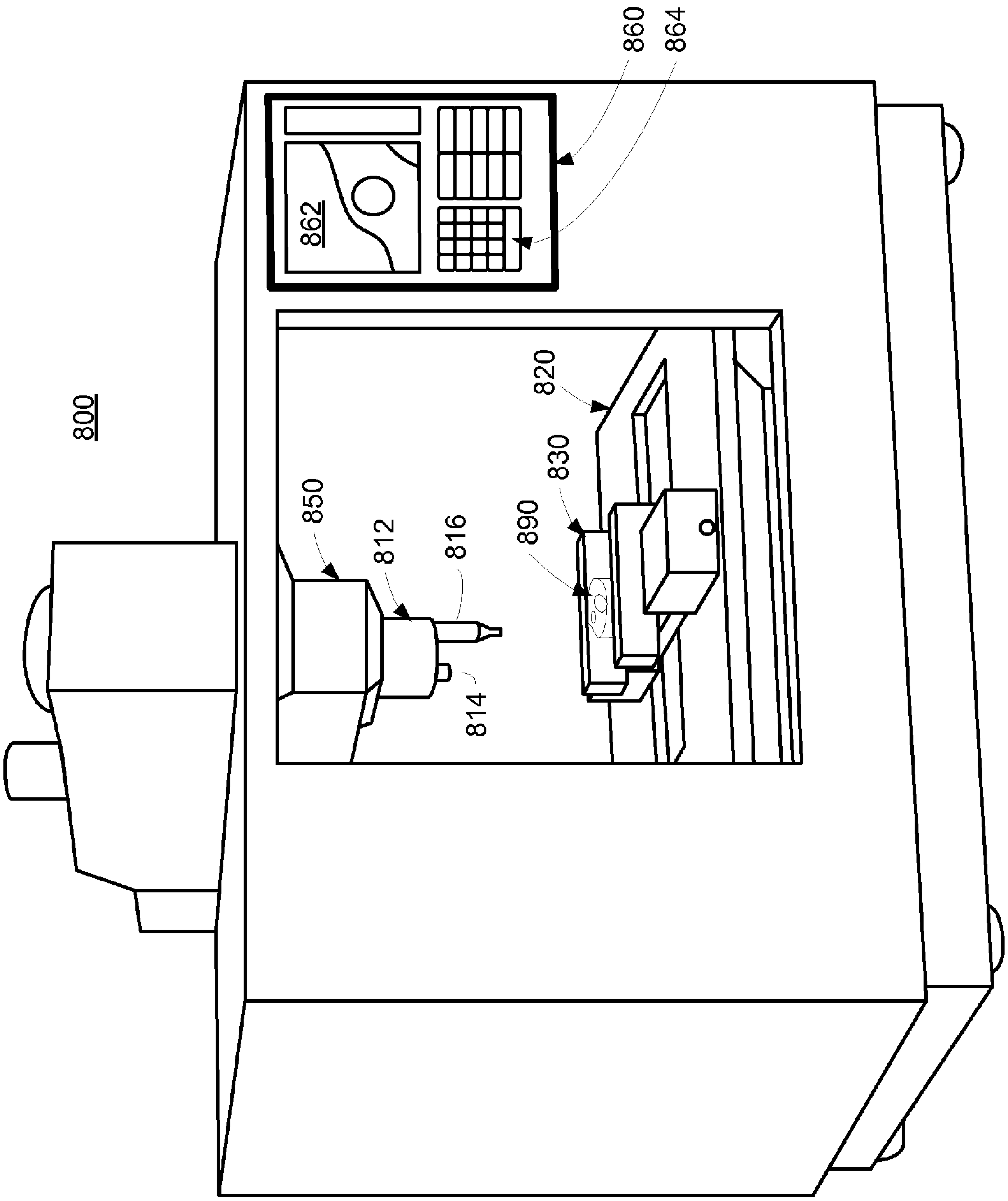


FIG. 8

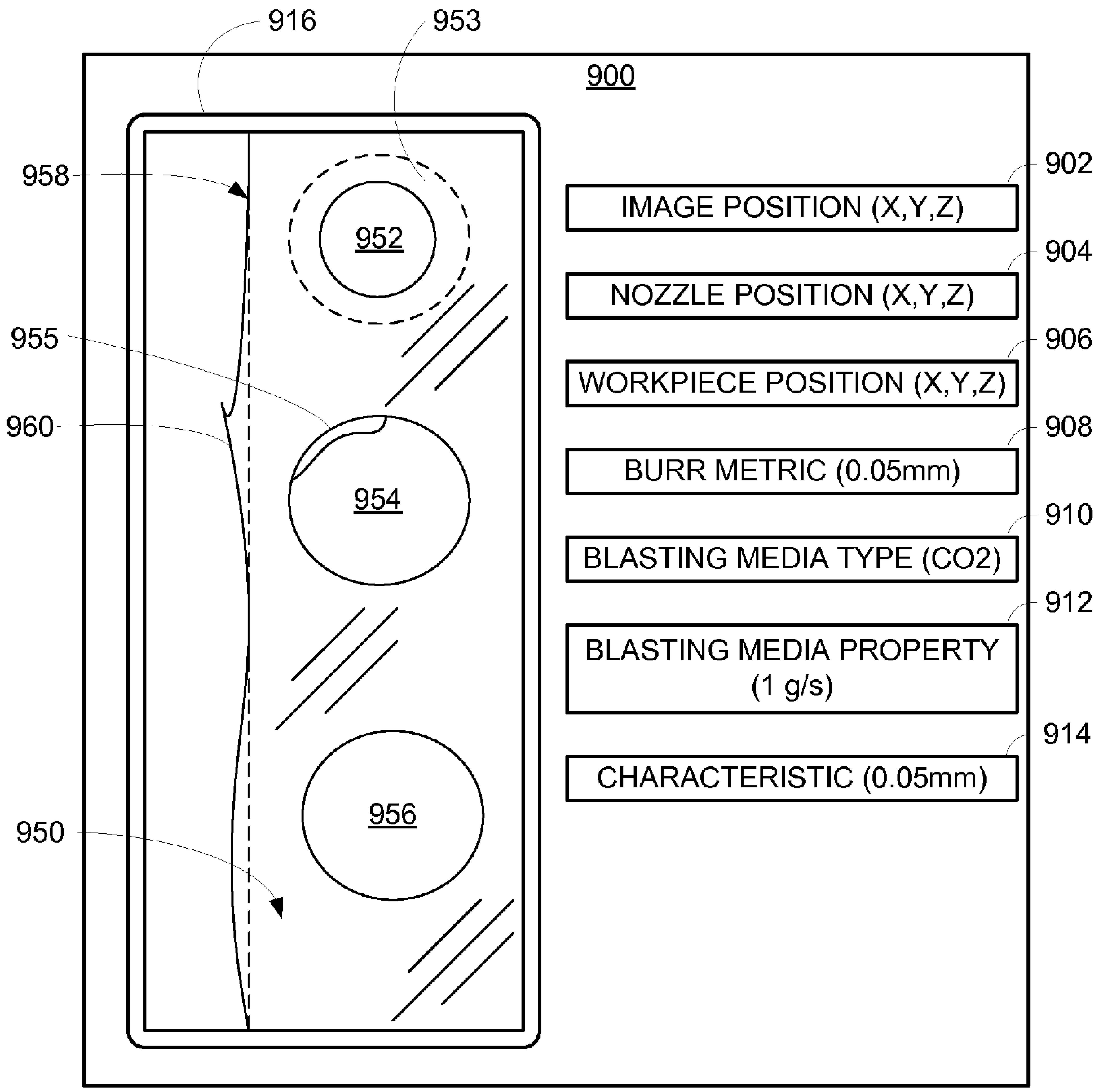

916
953
900
958
952
902
IMAGE POSITION (X,Y,Z)
904
NOZZLE POSITION (X,Y,Z)
955
906
WORKPIECE POSITION (X,Y,Z)
960
908
BURR METRIC (0.05mm)
954
910
BLASTING MEDIA TYPE (CO2)
912
BLASTING MEDIA PROPERTY (1 g/s)
914
CHARACTERISTIC (0.05mm)
956
950

FIG. 9

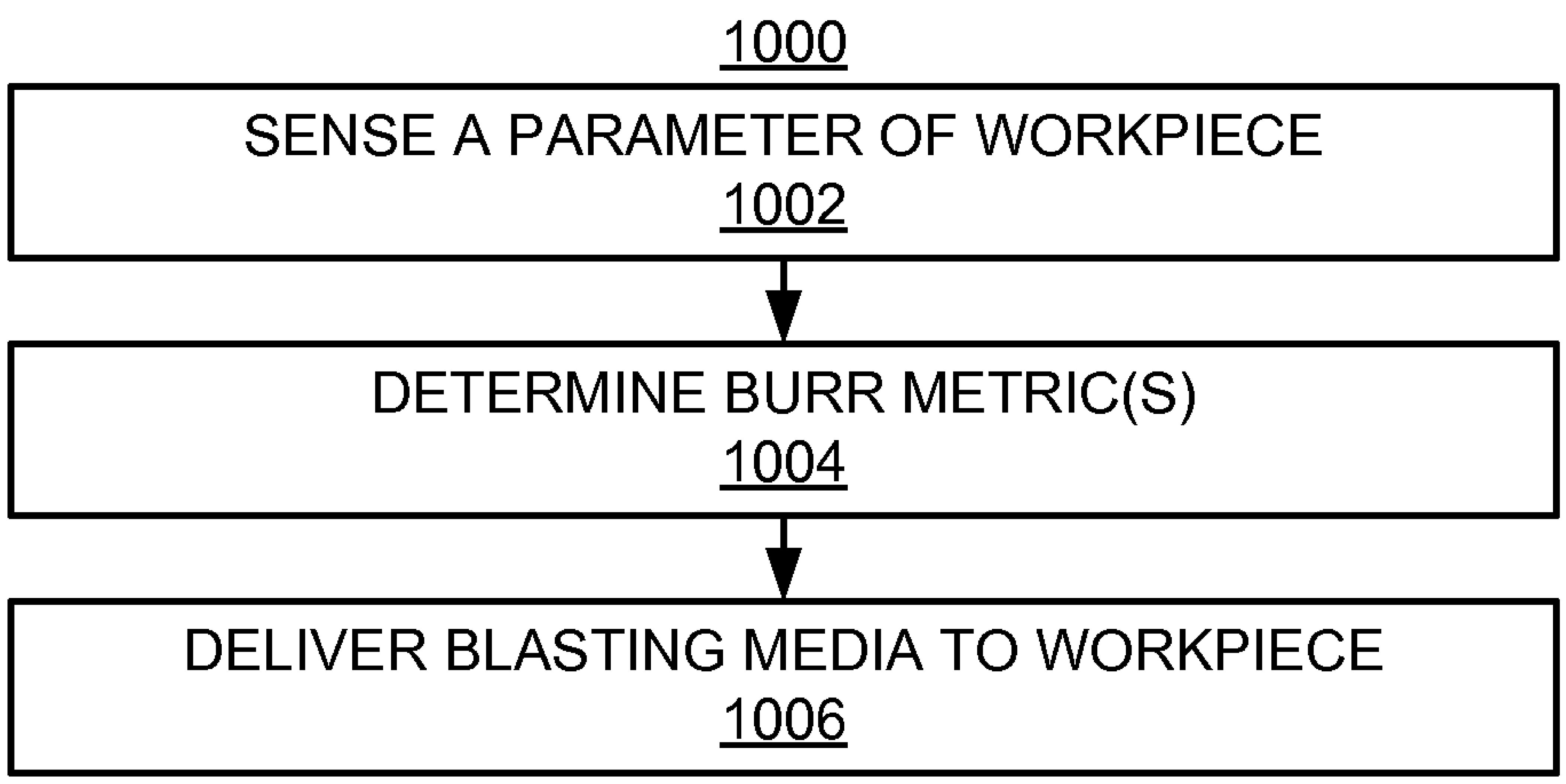

1000
SENSE A PARAMETER OF WORKPIECE
1002
DETERMINE BURR METRIC(S)
1004
DELIVER BLASTING MEDIA TO WORKPIECE
1006

FIG. 10

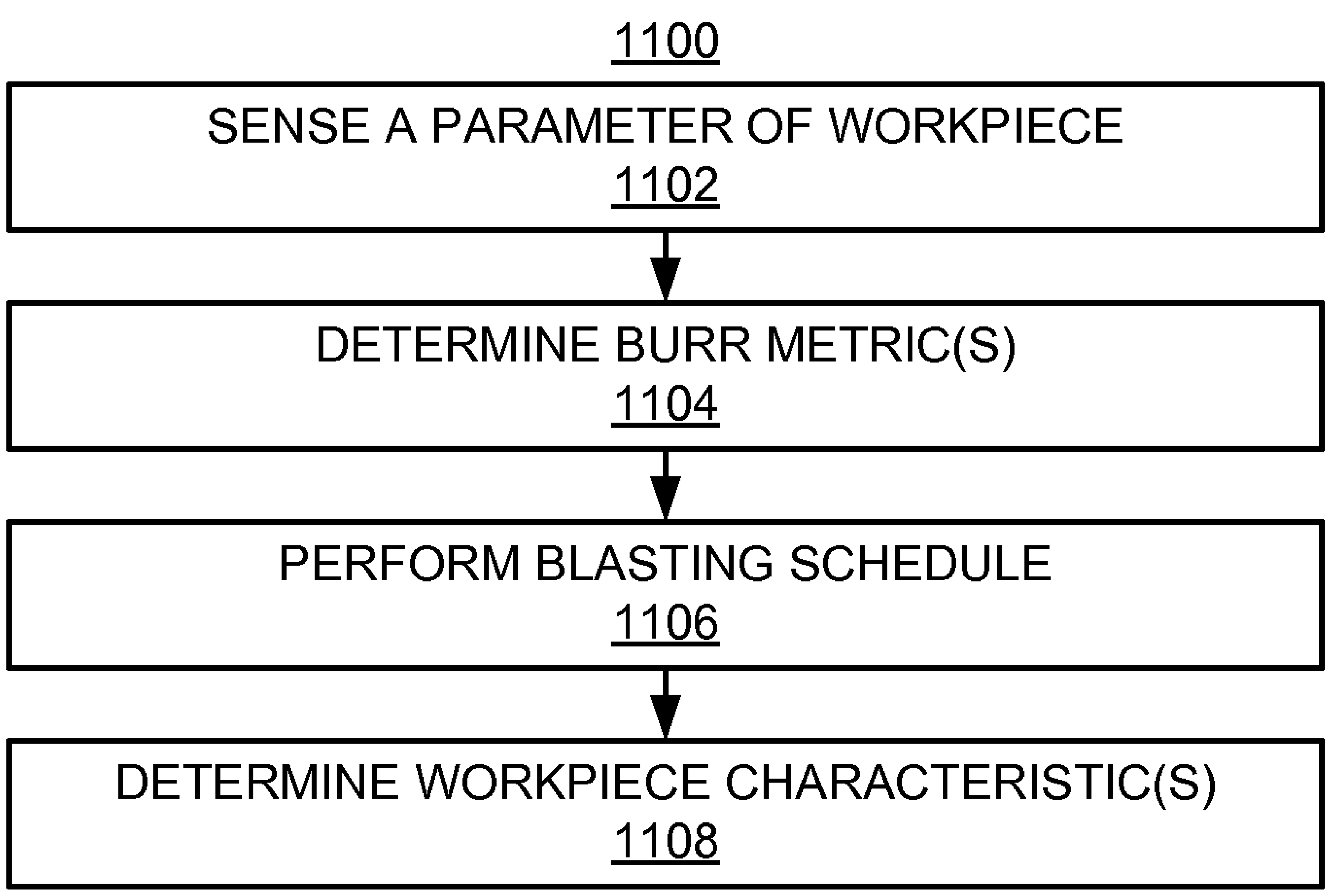

1100
SENSE A PARAMETER OF WORKPIECE
1102
DETERMINE BURR METRIC(S)
1104
PERFORM BLASTING SCHEDULE
1106
DETERMINE WORKPIECE CHARACTERISTIC(S)
1108

FIG. 11

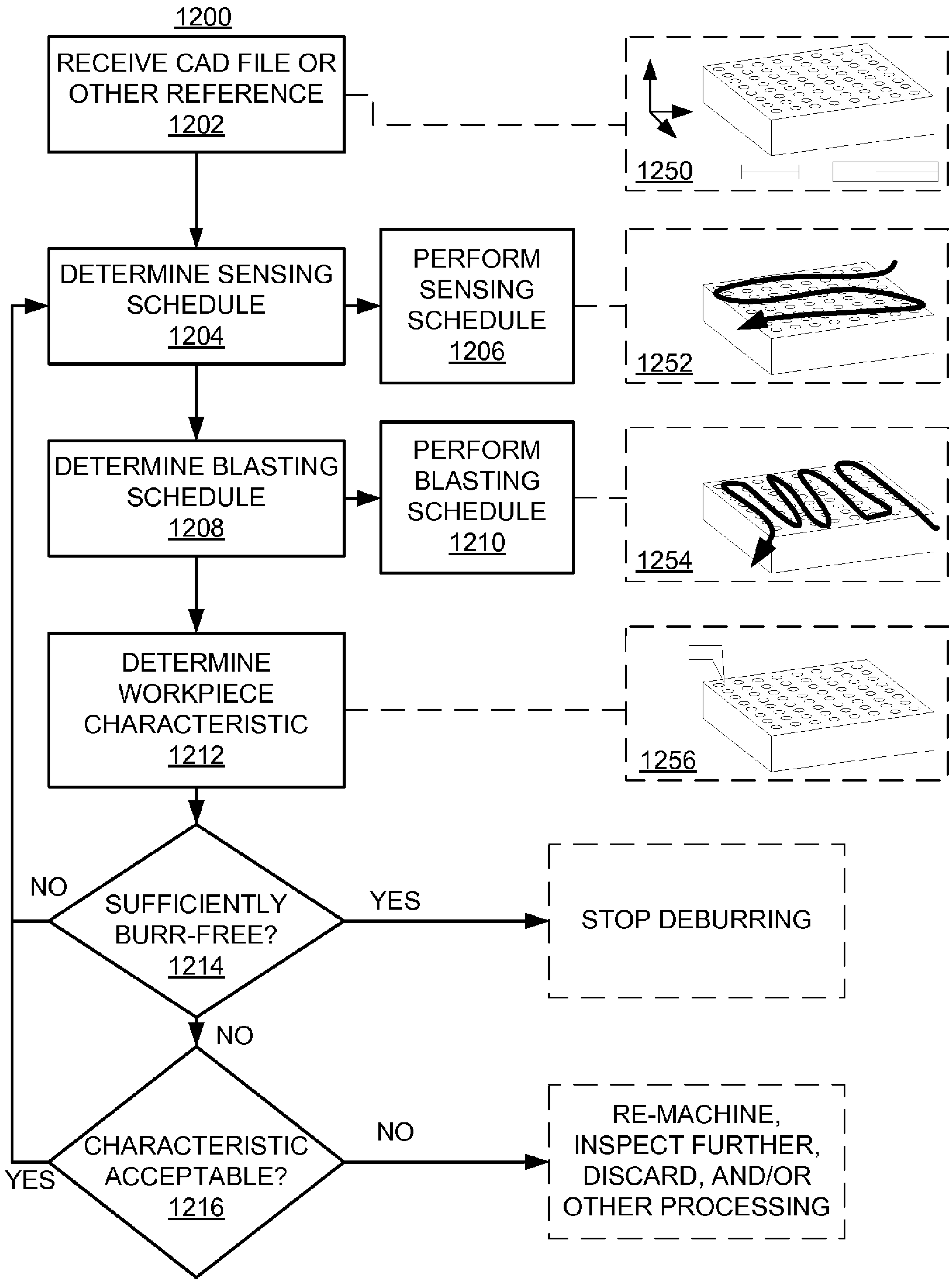

1200
RECEIVE CAD FILE OR OTHER REFERENCE 1202
1250
DETERMINE SENSING SCHEDULE 1204
PERFORM SENSING SCHEDULE 1206
1252
DETERMINE BLASTING SCHEDULE 1208
PERFORM BLASTING SCHEDULE 1210
1254
DETERMINE WORKPIECE CHARACTERISTIC 1212
1256
SUFFICIENTLY BURR-FREE? 1214
NO
YES
STOP DEBURRING
NO
CHARACTERISTIC ACCEPTABLE? 1216
YES
NO
RE-MACHINE, INSPECT FURTHER, DISCARD, AND/OR OTHER PROCESSING

FIG. 12

METHODS AND SYSTEMS FOR SENSOR-BASED DEBURRING

[0001] The present disclosure relates to sensor-based deburring, and more particularly relates to using sensor data to determine deburring schedules.

BACKGROUND

[0002] Machined parts may include burrs due to deformation or breakage of material occurring during processes such as grinding, milling, drilling, and cutting. Relatively soft materials such as, for example, aluminum and plastic, may be especially susceptible to forming burrs due to plastic deformation undergone during machining. Burrs may be attached or detached, and may impact the resulting dimensions of the part.

[0003] Blasting processes may be used to deburr parts. However, typical blasting media and processes may alter dimensions of the part via grinding action, and create an untidy mix of the blasting mix and burr material. Additionally, blasting may only be desired at particular portions of the part.

SUMMARY

[0004] In some embodiments, deburring a workpiece may include sensing a parameter of the workpiece using a sensor, determining a burr metric based at least in part on the parameter, and delivering a blasting media to at least one portion of the workpiece based at least in part on the burr metric. In some embodiments, deburring a workpiece may include sensing one or more parameters of the workpiece using a sensor, determining, using processing equipment, one or more burr metrics based at least in part on the output of the sensor, performing a blasting schedule based on the one or more burr metrics, and determining one or more workpiece characteristics based on one or more diagnostic tests.

[0005] In some embodiments, a deburring system may include a reference surface configured to secure a workpiece, a sensor configured to detect burrs on the workpiece and provide an output, a nozzle configured to direct a flow of a blasting media to the workpiece, and processing equipment coupled to the sensor. The processing equipment may be configured to control the flow of the blasting media based on the output of the sensor.

[0006] In some embodiments, a deburring module may include at least one sensor configured to sense a burr on the workpiece and provide an output, and a nozzle configured to the deliver a flow of a blasting media to the workpiece. The flow of the blasting media may be controlled by processing equipment based at least in part on the output of the at least one sensor.

BRIEF DESCRIPTION OF THE FIGURES

[0007] The above and other features of the present disclosure, its nature and various advantages will be more apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings in which:

[0008] FIG. **1** shows an illustrative deburring system, in accordance with some embodiments of the present disclosure;

[0009] FIG. **2** shows an illustrative deburring system having a deburring module, in accordance with some embodiments of the present disclosure;

[0010] FIG. **3** shows an illustrative deburring system having a deburring module and a metrology module, in accordance with some embodiments of the present disclosure;

[0011] FIG. **4** is a block diagram of an illustrative computer numerical controller (CNC) machine having several tools including a deburring tool, in accordance with some embodiments of the present disclosure;

[0012] FIG. **5** shows a perspective view of an illustrative reference and workpiece, in accordance with some embodiments of the present disclosure;

[0013] FIG. **6** shows a perspective view of the illustrative reference and workpiece of FIG. **5**, and a deburring tool having two sensors, and a nozzle, in accordance with some embodiments of the present disclosure;

[0014] FIG. **7** shows a perspective view of the illustrative reference, workpiece, and deburring tool of FIG. **6**, during sensing, in accordance with some embodiments of the present disclosure;

[0015] FIG. **8** shows a perspective view of an illustrative CNC machine configured to perform deburring, in accordance with some embodiments of the present disclosure;

[0016] FIG. **9** shows a screenshot of an illustrative deburring application, in accordance with some embodiments of the present disclosure;

[0017] FIG. **10** is a flow diagram of illustrative steps for deburring a workpiece based on a burr metric, in accordance with some embodiments of the present disclosure;

[0018] FIG. **11** is a flow diagram of illustrative steps for deburring a workpiece based on a burr metric, and checking one or more workpiece characteristics, in accordance with some embodiments of the present disclosure; and

[0019] FIG. **12** is a flow diagram of illustrative steps for deburring a workpiece using a deburring system and a metrology system, in accordance with some embodiments of the present disclosure.

DETAILED DESCRIPTION OF THE FIGURES

[0020] The present disclosure is directed towards techniques and arrangements for deburring. Processing of materials, especially relatively soft materials, may cause burr formation. For example, the techniques disclosed herein may be applied to deburring materials such as polyether ether ketone (PEEK), poly ether ketone (PEEK), nylon, poly amide imide (PAI), poly ether ketone ether ketone ketone (PEKEKK), poly phenylene sulfide (PPS), poly phenylene sulfone (PPSO), poly benzimidazole (PBI), thermoplastic poly imide (TPI), liquid crystal polymers (LCPs), polytetrafluororethylene (PTFE), polyvinylidene fluoride (PVDF), fluoropolymers (e.g., fluorinated ethylene-propylene, perfluoroalkoxy polymer, polyethylenetetrafluoroethylene, polychlorotrifluoroethylene), ultra-high-molecular-weight polyethylene (UHMWPE), any other suitable plastic, thermoplastic or metal, any other suitable material, or any combination thereof.

[0021] A deburring system may include one or more sensors configured to sense a parameter of a workpiece (e.g., a part, an assembly, or other item that may be deburred), and a nozzle configured to deliver blasting media to a workpiece. The blasting media may abrade the workpiece surface causing, for example, attrition, cleaning, or both, of the workpiece surface. The deburring tool may be a stand-alone tool, a module configured to couple to another tool, or a collection of components adapted to couple separately to another tool. The deburring system may sense the parameter, which may be indicative of a burr, and determine one or more burr metrics. Based on the burr metric, the deburring system may deliver blasting media (e.g., a gas or liquid flow seed with a particulate such as dry ice) to the workpiece, or a portion thereof to reduce the presence of burrs. Because the blasting process may alter the surface (e.g., alter the surface finish) or the bulk (e.g., warp the overall shape) of the workpiece, one or more workpiece characteristics may be determined to gauge these potential changes.

[0022] FIG. **1** shows an illustrative deburring system **100**, in accordance with some embodiments of the present disclosure. Deburring system **100** may include reference **120** (e.g., which may include a table top, or other reference surface), which may be used to secure a workpiece **190** in a controllable position and orientation. Deburring system **100** may include sensor **114** configured to sense a parameter of workpiece **190**, sensor **118** configured to sense a characteristic of workpiece **190**, and nozzle **116** configured to deliver a blasting media (e.g., as shown by jet **117**) to workpiece **190**. In some embodiments, processing equipment **130** may be communicatively coupled to sensor **114** and sensor **118**. For example, processing equipment **130** may be configured to provide power to sensors **114** and **118**, receive signals from sensors **114** and **118**, transmit signals to sensors **114** and **118**, or any combination thereof. Workpiece **190** may include one or more features **192** such as, for example, holes (e.g., blind or through holes), grooves, bosses (e.g., pins, raised lips, or other protruding structure), any other suitable feature, or any combination thereof. During forming, machining, or both, of workpiece **190**, for example, one or more burrs **194** may be formed. The one or more burrs **194** may include attached burrs (e.g., plastically deformed but not broken off), detached burrs (e.g., plastically deformed and broken off, but still lying on the surface of workpiece **190**), debris (e.g., pieces of other workpieces or tools lying on the surface of workpiece **190**), or a combination thereof.

[0023] Processing equipment **130** may be configured to process received signals, generate control signals, determine metrics, determine parameters, determine characteristics, perform any other suitable processing function, or any combination thereof. Processing equipment **130** may include a processor (e.g., a central processing unit, a microprocessor), cache, random access memory (RAM), read only memory (ROM), any other suitable components, or any combination thereof. In some embodiments, processing equipment **130** may include a sensor interface configured to communicate with sensors **114** and **118** via one or more communicative couplings, which may be a wired connection (e.g., using IEEE 802.3 ethernet interface, universal serial bus interface, or other multi-conductor cable connector interface), wireless coupling (e.g., using IEEE 802.11 "Wi-Fi" interface, Bluetooth interface, or other wireless interface), optical coupling, inductive coupling, any other suitable coupling, or any combination thereof.

[0024] Sensor **114** may sense one or more parameters of workpiece **190**. Parameters may include absolute dimensions, relative dimensions, areas, volumes, any other suitable parameters, or any combination thereof. In some embodiments, sensor **114** may include a camera configured to capture images of workpiece **190**. For example, sensor **114** may include a CCD camera configured to capture one or more images of one or more features **192** of workpiece **190**.

[0025] Sensor **118** may sense one or more characteristics of workpiece **190**. Characteristics may include absolute dimensions, relative dimensions, areas, volumes, flatness, surface properties, any other suitable characteristics of workpiece **190**, or any combination thereof. In some embodiments, sensor **118** may include a laser configured to provide a laser beam to the surface of workpiece **190**, and a laser detector configured to detect the reflected laser beam from the surface of workpiece **190**. In some such embodiments, processing equipment **130** may determine an angle of reflection, an angle of workpiece **190** relative to a reference angle (e.g., relative to 0° reference top surface of reference **120**). For example, sensor **118** may be scanned over a surface of workpiece **190** (e.g., using coupling **122** controlled by processing equipment **130**), and processing equipment **130** may determine the variation in angle (e.g., the flatness) of the surface of workpiece **190**.

[0026] In some embodiments, processing equipment **130** may be coupled to any or all of couplings **122**, **124**, and **126**, which may mechanically link sensor **118**, sensor **114**, and nozzle **116**, respectively, to reference **120**. Couplings **122**, **124**, and **126** may each include a mechanical or electromechanical coupling between sensor **118**, sensor **114**, and nozzle **116**, and reference **120**. In some embodiments, couplings **122**, **124**, and **126** may include one or more motion control actuators (e.g., threaded rod drives, geared drives, pulley drives, stepper motor drives or other suitable drives) controlled by a computer numerical controller (CNC), which may be included in processing equipment **130**. For example, a motion control actuator may include a linear screw coupled to a stepper motor controlled by processing equipment **130** to provide controlled linear motion, linear position control, or both. In a further example, three linear screws coupled to respective stepper motors all controlled by processing equipment **130** may be used to provide controlled 3-axis motion, 3-axis position control, or both. In a further example, a motion control actuator may include a servo motor configured to provide controlled angular motion, angular position control, or both. In some embodiments, any or all of couplings **122**, **124**, and **126** may include motion control actuators that are user-controlled. For example, any or of **122**, **124**, and **126** may include linear screws coupled to a hand crank that the user may turn to enact linear motion of the workpiece. In some embodiments, any or all of couplings **122**, **124**, and **126** may be fixed structural couplings, and accordingly sensor **118**, sensor **114**, or nozzle **116** may be configured to swivel, turn, or otherwise reorient to vary the sensing region of interest, nozzle target, or both. For example, nozzle **116** may remain in a fixed translational position, but may be able to be rotated to direct a jet of blasting material to different locations on workpiece **190**. In some embodiments, any or all of couplings **122**, **124**, and **126** may include a frame or other structural components to which motion control actuators may be mounted. For example, couplings **122**, **124**, and **126** may be similar to the motion control actuators of a bed-type milling machine in which reference **120** may be moved in a plane normal to the sensing or nozzle direction, and accordingly sensor **118**, sensor **114**, or nozzle **116** may be moved in a sensing or nozzle direction (e.g., the spindle axis of a milling machine).

[0027] In some embodiments, deburring system **100** may include blasting media delivery system **140** and optionally blasting media container **150**. Blasting media delivery system **140** may include, for example, a shaver, pump, compressor, filter, conduits, flow control components, pressure regulators, orifices, valves, any other suitable components for delivering a blasting media to nozzle **116**, or any combination thereof. Blasting media container **150** may include, for example, a tank or other suitable reservoir, configured to contain a blasting media to be delivered to nozzle **116** by blasting media delivery system **140**. For example, blasting media container **150** may be configured to contain blocks of dry ice. Accordingly, blasting media delivery system **140** may include a shaver configured to shave the blocks of dry ice into particles, and a gas entrainment system (e.g., including an air compressor and suitable flow conduits) configured to entrain the dry ice particles in a convective flow of air through a flexible conduit (e.g., as shown by conduit **142**) to nozzle **116**. In a further example, blasting media container **150** may be configured to contain sand particles (e.g., silicon dioxide or any other metal oxide that may be used as a blasting media). Accordingly, blasting media delivery system **140** may include a lock-hopper configured to feed the sand particles into a convective gas flow, and a gas entrainment system (e.g., including an air compressor and suitable flow conduits) configured to entrain the sand particles in the convective flow through a flexible conduit to nozzle **116**. In a further example, blasting media container **150** may be configured to contain liquid water. Accordingly, blasting media delivery system **140** may include a liquid pump configured to pump the water through a flexible conduit to nozzle **116**. Any suitable blasting media, including solid, liquid, gas, or a combination thereof, may be delivered to nozzle **116** using blasting media delivery system **140** and blasting media container **150**.

[0028] In some embodiments, processing equipment **130** may be configured to control the flow of blasting media through nozzle **116** by controlling components of blasting media delivery system **140**, controlling a property of nozzle **116**, or both. For example, processing equipment **130** may be configured to control the speed of an air compressor of blasting media delivery system **140** used to control an entraining air flow used to entrain blasting particulate. In a further example, processing equipment **130** may be configured to control a valve setting of a flow control valve of blasting media delivery system **140** used to control an entraining air flow used to entrain blasting particulate. In a further example, processing equipment **130** may be configured to control a feed setting (e.g., speed control, position control, or both) of a linear feed screw of blasting media delivery system **140** used to control a particulate feed rate into an entraining flow.

[0029] In some embodiments, deburring system may include interface **160**, configured to allow user interaction. For example, interface **160** may include a display screen, a touchscreen, a keyboard (e.g., a QWERTY keyboard), a keypad (e.g., a numeric keypad, a command button keypad), a mouse, a speaker, a microphone, any other suitable component configured to receive user input, any other suitable component configured to provide output to a user, or any combination thereof. Processing equipment **130** may be configured to communicate with interface **160** via any suitable communication coupling. For example, interface **160** may include, for example, a cathode ray tube screen, a liquid crystal display screen, a light emitting diode display screen, a plasma display screen, any other suitable display screen that may provide graphics, text, images or other visuals to a user, or any combination of screens thereof. In a further example, interface **160** may include a touchscreen display, which may provide tactile interaction with a user by, for example, offering one or more soft commands on a display screen. In a further example, interface **160** may include an audio device may include a microphone, and processing equipment **130** may process audio commands received via interface **160** caused by a user speaking into the microphone. Interface **160** may be coupled to processing equipment **130** using any suitable wired connection (e.g., using IEEE 802.3 ethernet, or universal serial bus interface, coaxial cable connection, tip-ring-seal RCA type connection), wireless coupling (e.g., using IEEE 802.11 "Wi-Fi", Infrared, or Bluetooth), optical coupling, inductive coupling, any other suitable coupling, or any combination.

[0030] FIG. **2** shows an illustrative deburring system **200** having a deburring module **210**, in accordance with some embodiments of the present disclosure. Couplings internal to deburring module **210** are not illustrated in FIG. **2**, but may include wired couplings, wireless couplings, optical couplings, fluid couplings, any other suitable couplings or components, or any combination thereof. In some embodiments, sensor **214** and nozzle **216** may be included in deburring module **210**, along with any other suitable components. For example, deburring module **210** may be a single tool, configured to be installed on a CNC machine, a test stand, any other suitable system, or any combination thereof. Deburring module **210** may include sensor **214** configured to sense a parameter of workpiece **290**, nozzle **216** configured to deliver a blasting media to workpiece **290** (e.g., as shown by jet **217**), and optionally a second sensor (not shown) configured to sense a characteristic of workpiece **290**. In some embodiments, processing equipment **230** may be communicatively coupled to sensor **214**. For example, processing equipment **230** may be configured to provide power to sensor **214**, receive signals from sensor **214**, transmit signals to sensor **214**, or any combination thereof. Workpiece **290** may include one or more features **292** such as, for example, holes, grooves, bosses, any other suitable feature, or any combination thereof. One or more burrs **294** may include attached burrs, detached burrs, debris, or a combination thereof.

[0031] Processing equipment **230** may be configured to process received signals, generate control signals, determine metrics, determine parameters, determine characteristics, perform any other suitable processing function, or any combination thereof. Sensor **214** may sense one or more parameters of workpiece **290**. Parameters may include absolute dimensions, relative dimensions, areas, volumes, any other suitable parameters, or any combination thereof. In some embodiments, sensor **214** may include a camera configured to capture images of workpiece **290**. For example, sensor **214** may include a CCD camera configured to capture one or more images of one or more features **292** of workpiece **290**. In some embodiments, deburring module **210** may include processing equipment configured to perform signal processing from sensor **214** (e.g., image processing, digitization, filtering, amplification, data storage in memory) separate from or in concert with processing equipment **230**.

[0032] In some embodiments, processing equipment **230** may be coupled to coupling **222**, which may mechanically link deburring module **210** (directly or indirectly) to reference **220**. Coupling **222** may include a mechanical or electromechanical coupling between deburring module **210** and reference **220**. In some embodiments, coupling **222** may include one or more motion control actuators controlled by a CNC, which may be included in processing equipment **230**.

[0033] In some embodiments, deburring system **200** may include blasting media delivery system **240** and optionally blasting media container **250**. Blasting media delivery system **240** may include, for example, a shaver, pump, compressor, filter, conduits (e.g., conduit **242** coupled to nozzle **216**), flow control components, pressure regulators, orifices, valves, any other suitable components for delivering a blasting media to nozzle **216**, or any combination thereof. Blasting media container **250** may include, for example, a tank or other suitable reservoir, configured to contain a blasting media to be delivered to nozzle **216** by blasting media delivery system **240**. In some embodiments, processing equipment **230** may be configured to control the flow of blasting media through nozzle **216** by controlling components of blasting media delivery system **240**, controlling a property of nozzle **216**, or both.

[0034] In some embodiments, deburring system may include interface **260**, configured to allow user interaction. For example, interface **260** may include a display screen, a touchscreen, a keyboard (e.g., a QWERTY keyboard), a keypad (e.g., a numeric keypad, a command button keypad), a mouse, a speaker, a microphone, any other suitable component configured to receive user input, any other suitable component configured to provide output to a user, or any combination thereof. Processing equipment **230** may be configured to communicate with interface **260** via any suitable communication coupling. Interface **260** may be coupled to processing equipment **230** using any suitable wired connection (e.g., using IEEE 802.3 ethernet, or universal serial bus interface, coaxial cable connection, tip-ring-seal RCA type connection), wireless coupling (e.g., using IEEE 802.11 "Wi-Fi", Infrared, or Bluetooth), optical coupling, inductive coupling, any other suitable coupling, or any combination.

[0035] FIG. **3** shows an illustrative deburring system **300** having a deburring module **310** and a metrology module **380**, in accordance with some embodiments of the present disclosure. Deburring system **300** may be similar to deburring system **200**, with the addition of metrology module **380**. Metrology module **380** may include sensor **318** configured to sense a characteristic of workpiece **290**, or feature **292** thereof. Sensor **318** may include a camera, laser system (e.g., an optical flatness detector), a mechanical flatness detector, a touch probe (e.g., to determine dimensions of workpiece **290** via a collection of surface touch points), any other suitable sensor, or any combination thereof. For example, sensor **318** may include a touch probe, and processing equipment **230** may take as input a sequence of touch measurements at a sequence of spatial points based on a computer aided design (CAD) file.

[0036] Analysis of the sequence of points may be used to determine, for example, a dimension, flatness, surface property, or any other suitable characteristic of workpiece **290**. In some embodiments, deburring module **380** may include processing equipment configured to perform signal processing from sensor **318** (e.g., image processing, digitization, filtering, amplification, data storage in memory) separate from or in concert with processing equipment **230**.

[0037] In some embodiments, processing equipment **230** may be coupled to coupling **324**, which may mechanically link metrology module **380** (directly or indirectly) to reference **220** (as shown), or any other suitable reference (not shown). Coupling **324** may include a mechanical or electromechanical coupling between metrology module **380** and reference **220**. In some embodiments, coupling **324** may include one or more motion control actuators controlled by a CNC, which may be included in processing equipment **230**.

[0038] In some embodiments, metrology module **380** need not be included in deburring system **300**. For example, workpiece **290** may be movable from reference **220** to a second reference (not shown), to which metrology module **380** may be coupled. Accordingly, metrology module **380** may perform one or more metrology operations separate from the deburring operations of deburring system **200**.

[0039] FIG. **4** is a block diagram of an illustrative computer numerical controller (CNC) machine **400** having several tools including a deburring tool **414**, in accordance with some embodiments of the present disclosure. CNC machine **400** may include, for example, tool selector **410**, tooling head **420**, one or more linkages **430**, one or more reference surfaces **440**, and processing equipment **450**. Tool selector **410** may be configured to select from multiple tools such as, for example, machining tool **412** (e.g., a drilling chuck, a lathe toolholder, a milling toolholder), deburring tool **414** (e.g., having a sensor and nozzle), metrology tool **416** (e.g., having a sensor configured to sense a workpiece characteristic), sensing tool **418**, any other suitable tool not included in FIG. **4**, or any combination thereof. Processing equipment **450** may be configured to control tool selector **410**, tooling head **420** (e.g., a spindle configured to receive a tool selected by tool selector **410**), one or more linkages **430**, any of tools **412**, **414**, **416**, and **418**, or any combination thereof. For example, processing equipment **450** may include a computer numerical controller configured to control motions of one or more linkages **430** (e.g., which may include linear or rotational actuators), and resulting relative positions between tooling head **420** and reference surfaces **440**. In some embodiments, CNC machine **400** need not include tool selector **410**, and various tools may be selected and installed by a user. In some embodiments, linkages **430** need not be controlled by processing equipment **450** but rather by a user operating hand cranks or other manual actuators. In some embodiments, linkages **430** may be controlled by processing equipment **450** in response to user input to interface **460** (e.g., by entering one or more position commands, motion commands, or spatial patterns).

[0040] FIG. **5** shows a perspective view of an illustrative reference **550** and workpiece **590**, in accordance with some embodiments of the present disclosure. Arrangement **500** includes workpiece **590** secured to plate **560** (e.g., via bolts and or a clamp that are not shown). Plate **560** is coupled to reference **550** using illustrative linear actuators **510** (e.g., which may include a screw and stepper motor assembly) configured to move plate **560** relative to reference **550** in the plane defined by the double-tipped arrows in FIG. **5**. FIG. **6** shows a perspective view of illustrative reference **550** and workpiece **590** of FIG. **5**, and a deburring tool **610** having sensors **614** and **618**, and a nozzle **616** configured to deliver blasting media **617**, in accordance with some embodiments of the present disclosure. Arrangement **600** may be used to sense one or more parameters of workpiece **590**, and deliver blasting media **617** based on a burr metric determined by processing equipment (not shown), a user (not shown), or both. As shown, deburring tool **610** may be configured to travel in a direction normal to the plane of motion of plate **560** and reference **550**, as shown by the double-tipped arrow in FIG. **6** (e.g., similar to a bed-type milling machine). Deburring tool **610** is mechanically coupled to frame **620** having an internal linear actuator (not shown), allowing relative motion of deburring tool **610** and frame **620** in one dimension, and movement in up to three dimensions relative to workpiece **590**.

[0041] Nozzle **616** is shown delivering a jet of blasting media **617** to workpiece **590** (e.g., during a deburring process). In some embodiments, a sublimating particulate (e.g., dry ice) may be entrained in a gaseous flow (e.g., air), which avoids leaving any significant residue on workpiece **590**. Nozzle **616** may be fed by conduit **660**, which may couple to a blasting media delivery system (not shown). The flow of blasting media through nozzle **616** may be pulsed (e.g., periodic or aperiodic), continuous, or a combination thereof, depending upon the desired blasting schedule. In some embodiments, deburring tool **610** may include all or some of a blasting media delivery system. For example, deburring tool **610** may include a flow control valve (not shown), controlled by suitable processing equipment (not shown) via communicative coupling **662** (e.g., a ribbon cable as shown in FIG. **6** or any other suitable communicative coupling).

[0042] FIG. **7** shows a perspective view of illustrative reference **550**, workpiece **590**, and deburring tool **610** of FIG. **6**, during sensing, in accordance with some embodiments of the present disclosure. Arrangement **700** illustrates sensing processes of deburring tool **610**, using sensors **614** and **618**. Sensor **614** is shown as a camera, although any suitable sensor may be used. Sensor **614** may be configured to capture one or more images of workpiece **590**. In some embodiments, deburring tool **610** may include a lamp or other light source, configured to aid sensor **614** in capturing the one or more images of workpiece **590**. Sensor **618** is shown illustratively as a laser scanning sensor, having a laser source and a laser detector, although any suitable sensor may be used. Sensor **618** may be configured to scan the surface of workpiece **590** to check for flatness. Sensor **618** may provide a laser beam to the surface of workpiece **590**, and may detect the reflected beam from workpiece **590**. Changes in the reflection angle may be used to determine a surface profile of workpiece **590**, which may be used to determine flatness. In some embodiments, sensor **614**, sensor **618**, or both, may be configures to perform sensing while blasting media is delivered to workpiece **590** from nozzle **616**. In some embodiments, sensor **614**, sensor **618**, or both, may be configures to perform sensing sequentially with (e.g., before or after) the delivery of blasting media to workpiece **590** from nozzle **616**.

[0043] FIG. **8** shows a perspective view of an illustrative CNC machine **800** configured to perform deburring, in accordance with some embodiments of the present disclosure. It will be understood that CNC machine **800** is illustrative, and that the present disclosure may be implemented using any suitable CNC machine, any other suitable machine, or any combination thereof. CNC machine **800**, as illustrated, includes tooling head **850**, tool holder **812**, sensor **814**, nozzle **816**, vice **830** (e.g., for clamping workpiece **890**) mounted to reference **820**, and interface **860**. Reference **820**, as shown in FIG. **8**, includes a horizontal reference surface to which vice **830** may be affixed. Reference **820** may be movable in the horizontal plane using one or more actuators (e.g., linear, rotary, or both), which may be controlled by processing equipment (not shown). Tooling head **850** may be configured to be moved in the vertical direction, adjusting the distance between workpiece **890** and sensor **814** and the tip of nozzle **816**. Accordingly, the relative positions of workpiece **890** and the illustrated tools (i.e., sensor **814** and nozzle **816**) may be adjustable in one, two, or three spatial dimensions (e.g., via translation), and may have an adjustable orientation (e.g., via rotation). Although not shown in FIG. **8**, nozzle **816** may be coupled to a blasting media delivery system, which may be configured to deliver a suitable blasting media to nozzle **816** for blasting workpiece **890**. Interface **860** (e.g., which may be controlled by processing equipment that is not illustrated in FIG. **8**) may include display screen **862**, configured to provide a visual display to a user. For example, an image of workpiece **890**, one or more parameter values, one or more characteristics of workpiece **890**, any other information, or any combination thereof, may be displayed on display screen **862**. Interface **860** may include keypad **864**, having one or more hard command buttons, alphanumeric keys, any other suitable hard buttons configured to allow user input, or any combination thereof. For example, a user may use interface **860** to provide a sensing schedule, a blasting schedule, or both, to CNC machine **800** for performing a deburring procedure. In a further example, not shown in FIG. **8**, interface **860** may be a computer system (i.e., having processing equipment) communicatively coupled to CNC machine **800**.

[0044] FIG. **9** shows a screenshot **900** of an illustrative deburring application, in accordance with some embodiments of the present disclosure. It will be understood that screenshot **900** is illustrative, showing some exemplary information which may be provided by an interface (e.g., of a system such as CNC machine **800** of FIG. **8**, or CNC machine **400** of FIG. **4**). In some embodiments, processing equipment may determine any of the information displayed in screen shot **900**, but not necessarily display the information to a user. Screenshot **900** includes image position display **902**, nozzle position display **904**, workpiece position display **906**, burr metric display **908**, blast media type display **910**, blast media property display **912**, workpiece characteristic display **914**, image display **916**, any other suitable information display not shown in FIG. **9**, or any combination thereof. For example, image position display **902** may include Cartesian coordinates (e.g., relative to some reference) of the center of an image captured by a sensor (e.g., a camera) of a deburring system. In a further example, nozzle position display **904** may include Cartesian coordinates (e.g., relative to some reference) of a nozzle of a deburring system. In a further example, nozzle position display **906** may include Cartesian coordinates (e.g., relative to some reference) of a workpiece undergoing a deburring technique. In a further example, burr metric display **908** may include a numerical value quantifying the presence of a burr (e.g., a burr size such as 0.05 mm). In a further example, blasting media type display **910** may include an alphanumeric display of a blasting media indicator (e.g., a type of media, an index corresponding to a particular blasting media). In a further example, blasting media property display **912** may include an alphanumerical display of a blasting media property such as a flow rate, a pressure, a seeding density (e.g., mg CO_2 particles per cc entraining gas), a temperature, an exit velocity of blasting media from a nozzle, any other suitable blasting media property, or any combination thereof. In a further example, characteristic display **914** may include a numerical value quantifying a workpiece characteristic (e.g., a surface deviation of 0.05 mm).

[0045] Image display **916** may be based on information received from a sensor of a deburring system implementing the deburring application. Image display **916** of FIG. **9** shows an illustrative image of a workpiece **950** having features (e.g., machined holes **952**, **954**, and **956**) near edge **958**. Holes **952** and **954** both exhibit burrs (i.e., burrs **953** and **955**, respectively), while hole **956** is relatively clean. Hole **952** exhibits circumferential burr **953**, shown by the dashed circle indicating the radial edge of the hole excluding burr **953**. Hole **954** exhibits relatively smaller burr **955** than burr **953**. Edge **958** also exhibits a burr **960**, exhibited as an excursion from the straight edge shown by the dashed line in FIG. **9**. In some embodiments, image position display **902** may correspond to the image displayed in image display **916**. In some embodiments, images such as the image displayed in image display **916** may be used by processing equipment to determine a burr metric (e.g., as displayed in burr metric display **908**). In some such embodiments, the processing equipment may use an image processing algorithm to determine one or more dimension of a workpiece, a dimension of a feature of the workpiece. For example, the processing equipment may apply image processing (e.g., edge finding techniques) to the image of image display **916**, and may determine that hole **952** has a diameter 0.05 mm less than an expected value. The processing equipment may accordingly determine that burr **953** is 0.05 mm thick, and may quantify this deviation from the expected value with a burr metric (e.g., calculate a burr metric of 0.05). In a further example, the processing equipment may apply image processing to the image of image display **916**, and may determine that hole **954** has an irregular edge relative to an expected edge (e.g., a circle in this example). The processing equipment may accordingly determine that burr **955** is present, and may quantify this deviation from the expected value with a burr metric (e.g., calculate a burr metric based on the size of the burr). In a further example, the processing equipment may apply image processing to the image of image display **916**, and may determine that holes **952** and **954** exhibit burrs, and may apply a qualitative assessment as a burr metric (e.g., the workpiece or each feature thereof is "sufficiently burr-free" or "insufficiently burr-free"). In a further example, the processing equipment may apply image processing to the image of image display **916**, and may apply a predetermined image template (e.g., including the expected edges of the workpiece and features) to the processed image to determine deviations from the template. The processing equipment may implement any suitable image processing techniques such as, for example, feature extraction (e.g., edge detection, predetermined pattern detection). For example, the processing equipment may take as input a computer aided design (CAD) file for use as a template with which to compare one or more images of a workpiece. In a further example, a deburring system may provide image display **916** to a user via an interface, and the user may identify the presence of a burr (e.g., using an interface). The user may accordingly input a command to the interface to deburr the portion of the workpiece identified as having the burr.

[0046] FIG. **10** is a flow diagram **1000** of illustrative steps for deburring a workpiece based on a burr metric, in accordance with some embodiments of the present disclosure. The illustrative techniques of flow diagram **1000** may be implemented in accordance with any of the systems disclosed herein.

[0047] Step **1002** may include sensing one or more parameters of the workpiece, using one or more sensors. The one or more sensors may include a camera, an acoustic system (e.g., ultrasound emitters and detectors), a laser system (e.g., configured to scan the workpiece and features thereof), any other suitable sensors or sensing systems configured to sense a parameter of a workpiece, or any combination thereof. For example, the deburring system may include a camera configured to capture images of the workpiece. In some embodiments, a deburring system may include multiple sensors for sensing one or more parameters of the workpiece. Parameters may include distances, areas, shapes, any other absolute or relative parameters, or any combination thereof.

[0048] Step **1004** may include processing equipment determining a burr metric based at least in part on the one or more parameters of step **1002**. In some embodiments, the processing equipment may determine a quantitative burr metric. For example, the processing equipment may determine a length scale indicative of a burr size, an actual dimension of a feature, a deviation of an actual feature dimension from an expected dimension, any other suitable length scale, or any combination thereof. In a further example, the processing equipment may determine a representative length scale indicative of multiple dimensions, multiple features, or both such as an average burr size, an average actual dimension of a feature, an average deviation of an actual feature dimension from an expected dimension, any other suitable averaged value, any other suitable value representative of a set of values, or any combination thereof. In some embodiments, the processing equipment may determine a qualitative burr metric. For example, the processing equipment may determine a category of a workpiece, or a feature thereof, such as "burr-free", "burr present", "sufficiently burr-free", "insufficiently burr-free", any other suitable categorization, or any combination thereof. In a further example, the processing equipment may determine a letter grading or other hierarchical quality identifier (e.g., "A" being sufficiently burr-free, and "F" requiring further deburring). Any suitable quantitative burr metric, qualitative burr metric, or both, may be determined by the processing equipment based on the sensed parameter of step **1002**.

[0049] Step **1006** may include the deburring system delivering a blasting media to the workpiece using a nozzle and blasting media delivery system based on the burr metric of step **1004**. In some embodiments, the deburring system may include a blasting media delivery system, and optionally a blasting media container, configured to deliver a suitable blasting media to the workpiece via a nozzle of the deburring system. In some embodiments, a quantitative burr metric may be compared with a threshold value, and the deburring system may deliver the blasting media based on the comparison. For example, at step **1004** the processing equipment may determine a burr size (i.e., a burr metric) and compare the burr size to a threshold at step **1006**. If the burr metric exceeds the threshold, the processing equipment may transmit control signals to the blasting media delivery system to deliver blasting media. The processing equipment may control one or more blasting media properties such as a flow rate, a pressure, a seeding density, a temperature, an exit velocity of blasting media from a nozzle, any other suitable blasting media property, or any combination thereof.

[0050] FIG. **11** is a flow diagram **1100** of illustrative steps for deburring a workpiece based on a burr metric, and checking one or more workpiece characteristics, in accordance with some embodiments of the present disclosure. The illustrative techniques of flow diagram **1100** may be implemented in accordance with any of the systems disclosed herein.

[0051] Step **1102** may include sensing one or more parameters of the workpiece, using one or more sensors. The one or more sensors may include a camera, an acoustic system (e.g., ultrasound emitters and detectors), a laser system (e.g., configured to scan the workpiece and features thereof), any other suitable sensors or sensing systems configured to sense a parameter of a workpiece, or any combination thereof. For example, the deburring system may include a camera configured to capture images of the workpiece. In some embodiments, a deburring system may include multiple sensors for sensing one or more parameters of the workpiece. Parameters may include distances, areas, shapes, any other absolute or relative parameters, or any combination thereof.

[0052] Step **1104** may include determining a burr metric based at least in part on the one or more parameters of step **1102**. In some embodiments, the processing equipment may determine a quantitative burr metric. For example, the processing equipment may determine a length scale indicative of a burr size, an actual dimension of a feature, a deviation of an actual feature dimension from an expected dimension, any other suitable length scale, or any combination thereof. In a further example, the processing equipment may determine a representative length scale indicative of multiple dimensions, multiple features, or both such as an average burr size, an average actual dimension of a feature, an average deviation of an actual feature dimension from an expected dimension, any other suitable averaged value, any other suitable value representative of a set of values, or any combination thereof. In some embodiments, the processing equipment may determine a qualitative burr metric. For example, the processing equipment may determine a category of a workpiece, or a feature thereof, such as "burr-free", "burr present", "sufficiently burr-free", "insufficiently burr-free", any other suitable categorization, or any combination thereof. In a further example, the processing equipment may determine a letter grading or other hierarchical quality identifier (e.g., "A" being sufficiently burr-free, and "F" requiring further deburring). Any suitable quantitative burr metric, qualitative burr metric, or both, may be determined by the processing equipment based on the sensed parameter of step **1102**.

[0053] Step **1106** may include the deburring system delivering a blasting media to the workpiece using a nozzle and blasting media delivery system based on the burr metric of step **1104**. In some embodiments, the deburring system may include a blasting media delivery system, and optionally a blasting media container, configured to deliver a suitable blasting media to the workpiece via a nozzle of the deburring system. In some embodiments, a quantitative burr metric may be compared with a threshold value, and the deburring system may deliver the blasting media based on the comparison. For example, at step **1104** the processing equipment may determine a burr size (i.e., a burr metric) and compare the burr size to a threshold at step **1106**. If the burr metric exceeds the threshold, the processing equipment may transmit control signals to the blasting media delivery system to deliver blasting media. The processing equipment may control one or more blasting media properties such as a flow rate, a pressure, a seeding density, a temperature, an exit velocity of blasting media from a nozzle, any other suitable blasting media property, or any combination thereof.

[0054] Step **1108** may include one or more workpiece characteristics using a metrology tool such as a metrology sensor. The one or more characteristics may include dimensions (e.g., lengths, angles, areas, or volumes of the workpiece, or a feature thereof), surface characteristics (e.g., surface roughness, surface flatness), any other suitable characteristics, or any combination thereof. In some embodiments, a laser sensor may be used to determine the workpiece characteristic. For example a line of sight laser measurement may be used to map points, edges, or faces of with workpiece to check dimensions, flatness/straightness, or both. In a further example, a laser beam reflected from the workpiece surface to a photodetector may be used to determine variations in the surface flatness. In some embodiments, an imaging sensor may be used to determine the workpiece characteristic. For example a camera may be used to capture an image of the workpiece, and image processing (e.g., edge finding techniques, feature finding techniques) may be applied to the image to determine dimensions, flatness, or both of the workpiece. In some embodiments, a roughness sensor may be used to determine the workpiece characteristic. For example, a contact probe may be used to measure surface roughness (e.g., a rugosity value, or roughness value). In a further example, a microscope (e.g., a scanning laser microscope, an optical microscope) may be used to determine a surface profile and corresponding roughness. In a further example, an interferometer may be used to determine a surface profile and corresponding roughness. In some embodiments, a touch probe (e.g., a stylus configured to contact the workpiece) may be used to determine one or more surface points (e.g., coordinates) of the workpiece to generate a surface profile, determine one or more dimensions, or both.

[0055] In some embodiments, step **1108** may be performed to determine whether the blasting schedule of step **1106** has appreciably altered the workpiece. For example, step **1106** may include blasting the workpiece with a flow of entrained dry ice particles (e.g., which at 1 atm sublimate at a temperature of about −78.5° C.), and step **1108** may be performed to determine if any warping of the workpiece has occurred due to temperature gradients. In a further example, step **1106** may include blasting the workpiece with dry ice particles, and step **1108** may be performed to determine if one or more dimensions of features (e.g., holes, edges, grooves or other features) of the workpiece have been altered. In a further example, step **1106** may include blasting the workpiece with dry ice particles, and step **1108** may be performed to determine if the abrasion of the dry ice particles has altered the surface roughness of the workpiece.

[0056] FIG. **12** is a flow diagram **1200** of illustrative steps for deburring a workpiece using a deburring system and a metrology system, in accordance with some embodiments of the present disclosure. The illustrative techniques of flow diagram **1200** may be implemented in accordance with any of the systems disclosed herein.

[0057] Step **1202** may include processing equipment receiving a CAD file (e.g., an *.iges file), a computer aided machining (CAM) file, a scanned image file, any other suitable reference that includes dimension and feature information of a workpiece, or any combination thereof. For example, the processing equipment may retrieve a CAD file corresponding to a particular workpiece from memory storage. In a further example, the processing equipment may receive user input of a CAD file in the form of a removable memory storage device. In a further example, the processing equipment may host a CAD application, with which a user may generate a CAD file of a particular workpiece. Panel **1250** shows an illustrative CAD file of a workpiece.

[0058] Step **1204** may include processing equipment determining a sensing schedule based on the reference of step **1202**. The sensing schedule may include a sequence of positions (e.g., of a sensor relative to the workpiece), times, velocities (e.g., of a sensor relative to the workpiece), accelerations (e.g., of a sensor relative to the workpiece), sensor identifications (e.g., which sensor to use at a particular location), sensor properties (e.g., focus distance, sensor angle, sensor output conditioning), any other suitable information, or any combination thereof. For example, a sensing schedule may include a desired sensing path generated from a CAD file along the workpiece as shown by the solid arrow in panel **1252**. Step **1206** may include the deburring system performing the sensing schedule determined at step **1204**. For example, the deburring system may include a CNC machine having one or more linear actuators configured to move a sensing tool relative to the workpiece according to the sensing schedule. In a further example, the deburring system may adjust the target area of a sensor on the workpiece (e.g., adjust the focus and angle of a camera directed at the workpiece) according to the sensing schedule. In some embodiments, step **1204** may include the processing equipment processing and storing sensor output as the sensing schedule is performed. For example, the processing equipment may process and store a sequence of images taken as a camera is scanned over the surface of the workpiece.

[0059] Step **1208** may include processing equipment determining a blasting schedule based on the sensor schedule, or a portion thereof, performed at step **1206**. The blasting schedule may include a sequence of positions (e.g., of a nozzle relative to the workpiece), times, velocities (e.g., of a nozzle relative to the workpiece), accelerations (e.g., of a nozzle relative to the workpiece), blasting media identifications (e.g., which blasting media to use at a particular location), blasting media properties (e.g., what flow rate of blasting media to use at a particular location), any other suitable information, or any combination thereof. For example, a blasting schedule may include a desired blasting path generated along the workpiece as shown by the solid arrow in panel **1252**, based on the reference of step **1202**, and the sensor output from step **1206**. Panel **1254** shows a desired nozzle path, illustrated by the solid arrow, corresponding to an illustrative blasting schedule. The spatial path, relative timing, or both, of the blasting schedule and the sensing schedule may be, but need not be, the same. Step **1210** may include the deburring system delivering blasting media to the workpiece according to the blasting schedule determined at step **1208**. At each blasting location, the deburring system may adjust the blasting media type, flow rate, any other suitable property, or any combination thereof according to the blasting schedule. The blasting schedule may include general blasting information (e.g., for blasting the entire workpiece without finer spatial variation), feature-specific blasting information (e.g., for blasting one or more features with a specific blasting media having specific properties), position-specific blasting information (e.g., for blasting one or more spatial positions with a specific blasting media having specific properties), any other suitable information, or any combination thereof.

[0060] In some embodiments, steps **1206** and **1210** may be performed in substantially real time (e.g., during a single pass over the workpiece). For example, the sensor may move according to a schedule relative to the workpiece, sensing parameters of one or more features. The nozzle may move according to the same schedule (e.g., may be rigidly attached to the sensor, or may be independently controlled) but at a lag behind the sensor. As the sensor captures information, the processing equipment may determine a burr metric in real time, and determine a desired blasting schedule in real time. Accordingly, the deburring system may perform a single pass over the surface of the workpiece, during which both sensing and blasting may be performed. In some embodiments, steps **1206** and **1210** may be performed in sequentially. For example, the sensor may move according to a schedule relative to the workpiece, sensing parameters of one or more features. After the sensor makes a first pass, the processing equipment may determine one or more burr metrics (e.g., a scalar field of burr metrics), and determine a desired blasting schedule based on the one or more burr metrics. Accordingly, the deburring system may perform a second pass over the surface of the workpiece with the nozzle, during which blasting may be performed. The deburring system may use real time deburring, sequential deburring, or a combination thereof. In some embodiments, step **1206**, step **1208**, or both, may include determining a burr metric based at least in part on the sensor output of step **1206**.

[0061] Step **1212** may include processing equipment determining one or more workpiece characteristics based on a sensor output. During blasting at step **1210**, the workpiece may undergo changes in surface roughness, dimensions, and/or other properties. A sensor coupled to the processing equipment may be used to sense the one or more characteristics. Step **1212** may include determining if such changes have occurred, and if so, whether the changes are acceptable. Panel **1256** shows an illustrative touch sensor used to measure one or more spatial points of a workpiece surface. The touch sensor may be used to generate a sequence of surface points, from which surfaces, dimensions, any other suitable absolute or relative reference geometry, or any combination thereof may be determined. In some embodiments, the same sensor may be used to perform both steps **1206** and **1212**. For example, a camera may be used to sense parameters of the workpiece (e.g., by capturing one or more images of the workpiece and applying image processing), and also sense characteristics of the workpiece (e.g., by capturing one or more images of the workpiece and applying image processing). In some embodiments, different sensors may be used to perform steps **1206** and **1212**.

[0062] Step **1214** may include processing equipment determining whether a workpiece is sufficiently burr-free. In some embodiments, step **1214** may include repeating steps **1204** and **1206** to determine whether the blasting schedule of steps **1208** and **1210** were adequate. In some embodiments, if the processing equipment determines that the workpiece is sufficiently burr-free, then the workpiece need not be further inspected or deburred, and may undergo subsequent processing apart from deburring. In some embodiments, if the processing equipment determines that the workpiece is sufficiently burr-free, the processing equipment may proceed to step **1216** (this procession not shown in FIG. **12**). In some embodiments, if the processing equipment determines that the workpiece is not sufficiently burr-free, then the processing equipment may proceed to the step **1216** as shown. In some embodiments, if the processing equipment determines that the workpiece is not sufficiently burr-free, then the processing equipment may repeat any or all of steps **1204-1212** (also shown). In some embodiments, if the processing equipment determines that the workpiece is not sufficiently burr-free, then the processing equipment may require user input to proceed to further deburring, or performing other processes. For example, if the workpiece is determined to be insufficiently burr-free, a user inspection and input (e.g., to a suitable interface) may be required before the processing equipment proceeds.

[0063] Step **1216** may include processing equipment determining whether a workpiece characteristic determined at step **1212** is acceptable. In some embodiments, the processing equipment may compare the one or more characteristics to predetermined thresholds or tolerances. For example, a surface roughness determined at step **1212** may be compared to a roughness threshold, and if the roughness exceeds the threshold (e.g., larger than an upper threshold or less than a lower threshold), the roughness may be determined to be unacceptable. In a further example, one or more dimensions of the workpiece (or point measurements) measured at step **1212** may compared to corresponding tolerances, and if the dimensions are within the tolerances, the one or more dimensions may be determined to be acceptable. In a further example, a flatness of the workpiece measured at step **1212** may compared to a corresponding flatness tolerance, and if the flatness is within the tolerances, the flatness may be determined to be acceptable. If the processing equipment determines that the one or more characteristics are not acceptable, the processing equipment may stop the deburring process, indicate re-machining may be necessary, indicate to a user that further inspection may be necessary, indicate to a user to discard the workpiece, any other suitable processing function, or any combination thereof. In some embodiments, the processing equipment may provide the one or more workpiece characteristic values to a user via an interface. In some such embodiments, the interface may be configured to receive a user input as to whether the characteristic is acceptable or not.

[0064] The foregoing is merely illustrative of the principles of this disclosure and various modifications may be made by those skilled in the art without departing from the scope of this disclosure. The above described embodiments are presented for purposes of illustration and not of limitation. The present disclosure also can take many forms other than those explicitly described herein. Accordingly, it is emphasized that this disclosure is not limited to the explicitly disclosed methods, systems, and apparatuses, but is intended to include variations to and modifications thereof, which are within the spirit of the following claims.

What is claimed is:

1. A deburring system comprising:

a reference surface configured to secure a workpiece;

a sensor configured to detect burrs on the workpiece and provide an output;

a nozzle configured to direct a flow of a blasting media to the workpiece; and

processing equipment coupled to the sensor, and wherein the processing equipment is configured to control the flow of the blasting media based on the output of the sensor.

2. The deburring system of claim **1**, wherein the sensor comprises a camera configured to capture an image of the workpiece.

3. The deburring system of claim **1**, wherein the processing equipment is further configured to control the flow of the blasting media based on a computer program specific to the workpiece, wherein the computer program comprises a dimension of the workpiece.

4. The deburring system of claim **1**, further comprising at least one motion control actuator mechanically coupled to the reference surface and the nozzle, wherein the at least one motion control actuator is communicatively coupled to the processing equipment, and wherein the processing equipment is further configured to control the at least one motion control actuator to move the reference surface relative to the nozzle.

5. The deburring system of claim **1**, further comprising at least one motion control actuator mechanically coupled to the reference surface and the nozzle, wherein the at least one motion control actuator is communicatively coupled to the processing equipment, and wherein the processing equipment is further configured to control the at least one motion control actuator to move the nozzle relative to the reference surface.

6. The deburring system of claim **1**, further comprising:

a blasting media container configured to contain the blasting media;

a blasting media delivery system coupled to the blasting media container and the nozzle, wherein the blasting media delivery system configured to deliver the blasting media to the nozzle.

7. The deburring system of claim **6**, wherein the blasting media container is configured to contain dry ice, and wherein the blasting media delivery system further comprises a blade to shave dry ice into dry ice particles, and wherein the blasting media delivery system is further configured to entrain the dry ice particles with a gas flow and deliver the entrained particles to the nozzle.

8. The deburring system of claim **6**, wherein the blasting media delivery system further comprises a flexible hose coupled to the nozzle.

9. The deburring system of claim **1**, further comprising a display screen, wherein the processing equipment is further configured to display information on the display screen based at least in part on the output of the sensor.

10. The deburring system of claim **1**, wherein the processing equipment is further configured to determine a burr metric based at least in part on the output of the sensor.

11. The deburring system of claim **10**, wherein the processing equipment is further configured to control the flow of the blasting media based at least in part on the burr metric.

12. The deburring system of claim **1**, further comprising a metrology sensor for measuring a characteristic of the workpiece.

13. The deburring system of claim **12**, wherein the metrology sensor for measuring the characteristic of the workpiece comprises at least one of a flatness sensor for measuring flatness, a dimension sensor for measuring a dimension, a roughness sensor for measuring a surface roughness.

14. A deburring module for deburring a workpiece, the deburring module comprising:

at least one sensor configured to sense a burr on the workpiece and provide an output; and

a nozzle configured to the deliver a flow of a blasting media to the workpiece, wherein the flow of the blasting media is controlled by processing equipment based at least in part on the output of the at least one sensor.

15. The deburring module of claim **14**, further comprising a frame mechanically coupled to the nozzle and the at least one sensor, wherein the frame is configured to be coupled to a motion control actuator.

16. The deburring module of claim **14**, wherein the nozzle is further configured to be coupled to a blasting media delivery system, wherein the blasting media delivery system is controllable using the processing equipment.

17. The deburring module of claim **14**, wherein the at least one sensor comprises a camera configured to capture an image of the workpiece.

18. The deburring module of claim **14**, wherein the at least one sensor comprises a first sensor and a second sensor, wherein the first sensor is configured to sense the burr on the workpiece, and the second sensor is configured to determine a characteristic of the workpiece.

19. The deburring module of claim **14**, wherein the blasting media comprises a particulate entrained in a gas flow.

20. A method for deburring a workpiece, the method comprising:

sensing a parameter of the workpiece using a sensor;

determining a burr metric based at least in part on the parameter; and

delivering a blasting media to at least one portion of the workpiece based at least in part on the burr metric.

21. The method of claim **20**, wherein the sensing the parameter of the workpiece comprises capturing an image of the workpiece using a camera.

22. The method of claim **21**, further comprising applying image processing to the image using processing equipment.

23. The method of claim **20**, wherein the delivering the blasting media to the at least one portion of the workpiece further comprises controlling a flow of the blasting media.

24. The method of claim **20**, wherein the parameter comprises one of a distance, an area, a shape, and a volume.

25. The method of claim **20**, wherein the sensing the parameter, the determining the burr metric, and the delivering the blasting media are performed during a single pass over the workpiece.

26. The method of claim **20**, wherein the sensing the parameter is performed during a first pass over the workpiece, and the delivering the blasting media is performed during a second pass over the workpiece, wherein the determining the burr metric is performed prior to or during the second pass.

27. A method for deburring a workpiece, the method comprising:

sensing one or more parameters of the workpiece using a sensor;

determining, using processing equipment, one or more burr metrics based at least in part on the output of the sensor;

performing a blasting schedule based on the one or more burr metrics, wherein the blasting schedule comprises delivering a controlled flow of a blasting media to the workpiece; and

determining one or more workpiece characteristics based on one or more diagnostic tests.

28. The method of claim **27**, wherein the sensing the parameter and the performing the blasting schedule are performed during a single pass over the workpiece.

29. The method of claim **27**, wherein the sensing the parameter is performed during a first pass over the workpiece, and the performing the blasting schedule is performed during a second pass over the workpiece, wherein the determining the one or more burr metrics is performed prior to or during the second pass.

30. The method of claim **27**, wherein the one or more diagnostic tests comprise an optical flatness test.

31. The method of claim **27**, wherein the one or more diagnostic tests comprise an optical dimension test.

32. The method of claim **27**, wherein the one or more diagnostic tests comprise a surface roughness test.

33. The method of claim **27**, wherein the one or more diagnostic tests comprise using a touch probe to measure one or more surface points of the workpiece, wherein the one or more surface points are used to determine a dimension of the workpiece.

34. The method of claim **27**, further comprising determining whether to repeat the steps of claim **27** based at least in part on the one or more workpiece characteristics.

35. The method of claim **27**, further comprising receiving a reference corresponding to the workpiece, wherein the reference comprises dimension information of the workpiece.

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