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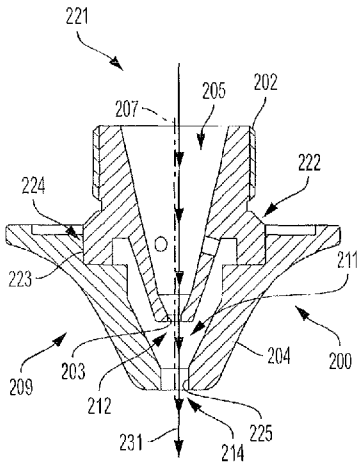


FIG. 2

(57) Abstract: A double nozzle (200) for a laser processing head includes an inner body portion (202) having an interior surface (203) defining a first bore (205), and an exterior surface (223), the bore (205) aligned with a central longitudinal axis of the body. The double nozzle includes an outer body portion (204) having an interior surface (225) defining a second bore that is substantially aligned to the longitudinal axis. The outer body portion (204) is matingly engaged with a region of the exterior surface of the inner body portion. The region between the exterior surface of the inner body portion (202) and the interior surface of the outer body portion (204) defines at least six coaxial fluid flow paths (465A-465F) through an interior annular flow volume of the double nozzle. Each fluid flow path is defined at least in part by a corresponding feature formed in at least one of the inner body portion (202) or the outer body portion (204).

DOUBLE NOZZLE FOR A LASER PROCESSING HEAD

RELATED APPLICATIONS

[0001] This application is a continuation-in-part of U.S. Patent Application No. 15/339,077, which was filed on October 31, 2016 and entitled "Highly Positioned Laser Processing Nozzle," which claims the benefit of U.S. Provisional Patent Application No. 62/248,943, which was filed on October 30, 2015 and entitled "Highly Positioned Laser Processing Nozzle." This application also claims the benefit of U.S. Provisional Patent Application No. 62/360,908, which was filed on July 11, 2016 and entitled "Multiple Flow Grooved Highly Positioned Laser Processing Nozzle." The entire contents of these applications are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The invention relates generally to the field of laser cutting systems and processes. More specifically, the invention relates to improved alignment of a laser beam and fluid flow within a double nozzle.

BACKGROUND

[0003] Material processing apparatuses, such as laser cutting machines, are widely used in the cutting, welding, and heat treating of materials. A laser-cutting machine generally includes a high-power laser, a nozzle, a gas stream, an optical system, and a computer numeric control (CNC) system. The laser beam and gas stream pass through an orifice of the nozzle and impinge upon a workpiece. The laser beam heats the workpiece, which, in conjunction with any chemical reaction between the gas and workpiece material, alters (e.g., liquefies and/or vaporizes) a selected area of workpiece, allowing an operator to cut or otherwise modify the workpiece. The laser optics and CNC are used to position and direct the laser beam relative to the workpiece during a cutting operation. Lasers are frequently used in material processing applications because laser beams can be focused to small spot sizes, thereby achieving the intensity and power density desired to process industrial-strength materials, such as metals.

[0004] In conventional laser cutting systems, alignment of system components (e.g., nozzles) can be critical to system life and performance. For example, alignment of the

nozzle bore and/or orifice to the nozzle holder and laser cutting head optics can be critical to proper functioning of the laser cutting process. In addition, alignment of the laser beam and the gas jet can be critical to achieving uniform cut quality around all sides of the workpiece. One instance in which alignment issues manifest is during component replacement and installation, during which the nozzle bore(s) and/or orifice(s) must be aligned with a longitudinal axis of the laser head, and thus the laser beam, so as to avoid non-symmetric gas flow about the beam. The problem is compounded because conventional nozzles must be replaced frequently, and each nozzle replacement can involve a complex installation and verification to prove alignment. In addition, because components must often be replaced in the field, significant machine down time and technician expertise can be required to ensure proper installation and alignment. Field replacement can also require specialized tools to attain, verify, and maintain proper component alignment.

[0005] One type of nozzle, a "double nozzle," has specific benefits for laser cutting applications but also creates unique issues around alignment of component parts. Structurally, a double nozzle typically has two pieces (e.g., an inner and an outer nozzle portion) that are press-fitted or threaded together. A primary function of a double nozzle is to create two separate flows of gas within an inner and an outer nozzle portion. One flow of gas is delivered through a central bore and positioned along the axis of the laser beam itself, while a second flow of gas surrounds the central bore and provides a coaxial flow of lower pressure gas. The central flow helps to remove material during the cutting process as the laser beam heats the material and the process gas ejects the material from the kerf, while the lower pressure coaxial flow provides a protective flow around the central flow, preventing entrainment of air into the molten kerf and surrounding the kerf with the correct gas chemistry for the material being processed.

[0006] Figure 1 shows a prior art double nozzle configuration. In this embodiment, a double nozzle 100 includes an inner body portion 102 (e.g., inner nozzle portion or inner nozzle) and an outer body portion 104 (e.g., outer nozzle portion or outer nozzle) joined at an interface surface 124. The inner body portion 102 has an orifice 112 that permits the laser beam to pass through the double nozzle 100. The outer body portion 104 has an orifice 114 and an alignment surface 122 for aligning the double nozzle 100 with a laser machining head (not shown). In this configuration, two separate surface interfaces

determine alignment of the inner nozzle orifice 112 relative to a longitudinal axis 107 of the laser machining head and thus the laser beam itself: (1) the alignment surface 122 with the laser machining head; and (2) the nozzle interface 124 between the inner body portion 102 and the outer body portion 104.

[0007] The inner nozzle orifice 112 of inner body portion 102 in Figure 1 is smaller than the outer nozzle orifice 114 and is located closer to the laser beam during operation than the outer nozzle orifice 114. Thus, alignment of the inner nozzle orifice 112 can be particularly important to performance and life of the double nozzle 100. The alignment of the inner nozzle orifice 112 with the longitudinal axis 107 of the laser machining head, and thus the laser beam via two separate interfaces, depends on the accuracy and precision of four separate surfaces that create each of these two-surface interfaces. Therefore, a high level of manufacturing precision is required on these four surfaces, as well as installation accuracy and verification to ensure proper life and performance; misalignment in any of these components can have a dramatic impact on alignment of the inner nozzle orifice 112 relative to longitudinal axis 107 of the laser beam. What is needed is a double nozzle configuration that reduces the number of opportunities for misalignment, thereby improving alignment of the laser beam and the nozzle bore and/or orifice, and simplifies installation and operation.

SUMMARY OF THE INVENTION

[0008] In some embodiments, the present invention relates to systems and methods for aligning a laser beam within a nozzle bore and/or orifice of a laser cutting system. In particular, certain surfaces between constituent parts of the nozzle are re-designed (e.g., the surface between an inner bore of a double nozzle and a longitudinal axis of the laser machining head) so that the number of interface surfaces (i.e., opportunities for misalignment) is minimized. In a new configuration in accordance with the present invention, alignment of the beam and the nozzle bore, and consequently gas shrouding and alignment, are improved. In addition, manufacturing tolerances on nozzle interfaces are loosened, and operation and installation of the system are simplified.

[0009] One advantage of the invention is to provide a more uniform secondary fluid flow and/or an improved functional alignment with respect to standard designs (e.g., three-milled flats). Another advantage of the invention is to provide improved alignment of a

double nozzle that is nearly equal to that of a single nozzle. Another advantage of the invention is to enable a more reliable, repeatable operation (e.g., whether attended or unattended; hand loaded or auto-loaded; and/or hand aligned or machine aligned). Another advantage of the invention is to minimize the chance for assembly errors and mixing of parts (e.g., particularly if outer and inner nozzles are pre-assembled and fastened within a cartridge). Another advantage of the invention is to provide a non-press fit relationship of the inner and the outer nozzle portions. Another advantage of the invention is increase the alignment along conical surfaces, which can also improve radial alignment. Another advantage of the invention is to enable centering of a nozzle into a chamfer or cone region without using a threaded configuration. Another advantage of the invention is to simplify the assembly process and need for an extensive interference and/or press fit to hold the inner and outer nozzles together.

[0010] In one aspect, the invention features a double nozzle for a laser processing head. The double nozzle includes an inner body portion having (i) an interior surface defining a first bore, and (ii) an exterior surface, the bore aligned with a central longitudinal axis of the body. The double nozzle also includes an outer body portion having an interior surface defining a second bore that is substantially aligned to the longitudinal axis. The outer body portion is matingly engaged with a region of the exterior surface of the inner body portion. The region between the exterior surface of the inner body portion and the interior surface of the outer body portion defines at least six coaxial fluid flow paths through an interior annular flow volume of the double nozzle. Each fluid flow path is defined at least in part by a corresponding feature formed in at least one of the inner body portion or the outer body portion.

[0011] In some embodiments, the region includes an interface between the exterior surface of the inner body portion and the interior surface of the outer body portion. In some embodiments, the coaxial fluid flow paths are shaped to increase fluid flow and uniformity of fluid flow through the double nozzle. In some embodiments, each of the fluid flow paths is defined at least partially by a corresponding feature in the exterior surface of the inner body portion. In some embodiments, each of the fluid flow paths is defined at least partially by a corresponding feature in the interior surface of the outer body portion. In some embodiments, each of the fluid flow paths includes a scalloped or curved surface. In some embodiments, the interface between the exterior surface of the

inner body portion and the interior surface of the outer body portion is at least partially defined by one or more step features. In some embodiments, each of the features is configured to assist with seating and alignment of the inner body portion relative to the outer body portion during assembly of the double nozzle. In some embodiments, the substantial alignment is less than about 0.002 inches.

[0012] In another aspect, the invention features a double nozzle for a laser processing head. The double nozzle includes an inner body portion having an interior surface defining a first bore, a first exterior circumferential surface disposed toward a distal end of the inner body portion, and a second exterior circumferential surface disposed toward a proximal end of the inner body portion. The second exterior circumferential surface is shaped to mate and align with the laser processing head. The double nozzle also includes an outer body portion having an interior surface defining a second bore. The outer body portion matingly engages with the first exterior circumferential surface of the inner body portion and is isolated from direct alignment contact with the laser processing head. The inner body portion and the outer body portion are aligned to define a coaxial fluid flow path therethrough.

[0013] In some embodiments, the second exterior circumferential surface is tapered relative to a longitudinal axis of the double nozzle. In some embodiments, the tapered surface is at an angle of about 4.5 degrees to about 5.5 degrees with respect to the longitudinal axis. In some embodiments, the double nozzle further includes a set of fluid flow paths formed between the inner body portion and the outer body portion. In some embodiments, the set of fluid flow paths is formed at an interface between the first exterior circumferential surface of the inner body portion and the outer body portion. In some embodiments, the set of fluid flow paths includes six distinct flow paths. In some embodiments, the second exterior circumferential surface includes a conical interference interface with the interior surface of the outer body portion, the conical interface including a spacing of about 0.001 to 0.003 inches between the surfaces. In some embodiments, the inner body portion and the outer body portion are crimped using a force of about 2000 lbF. In some embodiments, the second bore of the outer body portion includes an axial stop for positioning relative to the inner body portion. In some embodiments, the inner body portion has a conical datum feature received by the second bore of the outer body portion. In some embodiments, the inner body portion and the outer body portion can provide at

least about 25% improvement in alignment. That is, the new designs and configurations described herein can provide better alignment than conventional systems. In some embodiments, the double nozzle is configured to provide a better flow profile than some conventional systems. For example, in some cases, the systems and methods herein can yield a flow that is more uniform and allow for a wider range of adjustment in flow rate than some conventional systems. By way of an example comparison, a 3-slot nozzle can produce pressures that vary between 1 psi and 1.33 psi, which can be a peak-peak variation of 28% about the mean. Whereas, in some examples, the inventive nozzles described herein can also produce pressures that vary between 1.51 psi and 1.57 psi, which can be a peak-peak variation of 4% about the mean. In other words, the inventive multiple flow grooved nozzles described herein can result in ~7x reduction in flow non-uniformities compared to some conventional 3-slot nozzles.

[0014] In another aspect, the invention features a method of cutting a workpiece using a laser cutting system. The method includes providing a laser processing head and a double nozzle. The double nozzle has an inner body portion, an outer body portion, and an axial bore. The inner body portion has a first exterior surface shaped to complement a contoured alignment surface on the laser processing head and a second exterior surface shaped to complement an interior circumferential mating surface of the outer body portion. The outer body portion is secured to the inner body portion along the circumferential mating surface and isolated from direct alignment contact with the laser processing head. The method further includes installing the double nozzle in the laser processing head to align to a longitudinal axis of the laser processing head. The method further includes

flowing a fluid through a primary flow path and at least one secondary flow path formed in the double nozzle. The method further includes generating a laser beam along the longitudinal axis of the laser processing head. The method further includes cutting a workpiece with the laser beam as it exits the double nozzle.

[0015] In some embodiments, the second exterior surface is tapered relative to a longitudinal axis of the double nozzle. In some embodiments, the taper is at an angle of about 4.5 degrees to about 5.5 degrees relative to the longitudinal axis. In some embodiments, the double nozzle further comprises a set of fluid flow paths formed between the inner body portion and the outer body portion. In some embodiments, the set of fluid flow paths is formed at an interface between the first exterior surface of the inner

body portion and the outer body portion. In some embodiments, the set of fluid flow paths includes six distinct flow paths. In some embodiments, the second exterior surface is a conical interference interface with the interior surface of the outer body portion, the conical interface including a spacing of about 0.001 to 0.003 inches between the surfaces. In some embodiments, the inner body portion and the outer body portion are crimped using a force of about 2000 lbF. In some embodiments, the second bore of the outer body portion includes an axial stop for positioning relative to the inner body portion. In some embodiments, the inner body portion has a conical datum feature received by the second bore of the outer body portion. In some embodiments, the inner body portion and the outer body portion can provide at least about 25% improvement in alignment. That is, the new designs and configurations described herein can provide better alignment than conventional systems. In some embodiments, the double nozzle is configured to provide a better flow profile than some conventional systems. For example, in some cases, the systems and methods herein can yield a flow that is more uniform and allow for a wider range of adjustment in flow rate than some conventional systems. By way of an example comparison, a 3-slot nozzle can produce pressures that vary between 1 psi and 1.33 psi, which can be a peak-peak variation of 28% about the mean. Whereas, in some examples, the inventive nozzles described herein can also produce pressures that vary between 1.51 psi and 1.57 psi, which can be a peak-peak variation of 4% about the mean. In other words, the inventive multiple flow grooved nozzles described herein can result in ~7x reduction in flow non-uniformities compared to some conventional 3-slot nozzles.

[0016] In some embodiments, the contoured surface of the nozzle has an arcuate shape and may be sectioned or may have a tapered alignment surface to promote even seating. In some embodiments, the inner nozzle has all or many of its “flow-creating” features positioned highly to a tapered seat. In some embodiments, the outer nozzle is highly positioned to inner and fastened to ensure alignment, safe operation at high pressure, seal of gas and conductivity of capacitive circuit. Because slip fits, press fits, and diametrical mating features have inherent variation, in order to ensure consistent performance, tight tolerances must be maintained on double nozzles of this design (tolerances that are difficult to achieve even with high precision CNC lathes).

[0017] In some embodiments, an interface surface between the double nozzle and the laser machine head is formed directly on the inner body portion of the double nozzle. In some

embodiments, complementary countered surfaces are formed on the machining head and the inner body portion, which can center and align the bore with the longitudinal axis of the head. In some embodiments, the invention features both of these improvements in a "hybrid" design. In such embodiments, the invention can include a tapered seat on the inner nozzle component to functionally align the primary gas flow with the laser beam and head. The nozzle bore and the angled functional datum feature can be machined simultaneously such that they are highly positioned and coaxial. In some embodiments, the double nozzle design is further improved with a tapered or shaped interface between the inner nozzle and the outer nozzle, such that the radial position errors are minimized through hard contact of the tapered or shaped surfaces. This tapered contact method can improve coaxiality at the expense of axial alignment, which can be functionally less sensitive or critical. In some embodiments, the tapered seat on the inner nozzle and the shaped interface between the inner and outer nozzle are separable concepts, which may be used together or separately to achieve the results and benefits described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The foregoing discussion will be understood more readily from the following detailed description of the invention when taken in conjunction with the accompanying drawings.

[0019] Figure 1 is a cross-sectional diagram of a prior art double nozzle for a laser cutting system.

[0020] Figure 2 is a cross-sectional diagram of an improved double nozzle for a laser cutting system, according to an illustrative embodiment of the invention.

[0021] Figure 3 is a three-dimensional half-sectional view of an improved double nozzle for a laser cutting system, according to an illustrative embodiment of the invention.

[0022] Figure 4 is a cross-sectional diagram of an improved double nozzle for a laser cutting system in which the inner body portion is conically seated within the outer body portion, according to an illustrative embodiment of the invention.

[0023] Figures 4A-4B show perspective views of double nozzles having more than three slots, according to illustrative embodiments of the invention.

[0024] Figure 5A shows a three-dimensional measured flow mapping of a standard three-slot design for a double nozzle.

[0025] Figure 5B shows a three-dimensional measured flow mapping of a six-groove design for a double nozzle, according to an illustrative embodiment of the invention.

[0026] Figure 6 shows a perspective view of an inner body portion of a double nozzle, according to an illustrative embodiment of the invention.

[0027] Figure 7 shows a cross-sectional view from the side of the nozzle of one possible step feature of a double nozzle, according to an illustrative embodiment of the invention.

DETAILED DESCRIPTION OF THE DRAWINGS

[0028] Figure 2 is a cross-sectional diagram of an improved double nozzle 200 for a laser cutting system, according to an illustrative embodiment of the invention. The double nozzle 200 includes an inner body portion 202 having an interior surface 203 defining an inner nozzle bore 205 and an inner nozzle orifice 212. The inner body portion 202 has a first exterior circumferential surface 223 disposed toward a distal end 209 of the inner body portion 202. The inner body portion 202 has a second exterior circumferential surface 222 disposed toward a proximal end 221 of the inner body portion 202. The double nozzle 200 also includes an outer body portion 204 having an interior surface 225 defining an outer nozzle bore 211 and an outer nozzle orifice 214. The second exterior circumferential surface 222 is shaped to mate and align (e.g., directly) with the laser processing head (not shown). The outer body portion 204 is matingly engaged with the first exterior circumferential surface 223 of the inner body portion 202 and is isolated (e.g., substantially) from direct alignment contact with the laser processing head. The inner body portion 202 and the outer body portion 204 are aligned to define a coaxial fluid flow path 231 therethrough.

[0029] Generally, the double nozzle 200 has similar external and internal dimensions to the prior art double nozzle 100 shown and described above in Figure 1. However, the double nozzle 200 has fewer interface surfaces between the inner nozzle bore 212 of the inner body portion 202 and the longitudinal axis 207 of the laser beam. Specifically, the double nozzle 200 has one interface as a result of forming the second exterior

circumferential surface 222 (the nozzle machining head interface surface) directly on the inner body portion 202. Thus, the reduction in interface surfaces can be due to a relocation of the interface 224 between the inner and outer body portions 202, 204, as compared with the interface 124 of the prior art. Such a re-configuration reduces the number of "direct alignment contact" surfaces, e.g., surfaces that control alignment of inner nozzle bore 212 relative to longitudinal axis 207 (even though, in some configurations, some physical contact may be present between the surfaces). In this case, the number of direct alignment contact surfaces is two (i.e., the nozzle machining head interface surface 222 and its complementary surface on the laser head) from the four surfaces shown in the prior art configuration of Figure 1. Thus, the double nozzle 200 provides a more direct connection between the longitudinal axis 207 and the inner nozzle bore 212, loosens manufacturing requirements on outer body portion 204, and reduces installation complexity and verification procedures. In this configuration, the laser beam and the gas flow can be insulated from direct effects of any assembly errors.

[0030] In some embodiments, the inner and outer body portions 202, 204 may be affixed by a variety of methods including friction welding or press fits. In some embodiments, the nozzle machining head interface surface 222 of the double nozzle 200 can include a contoured surface shaped to complement a contoured alignment surface on the laser machining head. Thus, when a technician installs the double nozzle 200 in a laser machining head, the contoured surface of the double nozzle 200 mates with the contoured alignment surface of the laser machining head, facilitating alignment of the double nozzle 200 with the longitudinal axis 207. This alignment occurs because as the double nozzle 200 is installed in the laser machining head, the contoured mating surface contacts the first contoured alignment surface centering the double nozzle 200, thereby causing the longitudinal axis 207 of the double nozzle 200 to align with the torch axis and thus the laser beam. As a result, the double nozzle 200 becomes centered about the laser beam to provide a concentric uniform annular gas flow about the laser beam to facilitate torch operation. This radially-centered double nozzle 200 avoids the field replacement and alignment problems of the prior art, and/or reduces or eliminates the high precision manufacturing requirements of multiple parts.

[0031] In some embodiments, the contoured surface is an arcuate section and/or a linear taper. Such an arcuate section can have a fixed radius of curvature or several radii of

curvature. Contoured or tapered alignment surfaces can promote even seating and alignment of the double nozzle 200 and the inner nozzle bore 212 relative to the longitudinal axis 207. The angle formed between the taper and the axis of the laser beam can be any value less than 90 degrees, preferably less than about 45 degrees and, more preferably, less than about 20 degrees. Such configurations can help to pair contoured mating surfaces with contoured alignment surfaces to centrally dispose the double nozzle 200 along the longitudinal axis 207.

[0032] Figure 3 is a three-dimensional half-sectional view of an improved double nozzle 300 for a laser cutting system, according to an illustrative embodiment of the invention. The double nozzle 300 includes an inner body portion 302 having an inner nozzle bore 312 and an outer body portion 304 having an outer nozzle bore 314, both of which are oriented along a longitudinal axis 307 of the laser beam. The double nozzle 300 has a similar configuration to the double nozzle 200 shown and described above in Figure 2, with several notable differences. For example, in this configuration, the interface 324 between the inner body portion 302 and the outer body portion 304 is tapered in a "conical seating" arrangement with respect to the longitudinal axis 307. As shown, this "conical interference" interface 324 is a "conical interference interface," which can have a linear dimension of about 0.001 to 0.003 inches. In some embodiments, the conical interference interface 324 can be pressed and crimped, e.g., to about 2000lbF. The inner body portion 302 also includes an exterior surface 322. The exterior surface 322 can include a conical datum feature that is aligned to the through bore. The outer body portion 304 can have an "axial stop" 306. The conical interference interface 324 and/or the axial stop 306 can help align the inner body portion 302 to the outer body portion 304 and the longitudinal axis 307.

[0033] Figure 4 is a cross-sectional diagram of another improved double nozzle 400 for a laser cutting system, according to an illustrative embodiment of the invention. The double nozzle 400 includes an inner body portion 402 having an inner nozzle bore 412 and an outer body portion 404 having an outer nozzle bore 414, which are oriented along a longitudinal axis 407 of the laser beam. The double nozzle 400 has a similar configuration to the double nozzle 300 shown and described above in Figure 3 with respect to the "conical seating" arrangement, although the Figure 4 configuration does not employ the reduced number of interface surfaces shown in Figure 2. In the Figure 4 configuration, the

inner body portion 402 is conically seated within the outer body portion 404. The conical seating itself improves alignment of inner nozzle bore 412 and outer nozzle bore 414 with respect to the longitudinal axis 407 (and hence the laser beam), independent of the benefits of the redesign shown in Figure 2.

[0034] Generally, coaxiality of the inner body portion and the outer body portion can be further improved by avoiding slip fits and press fits in favor of a clearance fit, with inner and outer body portions adjusted to a coaxial position via precise tooling and subsequently attached to each other (e.g., via screws, tabs, welds, glue bonds, solder joints or another method that results in the two parts being fixed in a highly positioned coaxial arrangement). In some embodiments, the inner and outer body portions can be made to have a low impedance, high conductivity bond (e.g., to allow for high frequency AC capacitive height sensing signals to pass between the inner body portion and the outer body portion). Such a configuration can be achieved through direct contact of fasteners, conductive elements within expox mix, soft solder, silver braze, or welding (e.g., laser welding, friction welding, or ebeam welding). Alternatively or in conjunction with the screwed and/or tapered surfaces for alignment discussed herein, nozzles can be formed pre-aligned and fixtured, and/or glued or otherwise welded, bonded, fastened and joined for industrial cutting applications and solutions.

[0035] In some embodiments, uniformity of the double nozzle flow is important to the consistency of the cut process. Currently, most double nozzles are characterized by an inner nozzle with a tri-lobe feature and three slots to meter and distribute the flow about the central process gas bore. However, these three slots can create a non-uniform flow within the double nozzle. In contrast, in some embodiments, the invention uses more than three slots. For example, Figure 4A shows a double nozzle 450 having twelve slots 455A-L, and Figure 4B shows a double nozzle 460 having six slots 465A-465F. The configurations of the nozzles 450, 460 can improve alignment between nozzles 450 and 460 as well as enhance the process consistency and cut quality over traditional three-slot or three-bore configurations. In some embodiments, the distinct flow passages including the "slots" shown in Figures 4A-4B can take a variety of other forms, e.g., can be holes, grooves, channels, or other features configured to form distinct co-axial fluid flow paths through the double nozzle and/or to improve fluid flow and decrease non-uniformity of fluid flow (e.g., from the perspective of the laser beam). In the industry, the conventional

wisdom has been to form flats or drill holes, rather than to use a form of "scalloped" slots or other features, because of the complexity that these features introduce (e.g., in construction of the parts), and in this respect the invention moves away from this conventional teaching. With the "slots" or corresponding features bored out of at least one of the inner or outer nozzle portions, corresponding features are naturally generated in the remaining terrain of the respective nozzle portion, e.g., ribs, struts, walls, or partitions (such as features 459A-L or features 466A-F).

[0036] As shown in Figure 4A, compared to conventional three slotted double nozzles there are more points or areas of contact in the interface region between the exterior surface of the inner nozzle 460 and the interior surface of the outer nozzle 461. In some embodiments, this increased number of contact areas (e.g., points of contact and/or points of alignment influence) results in an improved alignment between inner nozzle 460 and outer nozzle 461. For example, if the inner nozzle 460 includes twelve (or six, or another number greater than three) corresponding ribs for making contact, the effect of any one rib being out of alignment can be negligible, as there are still more than sufficient ribs to ensure proper alignment. However, using a design having only three ribs, if one rib is out of alignment, there are only two others to compensate, which can mean a larger total effect on alignment or misalignment for the whole configuration as each rib can have a greater impact, effect or influence on alignment under these circumstances. In addition, in some embodiments the total amount of contact surface area between the inner nozzle 460 and the outer nozzle 461 is reduced. Some past designs have included significant surface area contact between the inner and outer nozzles, which can provide higher-than-needed opportunities for misalignment (e.g., due to surface imperfections on the parts). In addition, it is not always obvious or practical to notice and/or correct such deficiencies in the field. In contrast to the conventional teachings, Figure 4B shows a reduced contact surface area between the ribs 466A-466F of the inner nozzle 460 and the outer nozzle 461, reducing the opportunities for misalignment. Using such configurations, an improvement of about 50% improvement in alignment has been observed: whereas prior art embodiments have seen discrepancies in alignment of about 0.003 inches between an inner nozzle and an outer nozzle, configurations in accordance with the principles of Figure 4B can achieve discrepancies of about half that amount, e.g., about 0.0015 inches.

[0037] Further, as shown in Figure 4B, each of the features of the current invention has a comparatively smaller contact area and circumferential width than the comparable counterpart ribs on the conventional three slot design. This reduction in circumferential width results in a more uniform and consistent gas flow between the inner nozzle 460 and outer nozzle 461 as these interfaces between the inner nozzle 460 and the outer nozzle 461 have a reduced effect on gas flow interrupted by their presence and as such limit the size of downstream flow dead spots.

[0038] Figure 5A shows a three-dimensional measured flow mapping of a standard three-slot design for a double nozzle, while Figure 5B shows a three-dimensional measured flow mapping of a six-groove design for a double nozzle, according to an illustrative embodiment of the invention. The Figure 5B diagram shows improved (e.g., more even or radially symmetric) distribution, including with fewer interruptions in comparison to the Figure 5A. In particular, Figure 5A shows non-uniformity of the outer flow, and the bumps (e.g., bumps 501 and 502) and dips (e.g., dip 503), caused by corresponding slots, can be easily visualized. The bumps shown in Figure 5A are diametrically opposed to the slot location, and the dips fall in between the bumps, indicating that the slot flow "shoots" across and under the inner nozzle to exit the nozzle bore at a diametrically opposite location. In contrast, Figure 5B shows that in the six-groove design, the outer pressure shelf is more uniform (e.g., less impacted by the more numerous but comparatively smaller features). Thus, the flow characteristics within the double nozzle can be dramatically impacted by the shape and/or size of the features (e.g., slots, holes, or other features) defining the fluid passageways.

[0039] Figure 6 shows a perspective view of an inner body portion 600 of a double nozzle, according to an illustrative embodiment of the invention. As above, the inner body portion 600 defines six features (e.g., slots 601A-601F, which when mated with the outer body portion form six flow passages about the central bore) in between six corresponding "ribs" or features 602A-602F. In some embodiments, the features 601A-601F have a "scalloped" shape, or another shape with a defined curvature. In some embodiments, the features 602A-602F further include step features (e.g., 603A and 603F as depicted, with corresponding features for the remaining ribs not visible in this view) that assist with seating and alignment of the inner body portion 600 relative to the outer nozzle (not shown) during assembly. In some embodiments, the step features 603A-603F help to

reduce the area over which an interference fit is needed, which can have benefits for assembly, such as reduced likelihood of pinching, rocking, or misalignment. In some embodiments, the slots can be formed in the outer nozzle, in addition to or alternatively to being formed in the inner body portion 600. In some embodiments step features 603A-603F may be located in the rearmost portion of inner body portion 600 (e.g., occupying about less than the back 20% of the inner body portion, in one embodiment occupying about less than the back 10% of the inner body portion). Features 601A-601F are raised radially outward slightly relative to the forward portions of features 602A-602F. Features 602A-602F are sized to contact an interior surface of outer nozzle 461 during assembly, the six features roughly aligning inner body portion 600 with outer nozzle 461 during the initial part of assembly. Then once inner body portion 600 is substantially inserted within outer nozzle 461 (e.g., greater than about 50% inserted or in some cases greater than about 80% inserted longitudinally) step features 603A-603F begin to contact an interior surface of outer nozzle 461 in an interference fit style fashion, further driving alignment between inner body portion 600 and outer nozzle 461 and securing inner body portion 600 within outer nozzle 461.

[0040] Figure 7 shows a cross-sectional view from the side of the nozzle of one possible step feature 702 of a double nozzle, according to an illustrative embodiment of the invention. In this view, an outer nozzle 704 and an inner nozzle 706 are shown interfacing at or near the step feature 702. The outer nozzle 704 includes an interior surface 708 (depicted without diagonal shading). In this embodiment, the step feature 702 can be formed in the outer nozzle 704 and perform the same or substantially the same function as described above.

[0041] While the invention has been particularly shown and described with reference to specific preferred embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the following claims.

What is claimed is:

1. A double nozzle for a laser processing head, the double nozzle comprising:

an inner body portion having (i) an interior surface defining a first bore, and (ii) an exterior surface, the bore aligned with a central longitudinal axis of the body; and

an outer body portion having an interior surface defining a second bore that is substantially aligned to the longitudinal axis, the outer body portion matingly engaged with a region of the exterior surface of the inner body portion,

wherein the region between the exterior surface of the inner body portion and the interior surface of the outer body portion defines at least six coaxial fluid flow paths through an interior annular flow volume of the double nozzle, each fluid flow path defined at least in part by a corresponding feature formed in at least one of the inner body portion or the outer body portion.

2. The double nozzle of claim 1 wherein the region includes an interface between the exterior surface of the inner body portion and the interior surface of the outer body portion.

3. The double nozzle of claim 1 wherein the coaxial fluid flow paths are shaped to increase fluid flow and uniformity of fluid flow through the double nozzle.

4. The double nozzle of claim 1 wherein each of the fluid flow paths is defined at least partially by a corresponding feature in the exterior surface of the inner body portion.

5. The double nozzle of claim 1 wherein each of the fluid flow paths is defined at least partially by a corresponding feature in the interior surface of the outer body portion.

6. The double nozzle of claim 1 wherein each of the fluid flow paths includes a scalloped or curved surface.

7. The double nozzle of claim 2 wherein the interface between the exterior surface of the inner body portion and the interior surface of the outer body portion is at least partially defined by one or more step features.

8. The double nozzle of claim 1 wherein each of the features is configured to assist with seating and alignment of the inner body portion relative to the outer body portion during assembly of the double nozzle.

9. The double nozzle of claim 1 wherein the substantial alignment is less than about 0.002 inches.

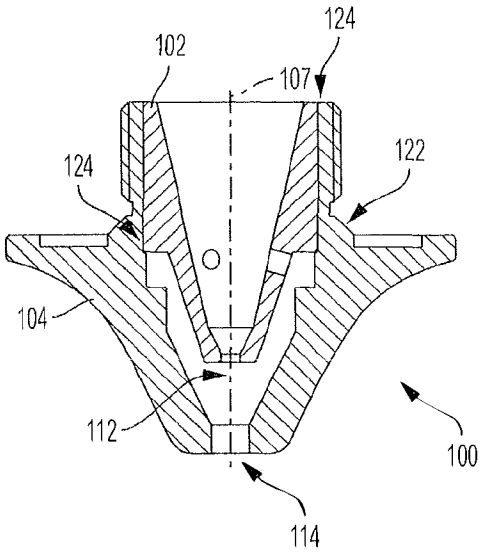

102
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FIG. 1

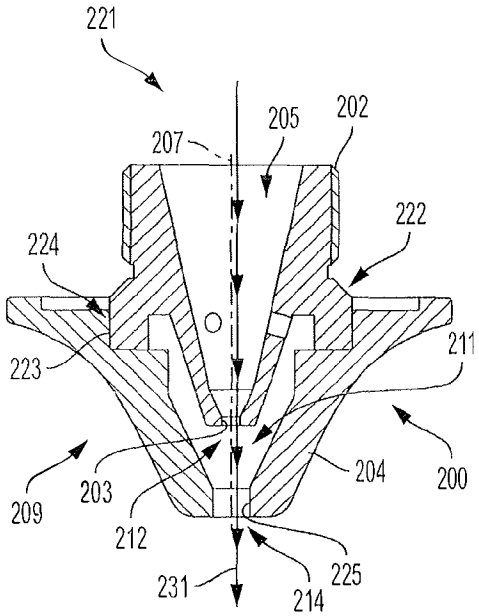

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FIG. 2

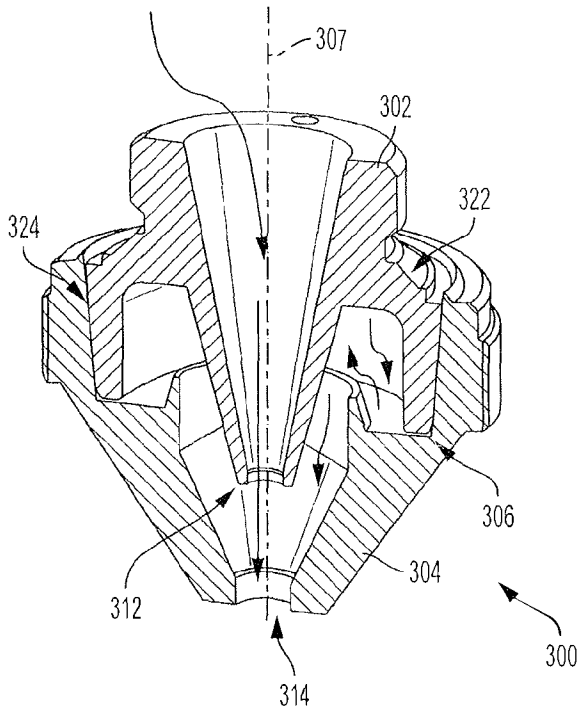


FIG. 3

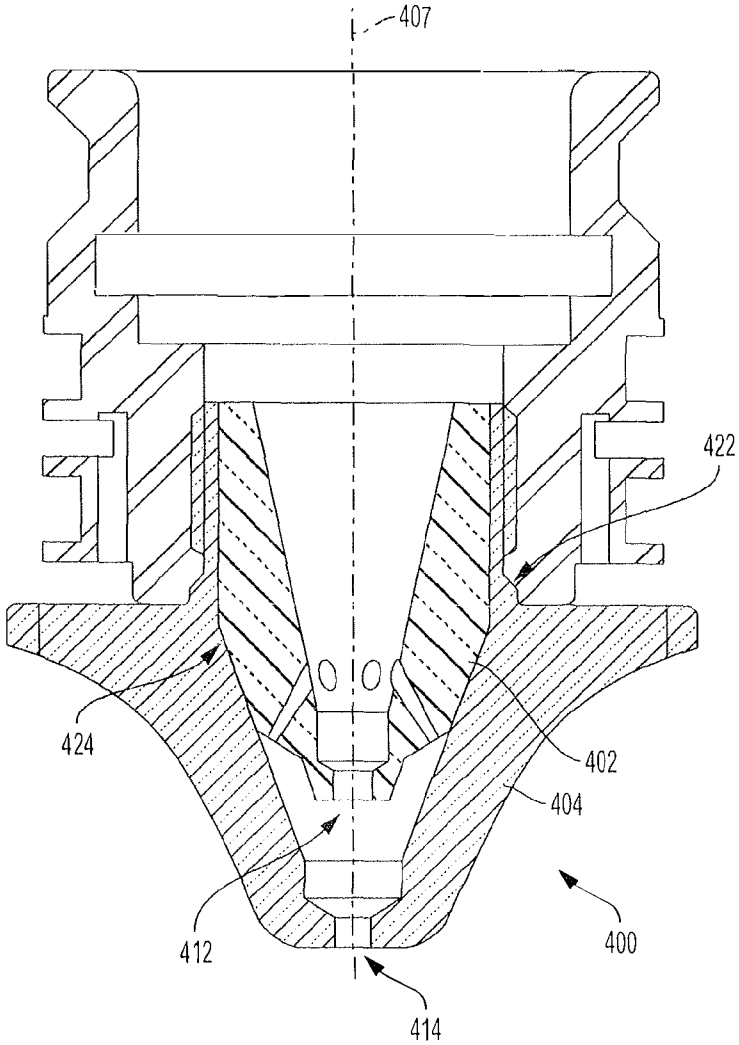


FIG. 4

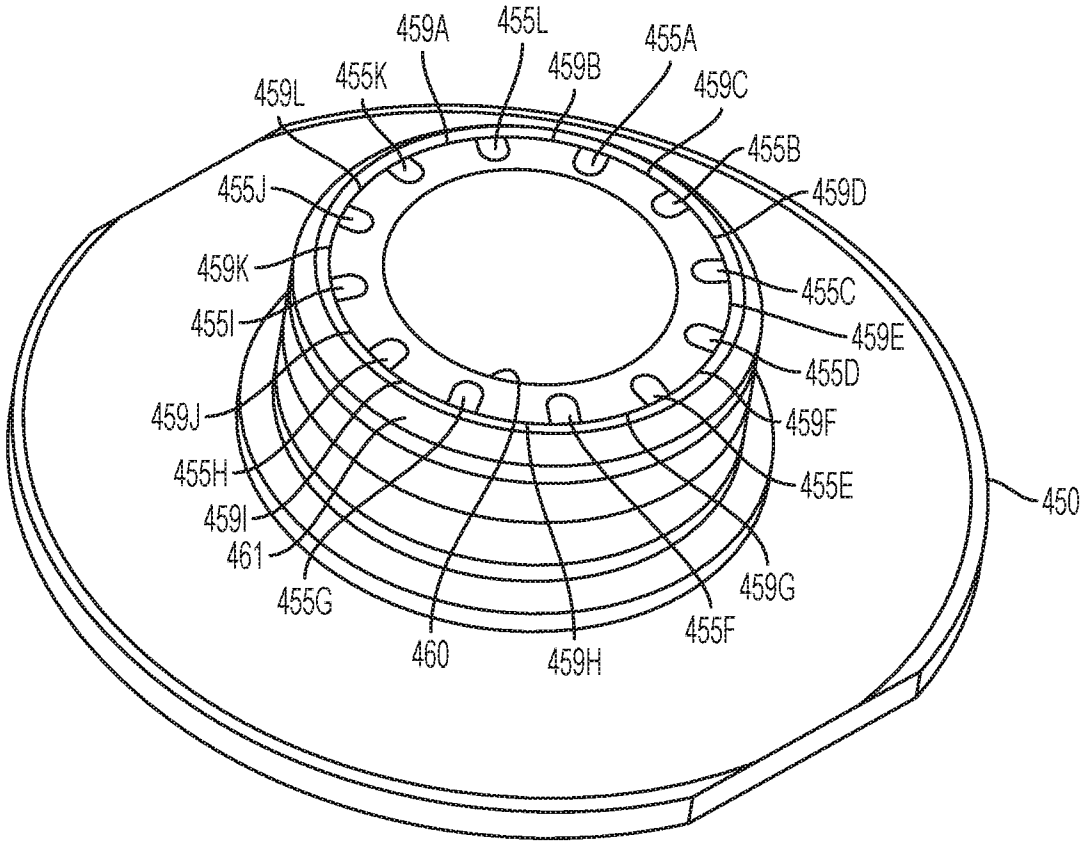

459A
455L
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459L
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459C
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455J
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455F
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459H

FIG. 4A

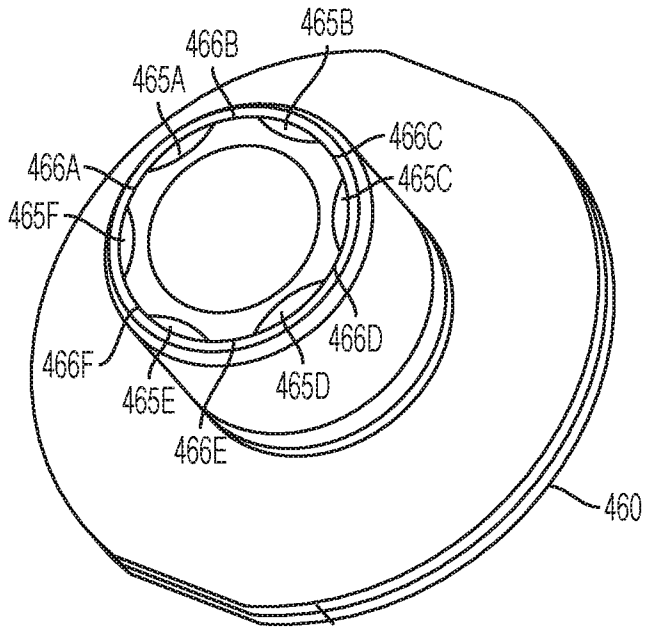

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466C
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465C
465F
466D
466F
465D
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FIG. 4B

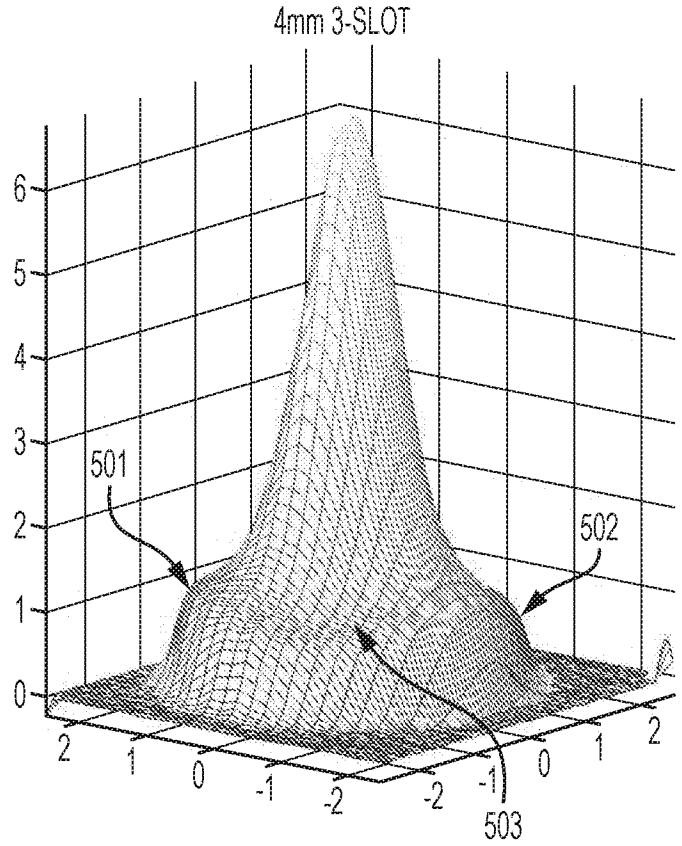

4mm 3-SLOT
501
502
503
6
5
4
3
2
1
0
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1
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-1
-2
-2
-1
0
1
2

FIG. 5A

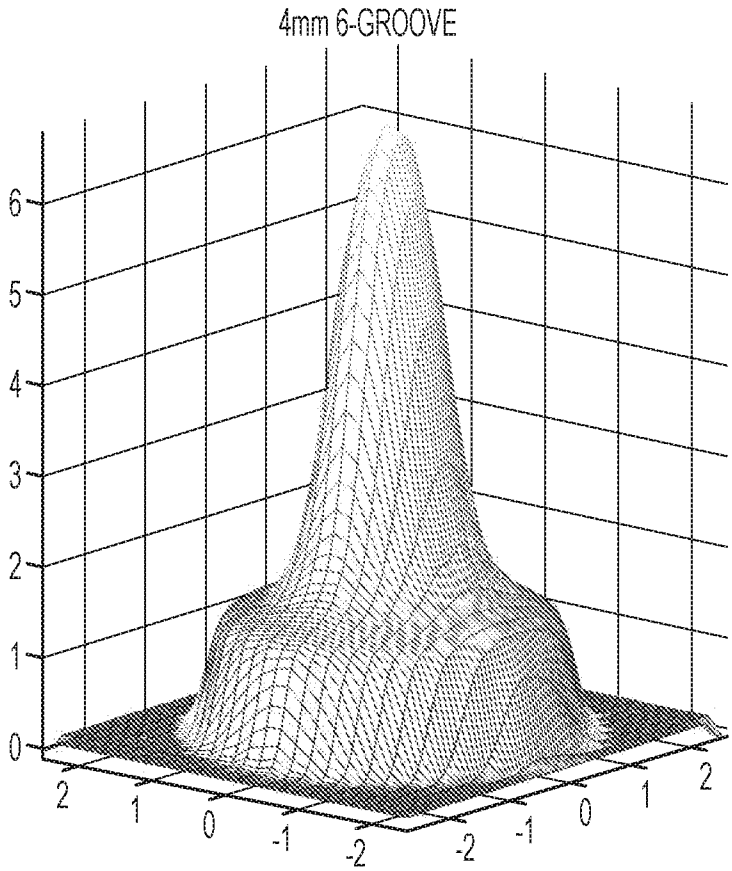

4mm 6-GROOVE
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1
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-1
-2
-2
-1
0
1
2

FIG. 5B

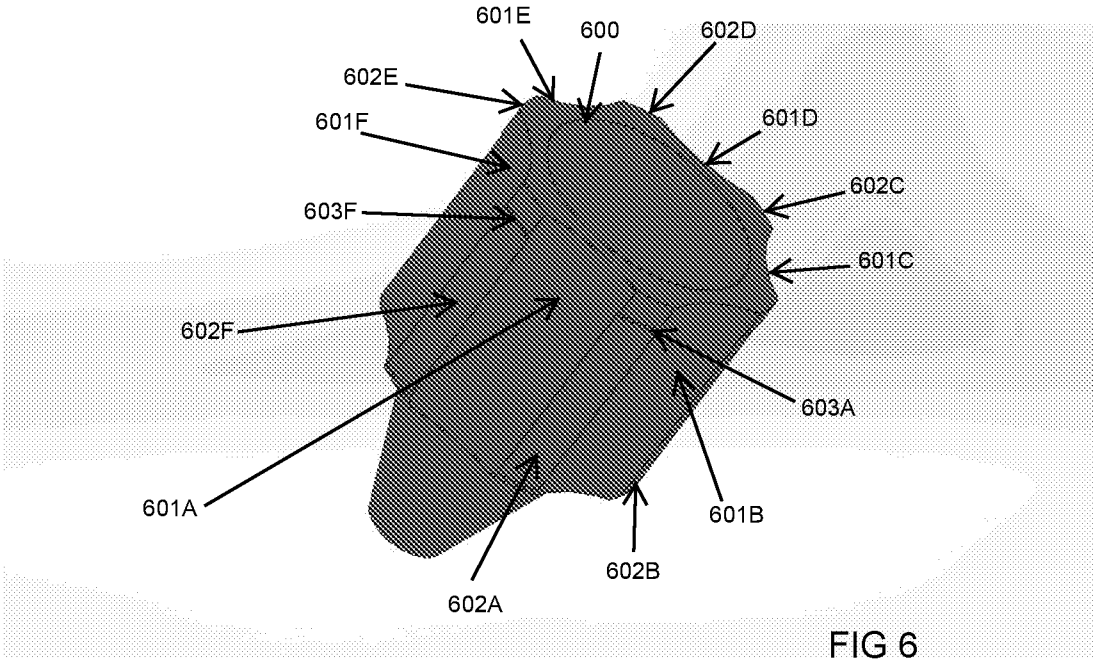

601E
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601F
601D
603F
602C
601C
602F
603A
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602B
602A

FIG 6

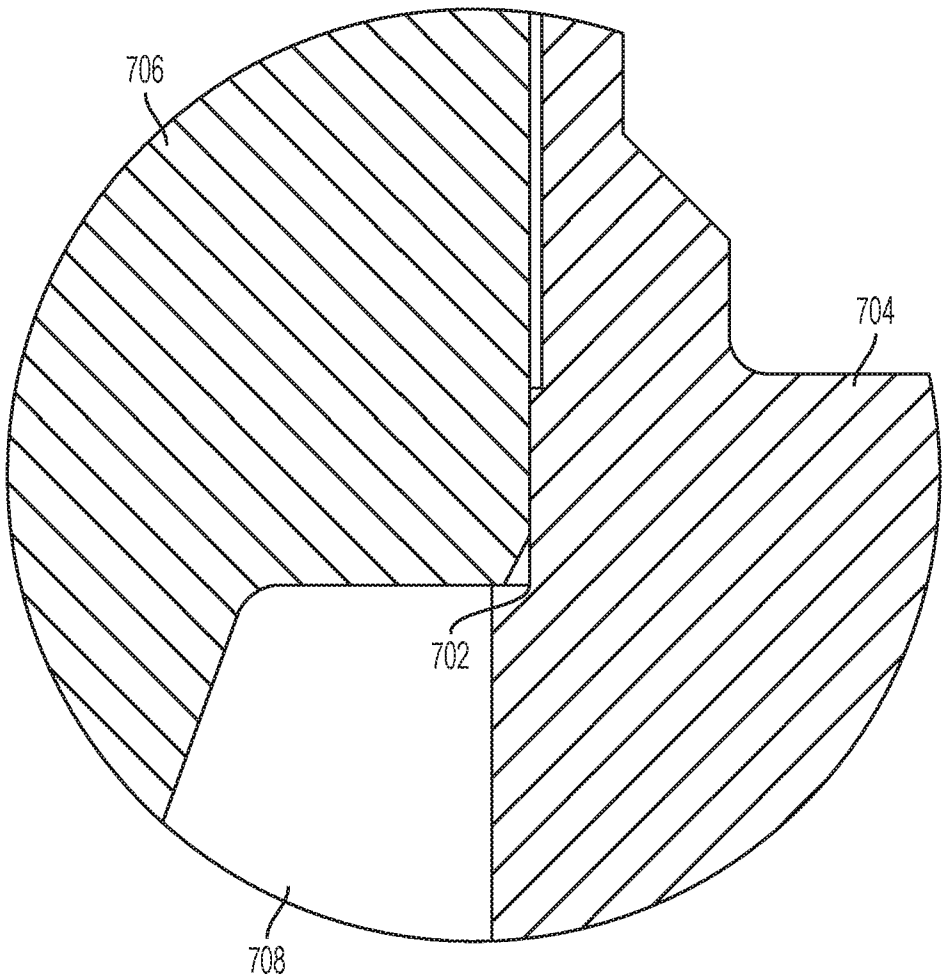


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/041582

A. CLASSIFICATION OF SUBJECT MATTER
INV. B23K26/14 H05H1/34
ADD.

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)
B23K H05H

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP H11 90672 A (AMADA CO LTD) 6 April 1999 (1999-04-06) abstract; figures 1, 2, 5 -----	1-9

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 August 2017	05/09/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Cazacu, Corneliu

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2017/041582

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP H1190672 A	06-04-1999	JP 3749356 B2	22-02-2006
		JP H1190672 A	06-04-1999