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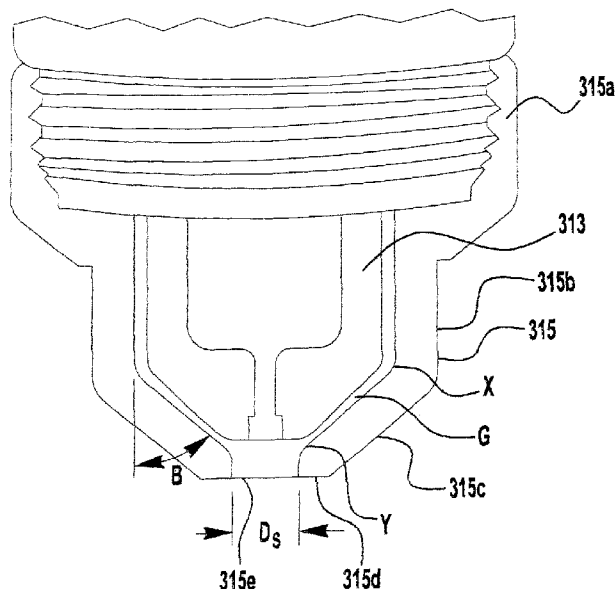
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**FIG. 6**

(57) Abstract: Embodiments of the present invention are directed to an air cooled, retract-start plasma cutting torch having improved performance. The torch comprises any one, or a combination of an improved nozzle (313), electrode, shield cap (315) and swirl ring, where these components have improved geometries and physical properties which optimize plasma jet performance during cutting.



**IMPROVED AIR COOLED PLASMA TORCH AND COMPONENTS THEREOF****TECHNICAL FIELD**

5 [01] Devices, systems, and methods consistent with the invention relate to cutting, and more specifically to devices, systems and methods related to plasma arc cutting torches and components thereof.

**BACKGROUND**

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[02] In many cutting, spraying and welding operations, plasma arc torches are utilized. With these torches a plasma gas jet is emitted into the ambient atmosphere at a high temperature. The jets are emitted from a nozzle and as they leave the nozzle the jets are highly under-expanded and very focused. However, because of the high temperatures associated with the ionized plasma jet many of the components of the torch are susceptible to failure. This failure can significantly interfere with the operation of the torch and prevent proper arc ignition at the start of a cutting operation.

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[03] Further limitations and disadvantages of conventional, traditional, and proposed approaches will become apparent to one of skill in the art, through comparison of such approaches with embodiments of the present invention as set forth in the remainder of the present application with reference to the drawings.

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**BRIEF SUMMARY OF THE INVENTION**

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[04] In order to improve electrical and thermal properties, an air cooled plasma cutting torch according to claim 1 is proposed. Preferred embodiments may be taken from the subclaims, description and drawings. An exemplary embodiment of the present invention is an air cooled plasma torch having and components thereof that are designed to optimize performance and durability of the torch. Specifically, exemplary embodiments of the present invention can have an improved electrode, nozzle, shield and/or swirl ring configuration.

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**BRIEF DESCRIPTION OF THE DRAWINGS**

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[05] The above and/or other aspects of the invention will be more apparent by describing in detail exemplary embodiments of the invention with reference to the accompanying drawings, in which:

5 [06] FIG. 1 is a diagrammatical representation of an exemplary cutting system which can be used with embodiments of the present invention;

[07] FIG. 2 is a diagrammatical representation of a portion of the head of a torch utilizing known components;

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[08] FIG. 3 is a diagrammatical representation of a portion of the head of an exemplary embodiment of a torch of the present invention;

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[09] FIGs. 4a-4c are diagrammatical representations of an exemplary embodiment of an electrode of the present invention;

[10] FIGs. 5a - 5b are diagrammatical representations of an exemplary embodiment of a nozzle of the present invention;

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[11] FIG. 6 is a diagrammatical representation of an exemplary embodiment of a shield of the present invention;

[12] FIG. 7 is a diagrammatical representation of an exemplary embodiment of a swirling ring of the present invention; and

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[13] FIG. 8 is a diagrammatical representation of a comparison between the plasma arc and plasma jet flow of embodiments of the present invention, as compared to known air cooled torch configurations.

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## DETAILED DESCRIPTION

[14] Reference will now be made in detail to various and alternative exemplary embodiments and to the accompanying drawings, with like numerals representing substantially identical structural elements. Each example is provided by way of explanation, and not as a limitation. In fact, it will be apparent to those skilled in the art that modifications

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and variations can be made without departing from the scope or spirit of the disclosure and claims. For instance, features illustrated or described as part of one embodiment may be used on another embodiment to yield a still further embodiment. Thus, it is intended that the present disclosure includes modifications and variations as come within the scope of  
5 the appended claims and their equivalents.

[15] The present disclosure is generally directed to air cooled plasma arc torches useful various cutting, welding and spraying operations. Specifically, embodiments of the present invention are directed to air cooled plasma arc torches. Further exemplary embodiments are directed to air cooled plasma arc torches which are retract arc torches. As generally understood, retract arc torches are torches where the electrode is in contact with the nozzle for arc initiation and then the electrode is retracted from the nozzle so that the arc is then directed through a throat of the nozzle. In other types of retract torches, the electrode stays stationary and the nozzle is moved. Embodiments of the present invention apply to  
10 both types. The construction and operation of these torches are generally known, and thus their detailed construction and operation will not be discussed herein. Further, embodiments of the present invention can be used in either handheld or mechanized plasma cutting operations. It should be noted that for purposes of brevity of clarity, the following discussion will be directed to exemplary embodiments of the present invention which are primarily directed to a hand held plasma torch for cutting. However, embodiments of the present invention are not limited in this regard and embodiments of the present invention can be used in welding and spraying torches without departing from the spirit or scope of the present invention. Various types and sizes of torches are possible at varying power levels if desired. For example, exemplary embodiments of the present invention can be used on  
25 cutting operation that utilize a cutting current in the range of 40 to 100 amps, and can cut workpieces having a thickness of up to 0.075 inches, and in other embodiments can cut workpieces of a thickness of up to 1.5 inches. Further, the torches and components described herein could be used for marking, cutting or metal removal. Additionally, exemplary embodiments of the present invention, can be used with varying currents and varying  
30 power levels. The construction and utilization of air coolant systems of the type that can be used with embodiments of the present invention are known and need not be discussed in detail herein.

[16] Turning now to Figure 1, an exemplary cutting system 100 is shown. The system  
35 100 contains a power supply 10 which includes a housing 12 with a connected torch as-

sembly 14. Housing 12 includes the various conventional components for controlling a plasma arc torch, such as a power supply, a plasma starting circuit, air regulators, fuses, transistors, input and output electrical and gas connectors, controllers and circuit boards, etc. Torch assembly 14 is attached to a front side 16 of housing. Torch assembly 14 includes within it electrical connectors to connect an electrode and a nozzle within the torch end 18 to electrical connectors within housing 12. Separate electrical pathways may be provided for a pilot arc and a working arc, with switching elements provided within housing 12. A gas conduit is also present within torch assembly to transfer the gas that becomes the plasma arc to the torch tip, as will be discussed later. Various user input devices 20 such as buttons, switches and/or dials may be provided on housing 12, along with various electrical and gas connectors.

[17] It should be understood that the housing 12 illustrated in FIG. 1 is but a single example of a plasma arc torch device that could employ aspects of the inventive the concepts disclosed herein. Accordingly, the general disclosure and description above should not be considered limiting in any way as to the types or sizes of plasma arc torch devices that could employ the disclosed torch elements.

[18] As shown in FIG. 1, torch assembly 14 includes a connector 22 at one end for attaching to a mating connector 23 of housing 12. When connected in such way, the various electrical and gas passageways through the hose portion 24 of torch assembly 14 are connected so as to place the relevant portions of torch 200 in connection with the relevant portions within housing 12. The torch 200 shown in FIG. 1 has a connector 201 and is of the handheld type, but as explained above the torch 200 can be of the mechanized type. The general construction of the torch 200, such as the handle, trigger, etc. can be similar to that of known torch constructions, and need not be described in detail herein. However, within the torch end 18 are the components of the torch 200 that facilitate the generation and maintenance of the arc for cutting purposes, and some of these components will be discussed in more detail below. Specifically, the some of the components discussed below, include the torch electrode, nozzle, shield and swirl ring.

[19] FIG. 2 depicts the cross-section of an exemplary torch head 200a of a known construction. It should be noted that some of the components of the torch head 200a are not shown for clarity. As shown, the torch 200a contains a cathode body 203 to which an electrode 205 is electrically coupled. The electrode 205 is inserted into an inside cavity of a

nozzle 213, where the nozzle 213 is seated into a swirl ring 211 which is coupled to an isolator structure 209 which isolates the swirl ring, nozzle etc. from the cathode body 203. The nozzle 213 is held in place by the retaining cap assembly 217a-c. As explained previously, this construction is generally known.

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[20] As shown, the electrode 205 has a thread portion 205a which threads the electrode 205 into the cathode body 203. The electrode 205 also has a center helical portion 205b. The helical portion 205b has a helical coarse thread-like pattern which provides for flow of the air around the section 205b. However, because of this section special tooling is required to remove the electrode 205 from the cathode body 203. Downstream of the center portion 205b is a cylindrical portion 205c, which extends to the distal end 205d of the electrode 205. As shown, the cylindrical portion is inserted into the nozzle 213, such that the distal end 205d is close to the throat 213b of the nozzle 213. The cylindrical portion can include a flat surface at the center portion 205b so that a specialized tool can grab the electrode 205 to remove it from the cathode. Typically, the transition from the cylindrical portion 205c to the distal end 205d includes a curved edge leading a flat end face on the distal end 205d. In a retract start torch this flat end face is in contact with the inner surface of the nozzle 213 to initiate the arc start. Once the arc is ignited the electrode 205 is retracted and a gap is created between the electrode 205 and the nozzle 213 (as shown), at which time the plasma jet is directed through the throat 213b of the nozzle 213 to the workpiece. It is generally understood, that with this configuration, known electrodes 205 can begin to fail during arc initiation after about 300 arc starts. Typically, the electrode 205 is chrome or nickel plated to aid in increasing the life of the electrode 205. Once this event begins to occur, the electrode 205 may need to be replaced.

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[21] Also, as shown a hafnium insert 207 is inserted into the distal end 205d of the electrode 205. It is generally known that the plasma jet/arc initiates from this hafnium insert 207, which is centered on the flat surface of the distal end 205d.

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[22] As briefly explained above, the torch 200a also includes a nozzle 213 which has a throat 213b through which the plasma jet is directed during cutting. Also, as shown the nozzle 213 contains a cylindrical projection portion 213a through which the throat 213b extends. This projection portion 213a provides for a relatively long throat 213b and extends into an cylindrical opening in the shield 215, which also has a cylindrical projection portion 215a.

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As shown, an air flow gap is created between each of the projection portions 213a/215a to

allow a shielding gas to be directed to encircled the plasma jet during cutting. In air cooled torches, each of these respective projection portions 213a/215a direct the plasma jet and shield gas to the getting operation. However, because of the geometry of each of the nozzle 213 and the shield cap 215, these projection portions can tend to heat up significantly. This heat can cause the heat band on the nozzle 213 to extend significantly along its length. This increased heat band and high heat can cause the components to deteriorate and fail, causing the need for replacement. Further, their performance can degrade over time which can cause less than optimal cutting results. Therefore, improvements are needed for known air cooled torch configurations.

[23] Turning now to Figure 3, an exemplary embodiment of a torch head 300 is shown. The torch head 300 can be used in the torch 200 shown in Figure 1, and like Figure 2, not all of the components and structure is shown to simplify the Figure (for example, handle, outer casing, etc.). Further, in many respects (except those discussed below) the construction and operation of the torch head 300 is similar to known torch heads, such that all of the details of its construction need not be discussed herein. However, as will be explained in more detail below, each of the electrode 305, nozzle 313, shield cap 315 and swirl ring 311 of the torch head 300 are constructed differently than known torches and torch components and provide for a cutting torch with optimized cutting performance and durability. Further, like the torch 200a in Figure 2, the torch 300 in Figure 3 is an air cooled, retract-type torch. Further understanding of exemplary embodiments of the present invention is provided in the discussions below, in which each of the electrode, nozzle, shield cap and swirl ring are discussed.

[24] Turning now to Figures 4a through 4c, an exemplary embodiment of an air cooled electrode 305 of the present invention is shown. The electrode has a thread portion 305a which allows the electrode 305 to be secured to the cathode body in the torch head. Adjacent to the thread portion 305a is a wider securing portion 305b which is larger in diameter than the thread portion 305a and the downstream cylindrical portion 305c (discussed more below). Unlike known electrodes the securing portion 305b has a nut portion 305e which is configured to allow a standard socket-type tool to remove and install the electrode 305. As explained previously, known electrodes do not have such a configuration and require a special tool for installation and removal. Embodiments of the present invention allow for standard tools to be used because of the nut portion 305e. In the embodiment shown, a six-sided hex-head nut configuration is used. Of course, other standard nut configurations

can be used. As shown, adjacent the nut portion 305e is a seat portion 305f which has the widest diameter  $D'$  of the electrode 305. This portion is used in aiding the seating of the electrode 305 within the cathode body.

[25] Adjacent to the nut portion 305e is a cylindrical portion 305c, which has an end portion 305d with a flat end face 305g. The cylindrical portion 305c has a diameter  $D$ , where the ratio of the widest diameter  $D'$  to the diameter  $D$  is in the range of 1.4 to 1.8, and in other exemplary embodiments is in the range of 1.4 to 1.6. Further, as compared to known air cooled electrodes, which are used for cutting applications in the range of 40 to 100 amps, the diameter  $D$  of the cylindrical portion 305c is in the range of 15 to 25% larger than the diameter of the cylindrical portion of known electrodes. In exemplary embodiments, the maximum diameter of the cylindrical portion 305c is in the range of 0.2 to 0.4 inches. The end portion 305d of the electrode 305 has flat surface portion 305g which has a hafnium insert 307 inserted into a center point of the flat surface portion 305g. The use and function of the hafnium insert 307 is generally known and will not be discussed in detail herein. However, in embodiments of present invention, the hafnium insert 307 is a cylindrically shaped insert which has a length to diameter ratio in the range of 2 to 4, and in other exemplary embodiments the length to diameter ratio is in the range of 2.25 to 3.5. Thus, exemplary embodiments of the present invention allow for optimal current transfer into the insert 307 while at the same time providing optimum heat transfer abilities. As such, the usable life of the hafnium insert and electrode of the present invention is greatly increased over known configurations. It is noted that although the hafnium insert 307 is described as cylindrical it is understood that in some exemplary embodiments, either or both of the ends of the insert 307 may not be flat because, in some exemplary embodiments, the ends may have either a generally concave or convex shape.

[26] As shown in Figures 4a to 4c the end portion 305d transitions to the flat surface portion 305g via a generally curved edge. The flat surface portion 305g is the portion of the face of the end of the electrode 305 which is flat, as opposed to the transition edge which transitions the flat surface portion 305g to the side walls of the cylinder portion 305c. However, unlike known electrodes, the flat surface portion 305g has a diameter such that the ratio of the diameter  $d$  to the diameter  $D$  is in the range of 0.8 to 0.95. In further exemplary embodiments, the ratio is in the range of 0.83 to 0.91. Such a ratio optimizes the surface contact between the flat surface portion 305g and the interior of the nozzle 313 during arc start, while at the same time ensuring that there are minimal heat concentrations and ideal



heat transfer between the flat surface portion 305g and the cylindrical portion 305c. As explained above, in a retract-start, air cooled torch the electrode 305 is placed into contact with the nozzle 313 via the flat surface portion 305g. This is typically done by a spring type mechanism (not shown for clarity). This allows an arc to be started between the insert 307 and the nozzle 313 at start and once the shield gas air flows reaches a desired pressure level, the electrode is retracted from the nozzle 313 - creating a gap - which then causes the arc to move from the nozzle 313 to the workpiece. By having an electrode 305 with a configuration described above, embodiments of the present invention can significantly increase the usable life of the electrode 305, and thus the torch. This ensures that optimal starting and cutting is maintained with minimal downtime and replacement.

[27] It is further noted that in some exemplary embodiments, the electrode 305 can be made primarily of copper and is not coated with either chrome or nickel.

[28] Turning now to Figures 5a and 5b, an exemplary embodiment of a nozzle 313 of the present invention is depicted. The nozzle 313 has an end portion 313a which allows the nozzle 313 to be secured by the retainer assembly. Adjacent to the end portion 313a is a main cylindrical portion 313b which extends from the end portion 313a to a tip portion 313c, where the tip portion 313c transitions the nozzle from the cylindrical portion 313b to a tip surface portion 313h. Unlike known nozzles, the tip portion 313c is an angled portion - as shown - which does not have any additional cylindrical extension portion (e.g., see 213a in Figure 2). Rather, the tip surface portion 313h is directly adjacent to the angled surface of the tip portion 313c such that the tip portion 313c is a truncated cone shape. This is unlike known nozzle configurations for air cooled torches. The angled portion of the tip portion 313h has an angle A in the range of 30 to 60 degrees, as shown. In other exemplary embodiments, the angle A is in the range of 40 to 50 degrees. Further, as shown, the nozzle 313 contains a cavity 313i into which the electrode 305 is inserted as shown in Figure 3. The nozzle 313 also has a throat 313d through the tip portion 313c having a length L, where the throat has a length to diameter ratio in the range of 3 to 4.5, where the diameter is the smallest diameter of the throat 313d. In other exemplary embodiments, the ratio is in the range of 3 to 4. The length L is the length of the throat 313d from the inner surface of the cavity 313i to the tip surface 313h. This aspect of the nozzles of the present invention aids in minimizing the voltage drop of the plasma jet/arc along the length of the throat 313d. In known nozzles, the voltage drop can be appreciable, thus adversely affecting the operation and effectiveness of the torch. In exemplary embodiments of the present invention,

embodiments of the present invention can provide an optimized performance where the maximum voltage drop across the throat is less than 20 volts, regardless of the operational current level and gas flow rates and patterns. In other exemplary embodiments, the maximum voltage drop is in the range of 5 to 15 volts, and in yet further exemplary embodiments, the voltage drop is less than 5 volts. That is, nozzle and throat configurations of  
5       embodiments of the present invention can achieve the above optimal voltage drop performance over a current operational range of 40 to 100 amps with all known operational gas flow patterns and rates. This performance has not been attained by known configurations. Also, as shown, the throat 313d has an inlet portion 313e which transitions from a  
10       wider opening to a narrow throat portion 313f - which has the smallest diameter of the throat 313d. The narrow throat portion 313f transitions to a wider expansion portion 313g which has an exit diameter that is larger than the diameter of the narrow throat portion 313f and is smaller than the diameter than the inlet to the inlet portion 313e. That is, the diameter of the inlet to the inlet portion 313e is larger than the diameter of the outlet of the ex-  
15       pansion portion 313g. In exemplary embodiments of the present invention, the ratio of inlet diameter (diameter at most upstream point of inlet 313e) to outlet diameter (diameter at most downstream point of expansion 313g) is in the range of 1.5 to 4.

[29]       Embodiments of the nozzle 313 as described herein have significantly approved  
20       thermal properties over known nozzle configurations. Specifically, nozzles of the present invention operate at a much cooler temperature and have a much smaller heat band than known nozzles. Because of the configuration of the known nozzles, their tips can reach very high heat levels, which tends to cause molten spatter to adhere to the tips of the nozzles and can lead to the premature failure of the nozzle. Specifically, embodiments of the  
25       present invention provide a heat band which is contained within the tip portion 313c and has minimal extension into the cylindrical portion 313b. In fact, in some exemplary embodiments, the nozzle 313 and tip 313c is configured such that the heat band does not extend to the cylindrical portion 313b at all during operation. It should be understood that the heat band is the shortest band (or length) of the nozzle 313, measured from the tip surface  
30       313h, in which the average temperature of the nozzle 313 reaches 350 degrees C during sustained operation 100 amps, where sustained operation is at least an amount of time where the temperature of the nozzle 313 reaches a temperature equilibrium during operation. (Of course, it is to be understood that normal operation includes normal flow of cooling and shielding gas at 100 amps). This is not achievable with known nozzle structures and  
35       configurations. An exemplary heat band 313z is shown in Figure 5b, where the heat band

313z stays within the tip portion 313c during normal operation and does not extend to the cylindrical portion 313b. Thus, exemplary embodiments of the present invention provide optimized thermal properties to achieve optimized cutting performance and component life. To be clear, it is understood that during operation, the temperature at the tip of the nozzle 313 is the highest, and can reach temperatures of 600 degrees C. In prior nozzle configurations, the heat band typically extends beyond the nozzle extension portion 213a and the tapered portion (see Figure 2) and extends into the cylindrical portion. Exemplary embodiments of the present invention are considerably improved as the heat band is entirely within the most distal portion of the nozzle - the truncated conical portion - as shown in Figure 5b.

[30] Figure 6 depicts an exemplary embodiment of a shield cap 315 installed on the end of the torch and shielding the nozzle 313. The function of the shield cap is generally known and need not be described in detail herein. However, like the nozzle 313 discussed above, the shield cap 315 does not have the extension portion 215a shown in Figure 2. Instead, like the nozzle 313, the tip of the shield cap is a truncated cone - as shown in Figure 6. The shield cap 315 has a threaded end portion 315a which allows the shield cap to be secured to the retainer assembly 217c. The shield cap 315 also has a cylindrical portion 315b which is positioned in between the end portion 315a and the shield cap tip portion 315c. When the torch is assembled the cylindrical portion 315b of the shield cap 315 is adjacent to the cylindrical portion 313b of the nozzle 313, as shown in Figure 6, such that a gap exists between the nozzle 313 and the shield cap 315. The shielding gas is directed through this gap during a cutting operation. In exemplary embodiments of the present invention, the gap between the respective cylindrical portions is in the range of 0.01 to 0.06 inches, and in other exemplary embodiments, is in the range of 0.2 to 0.4 inches. Also, as shown, the shield cap 315 has a tip portion 315c which is also shaped as a truncated cone having a tip end surface 315d. Unlike known shield caps, there is not cylindrical extension portion as shown in Figure 2. Further, the shield cap 315 has a circular opening 315e which is centered on the throat 313d when the components are assembled as shown. In exemplary embodiments of the present invention, the opening has a diameter  $D_s$  which is in the range of 1.25 to 4.1 times the smallest diameter of the nozzle throat 313d (diameter of the narrow throat portion 313f). In other exemplary embodiments, the diameter  $D_s$  is in the range of 1.75 to 2.5 times the smallest diameter of the throat 313d. Further, in exemplary embodiments of the present invention, the diameter  $D_s$  is greater than the exit diameter of the throat expansion portion 313g, but less than the diameter of the tip surface portion

313h. In exemplary embodiments of the present invention, the ratio of the diameter  $D_s$  to the diameter of the tip surface portion 313h of the nozzle 313 is in the range of 0.98 to .9.

[31] Additionally, as shown in Figure 6, the tip portion 315c of the shield cap 315 is constructed such that the interior angled surface 315f of the tip portion 315c is angled at an angle B which is larger than the angle A (on the nozzle) so that the gap G between the exterior of the nozzle 313 and shield cap 315 - in their respective tip regions - decreases in width along the length of the gap G from the upstream end X to the downstream end Y (whereas the angles A and B are measured from a line parallel to the centerline of the torch). In exemplary embodiments of the present invention, the angle B is in the range of 35 to 70 degrees, but is larger than the angle A. In other exemplary embodiments, the angle B is in the range of 45 to 60 degrees. That is, the gap distance between the interior surface of the shield cap 315 at the beginning (point x) of the tip portion 315c and the exterior of the nozzle (measured normal to the interior surface of the shield cap) is greater than the gap distance between the interior surface of the shield cap 315 at the end (point y) of the tip portion 315c and the exterior of the nozzle (measured normal to the interior surface of the shield cap). By decreasing the width of the gap G the shield gas air flow is accelerated near the exit of the torch - which aids in stabilizing the plasma jet and improves performance of the torch. In exemplary embodiments of the present invention, the width of the gap at point X is in the range of 0.03 to 0.05 inches. Further, in exemplary embodiments, the width of the of the gap G decreases by 30 to 60 % from point X to point Y. For clarity, the point X is located at the widest point between the interior of the shield cap 315 and the exterior of the nozzle 313, along their respective tip portions, and the point Y is located at the narrowest point between the interior of the shield cap 315 and the exterior of the nozzle 313, along their respective tip portions. It is noted that while in some exemplary embodiments, the point Y is located at the transition between the exterior angled surface of the nozzle tip portion 313c to the tip surface 313h, this may not be the case in other exemplary embodiments. Improved torch performance and durability can be achieved by incorporating exemplary embodiments of the components discussed above.

[32] It is also noted that in some exemplary embodiments, the shield cap 315 can have additional gas flow ports 319 (depicted in Figure 3). These ports 319 provide additional gas flow to the cutting area and can help cool the shield cap and keep debris away from the cutting area.

[33] Turning now to Figure 7, an exemplary embodiment of a swirl ring 311 is depicted. Unlike existing swirl rings, embodiments of the present invention have two regions, an upper region 311a and a lower region 311b. Known swirl rings typically have a single region having a constant outside diameter along its entire length, and where the length of the ring is relative short as compared to what is shown in Figure 7. For example, as shown in Figure 2, the swirl ring 211 extends from the top edge of the nozzle 205 to the bottom of the isolator 209. However, this configuration can lead to early failure of the swirl ring 211, particularly at the top of the swirl ring 211 where it connects with the isolator 209. Exemplary embodiments of the present invention eliminate this failure mode, as well as improve the overall performance of the ring and the torch. As shown in Figure 7, the upper portion 311a has a larger outer diameter than the lower region 311b, and in some exemplary embodiments has a length longer than that of the lower region 311b. This upper region has a cavity 311f into which the isolator 209 is inserted (see Figure 3). This insertion aids in strengthening and centering of the swirl ring 311. The swirl ring 311 can be press fit, screwed onto, or simply seated with the isolator 209. On the outside surface of the upper portion 311a of the ring 311 are a plurality of channels 311c. The channels 311c aid in stabilizing the gas flow to the bottom portion 311b of the swirl ring 311. Known torches do not employ such flow channels, and as such the gas flow can be turbulent as it reaches the swirl ring. This turbulent flow can compromise the performance of the torch. Embodiments of the present invention use the channels 311c to stabilize the gas flow from the upper regions of the torch head to the lower portion 311b of the ring 311. The stabilized flow is then directed to the holes 311d/311e in the bottom portion 311b and because the flow has been stabilized the performance of these holes are optimized. As shown, the bottom portion 311b has a plurality of gas flow holes 311d/311e which pass from the outer surface of the bottom portion 311b to an inner cavity of the bottom portion 311b. In some exemplary embodiments, the channels 311c run along the entire length of the upper portion and run parallel to a centerline of the swirl ring. However, in other exemplary embodiments, the channels 311c can run along only a portion of the length of the upper portion, and in further embodiments, the channels can be angled such that they impart a swirl flow to the gas passing through the channels. As shown, exemplary embodiments have at least four rings of holes, where at least two upper rings 311d have a first hole configuration and at least two lower rings 311e have a second configuration. The operation of the holes will be discussed below.

[34] As discussed previously, prior to start of the torch, the nozzle and the electrode

are in contact with each other. This can be attained via a mechanical spring bias. When the operation is started, both current and gas is caused to flow. The current ignites the arc and the gas pressure will cause the cathode/electrode to be pushed away from the nozzle - pushing against the spring bias. In exemplary embodiments of the present invention, the upper holes 311d facilitate this retraction via the gas pressure. That is, the holes 311d are formed such that each of their respective centerlines is perpendicular to the centerline of the ring 311. Further, in exemplary embodiments of the present invention, all of the holes 311d have the same dimensions (e.g., diameter) and each of the upper rows of holes 311d have the same number of holes 311d (i.e., same radial spacing). However, in other exemplary embodiments the holes 311d can have varying diameters (e.g., two sets of holes, a first diameter and a second diameter), and/or each of the rows of holes 311d can have different hole spacing. That is, in some exemplary embodiments, the row of holes 311d closest to the upper portion 311a can have less or more holes 311d than the adjacent row of holes. The configuration can be optimized to achieve the desired performance. In the embodiment shown in Figure 7 the holes 311d have a cylindrical shape (circular cross-section), however in other exemplary embodiments, at least some of the holes can have non-circular cross-sections (e.g., elliptical, oval, etc.).

[35] Unlike the upper rows of holes 331d, the bottom rows of holes 311e are used to provide a swirl or rotation to the gas as it flows into the cavity adjacent the electrode 305. Thus, in exemplary embodiments of the present invention, the bottom rows of holes 311e have a different hole geometry, where the centerlines of the holes are angled with respect to the centerline of the ring 311. This angling directs the gas flow in such a way as to impart improved rotation in the gas flow. In exemplary embodiments of the present invention, the holes 311e are angled such that the centerlines of each of the respective holes 311e are have an angle in the range of 15 to 75 degrees relative to the centerline of the ring 311. In other embodiments, the angle is in the range of 25 to 60. In exemplary embodiments, the holes 311e are formed such that, while they are angled to the centerline of the ring 311 they are oriented such that their respective centerlines lie in a plane cutting through the ring 311 at the centerline of the holes 311e. That is, all of the holes centerlines are co-planar. However, in other exemplary embodiments, the holes 311e can also be angled such that their centerlines are not co-planar. That is, in some embodiments, the hole centerlines are angled towards the end bottom end of the ring 311 (i.e., angled towards the end of the torch). Such embodiments will impart both a swirl flow to the gas flow, but also project the gas flow downward.

[36] Much like the holes 311d in the upper rows, the holes 311e in the lower rows can have the same geometry and orientation, and there can be the same number of holes in each of the respective rows. However, in other exemplary embodiments, this need not be the case. For example, in some embodiments the holes 311e can have different diameters and/or cross-sections. Further, embodiments can utilize a different number of holes in each of the respective rows. Additionally, the angling of the holes can be varied, where a first grouping of holes 311e has a first angle relative to the ring centerline, and a second group of holes 311e has a second angle relative to the ring centerline. Further, in even other exemplary embodiments the holes 311e can have different orientations, where some holes are angled down and other are not, and can be angled down at a different angle. As an example, every other hole 311e within each respective row can have a different geometry/orientation, or the holes 311e in one row (the row adjacent the upper rows) can have a first geometry/orientation, while the holes 311e in the most distal row (away from the upper holes) can have a second geometry/orientation. As another example, in some exemplary embodiments, the lowest row of holes 311e (closest to the bottom of the ring 311) are angled both radially and downwardly, whereas the adjacent row of holes 311e are only angled radially. Of course the opposite configuration can also be used. Thus, embodiments of the present invention allow for the gas flow to be optimized - which greatly improves the performance of the torch and the stability of the plasma jet.

[37] Figure 8 depicts an exemplary comparison between the performance of a known torch and an exemplary torch of the present invention. As can be seen, various advantages can be achieved with embodiments of the present invention. For example, as shown with the prior art torch, the primary jet of the plasma core is very short and there is an abrupt gas expansion and high heat concentration at the exit of the nozzle. Further, because the shield gas exits the shield cap remote from the nozzle exit an eddy can be created in the region between the shield gas and the nozzle jet. This eddy can cause molten spatter to be retained in this region long enough to be adhered to the surface of the nozzle - ultimately causing early failure of the torch and its components, or otherwise degrading the cutting operation. This is to be compared to an exemplary torch of the present invention (right side). As shown, there is a more controlled exit velocity at the exit of the nozzle and little or no heat concentration at the exit of the nozzle and the primary jet core is considerably longer. This allows for more stable and consistent cutting of high thickness materials. Further, there is no eddy region which will allow spatter to be adhered to the nozzle 313.

[38] Therefore, various embodiments of the present invention, provide an improved air cooled, retract type cutting torch which can provide more precision for a longer period of type and a larger number of start cycles. For example, in embodiments of the present invention which use a cutting current in the range of 40 to 100 amps, embodiments of the present invention can more than double the number of arc starts that can occur before an arc start failure occurs. This represents a significant improvement over known air cooled torch configurations.

[39] While the claimed subject matter of the present application has been described with reference to certain embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the scope of the claimed subject matter. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the claimed subject matter without departing from its scope. Therefore, it is intended that the claimed subject matter not be limited to the particular embodiment disclosed, but that the claimed subject matter will include all embodiments falling within the scope of the appended claims.



## REFERENCE NUMBERS

10	power supply	305e	nut portion
12	housing	305f	seat portion
14	torch assembly	305g	surface portion
16	front side	307	hafnium insert
18	torch end	311	swirl ring
22	connector	311a	upper region
23	mating connector	311b	lower region
24	hose portion	311c	channels
100	cutting system	311d	hole
200	torch	311e	hole
200a	torch head	311f	cavity
201	connector	313	nozzle
203	cathode body	313a	end portion
205	electrode	313b	cylindrical portion
205a	thread portion	313c	tip portion
205b	helical portion	313d	throat
205c	cylindrical portion	313e	inlet portion
205d	distal end	313f	narrow throat portion
207	hafnium insert	313g	expansion portion
209	isolator structure	313h	surface portion
211	swirl ring	313i	cavity
213	nozzle	313z	heat band
213a	projection portion	315	shield cap
213b	throat	315a	end portion
215	shield cap	315b	cylindrical portion
215a	projection portion	315c	tip portion
217a-c	cap assembly	315d	end surface
300	torch head	315e	circular opening
305	electrode	315f	interior angled surface
305a	thread portion	319	gas flow ports
305b	securing portion		
305c	cylindrical portion	A	angle
305d	end portion	B	angle

D      diameter  
D'     diameter  
G      gap

L      length  
X      upstream end  
Y      downstream end

I claim:

1. An air cooled plasma cutting torch, said torch comprising:  
an electrode (305) having a hafnium insert from which a plasma jet is originated for  
cutting a workpiece;  
a nozzle (313) having a cylindrical portion (313b) and a truncated cone portion  
downstream of said cylindrical portion, said truncated cone portion directly transi-  
tions to a distal end surface and said truncated cone portion has a throat (313d)  
through which said plasma jet is passed during cutting, where said cylindrical por-  
tion forms a cavity (313i) into which at least some of said electrode is positioned  
and a gap is formed between said electrode and said cylindrical portion, and where  
said truncated cone portion has an angled outer surface which is angled relative to  
a centerline of said nozzle by an angle in the range of 30 to 60 degrees, and where  
said throat couples said cavity with said distal end surface; and  
a shield cap (315) having a cylindrical portion (315b) and a truncated cone portion  
which has an end surface (315d), where said shield cap truncated cone portion has  
a hole (315e) through said end surface through which said plasma jet passes during  
cutting and said truncated cone portion directly transitions to said end surface;  
where said shield cap cylindrical portion (315b) forms a cavity into which at least  
some of said nozzle cylindrical portion (313b) is inserted and a gap (G) is formed  
between said nozzle and said shield cap, where said shield cap truncated cone por-  
tion has an inner angled surface which is angled relative to a centerline of said  
shield cap by an angle which is larger than said angle of said angled outer surface  
of said nozzle, such that a gap (G) between said inner angled surface and said an-  
gled outer surface decreases in a downstream direction.
2. The air cooled plasma cutting torch of claim 1, wherein said angle is in the range of  
40 to 50 degrees.
3. The air cooled plasma cutting torch of claim 1 or 2, wherein said throat (313d) has a  
length from an inlet to said throat to an outlet of said throat, and where a ratio of  
said length to a diameter of said throat is in the range of 3 to 4.5 or, preferably, in  
the range of 3 to 4, where said diameter is the smallest diameter of said throat.
4. The air cooled plasma cutting torch of anyone of the claims 1 to 3, wherein a maxi-

maximum voltage drop along a length of said throat is 20 volts or, preferably, in the range of 5 to 15 volts or, even more preferably, less than 5 volts, regardless of an operational current of said air cooled plasma cutting torch, where said length is a length from an inlet of said throat to and exit of said throat.

5. The air cooled plasma cutting torch of anyone of the claims 1 to 4, wherein said current operational range is 40 to 100 amps.
6. The air cooled plasma cutting torch of anyone of the claims 1 to 5, wherein said throat has an inlet with a first diameter and an exit with a second diameter and a ratio between said first diameter to said second diameter is in the range of 1.5 to 4.
7. The air cooled plasma cutting torch of anyone of the claims 1 to 6, wherein said hole has a diameter which is in the range of 1.25 to 4.1 or, preferably, in the range of 1.75 to 2.5 times the smallest diameter of said throat.
8. The air cooled plasma cutting torch of anyone of the claims 1 to 7, wherein said hole has a diameter which is greater than a diameter of said throat at an exit of said throat.
9. The air cooled plasma cutting torch of anyone of the claims 1 to 8, wherein said inner angled surface has an angle in the range of 35 to 70 degrees or, preferably, in the range of 45 to 60 degrees.
10. The air cooled plasma cutting torch of anyone of the claims 1 to 9, wherein a largest distance of said gap between said inner angled surface and said outer angled surface is in the range of 0.03 to 0.05 inches.
11. The air cooled plasma cutting torch of anyone of the claims 1 to 10, wherein a width of said gap between said inner angled surface and said outer angled surface decreases by 30 to 60% from a widest portion of said gap to a narrowest portion of said gap.
12. The air cooled plasma cutting torch of anyone of the claims 1 to 11, wherein said nozzle has a thermal heat band during sustained use of said air cooled plasma cut-

ting torch at 100 amps which does not extend onto said cylindrical portion of said nozzle, wherein in the heat band the average temperature of the nozzle is 350 degrees.

13. An air cooled plasma cutting torch, said torch comprising:

an electrode (305) having a hafnium insert from which a plasma jet is originated for cutting a workpiece;

a nozzle (313) having a cylindrical portion (313b) and a truncated cone portion downstream of said cylindrical portion, said truncated cone portion directly transitions to a distal end surface and said truncated cone portion has a throat (313d) through which said plasma jet is passed during cutting, where said cylindrical portion forms a cavity (313i) into which at least some of said electrode is positioned and a gap is formed between said electrode and said cylindrical portion, and where said truncated cone portion has an angled outer surface which is angled relative to a centerline of said nozzle by an angle in the range of 30 to 60 degrees, and where said throat couples said cavity with said distal end surface; and

a shield cap (315) having a cylindrical portion (315b) and a truncated cone portion which has an end surface (315d), where said shield cap truncated cone portion has a hole (315e) through said end surface through which said plasma jet passes during cutting and said truncated cone portion directly transitions to said end surface; where said shield cap cylindrical portion (315b) forms a cavity into which at least some of said nozzle cylindrical portion (313b) is inserted and a gap (G) is formed between said nozzle and said shield cap, where said shield cap truncated cone portion has an inner angled surface which is angled relative to a centerline of said shield cap by an angle which is larger than said angle of said angled outer surface of said nozzle, such that a gap (G) between said inner angled surface and said angled outer surface decreases in a downstream direction,

wherein said throat has a length from an inlet to said throat to an outlet of said throat, and where a ratio of said length to a diameter of said throat is in the range of 3 to 4.5, where said diameter is the smallest diameter of said throat,

wherein said hole has a diameter which is in the range of 1.25 to 4.1 times the smallest diameter of said throat,

wherein said inner angled surface has an angle in the range of 35 to 70 degrees, and

wherein a largest distance of said gap between said inner angled surface and said

outer angled surface is in the range of 0.03 to 0.05 inches.

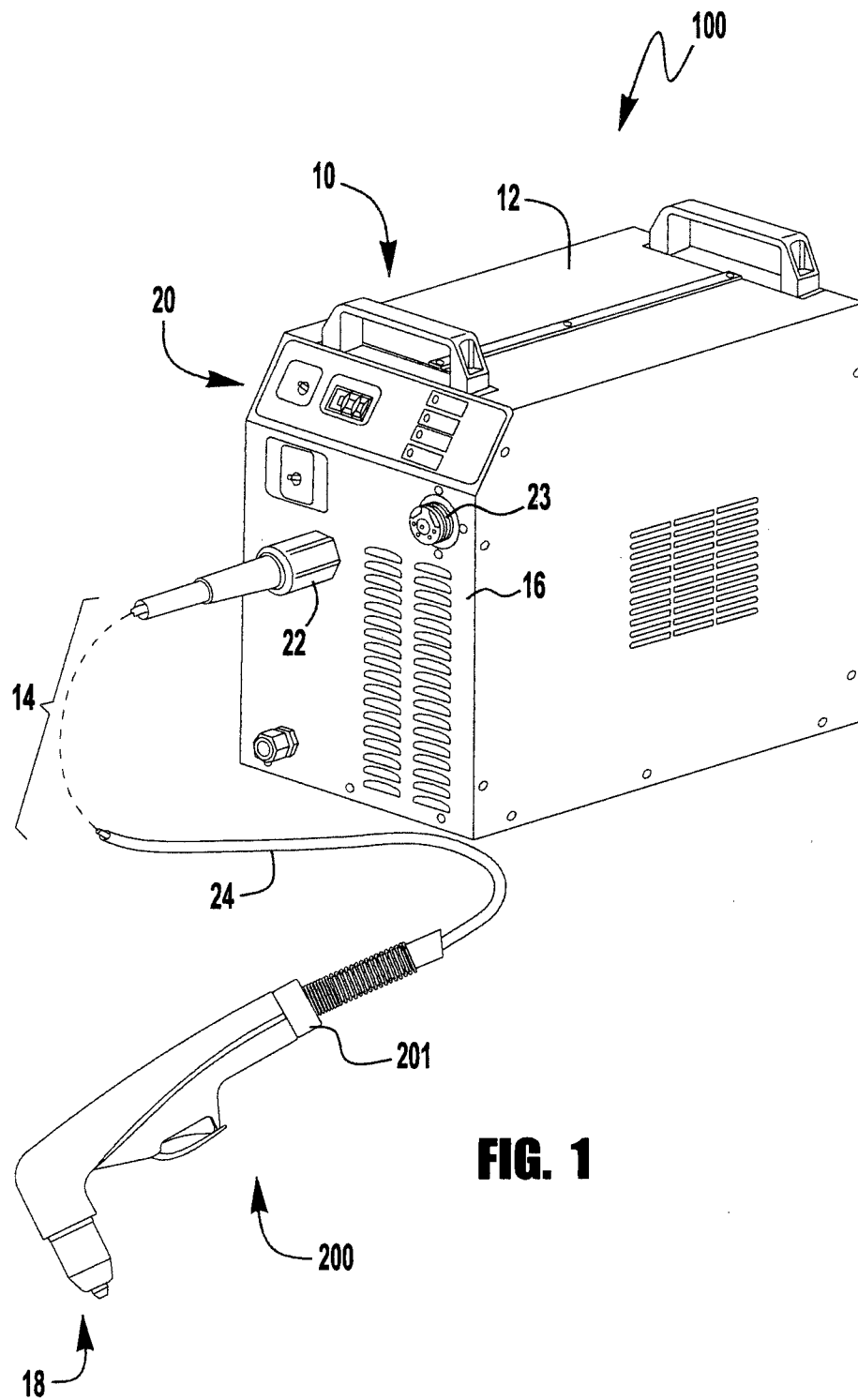
14. An air cooled plasma cutting torch, said torch comprising:  
an electrode (305) having a hafnium insert from which a plasma jet is originated for  
cutting a workpiece;  
a nozzle (313) having a cylindrical portion (313b) and a truncated cone portion  
downstream of said cylindrical portion, said truncated cone portion directly transi-  
tions to a distal end surface and said truncated cone portion has a throat (313d)  
through which said plasma jet is passed during cutting, where said cylindrical por-  
tion forms a cavity (313i) into which at least some of said electrode is positioned and  
a gap is formed between said electrode and said cylindrical portion, and where said  
truncated cone portion has an angled outer surface which is angled relative to a  
centerline of said nozzle by an angle in the range of 30 to 60 degrees, and where  
said throat couples said cavity with said distal end surface; and  
a shield cap (315) having a cylindrical portion (315b) and a truncated cone portion  
which has an end surface (315d), where said shield cap truncated cone portion has  
a hole (315e) through said end surface through which said plasma jet passes during  
cutting and said truncated cone portion directly transitions to said end surface;  
where said shield cap cylindrical portion (315b) forms a cavity into which at least  
some of said nozzle cylindrical portion (313b) is inserted and a gap (G) is formed  
between said nozzle and said shield cap, where said shield cap truncated cone por-  
tion has an inner angled surface which is angled relative to a centerline of said  
shield cap by an angle which is larger than said angle of said angled outer surface  
of said nozzle, such that a gap (G) between said inner angled surface and said an-  
gled outer surface decreases in a downstream direction,  
wherein said throat has a length from an inlet to said throat to an outlet of said  
throat, and where a ratio of said length to a diameter of said throat is in the range of  
3 to 4.5, where said diameter is the smallest diameter of said throat,  
wherein said hole has a diameter which is in the range of 1.25 to 4.1 times the smal-  
lest diameter of said throat,  
wherein said inner angled surface has an angle in the range of 35 to 70 degrees,  
wherein a largest distance of said gap between said inner angled surface and said  
outer angled surface is in the range of 0.03 to 0.05 inches,  
wherein a width of said gap between said inner angled surface and said outer an-  
gled surface decreases by 30 to 60% from a widest portion of said gap to a narrow-

est portion of said gap, and

wherein said nozzle has a thermal heat band during sustained use of said air cooled plasma cutting torch at 100 amps which does not extend onto said cylindrical portion of said nozzle, wherein in the heat band the average temperature of the nozzle is 350 degrees.

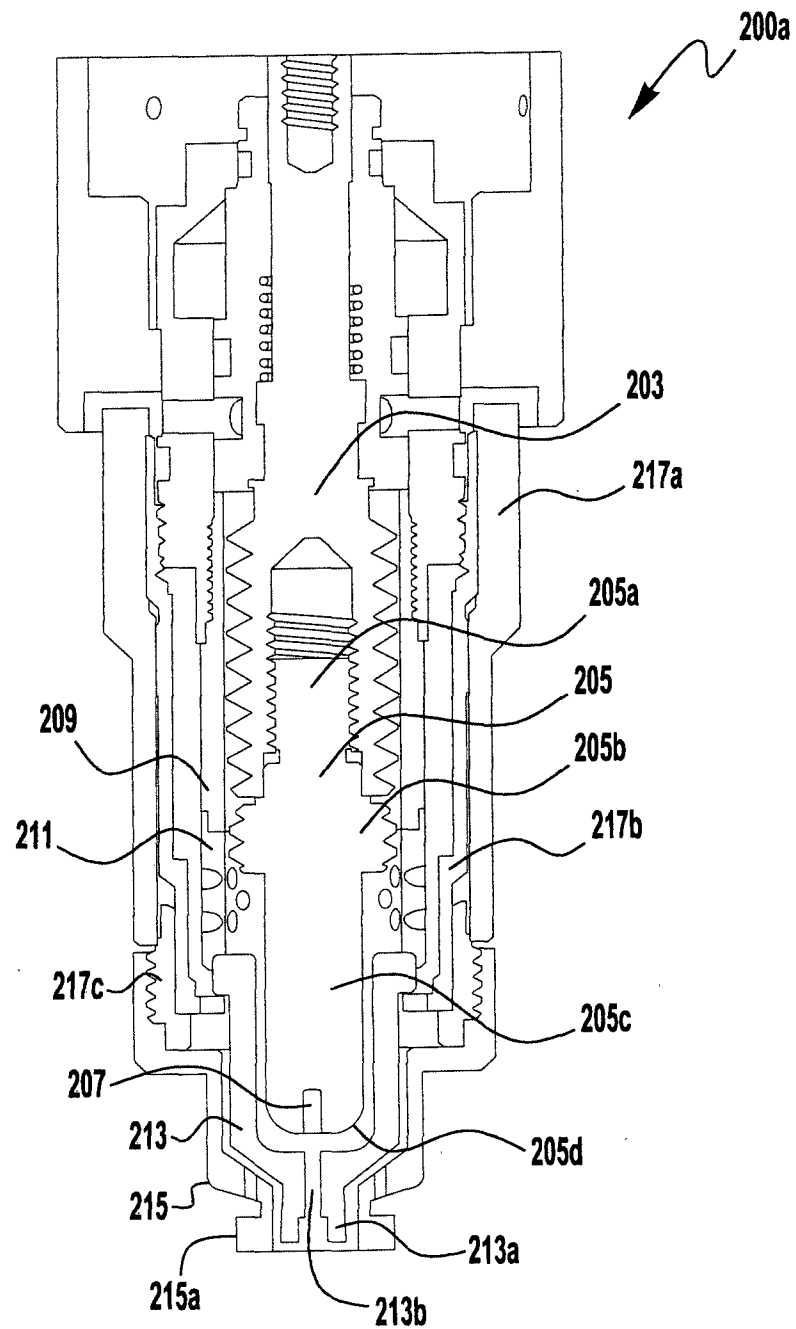
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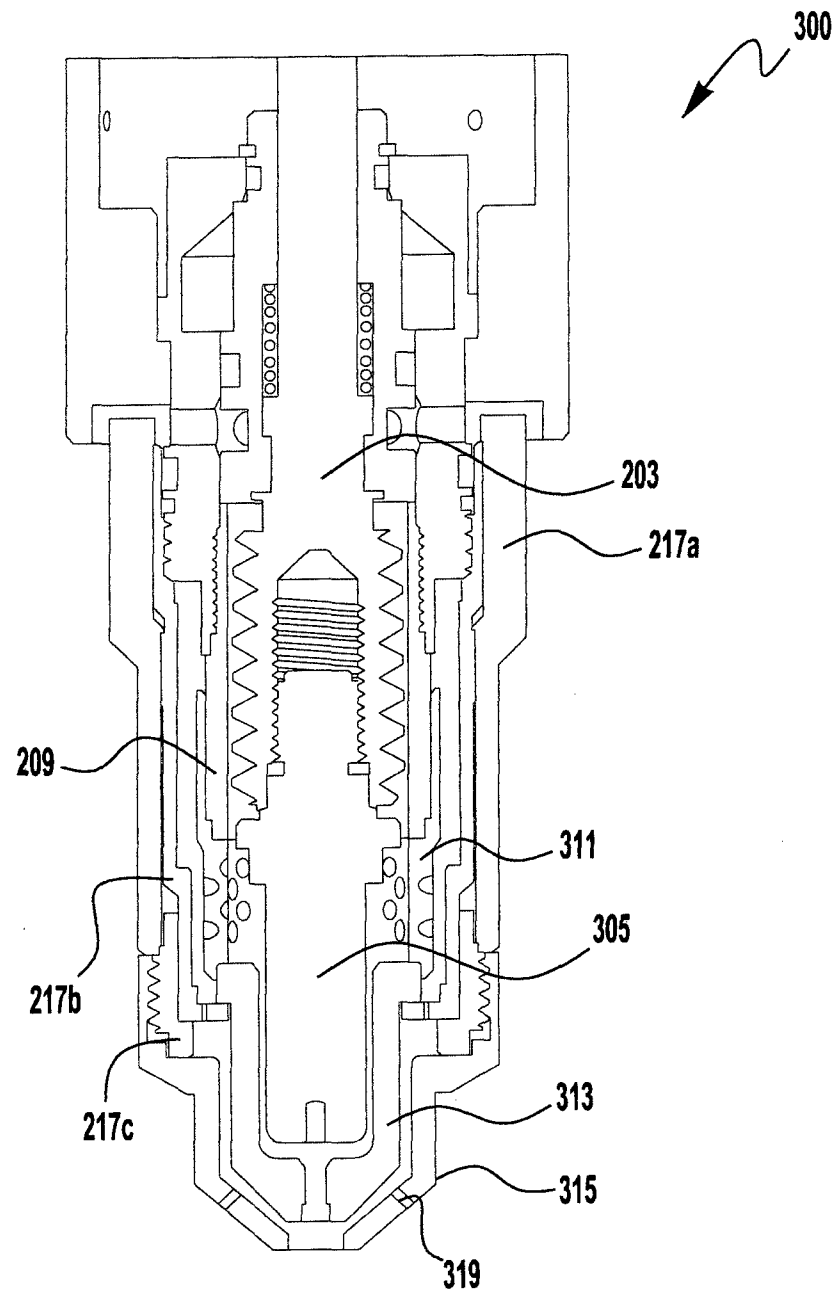


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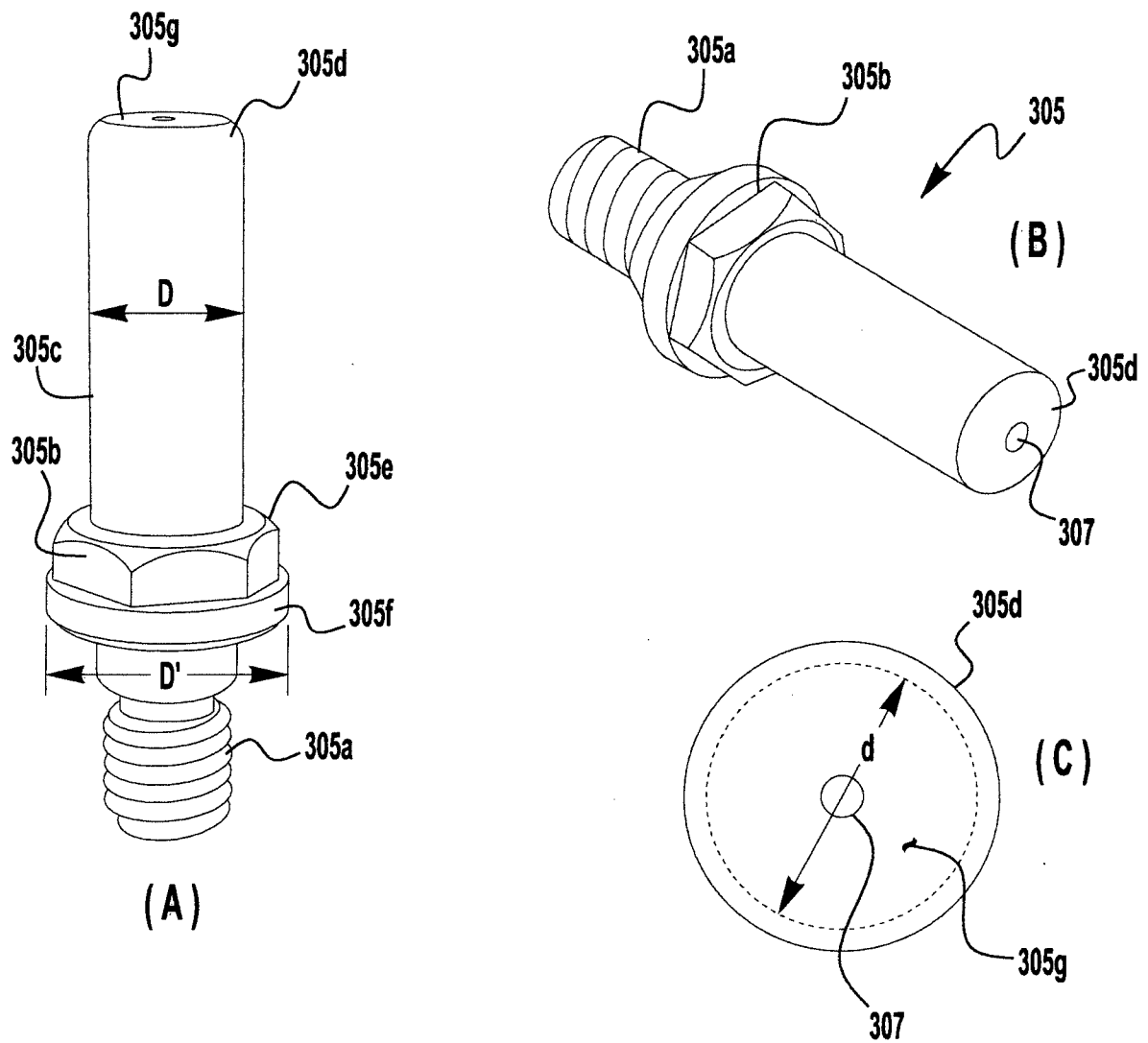
**FIG. 2**  
**PRIOR ART**

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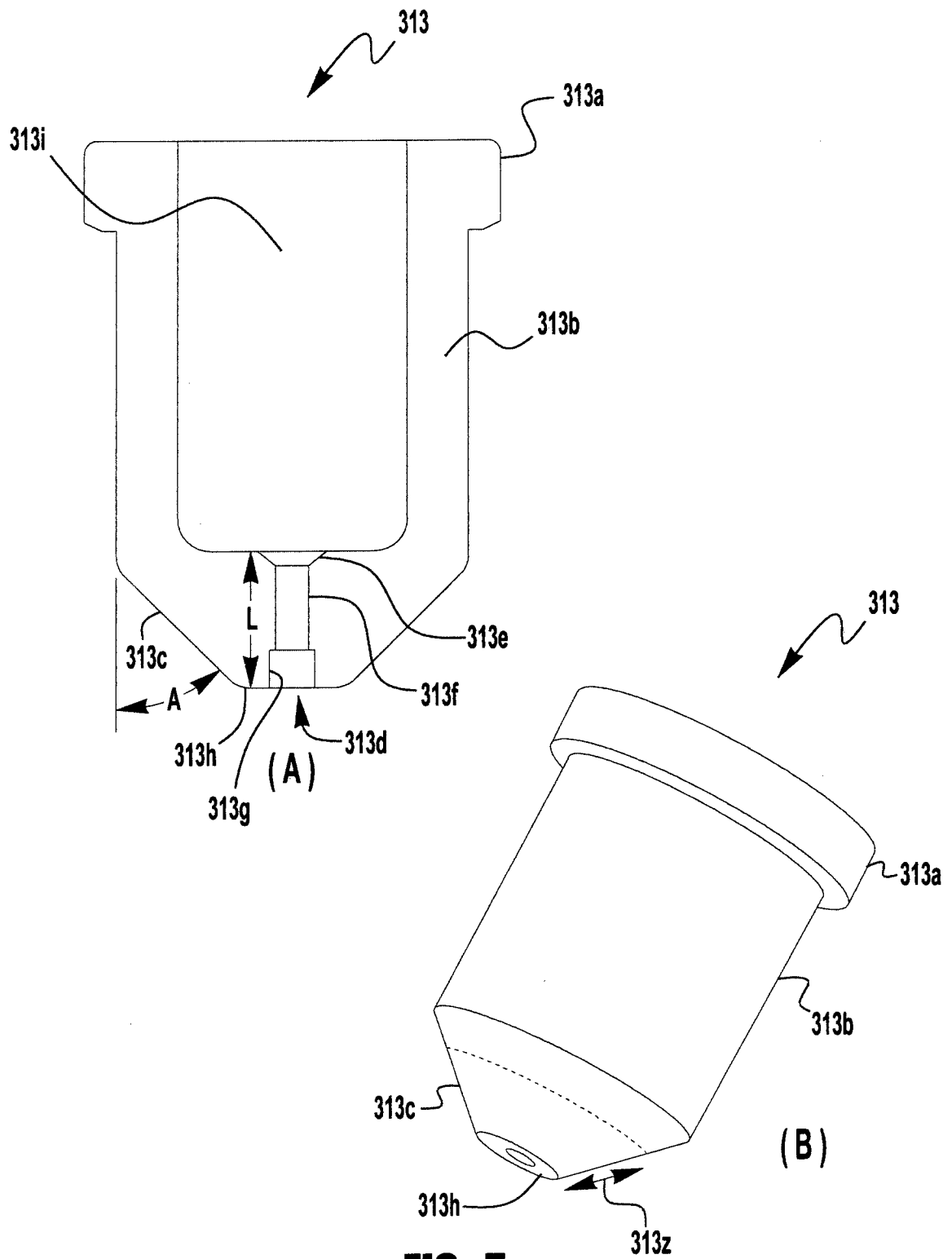
**FIG. 3**

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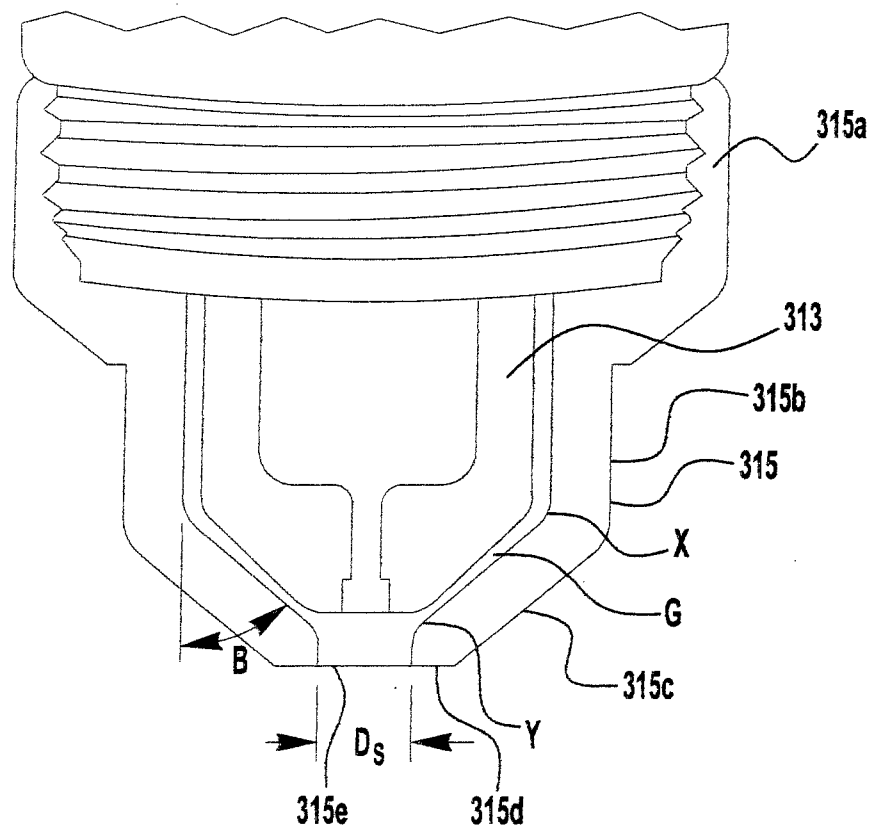


**FIG. 4**

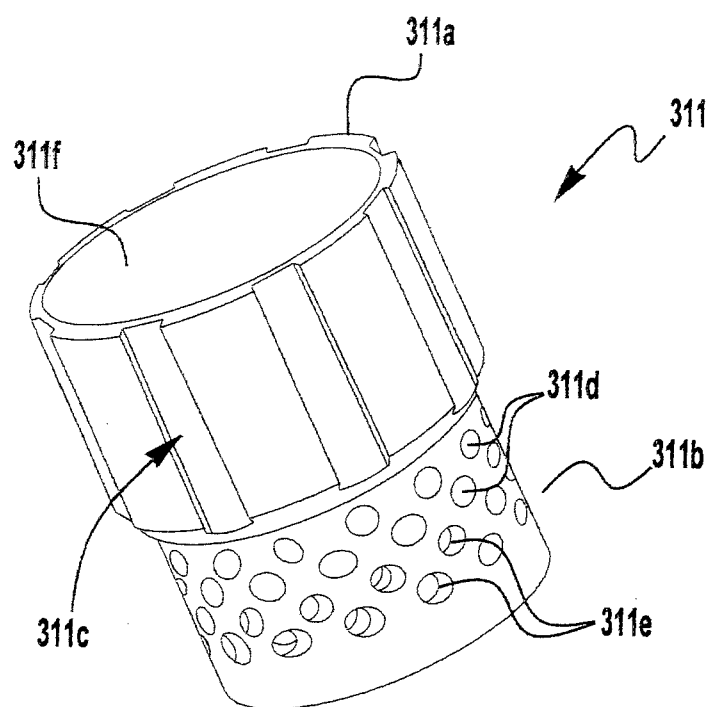
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**FIG. 6**

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**FIG. 7**



## INTERNATIONAL SEARCH REPORT

International application No  
PCT/IB2015/000702

A. CLASSIFICATION OF SUBJECT MATTER  
INV. 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)  
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, WPI Data

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Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

17 August 2015

Date of mailing of the international search report

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Name and mailing address of the ISA/

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## INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2015/000702

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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