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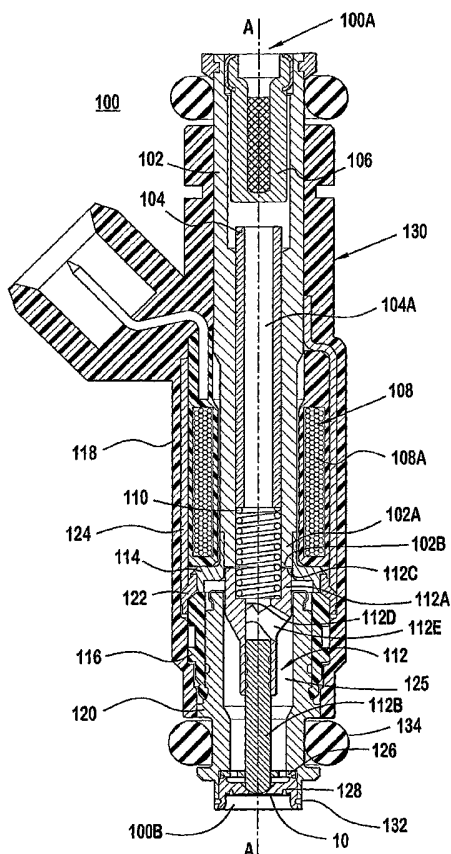
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(54) Title: FUEL INJECTOR WITH REDUCED SAUTER-MEAN-DIAMETER FUEL ATOMIZATION SPRAY BY FLUIDIC
METERING ORIFICE DISC AND METHODS



(57) Abstract: A fuel injector (100) is shown and described. The fuel injector (100) includes an inlet (100A), outlet (100B), seat (128 or 1000), closure member (112B), and a metering orifice disc (10, 200, 300, 300', 400, 500, 600, 700, 900). The metering orifice disc (10, 200, 300, 300', 400, 500, 600, 700, 900) is disposed between the seat (128 or 1000) and the outlet (100B). The metering orifice disc (10, 200, 300, 300', 400, 500, 600, 700, 900) includes a plurality of metering orifices (12 and 13) disposed about the longitudinal axis and a flow channel (14A, 14B, 15A, 15B) to each metering orifice disc (10, 200, 300, 300', 400, 500, 600, 700, 900) so that, when the inlet (100A) of the fuel injector (100) is provided with a pressurized fluid over a range of pressure from 300 kiloPascals to 400 kiloPascals, the metering orifice disc (10, 200, 300, 300', 400, 500, 600, 700, 900) provides an atomized fluid having a Sauter-Mean-Diameter of less than 70 microns proximate the outlet (100B) of the fuel injector (100). Various fuel injectors and disc configurations are disclosed. Various methods of atomizing and spray targeting are also provided.



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FUEL INJECTOR WITH REDUCED SAUTER-MEAN-DIAMETER FUEL ATOMIZATION SPRAY BY FLUIDIC METERING ORIFICE DISC AND METHODS

PRIORITY

This application claims the benefits of United States provisional patent application S.N. 60/514,779 entitled "Fluidic Flow Controller Orifice Disc," filed on 27 October 2003 (Attorney Docket No. 2003P16341), and U.S. Patent applications Serial Nos. 10/ (Attorney Docket No. 2003P16341US01) filed on 26 October 2004; 10/ (Attorney Docket No. 2004P18209US) filed on 26 October 2004; 10/ (Attorney Docket No. 2004P18208US) filed on 26 October 2004; 10/ (Attorney Docket No. 2004P18210US) filed on 26 October 2004; 10/ (Attorney Docket No. 2004P18211US) filed on 26 October 2004; and 10/ (Attorney Docket No. 2004P18213US), which applications are incorporated herein by reference in their entireties into this application.

Background Of the Invention

Most modern automotive fuel systems utilize fuel injectors to provide precise metering of fuel for introduction into each combustion chamber. Additionally, the fuel injector atomizes the fuel during injection, breaking the fuel into a large number of very small particles, increasing the surface area of the fuel being injected, and allowing the oxidizer, typically ambient air, to more thoroughly mix with the fuel prior to combustion. The metering and atomization of the fuel reduces combustion emissions and increases the fuel efficiency of the engine. Thus, as a general rule, the greater the precision in metering and targeting of the fuel and the greater the atomization of the fuel, the lower the emissions with greater fuel efficiency.

An electro-magnetic fuel injector typically utilizes a solenoid assembly to supply an actuating force to a fuel metering assembly. Typically, the fuel metering assembly is a plunger-style closure member which reciprocates between a closed

position, where the closure member is seated in a seat to prevent fuel from escaping through a metering orifice into the combustion chamber, and an open position, where the closure member is lifted from the seat, allowing fuel to discharge through the metering orifice for introduction into the combustion chamber.

The fuel injector is typically mounted upstream of the intake valve in the intake manifold or proximate a cylinder head. As the intake valve opens on an intake port of the cylinder, fuel is sprayed towards the intake port. In one situation, it may be desirable to target the fuel spray at the intake valve head or stem while in another situation, it may be desirable to target the fuel spray at the intake port instead of at the intake valve. In both situations, the targeting of the fuel spray can be affected by the spray or cone pattern. Where the cone pattern has a large divergent cone shape, the fuel sprayed may impact on a surface of the intake port rather than towards its intended target. Conversely, where the cone pattern has a narrow divergence, the fuel may not atomize and may even recombine into a liquid stream. In either case, incomplete combustion may result, leading to an increase in undesirable exhaust emissions.

Complicating the requirements for targeting and spray pattern is cylinder head configuration, intake geometry and intake port specific to each engine's design. As a result, a fuel injector designed for a specified cone pattern and targeting of the fuel spray may work extremely well in one type of engine configuration but may present emissions and driveability issues upon installation in a different type of engine configuration. Additionally, as more and more vehicles are produced using various configurations of engines (for example: inline-4, inline-6, V-6, V-8, V-12, W-8 etc.), emission standards have become stricter, leading to tighter metering, spray targeting and spray or cone pattern requirements of the fuel injector for each engine configuration. Thus, it is believed that there is a need in the art for a fuel injector that would alleviate the drawbacks of the conventional fuel injector in providing spray targeting and atomizing of fuel flow with minimal modification of a fuel injector.

Summary Of The Invention

The present invention provides a fuel injector that includes an inlet, outlet, seat, closure member, and a metering orifice disc. The inlet and outlet include a passage extending along a longitudinal axis from the inlet to the outlet, the inlet being communicable with a flow of fuel. The seat is disposed in the passage proximate the outlet. The seat includes a sealing surface that faces the inlet and a seat orifice extending through the seat from the sealing surface along the longitudinal axis A-A. The closure member is reciprocally located between a first position displaced from the seat, and a second position contiguous the sealing seat surface of the seat to form a seal that precludes fuel flow past the closure member. The metering orifice disc is disposed between the seat and the outlet. The metering orifice disc includes a plurality of metering orifices disposed about the longitudinal axis and a flow channel to each metering orifice disc so that, when the inlet of the fuel injector is provided with a pressurized fluid over a range of pressure from 300 kiloPascals to 400 kiloPascals and the closure member is actuated to the first position, the metering orifice disc provides an atomized fluid having a Sauter-Mean-Diameter of less than 70 microns proximate the outlet of the fuel injector.

In yet another aspect, a method of atomizing fuel flow through at least one metering orifice of a fuel injector is provided. The fuel injector includes an inlet, outlet and a passage extending along a longitudinal axis therethrough the inlet and outlet. The outlet has a seat and a metering orifice disc. The seat has a seat orifice and a closure member that occludes a flow of fuel through seat orifice. The metering orifice disc is disposed between the seat and the outlet. The metering orifice disc includes at least one metering orifice. The method can be achieved by: flowing fuel away from the longitudinal axis to the at least one metering orifice through two flow channels, each flow channel having a first cross-sectional area greater than a second cross-sectional area proximate the metering orifice; and impacting the flow of fuel through the two channels proximate the metering orifice to atomize the fuel proximate the outlet.

In a third aspect, the present invention provides a fuel injector that includes an inlet, outlet, seat, closure member, and a metering orifice disc. The inlet and outlet include a passage extending along a longitudinal axis from the inlet to the

outlet, the inlet being communicable with a flow of fuel. The seat is disposed in the passage proximate the outlet. The seat includes a sealing surface that faces the inlet and a seat orifice extending through the seat from the sealing surface along the longitudinal axis A-A. The closure member is reciprocally located between a first position displaced from the seat, and a second position contiguous the sealing seat surface of the seat to form a seal that precludes fuel flow past the closure member. The metering orifice disc is disposed between the seat and the outlet. The metering orifice disc includes: a generally planar surface, a plurality of metering orifices that extends through the generally planar surface, and first and second walls. The metering orifices are located radially outward of the seat orifice. Each of the metering orifices having a center defined by the surface of the metering orifice through the disc. The first wall has a first inner wall portion closest to the longitudinal axis and a first outer wall portion closest to the center of the metering orifice. The second wall has a second inner wall portion furthest from the center of the metering orifice and a second outer wall portion closest to the center of the metering orifice. The second wall confronts the first wall to define two channels that converge towards each metering orifice, each channel including a first distance between the first inner wall portion and second inner wall portion being greater than a second distance between the first outer wall portion and second outer wall portion.

In a fourth aspect of the present invention, a seat subassembly is provided. ~~The seat subassembly includes a seat, a metering orifice disc and a divider.~~ The seat has a sealing surface, a seat orifice, a first surface contiguous to the seat orifice, and a longitudinal axis extending therethrough the seat orifice. The metering orifice disc has a second surface confronting the first surface. The metering orifice disc includes a plurality of metering orifices extending through the metering orifice disc. The metering orifices are located about the longitudinal axis outside a virtual projection of a sealing surface of the seat onto the second surface of the metering orifice disc. The divider is interposed between the first and second surfaces and between each metering orifice and the seat orifice.

In a fifth aspect of the present invention, a metering orifice disc for a fuel injector is provided. The metering orifice disc includes a generally planar surface, a plurality of metering orifices, first and second walls. The generally planar surface

has a longitudinal axis extending generally transversely through the surface of the metering orifice disc. The plurality of metering orifices extends through metering orifice disc to define a centerline. The metering orifices are located radially outward of the longitudinal axis A-A. The first wall and second wall are disposed on the generally planar surface of the metering orifice disc. The first wall circumscribes a portion of the second wall. The second wall is disposed between each metering orifice and the longitudinal axis so that the first and second walls define two flow channels extending away from the longitudinal axis and converging towards each metering orifice.

In a sixth aspect of the present invention, a method of atomizing fuel flow through at least one metering orifice of a fuel injector is provided. The fuel injector has an inlet and an outlet and a passage extending along a longitudinal axis therethrough the inlet and outlet. The outlet has a closure member, seat and a metering orifice disc. The seat has a seat orifice. The closure member occludes a flow of fuel through seat orifice. The metering orifice disc is disposed between the seat and the outlet. The metering orifice disc includes at least one metering orifice that extends along the longitudinal axis through the generally planar surface to define a centerline. The method can be achieved by: flowing a first portion of fuel away from the longitudinal axis through a first channel; flowing a second portion of fuel away from the longitudinal axis through a second channel; and combining the first and second portions of fuel at the metering orifice.

In a seventh aspect, the present invention provides a fuel injector that includes an inlet, outlet, seat, closure member, and a metering orifice disc. The inlet and outlet include a passage extending along a longitudinal axis from the inlet to the outlet, the inlet being communicable with a flow of fuel. The seat is disposed in the passage proximate the outlet. The seat includes a sealing surface that faces the inlet and a seat orifice extending through the seat from the sealing surface along the longitudinal axis A-A. The closure member is reciprocally located between a first position displaced from the seat, and a second position contiguous the sealing seat surface of the seat to form a seal that precludes fuel flow past the closure member. The metering orifice disc is disposed between the seat and the outlet. The metering orifice disc includes a generally planar surface, at least two metering orifices, and at

least one flow channel. The at least two metering orifices are generally located along an axis extending radially away from the longitudinal axis and radially outward of the seat orifice. Each of the metering orifices has a center defined by the interior surface of the metering orifice extending through the disc. The at least one flow channel extends radially away from the longitudinal axis towards each of the at least two metering orifices.

In an eighth aspect, the present invention provides a method of atomizing fuel flow through at least one metering orifice of a fuel injector. The fuel injector has an inlet and an outlet and a passage extending along a longitudinal axis therethrough the inlet and outlet. The outlet has a closure member, seat and a metering orifice disc. The seat has a seat orifice. The closure member occludes a flow of fuel through seat orifice. The metering orifice disc being disposed between the seat and the outlet. The metering orifice disc includes at least one metering orifice that extends along the longitudinal axis through the generally planar surface. The method can be achieved by: flowing fuel through the seat orifice away from the longitudinal axis towards at least one metering orifice; and dividing the flow of fuel away from the longitudinal axis into a first flow path proximate a first metering orifice and a second flow path proximate a second metering orifice disposed outward of the first metering orifice.

In a ninth aspect, the present invention provides a method of making a metering orifice disc from a work piece. The work piece has a first surface spaced apart from a second surface over a first distance. The metering orifice disc has an outer diameter from 4 to 6 millimeters with at least one orifice disposed through the metering disc of about 75 to 150 microns in effective diameter. The method can be achieved by removing material from one of the first and second surfaces of the work piece to define a recessed surface between first and second walls, the recessed surface being located between the first and second surfaces of the work piece; and forming an orifice in the recessed surface proximate a shortest distance between the first and second walls to define two channels that extend towards the longitudinal axis, the orifice extends through the recessed surface to one of the first and second surfaces. The method can also include: generating a two-dimensional image that defines recessed surfaces on a transfer medium; applying a

photographically resistant masking film onto one of the first and second surfaces; transferring the image to the photographically resistant masking film disposed on the one surface; and dissolving portions of the work piece having the image of the recessed surface area on the work piece to define the recessed surface between the wall structures.

In a tenth aspect of the present invention, a method of making a valve seat from a work piece is provided. The work piece includes a first surface spaced apart from a second surface over a first distance. The method can be achieved by providing a seat orifice extending through the seat from the first surface along a longitudinal axis extending through the seat orifice to the second surface of the work piece; and removing material on the second surface of the work piece to define at least two flow channels extending generally transversely with respect to the longitudinal axis between first and second walls.

In an eleventh aspect, the present invention provides a fuel injector that includes an inlet, outlet, seat, closure member, and a metering orifice disc. The inlet and outlet include a passage extending along a longitudinal axis from the inlet to the outlet, the inlet being communicable with a flow of fuel. The seat is disposed in the passage proximate the outlet. The seat includes a sealing surface that faces the inlet and a seat orifice extending through the seat from the sealing surface along the longitudinal axis A-A. The closure member is reciprocally located between a first position displaced from the seat, and a second position contiguous the sealing seat surface of the seat to form a seal that precludes fuel flow past the closure member. The metering orifice disc is disposed between the seat and the outlet. The metering orifice disc includes: a generally planar surface, a plurality of metering orifices that extends through the generally planar surface, and first and second walls. The plurality of metering orifices extends through the generally planar surface. The metering orifices are located radially outward of the seat orifice, and each of the metering orifices has a center defined by the interior surface of the metering orifice through the disc. The first wall has a first inner wall portion closest to the longitudinal axis and a first outer wall portion closest to the center of the metering orifice. The second wall has a perimeter disposed about the longitudinal axis A-A. The second wall includes a plurality of projections that extend from the perimeter.

Each projection has a base and a free end. The base is contiguous to the perimeter to define a second inner wall portion. The base confronts the first wall to define two channels that converge towards each metering orifice, each channel including a first distance between the first inner wall portion and second inner wall portion being greater than a second distance between the first outer wall portion and second outer wall portion.

In a twelfth aspect of the present invention, a method of atomizing fuel flow through at least one metering orifice of a fuel injector is provided. The fuel injector has an inlet and an outlet and a passage extending along a longitudinal axis therethrough the inlet and outlet. The outlet has a closure member, seat and a metering orifice disc. The seat has a seat orifice. The closure member occludes a flow of fuel through seat orifice. The metering orifice disc being disposed between the seat and the outlet. The metering orifice disc includes at least one metering orifice that extends along the longitudinal axis through the generally planar surface to define a centerline. The method can be achieved by: flowing a portion of the fuel to a first surface of the metering orifice disc closest to the closure member; directing the portion of the fuel to the generally planar surface area spaced from the first surface and farther from the closure member; and flowing the portion of fuel away from the longitudinal axis to the at least one metering orifice through two flow channels, each channel having a first cross-sectional area located proximate the longitudinal axis and a second cross-sectional area spaced farther away from the longitudinal axis, the second cross-sectional area being smaller than the first cross-sectional area.

In a thirteenth aspect, the present invention provides a fuel injector that includes an inlet, outlet, seat, closure member, and a metering orifice disc. The inlet and outlet include a passage extending along a longitudinal axis from the inlet to the outlet, the inlet being communicable with a flow of fuel. The seat is disposed in the passage proximate the outlet. The seat includes a sealing surface that faces the inlet and a seat orifice extending through the seat from the sealing surface along the longitudinal axis A-A. The closure member is reciprocally located between a first position displaced from the seat, and a second position contiguous the sealing seat surface of the seat to form a seal that precludes fuel flow past the closure member.

The metering orifice disc is disposed between the seat and the outlet. The metering orifice disc includes: a generally planar surface, a plurality of metering orifices that extends through the generally planar surface, and first and second walls. The plurality of metering orifices extends through the generally planar surface. The metering orifices are located radially outward of the seat orifice. Each metering orifice includes an internal wall surface that defines a center of the metering orifice. The metering orifice disc includes an outer wall having a surface that defines first and second outer chords generally about the longitudinal axis A-A. The first outer chord intersects the second chord and has a length different than the length of the second outer chord. The metering orifice disc includes an inner wall having a surface that defines first and second inner chords. The first and second inner chords extend generally transverse to the longitudinal axis A-A. The first inner chord intersects the second inner chord. The first inner chord has a length different than the length of the second inner chord.

In a fourteenth aspect, a fuel injector is provided. The fuel injector includes an inlet, outlet, seat, closure member, and a metering orifice disc. The inlet and outlet include a passage extending along a longitudinal axis from the inlet to the outlet, the inlet being communicable with a flow of fuel. The seat is disposed in the passage proximate the outlet. The seat includes a sealing surface that faces the inlet and a seat orifice extending through the seat from the sealing surface along the longitudinal axis A-A. The closure member is reciprocally located between a first position displaced from the seat, and a second position contiguous the sealing seat surface of the seat to form a seal that precludes fuel flow past the closure member. The metering orifice disc is disposed between the seat and the outlet. The metering orifice disc includes: a generally planar surface, a plurality of metering orifices that extends through the generally planar surface, and first and second walls. The plurality of metering orifices extends through the generally planar surface. The metering orifices are located radially outward of the seat orifice. Each metering orifice includes an internal wall surface that defines a center of the metering orifice. The outer wall has a first outer wall portion closest to the longitudinal axis and a second outer wall portion closest to the center of the metering orifice; and an inner wall having first and second inner wall portions, each of the first and second inner wall portions including a first portion furthest from the center of the metering orifice

and a second portion closest to the center of the metering orifice. Each of the first and second inner walls confronts the outer wall to define a channel that has a first distance between the first outer wall portion and the first portion being greater than a second distance between the second outer wall portion and second portion. The first and second inner wall portions are spaced apart between respective first portions to define a third distance greater than a fourth distance between respective second portions.

In a fifteenth aspect of the present invention, a method of atomizing fuel flow through at least one metering orifice of a fuel injector is provided. The fuel injector has an inlet and an outlet and a passage extending along a longitudinal axis therethrough the inlet and outlet. The outlet has a closure member, seat and a metering orifice disc. The seat has a seat orifice. The closure member occludes a flow of fuel through seat orifice. The metering orifice disc being disposed between the seat and the outlet. The metering orifice disc includes at least one metering orifice that extends along the longitudinal axis through the generally planar surface to define a perimeter having a centerline. The method can be achieved by: flowing first and second portions of fuel generally simultaneously away from the longitudinal axis towards the at least one metering orifice; and directing one of the first and second portions of fuel along the first and second wall surfaces to arrive at the perimeter of the metering orifice at a different time interval than the other of the first and second portions of fuel.

In a sixteenth aspect of the present invention, a method of targeting fuel flow through a metering orifice disc of a fuel injector is provided. The fuel injector has an inlet and an outlet and a passage extending along a longitudinal axis therethrough the inlet and outlet. The outlet has a closure member, seat and a metering orifice disc. The seat has a seat orifice. The closure member occludes a flow of fuel through seat orifice. The metering orifice disc being disposed between the seat and the outlet. The metering orifice disc includes at least one metering orifice that extends along the longitudinal axis through the generally planar surface to define a centerline. The method can be achieved by: impacting first and second portions of a fuel flow proximate the at least one metering orifice disposed outward of the seat orifice; and accelerating the first and second portions of the fuel flow through the at

least one metering orifice to the outlet of the fuel injector at an oblique angle with respect to the longitudinal axis.

Brief Descriptions of the Drawings

The accompanying drawings, which are incorporated herein and constitute part of this specification, illustrate an embodiment of the invention, and, together with the general description given above and the detailed description given below, serve to explain the features of the invention.

Figure 1A illustrates a cross-sectional view of the fuel injector for use with the metering orifice discs of Figures 2-8 and 12.

Figure 1B illustrates a close-up cross-sectional view of the fuel outlet end of the fuel injector of Figure 1A.

Figure 2A illustrates a perspective view of a preferred embodiment of a metering orifice disc for use in a fuel injector.

Figure 2B illustrates a plan view of the metering orifice disc of Figure 2A.

Figure 3 illustrates another embodiment of the fuel metering orifice disc.

Figure 4A illustrates another embodiment of the metering orifice disc with a dual-pair of flow dividers symmetrically disposed about a longitudinal axis.

Figure 4B illustrates a plan view of yet another metering orifice disc, as a further modification of Figure 4A.

Figures 5A and 5B illustrate a unitary flow divider for the metering orifice disc.

Figure 6A illustrates a symmetric unitary flow divider with a plurality of deltoid shaped flow dividers located generally in-line with the projections of the unitary flow divider.

Figure 6B illustrates a non-symmetric unitary flow divider for a metering orifice disc.

Figure 7 illustrates yet another embodiment of the metering orifice disc.

Figure 8 illustrates a baseline metering orifice disc without the channels and dividers of Figures 2-7.

Figure 9 is a grayscale photograph of a fuel spray with the fuel metering disc of Figure 3 that provides an approximate visual indicator of the fuel droplet sizes in the fuel spray from the fuel injector of Figure 1.

Figure 10 illustrates a mask overlay disposed on a photographic resist film layer bonded to a surface of a work piece to provide for the metering orifice disc of Figure 2A.

Figures 11A-11B illustrate various flow divider configurations that can be used made by the techniques set forth herein for each of the embodiments of Figures 2-7.

Figure 12 illustrates an embodiment of the metering orifice disc with unitary flow dividers and eight metering orifices that can be made by the techniques described herein.

Figure 13 illustrates the cut-away perspective view of a valve seat formed by the techniques set forth in this application.

Detailed Description of the Preferred Embodiments

Figures 1-7 and 9-13 illustrate the preferred embodiments, including, as illustrated in Figure 1A, a fuel injector 100 that utilizes a metering orifice disc 10 located proximate the outlet of the fuel injector 100.

As shown in Figure 1A, the fuel injector 100 has a housing that includes an inlet tube 102, adjustment tube 104, filter assembly 106, coil assembly 108, biasing spring 110, armature assembly 112 with an armature 112A and closure member 112B, non-magnetic shell 114, a first overmold 116, second overmold 118, a body 120, a body shell 122, a coil assembly housing 124, a guide member 126 for the closure member 112A, a seat assembly 128, and the metering orifice disk 10.

Armature assembly 112 includes a closure member 112A. The closure member 112A can be a suitable member that provides a seal between the member and a sealing surface 128C of the seat assembly 128 such as, for example, a spherical member or a closure member with a hemispherical surface. Preferably, the closure member 112A is a closure member with a generally hemispherical end.

The closure member 112A can also be a one-piece member of the armature assembly 112.

Coil assembly 120 includes a plastic bobbin on which an electromagnetic coil 122 is wound. Respective terminations of coil 122 connect to respective terminals that are shaped and, in cooperation with a surround 118A, formed as an integral part of overmold 118, to form an electrical connector for connecting the fuel injector 100 to an electronic control circuit (not shown) that operates the fuel injector 100.

Inlet tube 102 can be ferromagnetic and includes a fuel inlet opening at the exposed upper end. Filter assembly 106 can be fitted proximate to the open upper end of adjustment tube 104 to filter any particulate material larger than a certain size from fuel entering through inlet opening 100A before the fuel enters adjustment tube 104.

In the calibrated fuel injector 100, adjustment tube 104 can be positioned axially to an axial location within inlet tube 102 that compresses preload spring 110 to a desired bias force. The bias force urges the armature/closure to be seated on seat assembly 128 so as to close the central hole through the seat. Preferably, tubes 110 and 112 are crimped together to maintain their relative axial positioning after adjustment calibration has been performed.

After passing through adjustment tube 104, fuel enters a volume that is cooperatively defined by confronting ends of inlet tube 102 and armature assembly 112 and that contains preload spring 110. Armature assembly 112 includes a passageway 112E that communicates volume 125 with a passageway 104A in body 130, and guide member 126 contains fuel passage holes 126A. This allows fuel to flow from volume 125 through passageways 112E to seat assembly 128, shown in the close-up of Figure 1B.

In Figure 1B, the seat assembly 128 includes a seat body 128A with a seat extension 128B. The seat extension 128B can be coupled to the body 120 with a weld 132 that is preferably welded from an outer surface of the body 120 to the seat extension 128B. The seat body 128A is coupled to a guide disc 126 with flow openings 126A. The seat body 128A includes a seat orifice 128D, preferably having a right-angle cylindrical wall surface with a generally planar face 128E at the bottom of the seat body 128A. The seat body 128A is coupled to the metering orifice disc

10 by a suitable attachment technique, preferably by a weld extending from the second surface 10B of the disc 10 through first surface 10A and into the generally planar face 128E of the seat body 128A. The guide disk 126, seat body 128A and metering orifice disc 10 can form the seat assembly 128, which is coupled to the body 120. Preferably, the seat body 128A and the metering orifice disc 10 form the seat assembly 128. It should be noted here that both the valve seat assembly 128 and metering orifice disc 10 can be attached to the body 120 by a suitable attachment technique, including, for example, laser welding, crimping, and friction welding or conventional welding.

Referring back to Figure 1A, non-ferromagnetic shell 114 can be telescopically fitted on and joined to the lower end of inlet tube 102, as by a hermetic laser weld. Shell 114 has a tubular neck that telescopes over a tubular neck at the lower end of inlet tube 102. Shell 114 also has a shoulder that extends radially outwardly from neck. Body shell 122 can be ferromagnetic and can be joined in fluid-tight manner to non-ferromagnetic shell 114, preferably also by a hermetic laser weld.

The upper end of body 130 fits closely inside the lower end of body shell 122 and these two parts are joined together in fluid-tight manner, preferably by laser welding. Armature assembly 112 can be guided by the inside wall of body 130 for axial reciprocation. Further axial guidance of the armature/closure member assembly can be provided by a central guide hole in member 126 through which closure member 112A passes. Surface treatments can be applied to at least one of the end portions 102B and 112C to improve the armature's response, reduce wear on the impact surfaces and variations in the working air gap between the respective end portions 102B and 112C.

According to a preferred embodiment, the magnetic flux generated by the electromagnetic coil 108A flows in a magnetic circuit that includes the pole piece 102A, the armature assembly 112, the body 120, and the coil housing 124. The magnetic flux moves across a side airgap between the homogeneous material of the magnetic portion or armature 112A and the body 120 into the armature assembly 112 and across a working air gap between end portions 102B and 112C towards the pole piece 102A, thereby lifting the closure member 112B away from the seat

assembly 128. Preferably, the width of the impact surface 102B of pole piece 102A is greater than the width of the cross-section of the impact surface 112C of magnetic portion or armature 112A. The smaller cross-sectional area allows the ferro-magnetic portion 112A of the armature assembly 112 to be lighter, and at the same time, causes the magnetic flux saturation point to be formed near the working air gap between the pole piece 102A and the ferro-magnetic portion 112A, rather than within the pole piece 102A.

The first injector end 100A can be coupled to the fuel supply of an internal combustion engine (not shown). The O-ring 134 can be used to seal the first injector end 100A to the fuel supply so that fuel from a fuel rail (not shown) is supplied to the inlet tube 102, with the O-ring 134 making a fluid tight seal, at the connection between the injector 100 and the fuel rail (not shown).

In operation, the electromagnetic coil 108A is energized, thereby generating magnetic flux in the magnetic circuit. The magnetic flux moves armature assembly 112 (along the axis A-A, according to a preferred embodiment) towards the integral pole piece 102A, i.e., closing the working air gap. This movement of the armature assembly 112 separates the closure member 112B from the sealing surface 128C of the seat assembly 128 and allows fuel to flow from the fuel rail (not shown), through the inlet tube 102, passageway 104A, the through-bore 112D, the apertures 112E and the body 120, between the seat assembly 128 and the closure member 112B, through the opening, and finally through the metering orifice disc 10 into the internal combustion engine (not shown). When the electromagnetic coil 108A is de-energized, the armature assembly 112 is moved by the bias of the resilient member 226 to contiguously engage the closure member 112B with the seat assembly 128, and thereby prevent fuel flow through the injector 100.

Referring to Figure 2A, a perspective view of a preferred metering orifice disc 10 is illustrated. A first metering disk surface 10A is provided with an oppositely facing second metering disk surface 10B. A longitudinal axis A-A extends through both surfaces 10A and 10B of the metering orifice disc 10. A plurality of metering orifices 12 is formed through the metering orifice disc 10 on a recessed third surface 10C. The metering orifices 12 are preferably located radially outward of the longitudinal axis and extend through the metering orifice disc 10 along the

longitudinal axis so that the internal wall surface of the metering orifice 12 defines a center 12a of the metering orifice 12. Although the metering orifices 12 are illustrated preferably as having the same configuration, other configurations are possible such as, for example, a non-circular flow opening with different sizes of the flow opening for one or more metering orifices.

The metering orifice disc 10 includes two flow channels 14A and 14B provided by two walls 16A and 16B. A first wall 16A surrounds the metering orifices 12. A second wall 16B, acting as a flow divider, is disposed between each metering orifice and the longitudinal axis. The first wall 16A surrounds at least one metering orifice and at least the second wall 16B. The second wall 16B is preferably in the form of a teardrop shape but can be any suitable shape as long as the second wall 16B divides a fuel flow proximate the longitudinal axis A-A into two flow channels 14A and 14 and recombine the fuel flow proximate the metering orifice 12 at a higher velocity than as compared to the velocity of the fuel at the beginning of the second wall 16B.

Referring to Figure 2B, a configuration of the first and second walls 16A and 16B is shown in an aerial view of the metering orifice disc 10. In this preferred configuration, the first wall 16A forms a preferably semicircular sector about both the metering orifice 12 and the second wall 16B. The first wall 16A has at least one inner end and preferably two inner ends 16A1 and 16A2 farthest from the center of a metering orifice 12 and an outer end 16A3 that is closest to the center of the metering orifice 12. The second wall 16B is located along an axis R1, R2, R3 ... Rn extending radially from the longitudinal axis A-A. The second wall has an inner end 16B1 farthest from the center of the metering orifice 12 and an outer end 16B2 closest to the center of the metering orifice 12. The utilization of the first and second walls 16A and 16B provides for the two flow channels 14A and 14B converging towards the metering orifice 12. Each flow channel is separated between the first wall 16A and second wall 16B by a plurality of distances A_{MAX} , A_2 , A_3 ... A_N (where A_N is generally equal to the minimum distance A_{MIN}) between them. Suffice to note, each flow channel has a maximum inner distance A_{MAX} between the respective farthest points 16A1 and 16B1 (from the center of the metering orifice 12) of the walls and a minimum distance A_{MIN} therebetween the closest points 16A3 and 16B2

to the center of the metering orifice. The reduction in the distances A_{MAX} and A_{MIN} is greater than 10 percent. Preferably, the distance A_{MIN} is generally the sum of 50 microns and the maximum linear distance extending across the confronting internal wall surfaces of the metering orifice 12. This change in the distances between the maximum points and minimum points of the walls reflects a reduction in the flow area of each channel that reaches a constant value proximate the metering orifice or contiguous to the perimeter of the metering orifice. It is believed that the reduction in cross-sectional area of the flow channel induces the flow of fuel from the seat orifice 128D to accelerate towards the metering orifice so that the flow of fuel through each flow channel impinges against each other. The impingement of the fuel proximate the metering orifice is believed to provide for the increased atomization of fuel proximate the outlet of the fuel injector 100.

In the preferred embodiment of Figures 2A and 2B, each metering orifice 12 is symmetrically disposed about the longitudinal axis in the preferred embodiment of Figures 2A and 2B so that the centerline of each metering orifice 12 is generally disposed equiangularly on a virtual bolt circle 20 about the longitudinal axis A-A; each metering orifice 12 is a chemically etched orifice having an effective diameter of about 150-200 microns with the overall diameter of the metering orifice disc 10 being a stainless steel disc of about 5.5 millimeters with an overall thickness of about 100-400 microns and a depth between the recessed surface 10C and the first surface 10A of about 75-300 with preferably 100 microns. As used herein, the term "effective diameter" denotes a diameter of an equivalent circular area for any non-circular area of the metering orifice.

A variation of the metering orifice disc 200 of Figure 2A is illustrated in Figure 3. In this embodiment, the metering orifices 12 are symmetrical about an axis C transverse to the longitudinal axis A-A so that a fuel spray emanating from the metering orifice disc 200 in an operational fuel injector is bi-symmetric to a plane defined by the longitudinal axis A-A and transverse axis C. Coincidentally, the centerline of each metering orifices 12 is generally on a first virtual bolt circle 20 in this preferred embodiment. The metering orifices 12 can be located on the bolt circle 20 at various arcuate distances $d1$ or $d2$ between the centers of adjacent metering orifices, which can be the same magnitude or different magnitude

depending on the desired spray targeting requirements. Preferably, each metering orifice 12 is a chemically etched so that its effective diameter is about 150-200 microns with the overall diameter of the metering orifice disc 200 being a stainless steel disc of about 5.5 millimeters with an overall thickness between the first and second surfaces 200A and 200B of about 100-400 microns and a thickness between the recessed or third surface 200C and the second surface 200B of about 100 microns.

In the preferred embodiment of Figure 3, there are ten metering orifices 12 disposed symmetric to a plane defined by longitudinal axis A-A and transverse axis C-C. Similar to the preferred embodiment of Figure 2A, the centerline of each metering orifices 12 is located generally on a virtual bolt circle in this preferred embodiment outside a virtual projection of the seat orifice 128D onto the surface 200C of the disc 200. Preferably, each metering orifice 12 is a chemically etched orifice with an effective diameter of about 150-200 microns with the overall diameter of the metering orifice disc 200 being a stainless steel disc of about 5.5 millimeters and a thickness between the recessed surface and the second surface of about 100 microns.

Referring to Figure 4A, a perspective view of a dual-pair of flow dividers for a metering orifice disc 300 is illustrated. A plurality of pairs of metering orifice 12 is formed through the metering orifice disc 300 on a recessed third surface 300C. Each pair of metering orifice 12 includes an inner metering orifice 12A and outer metering orifice 12B located generally outward of the longitudinal axis A-A and the inner metering orifice 12A. The metering orifices 12A and 12B are preferably located radially outward of a virtual projection 23 of the seat orifice 128D onto the disc 300. The metering orifices 12A and 12B extend through the metering orifice disc 300 along the longitudinal axis so that the internal wall surface of the metering orifice 12A or 12B defines respective centers 13A and 13B. Although the metering orifices 12A and 12B are illustrated preferably as having the same configuration, other configurations are possible such as, for example, a non-circular flow opening with different sizes of the flow opening for one or more metering orifices.

The inner metering orifice 12A includes at least one flow channel 14A and the outer metering orifice 12B includes at least one flow channel 15A formed by first

wall 16, second wall 17 and third wall 18. In the preferred embodiments, the inner metering orifice 12A includes two inner flow channels 14A and 14B provided by first wall 16 with second wall 17; and the outer metering orifice 12B includes two outer flow channels 15A and 15B provided by first wall 16 and third wall 18. The first wall 16 surrounds the metering orifices 12A and 12B. The second wall 17, acting as a flow divider, is disposed between each metering orifice 12A and the longitudinal axis A-A. The second wall 17 is preferably in the form of a teardrop shape but can be any suitable shape as long as the second wall 17 divides a fuel flow proximate the longitudinal axis A-A into two flow channels 14A and 14B and recombine the fuel flow proximate the metering orifice 12A at a higher velocity than as compared to the velocity of the fuel at the portion of the second wall 17 closest to the longitudinal axis A-A. The third wall 18 is preferably in the form of a generally deltoid shape that further sub-divides the fuel flow F radially outward of the inner metering orifice 12A and recombines the divided flow proximate the outer metering orifice 12B.

While Figure 4A illustrates a metering orifice disc 300 that has its metering orifices disposed generally equiangularly about the longitudinal axis, the preferred embodiment of Figure 4B illustrates a metering orifice disc 300' with its metering orifices disposed in a non-equiangularly configuration about the longitudinal axis. This configuration also has inner and outer channels 14 and 15.

The inner channel 14, which includes channels 14A and 14B, is defined by the first wall 16, second wall 17 and third wall 18. By way of example, a description of the metering orifices 12A and 12B aligned along axis B-B in Figure 4B is provided. In this configuration, the first wall 16 has inner portions 16A1 and 16A2 closest to the longitudinal axis A-A. The second wall 17 has an inner portion 17A closest to the longitudinal axis. The third wall 18 also has two inner portions closest to the longitudinal axis. The first wall 16 has an outer portion 16B closest to the center 13B of the outer metering orifice 12B. The second wall 17 has an outer portion 17B closest to the center 13A of the inner metering orifice 12A. The third wall 18 has an outer portion 18B closest to the center 13B of the outer metering orifice 12B.

The first inner channel 14A includes a first inlet area defined partially by first distance A_{MAX1} and a flow recombinant area defined partially by first minimum

distance A_{MIN1} . The first distance A_{MAX1} can be the distance between inner portions 17A and 18A1 of the respective second wall 17 and third wall 18. The second inner channel area 14B includes a second inlet area defined partially by first distance A_{MAX2} and a flow recombinant area defined partially by a first minimum distance A_{MIN1} between outer portion 17B and the inner portion 18A. The second distance A_{MAX2} can be the distance between inner portions 17A and 18A2 of the respective second and third walls 17 and 18. Each of the first and second inner channels 14A and 14B extends generally radially towards the outer metering orifice 12A such that a cross-sectional area of the channel between the walls 16 and 18 is preferably reduced as each channel converges upon the metering orifice 12A.

The first outer channel 15A includes a third inlet area defined partially by third distance A_{MAX3} and a flow recombinant area defined partially by a second minimum distance A_{MIN2} . The third distance can be the distance between the inner portions 16A1 and 18A1 of the first and third walls 16 and 18. The second outer channel 15B includes a fourth inlet area defined partially by fourth distance A_{MAX4} and a flow recombinant area defined partially by second minimum distance A_{MIN2} . The fourth distance can be the distance between the inner portions 16A2 and 18A2 of the first and third walls 16 and 18. Each of the first and second outer channels 15A and 15B extends generally radially towards the outer metering orifice 12B such that a maximum cross-sectional area of each of the channel between the walls 16 and 18 is reduced to a minimum cross-sectional area as the channel converges upon the metering orifice 12B. As used herein the maximum cross-sectional area of each channel is the product of the maximum distance (A_{MAX1} , A_{MAX2} , A_{MAX3} , or A_{MAX4}) and the thickness "t" between third surface 300'C and first surface 300'A, and the minimum cross-sectional area is the product of the minimum distance (A_{MIN1} , or A_{MAX2}) and the thickness "t." It is believed that the reduction in cross-sectional area of the flow channel induces the flow of fuel from the seat orifice to accelerate towards the metering orifice. Preferably, the reduction in the distance A_{MAX1} or A_{MAX2} to A_{MIN1} is about at least 10% and preferably about 90%; and the reduction in A_{MAX3} or A_{MAX4} to A_{MIN2} is at least 10% and preferably about 90% with the thickness t being generally constant. Preferably, the distance A_{MIN1} or A_{MIN2} generally the sum of 50 microns and the maximum linear distance extending across the confronting internal wall surfaces of the metering orifice 12A or 12B.

In the preferred embodiment of Figure 4A, each metering orifice 12A is symmetrically disposed about the longitudinal axis A-A so that the centerline of each metering orifice 12A or 12B is generally disposed equiangularly on a virtual bolt circle 20 about the longitudinal axis A-A; each metering orifice 12A or 12B is a chemically etched orifice having an effective diameter of about 150-200 microns with the overall diameter of the metering orifice disc 300 being a stainless steel disc of about 5.5 millimeters with an overall thickness of about 100-400 microns and a depth between the recessed surface 300C and the first surface 300A of about 75-300 with preferably 100 microns.

In the preferred embodiment of Figure 4B, the metering orifices 12A and 12B are symmetrical about an axis B-B transverse to the longitudinal axis A-A so that a fuel spray emanating from the metering orifice disc 300' in an operational fuel injector is bi-symmetric to a plane defined by the longitudinal axis A-A and transverse axis B-B. Coincidentally, the centerline 13A of each metering orifices 12A can be generally on a first virtual bolt circle 20 in this preferred embodiment and the centerline 13B of each metering orifices 12B can be generally on a second virtual circle 22 outward of the first virtual circle 20. Both virtual circles 20 and 22 are outside of the virtual projection 23 of the seat orifice 128D onto the surface 300'C of the metering orifice disc 300'. The metering orifices 12A can be located on the bolt circle 20 at various arcuate distances d1 or d2 between the centers of adjacent metering orifices, which can be the same magnitude or different magnitudes depending on the desired spray targeting requirements. The metering orifices 12B can be located on the bolt circle 22 at various arcuate distances d3 or d4 depending on the desired spray targeting requirements. Preferably, each metering orifice 12A or 12B is a chemically etched orifice having an effective diameter of about 150-200 microns with the overall diameter of the metering orifice disc 300' being a stainless steel disc of about 5.5 millimeters with an overall thickness of about 100-400 microns and a depth between the recessed surface 300'C and the first surface 300'A of about 75-300 with preferably 100 microns.

Referring to Figure 5A, a perspective view of a preferred metering orifice disc 400 utilizing a unitary flow divider is illustrated. In this embodiment, a plurality of metering orifices 12 is formed through the metering orifice disc 400 on a recessed

third surface 400C having a recessed distance "t1" as measured from a top surface of projection 17B of a unitary flow divider structure 17 to the third surface 400C. The metering orifices 12 are preferably located radially outward of the longitudinal axis and extend through the metering orifice disc 400 along the longitudinal axis so that the internal wall surface 400D of the metering orifice defines a center 13 of the metering orifice 12.

The unitary flow divider structure 17 can be provided with a member 17A that has a thickness "t2." The thickness t2 can be provided to reduce the "sac volume" between the seat orifice and the metering disc surface 400C, which is believed to be an advantage for the fuel injector 100. As known to those skilled in the art, a "sac volume" is defined as a volume downstream of a closure member against the sealing surface and upstream of the metering orifices. The thickness "t2" can be the same as the thickness "t1" of the projection 17 or greater than t1 so as to further decrease the sac volume. By providing this member 17A whose surface is closest to the closure member, the sac volume is reduced while causing the fuel flow through the seat orifice 128D to be directed towards the flow channels in conjunction with the third surface 10C.

The metering orifice disc 400 includes two flow channels 14A and 14B provided by two walls 16 and 17B. A first wall 16 surrounds a portion of the metering orifices 12. A second wall 17B, acting as a flow divider, is disposed between each metering orifice and the longitudinal axis. The first wall 16 surrounds at least one metering orifice and at least the second wall 17B. The second wall 17B is preferably in the form of a generally teardrop shape but can be any suitable shape as long as the second wall 17B divides a fuel flow proximate the longitudinal axis A-A into two flow channels 14A and 14 and recombine the fuel flow proximate the metering orifice 12 at a higher velocity than as compared to the velocity of the fuel at the beginning of the second wall 17B. The member 17A can be connected to the second wall 17B by a transition portion 17C by a suitable technique. Preferably, the member 17A, second wall 17B, and transition portion 17C are unitary or monolithic in construction as flow divider structure 17 so that, in addition to reducing the sac volume, structural integrity is believed to be enhanced for each of the second wall 17B against fuel pressure pulsations. In the preferred embodiment, the unitary

member 17A has an inner portion 17D defining a generally circular perimeter smaller than a virtual circle 22, which is defined by a virtual projection of the seat orifice 128D onto the metering disc surface 400C.

Referring to Figure 5B, a configuration of the first and second walls 16 and 17B is shown in an aerial view of the metering orifice disc 400. In this preferred configuration, the first wall 16 forms a preferably semicircular sector about both the metering orifice 12 and the second wall 17B. The first wall 16 has at least one inner end and preferably two inner ends 16A1 and 16A2 farthest from the center of a metering orifice 12 and an outer end 16A3 that is closest to the center of the metering orifice 12. The second wall 17B is located along an axis R1, R2, R3 ... Rn extending radially from the longitudinal axis A-A. The second wall 17B has an inner end 16B1 farthest from the center 13 of the metering orifice 12 and an outer end 16B2 closest to the center 13 of the metering orifice 12. The utilization of the first and second walls 16 and 17B provides for the two flow channels 14A and 14B converging towards the metering orifice 12. Each flow channel is separated between the first wall 16 and second wall 17B by a plurality of distances A_{MAX} , A_2 , A_3 ... A_N (where A_N is generally equal to the minimum distance A_{MIN}) between them. Suffice to note, each flow channel has a maximum inner distance A_{MAX} between the respective farthest points 16A1, 16A2 and 16B1 (from the center of the metering orifice 12) of the walls and a minimum distance A_{MIN} therebetween the closest points 16A3 and 16B2 to the center 13 of the metering orifice. The reduction in the distances A_{MAX} and A_{MIN} is greater than 10 percent. Preferably, the distance A_{MIN} is generally the sum of 50 microns and the maximum linear distance extending across the confronting internal wall surfaces 11 of the metering orifice 12. This change in the distances between the maximum points and minimum points of the walls reflects a reduction in the flow area of each channel that reaches a constant value proximate the metering orifice or contiguous to the perimeter of the metering orifice. It is believed that the reduction in cross-sectional area of the flow channel induces the flow of fuel from the seat orifice 128 to accelerate towards the metering orifice 12, thereby inducing increased atomization of the fuel as the fuel leaves the metering orifice and the outlet of the fuel injector.

In the preferred embodiment of Figures 5A or 5B, each metering orifice 12 is symmetrically disposed about the longitudinal axis in the preferred embodiment of Figures 5A and 5B so that the centerline 13 of each metering orifice 12 is generally disposed equiangularly on a virtual bolt circle 20 outside the virtual projection 22 of the seat orifice 128D about the longitudinal axis A-A such that the arcuate distances d1 and d2 between the centers 13 of adjacent metering orifices are generally equal; each metering orifice 12 is a chemically etched orifice having an effective diameter of about 150-200 microns with the overall diameter of the metering orifice disc 400 being a stainless steel disc of about 5.5 millimeters with an overall thickness of about 100-400 microns and a depth between the recessed surface 400C and the first surface 400A of about 75-300 with preferably 100 microns. As used herein, the term "effective diameter" denotes a diameter of an equivalent circular area for any non-circular area of the metering orifice.

Referring to Figure 6A, a perspective view of another preferred metering orifice disc 500 that utilizes a unitary flow divider 17 with a deltoid shaped flow divider 18 is illustrated. In this embodiment, the flow divider 17 can include a perimeter 17D smaller than a virtual projection of the seat orifice 128D onto the third surface 500C of the metering disc 500. A plurality of pairs of metering orifice 12 is formed through the metering orifice disc 500 on a recessed third surface 500C. Each pair of metering orifice 12 includes an inner metering orifice 12A and outer metering orifice 12B located generally outward of the longitudinal axis A-A and the inner metering orifice 12A. The metering orifices 12A and 12B are preferably located radially outward of a virtual projection 23 of the seat orifice 128D onto the disc 500. The metering orifices 12A and 12B extend through the metering orifice disc 500 along the longitudinal axis so that the internal wall surface of the metering orifice 12A or 12B defines respective centers 13A and 13B. Although the metering orifices 12A and 12B are illustrated preferably as having the same configuration, other configurations are possible such as, for example, a non-circular flow opening with different sizes of the flow opening for one or more metering orifices.

The inner metering orifice 12A includes at least one flow channel 14A, and the outer metering orifice 12B includes at least one flow channel 15A formed by first wall 16, second wall 17B and third wall 18. In the preferred embodiments, the inner

metering orifice 12A includes two inner flow channels 14A and 14B provided by first wall 16 with second wall 17B; and the outer metering orifice 12B includes two outer flow channels 15A and 15B provided by first wall 16 and third wall 18. The first wall 16 surrounds the metering orifices 12A and 12B. The second wall 17B, acting as a flow divider, is disposed between each metering orifice 12A and the longitudinal axis A-A. The second wall 17B is preferably in the form of a teardrop shape but can be any suitable shape as long as the second wall 17B divides a fuel flow proximate the longitudinal axis A-A into two flow channels 14A and 14B and recombine the fuel flow proximate the metering orifice 12A at a higher velocity than as compared to the velocity of the fuel at the portion of the second wall 17B closest to the longitudinal axis A-A. The third wall 18 is preferably in the form of a generally deltoid shape that further sub-divides the fuel flow F radially outward of the inner metering orifice 12A and recombines the divided flow proximate the outer metering orifice 12B.

While Figure 6A illustrates a metering orifice disc that has its metering orifices disposed generally equiangularly about the longitudinal axis, the preferred embodiment of Figure 6B illustrates a metering orifice disc 600 with its metering orifices disposed in a non-equiangularly manner about the longitudinal axis. This configuration is similar to the embodiment described and illustrated in Figure 6A in that the first wall 16 forms a preferably semicircular sector about both the metering orifices 12A, 12B and the second and third walls 17 and 18 to define inner and outer channels 14 and 15.

The inner channel 14, which includes channels 14A and 14B, is defined by the first wall 16, second wall 17B and third wall 18. By way of example, a description of the metering orifices 12A and 12B aligned along axis B-B in Figure 5B is provided. In this configuration, the first wall 16 has inner portions 16A1 and 16A2 closest to the longitudinal axis A-A. The second wall 17B has an inner portion 17C1 closest to the longitudinal axis. The third wall 18 also has two inner portions closest to the longitudinal axis. The first wall 16 has an outer portion 16B closest to the center 13B of the outer metering orifice 12B. The second wall 17B has an outer portion 17C2 closest to the center 13A of the inner metering orifice 12A. The third wall 18 has an outer portion 18B closest to the center 13B of the outer metering orifice 12B.

The first inner channel 14A includes a first inlet area defined partially by first distance A_{MAX1} and a flow recombinant area defined partially by first minimum distance A_{MIN1} . The first distance A_{MAX1} can be the distance between inner portions 17C1 and 18A1 of the respective second wall 17B and third wall 18. The second inner channel area 14B includes a second inlet area defined partially by first distance A_{MAX2} and a flow recombinant area defined partially by a first minimum distance A_{MIN1} between outer portion 17B and the inner portion 18A. The second distance A_{MAX2} can be the distance between inner portions 17C1 and 18A2 of the respective second and third walls 17 and 18. Each of the first and second inner channels 14A and 14B extends generally radially towards the outer metering orifice 12A such that a cross-sectional area of the channel between the walls 16 and 18 is preferably reduced as each channel converges upon the metering orifice 12A.

The first outer channel 15A includes a third inlet area defined partially by third distance A_{MAX3} and a flow recombinant area defined partially by a second minimum distance A_{MIN2} . The third distance can be the distance between the inner portions 16A1 and 18A1 of the first and third walls 16 and 18. The second outer channel 15B includes a fourth inlet area defined partially by fourth distance A_{MAX4} and a flow recombinant area defined partially by second minimum distance A_{MIN2} . The fourth distance can be the distance between the inner portions 16A2 and 18A2 of the first and third walls 16 and 18. Each of the first and second outer channels 15A and 15B extends generally radially towards the outer metering orifice 12B such that a maximum cross-sectional area of each of the channel between the walls 16 and 18 is reduced to a minimum cross-sectional area as the channel converges upon the metering orifice 12B. As used herein the maximum cross-sectional area is the product of the maximum distance (A_{MAX1} , A_{MAX2} , A_{MAX3} , or A_{MAX4}) and the thickness "t" between third surface 600C and first surface 600A, and the minimum cross-sectional area is the product of the minimum distance (A_{MIN1} , or A_{MAX2}) and the thickness t. It is believed that the reduction in cross-sectional area of the flow channel induces the flow of fuel from the seat orifice to accelerate towards the metering orifice. Preferably, the reduction in the distance A_{MAX1} or A_{MAX2} to A_{MIN1} is about at least 10% and preferably about 90%; and the reduction in A_{MAX3} or A_{MAX4} to A_{MIN2} is at least 10% and preferably about 90% with the thickness t being generally constant. Preferably, the distance A_{MIN1} or A_{MIN2} generally the sum of 50 microns

and the maximum linear distance extending across the confronting internal wall surfaces of the metering orifice 12A or 12B.

In the preferred embodiment of Figure 6A or 6B, each metering orifice 12A is symmetrically disposed about the longitudinal axis so that the centerline 13A of each metering orifice 12A is generally disposed equiangularly on a virtual bolt circle 20 about the longitudinal axis A-A; each metering orifice 12A or 12B is a chemically etched orifice having an effective diameter of about 150-200 microns with the overall diameter of the metering orifice disc 500 or 600 being a stainless steel disc of about 5.5 millimeters with an overall thickness of about 100-400 microns and a depth between the recessed surface 10C and the first surface 10A of about 75-300 with preferably 100 microns. As used herein, the term "effective diameter" denotes a diameter of an equivalent circular area for any non-circular area of the metering orifice.

In the preferred embodiment of Figure 6B, the metering orifices 12A and 12B are symmetrical about an axis B-B transverse to the longitudinal axis A-A so that a fuel spray emanating from the metering orifice disc 600 in an operational fuel injector is bi-symmetric to a plane defined by the longitudinal axis A-A and transverse axis B-B. Coincidentally, the centerline 13A of each metering orifices 12A can be generally on a first virtual bolt circle 20 in this preferred embodiment and the centerline 13B of each metering orifices 12B can be generally on a second virtual circle 22 outward of the first virtual circle 20. Both virtual circles 20 and 22 are outside of the virtual projection 23 of the seat orifice 128D onto the metering orifice disc 600. The metering orifices 12A can be located on the bolt circle 20 at various arcuate distances d_3 or d_4 between the centers of adjacent metering orifices, which can be the same magnitude or different magnitude depending on the desired spray targeting requirements. The metering orifices 12B can be located on the bolt circle 22 at various arcuate distances d_3 or d_4 , which can be the same magnitude or different magnitude depending on the desired spray targeting requirements. Preferably, each metering orifice 12A or 12B is a chemically etched orifice having an effective diameter of about 150-200 microns with the overall diameter of the metering orifice disc 600 being a stainless steel disc of about 5.5 millimeters with an overall thickness of about 100-400 microns and a depth between

the recessed surface 600C and the first surface 600A of about 75-300 with preferably 100 microns.

Referring to Figure 7, yet another preferred embodiment of the unitary flow divider 17 in a metering orifice disc 700 can be utilized for the fuel injector 100. In this embodiment, the fuel spray emanating from the metering orifices 12A and 12B are symmetric about a plane defined by longitudinal axis A-A and C-C. Similar to the embodiments described in Figures 6A and 6B, the divider 17 is unitary with a central portion 17A and projections 17B. Each metering orifice 12A or 12B has two flow channels with each channel converging towards the metering orifice 12A or 12B.

Although the respective metering orifice disc described in Figures 2-7, 11, and 12 is provided with various flow channel configuration, other flow channel configurations can also be utilized for all of its metering orifices or various combinations of channels for each metering orifice. Further, while the metering orifices 12 are illustrated preferably as having the same configuration, other configurations are possible such as, for example, a non-circular flow opening with different sizes of the flow opening for one or more metering orifices.

It has been discovered that the various metering orifice discs 10, 200, 300, 300', 400, 500, 600, 700 or 900 described herein were able to provide for increased atomization of fuel flowing through fuel spray axis 24 proximate the outlet of the fuel injector 100 to define a fuel cloud of atomized fuel 26 (Figure 9). As is known, atomization of fuel by a fuel injector under actual operating conditions can be predicted by using a suitable test fluid such as, for example, N-Heptane. The atomization of the test fluid from any fuel injector can be empirically measured by a technique known as Laser Diffraction with a SPRAYTEC® machine manufactured by the Malvern Instrument Company® of United Kingdom. This empirical measurement is believed to be a highly accurate predictor of the atomization of various types of fuel under actual operating conditions of the fuel injector 100 in an internal combustion engine such as, for example, a fuel pressure from 275 to 600 kiloPascals at various fuel flow rates from 0.5 to 4 grams per second.

When such technique is used to quantify the average size of the test fluid droplets, i.e., a Sauter-Mean-Diameter or D_{32} , it was discovered that the Sauter-

Mean-Diameter of the droplet size of the atomized fluid 26 (provided by the preferred embodiments in Figure 2 or at least one metering discs disclosed in any of the copending applications referenced above) is less than 72 microns and consistently about 50 microns with the fuel pressure being from about 300 to 400 kPa, at a test flow rate from 0.9 to 2.6 grams per second. In contrast, a baseline metering orifice disc 50 (with metering orifices 11A, shown here in Figure 8), without the flow channels, recessed surface and flow dividers, was unable to provide a flow spray with a Sauter-Mean-Diameter of less than 72 microns at generally similar fluid pressures and flow rates. In particular, the baseline disc 50 was tested with a fluid flow rate of 2 grams per second at about 300 kPa that resulted in a Sauter-Mean-Diameter of this baseline disc of about 75 microns. It is believed that applicant's preferred fuel injector is the first to achieve a Sauter-Mean-Diameter of about 50 microns under the test conditions described above.

The metering orifice discs 10, 200, 300, 400, 500, 600, 700 or 900 can be made by any suitable technique and preferably by at least two techniques. The first technique utilizes laser machining to selectively remove materials on the surface of the metering orifice disc 10, 200, 300, 400, 500, 600, or 900. The second technique utilizes chemical etching to dissolve portions of the metallic surface of the metering orifice disc 10, 200, 300, 400, 500, 600, 700 or 900.

In the first technique, a laser light source, such as a frequency doubled Neodymium: Yttrium-Aluminum-Garnet (Nd: YAG) laser with a suitable wavelength is used to ablate the surface of the metering orifice disc 10 in order to form the flow channel and drill the metering orifices 12. The laser can be pulsed so that its laser beam can vaporize the surfaces of the metering disc 10 as the laser scans across the first surface 10A. The laser wavelength can be from 190-350 nanometer with fluence in (Joules per centimeter squared) from 5 to greater than 20 J/m². The depth of material being removed (i.e., "etch depth") per pulse can be from 0.1 to greater than 0.25 microns per pulse. Further details of the metering orifices are described in U.S. Patent No. 6,600,132 granted on July 29, 2003, which is incorporated by reference in its entirety into this application.

In the second technique, a generally planar work piece 800 is cleaned. The work piece 800, shown exemplarily here as a generally rectangular strip of stainless

steel, includes a first surface 800A and a second surface 800B that faces in an opposite direction from the first surface 800A over a thickness of about 100-400 microns. One of the surfaces 800A and 800B of a work piece 800 can be coupled with a suitable photo sensitive material, such as, for example, a photopolymer, photosensitive lacquer, or preferably a photographic resistant film material (e.g., DuPont® Riston™ 4615 photoresist). In the preferred embodiment, a negative photo resist film 801 is adhered to the surface 800A. A photographic negative overlay 802 can be coupled to the photo resist film 801, which is on the surface 800A of the work piece 800, and both the film 801 and overlay 802 are exposed to an ultraviolet light ("UV") at a suitable wavelength (e.g., 140-900 nanometers). The overlay 802 includes covered area 802A so that the underlying film 801 is not exposed to UV light. The overlay includes uncovered areas 802B so that the underlying film 801 is exposed to UV light. After exposure to UV light, the work piece 800 and the photoresist film 801 is developed in a suitable developing solution (e.g., sodium hydroxide). After development of the film 801, areas 802A of the photoresist film 801 that has not been exposed to UV light will dissolve in the presence of a suitable chemical such as, for example, hydrofluoric, hydrochloric or nitric acid. For example, the cloverleaf shaped area of Figure 2 is not exposed to UV light as denoted by the dashed lines such that, in the presence of acids, the surface 800A of the work piece will dissolve into a recessed surface 10C of the disc 10. Similarly, after development of the film 801, areas 802B of the photoresist film 801 that has been exposed to UV light would harden after development by a suitable chemical, i.e., become generally impervious to acids or other chemicals. For example, the teardrop shaped areas exposed areas 802B in Figure 2 denotes cutouts that would allow UV light to penetrate through to the underlying film 801. Consequently, the film 801 would harden after development by a suitable chemical. The exposed (and hardened) areas 802B of the film 801 therefore would remain generally in place on top of the surface 800A of the work piece 800 while the acids dissolve or etch the metals around the areas 802B. Although the technique is described in conjunction with a dry negative photoresist film, other photoresist films such as, for example, a wet negative photoresist film or a positive photoresist in wet or dry form can also be used. This technique is believed to advantageous and is preferred because there are no mechanical forces applied to the work piece, and

the final product tends to be burr and stress-free. Moreover, other techniques can also be utilized such as, for example, UV type 3-D lithography, electroplating or electro-forming can be used to deposit layers of metals such as nickels to form the flow channels described herein. An alternative etching process can be provided by Buckbee-Mears Europe GmbH, Micro Etched Components, at Müllheim, Germany for etching of the metering orifice disc.

After the first and second walls defining flow channels are etched, the work piece 800 is cleaned for removal of the hardened film layer 101 and prepared for any other operations such as, for example, drilling of the metering orifices 12. The metering orifices 12 can be formed by the same techniques described above or by electro discharge ("EM") machining. By way of example, the work piece 800 can be flipped upside down so that the second surface 800B is exposed for laser machining, ED machining, or etching of the metering orifices 12 in accordance with the second technique described above. Thereafter, the work piece can be formed in various configurations such as, for example, a circular configuration for use in a fuel injector.

The divider formed by the etching techniques can be provided in configurations other than those illustrated in Figures 2-7 and 12. In a first configuration illustrated in Figure 11A and denoted by Roman numeral "I," the first wall 16A forms a preferably semicircular sector about both the metering orifice 12 and the second wall 16B. The first wall 16A has at least one inner end and preferably two inner ends 16A1 and 16A2 farthest from the center of a metering orifice 12 and an outer end 16A3 that is closest to the center 12A of the metering orifice 12. The second wall 16B is located along an axis R1, R2, R3 ... Rn extending radially from the longitudinal axis A-A. The second wall has an inner end 16B1 farthest from the center of the metering orifice 12 and an outer end 16B2 closest to the center of the metering orifice 12. The utilization of the first and second walls 16A and 16B provides for the two flow channels 14A and 14B converging towards the metering orifice 12. Each flow channel is separated between the first wall 16A and second wall 16B by a plurality of distances A_{MAX1} , A_2 , A_3 ... A_{MIN1} between them. Suffice to note, each flow channel has a maximum inner distance A_{MAX1} between the respective farthest points 16A1 and 16B1 (from the center of the metering orifice 12)

of the walls 16A and 16B and a minimum distance A_{MIN1} therebetween the closest points 16A3 and 16B2 to the center of the metering orifice. The reduction in the distances A_{MAX1} and A_{MIN1} is greater than 10 percent and preferably 90%-100%. Preferably, the distance A_{MIN} is generally the sum of 50 microns and the maximum linear distance extending across the confronting internal wall surfaces 10D of the metering orifice 12. This change in the distances between the maximum points and minimum points of the walls reflects a reduction in the flow area of each channel that reaches a constant value proximate the metering orifice or contiguous to the perimeter of the metering orifice. It is believed that the reduction in cross-sectional area of the flow channel 14A or 14B induces the flow of fuel from the seat orifice 128D to accelerate towards the metering orifice.

Preferably, the flow channel is defined by at least three surfaces: (1) the generally vertical wall surface of the first wall portion 16A, (2) the third surface 10C, and (3) the generally vertical wall surface of the second wall portion 16B. In the most preferred embodiment, a fourth surface is provided by the generally planar seat surface 128E of the seat 128A such that the flow channel 14A or 14B has a generally rectangular cross-section generally parallel to the longitudinal axis A-A.

In the divider configuration I of Figure 11A, the divider I has wall surfaces 16B3 and 16B4. The wall surfaces 16B3 and 16B4 define respective first inner chord IC1 and second inner chord IC2 whose lengths are not equal. The first wall portion 16A has preferably two wall surfaces 17A and 17B that define, respectively, first outer chord OC1 and second outer chord OC2, whose lengths are also not equal. Due to the differences in the lengths of the respective inner and outer chords, the first wall 16A and second wall 16B are not symmetric about any axis extending generally radially from the longitudinal axis A-A.

The asymmetric arrangements of both the first wall 16A and second wall 16B are believed to be advantageous for the atomization of fuel proximate the outlet of the fuel injector 100. Specifically, the flow paths F1 and F2 of fuel to the metering orifice 12 via flow channels 14A and 14B are forced to flow around the first and second walls 16A and 16B so that when the flow paths F1 and F2 are recombined proximate the metering orifice 12, they are imparted with a spin before the recombined flow of fuel enters the metering orifice 12 and out towards the outlet of

the fuel injector. In this configuration I, the effect of the spin to the fuel flow paths F1 and F2 is believed to reduce the amount of direct impact between the flow paths F1 and F2 as they recombine proximate the fuel metering orifice.

Another asymmetric arrangement is illustrated in the divider configuration II of the second wall 16B, shown here in Figure 11B. In this configuration, the outer chords OC1 and OC2 are generally equal but the inner chords IC1 and IC2 are not. However, the difference in the magnitude between the inner chords IC1 and IC2 is not to the extent shown in Figure 11A. It is believed that even though the difference in chord length is slight in configuration II, the flow paths F1 and F2 of the fuel are still imparted with a spin. It is believed that the effect of the spin, in this embodiment, does not outweigh the atomization effect by impingement of the flow paths F1 and F2 against each other proximate the metering orifice.

Another asymmetric arrangement of the second wall portion 16B is illustrated in the divider configuration III, shown here in Figure 11C. In configuration III, the second wall portion 16B is divided into two separate wall portions 16C and 16D. This arrangement provides for three flow paths: a central flow path Fo and two generally symmetric flow paths F1 and F2.

Each of the flow paths F1 and F2 flow through respective channels 14A and 14B and has an inlet area delineated by A_{MAX2} across point 16A1 and 16B1 of respective wall portions 16C and 16D. The point 16A1 is a portion on the first wall portion 16A closest to the longitudinal axis A-A while point 16B1 or 16B2 is a portion on the second wall portion 16B farthest from the center 12A of the metering orifice 12. The flow channel 14A or 14B includes an outlet area to the metering orifice 12 proximate points 16A3 with respect to points 16B3 and 16B4 of wall portions 16C and 16D to define a distance A_{MIN2} . Points 16B3 and 16B4 are portions of the wall 16C and 16D closest to the center 12A of the metering orifice 12.

The central flow path Fo is formed by flow channel 14C between the wall portions 16C and 16D with an inlet defined by a distance A_{MAX3} across points 16B1A and 16B1B and an outlet defined by distance A_{MIN3} across points 16B3 and 16B4. The central flow path Fo of the asymmetric configuration III is believed to provide at least one advantage not observed in other configurations of the flow channels described herein. Specifically, the central flow path Fo allows for fuel exiting a

metering orifice 12 to be oriented at an angle of separation with respect to the longitudinal axis greater than the angle of separation of the various metering disc configurations described herein. This greater angle of separation is also achieved with the use of metering orifice 12 whose internal wall surface 10D is preferably oriented generally parallel to the longitudinal axis A-A. Hence, even though each of the metering orifices 12 has its wall surface through the metering orifice disc 10 oriented generally parallel to the longitudinal axis, i.e. a "straight" orifice, the fuel flow through the metering orifice 12 with divider configuration III is oblique with respect to the longitudinal axis A-A. This advantage of the preferred embodiments is believed to allow for the benefits of a metering orifice whose internal wall is oriented at an angle relative to the longitudinal axis, i.e., an "angled" orifice rather than a straight orifice, but without the complexity or cost associated with the manufacturing of such angled metering orifice. As compared with a baseline metering orifice disc, the fuel flow from a metering disc 10 that has the divider configuration III and straight metering orifices 12 was observed to have respective centroids of the fuel flow divergent with respect to the longitudinal axis at an included angle Θ of about 15-25 degrees (between any two diametrically disposed metering orifices 12) as compared to about 8 degrees for a baseline metering orifice disc that utilizes straight metering orifices 12.

In the preferred embodiment of Figures 2-7, the metering orifice disc can include the divider configurations I, II, III for three of the metering orifices 12 and a symmetric configuration IV for the remainder of the metering orifices 12.

Preferably, each metering orifice 12 is a chemically etched orifice having an effective diameter of about 150-200 microns with the overall diameter of the metering orifice disc 10 being a stainless steel disc of about 5.5 millimeters with an overall thickness of about 100-400 microns and a depth between the recessed surface 10C and the first surface 10A of about 75-300 with preferably 100 microns. As used herein, the term "effective diameter" denotes a diameter of an equivalent circular area for any non-circular area of the metering orifice 12.

It should be noted that a metering orifice disc of the preferred embodiments can use the channel configuration of any one of configurations I, II, III, and IV for all of its metering orifices; and a combination of at least any two of configurations I, II,

III, and IV for respective metering orifices 12. Furthermore, the divider configurations I, II, III, and IV can be unitary or formed as a monolithic structure with a central portion that projects towards the seat orifice 128D. Additionally, the divider configurations I, II, III, and IV described and illustrated herein can also be combined with the multiple flow dividers.

While Figures 2-7, 11, or 12 illustrate various embodiments of a metering orifice disc 10, it should be noted that the same techniques described herein could also be used to form flow channels for a fuel injection valve seat. For example, as shown in Figure 13, a stainless steel valve seat 1000 is provided with a seat orifice 1030 and sealing surface 1032 for contiguous engagement with a closure member 1040 of a fuel injector (not shown). The seat 1000 has a first surface 1000A, second surface 1000B and a recessed surface 1000C formed by the etching technique described above. In this embodiment, the recessed surface 1000C allows for the formation of first wall 26A and second walls 26B with flow channels 14A and 14B to allow fuel flow F to be divided into flow paths F1 and F2 by the second walls 26B. The second walls 26B are preferably teardrop shaped walls but can be any suitable shape as set forth herein in relation to the metering orifice discs 10, 200, 300, 300', 400, 500, 600, 700, or 900 described herein. It is believed that by forming the flow channels in the surface of the seat 1000, a standard metering orifice disc 50, shown here in Figure 8, can be used to achieve the same advantages provided by the preferred metering discs of Figures 2-7, 11, and 12.

Alternatively, two metering orifice discs can be stacked and fixed together with all of the flow channels formed on one disc; part of the flow channels on one disc with the remainder on the other disc. Such stacking arrangement would have a central inlet orifice of about the same opening area as the seat orifice 30 on one disc while the other disc in the stacked arrangement would be provided with metering orifices so that fuel would flow through the central inlet orifice through the channels formed between the stacked discs and out through the metering orifices.

As described, the preferred embodiments, including the techniques of atomizing fuel are not limited to the fuel injector disclosed herein but can be used in conjunction with other fuel injectors such as, for example, the fuel injector sets forth in U.S. Patent No. 5,494,225 issued on Feb. 27, 1996, or the modular fuel injectors

set forth in U.S. Patent Nos. 6,676,044 and 6,793,162, and wherein all of these U.S. Patents are hereby incorporated by reference in their entireties.

While the present invention has been disclosed with reference to certain embodiments, numerous modifications, alterations and changes to the described embodiments are possible without departing from the sphere and scope of the present invention, as defined in the appended claims. Accordingly, it is intended that the present invention not be limited to the described embodiments, but that it has the full scope defined by the language of the following claims, and equivalents thereof.

What I Claim Is:

1. A fuel injector comprising:
 - an inlet and an outlet and a passage extending along a longitudinal axis from the inlet to the outlet, the inlet communicable with a flow of fuel;
 - a seat disposed in the passage proximate the outlet, the seat including a sealing surface that faces the inlet and a seat orifice extending through the seat from the sealing surface along the longitudinal axis;
 - a closure member being reciprocally located between a first position displaced from the seat, and a second position contiguous the sealing seat surface of the seat to form a seal that precludes fuel flow past the closure member;
 - a metering orifice disc disposed between the seat and the outlet, the metering orifice disc having a plurality of metering orifices disposed about the longitudinal axis and a flow channel to each metering orifice so that, when the inlet of the fuel injector is provided with a pressurized fluid over a range of pressure from 200 kiloPascals to 600 kiloPascals and the closure member is actuated to the first position, the metering orifice disc provides an atomized fluid having a Sauter-Mean-Diameter of less than 70 microns proximate the outlet of the fuel injector.
2. The fuel injector of claim 1, wherein the fluid comprises N-heptane provided at a flow rate of about 2 grams per second at a fluid pressure fed to the inlet of about 300 kiloPascals, and the Sauter-Mean-Diameter of the atomized fluid provided by the metering orifice disc proximate the outlet of the fuel injector is less than 60 microns.
3. The fuel injector of claim 2, wherein the plurality of metering orifices comprises a metering orifice having an effective through-opening diameter of about 100 to about 200 microns.
4. The fuel injector of claim 1, wherein the range of pressures comprises from 275 to 325 kiloPascals over a range of flow rates from 0.9 to 2.6 grams per second.
The fuel injector of claim 3, wherein the plurality of metering orifices comprise;

at least two metering orifices located generally along an axis extending radially away from the longitudinal axis and radially outward of the seat orifice; and

at least one flow channel that extends radially away from the longitudinal axis towards each of the at least two metering orifices, the at least one flow channel including:

a first wall having a first inner wall portion closest to the longitudinal axis and a first

outer wall portion closest to the center of the metering orifice; and

a second wall having a second inner wall portion furthest from the center of the metering orifice and a second outer wall portion closest to the center of the metering orifice, the second wall confronting the first wall to define a first distance between the first inner wall portion and second inner wall portion being greater than a second distance between the first outer wall portion and second outer wall portion.

5. The fuel injector of claim 5, wherein the respective centers of the at least two metering orifices being located on the axis extending radially away from the longitudinal axis.

6. The fuel injector of claim 6, wherein the at least one flow channel comprises two flow channels for each metering orifice.

7. The fuel injector of claim 1, wherein the metering orifice disc comprises:

a first wall having a first inner wall portion closest to the longitudinal axis and a first outer wall portion closest to the center of the metering orifice; and

a second wall having a perimeter disposed about the longitudinal axis, the second wall including a plurality of projections that extend from the perimeter, each projection having a base and a free end, the base contiguous to the perimeter to define a second inner wall portion, the base confronting the first wall to define two channels that converge towards each metering orifice, each channel including a first distance between the first inner wall portion and second inner wall portion being greater than a second distance between the first outer wall portion and second outer wall portion.

8. The fuel injector of claim 1, wherein the second wall comprises a portion that extends from the generally planar surface of the metering orifice disc towards the seat orifice.
9. The fuel injector of claim 9, wherein the portion comprises a generally circular portion disposed within a virtual projection of the seat orifice onto the generally planar surface of the metering orifice disc.
10. The fuel injector of claim 1, wherein the metering orifice disc comprises a generally circular stainless steel disc having an outer diameter of about 5.5 millimeters and a thickness of about 400 microns.
11. The fuel injector of claim 9, wherein the metering orifice disc comprises a generally circular stainless steel disc having an outer diameter of about 5.5 millimeters and a thickness of about 400 microns.
12. The fuel injector of claim 5, wherein the plurality of metering orifices includes at least two metering orifices diametrically disposed on a first virtual circle about the longitudinal axis.
13. The fuel injector of claim 4, wherein the plurality of metering orifices includes at least two metering orifices disposed at a first arcuate distance relative to each other on the first virtual circle.
14. The fuel injector of claim 13, wherein the plurality of metering orifices includes at least three metering orifices spaced at different arcuate distances on the first virtual circle.
15. The fuel injector of claim 14, wherein the channel comprises two flow channels for each metering orifice.
16. The fuel injector of claim 1, wherein the metering orifice disc comprises:
a disc surface confronting a seat surface disposed about the seat orifice, the plurality of metering orifices being located about the longitudinal axis outside a

virtual projection of a sealing surface of the seat onto the disc surface of the metering orifice disc; and

a divider interposed between the disc and seat surfaces and between each metering orifice and the seat orifice.

17. The fuel injector of claim 15, wherein divider defines at least two flow channels for each metering orifice.

18. The fuel injector of claim 17, wherein the flow channels are symmetric about an axis that extends from the longitudinal axis to a center of a metering orifice.

19. The fuel injector of claim 16, wherein the flow channels are asymmetric about an axis that extends from the longitudinal axis to a center of a metering orifice.

20. A method of atomizing fuel flow through at least one metering orifice of a fuel injector, the fuel injector having an inlet and an outlet and a passage extending along a longitudinal axis therethrough the inlet and outlet, the outlet having a seat and a metering orifice disc, the seat having a seat orifice, a closure member that occludes a flow of fuel through seat orifice in one position and permits flow in another position, the metering orifice disc being disposed between the seat and the outlet, the metering orifice disc including at least one metering orifice having a perimeter, the method comprising:

flowing first and second portions of the fuel away from the longitudinal axis to the at least one metering orifice through two respective flow channels, each flow channel having a first cross-sectional area greater than a second cross-sectional area proximate the at least one metering orifice; and

impacting the first and second portions of fuel against each other at the perimeter of the at least one metering orifice.

21. The method of claim 20, wherein the flowing comprises pressurizing fuel to the inlet of the fuel injector at 300 kiloPascals at a flow rate of about 2 grams per second and actuating the closure member to the another position.

22. A fuel injector comprising:

an inlet and an outlet and a passage extending along a longitudinal axis from the inlet to the outlet, the inlet communicable with a flow of fuel;

a seat disposed in the passage proximate the outlet, the seat including a sealing surface that faces the inlet and a seat orifice extending through the seat from the sealing surface along the longitudinal axis;

a closure member being reciprocally located between a first position displaced from the seat, and a second position contiguous the sealing seat surface of the seat to form a seal that precludes fuel flow past the closure member;

a metering orifice disc disposed between the seat and the outlet, the metering orifice disc including:

a generally planar surface;

a plurality of metering orifices that extends through the generally planar surface, the metering orifices being located radially outward of the seat orifice, each of the metering orifices having a center defined by the interior surface of the metering orifice through the disc;

a first wall having a first inner wall portion closest to the longitudinal axis and a first outer wall portion closest to the center of the metering orifice;

a second wall having a second inner wall portion furthest from the center of the metering orifice and a second outer wall portion closest to the center of the metering orifice, the second wall confronting the first wall to define two channels that converge towards each metering orifice, each channel including a first distance between the first inner wall portion and second inner wall portion being greater than a second distance between the first outer wall portion and second outer wall portion.

23. The fuel injector of claim 22, wherein the plurality of metering orifices includes at least two metering orifices diametrically disposed on a first virtual circle about the longitudinal axis.

24. The fuel injector of claim 23, wherein the plurality of metering orifices includes at least two metering orifices disposed at a first arcuate distance relative to each other on the first virtual circle.

25. The fuel injector of claim 23, wherein the plurality of metering orifices includes at least three metering orifices spaced at different arcuate distances on the first virtual circle.

26. The fuel injector of claim 22, wherein the two flow channels are formed by a first wall and a second wall disposed on the generally planar surface of the metering orifice disc, the first wall circumscribing a portion of the second wall.

27. The fuel injector of claim 26, wherein the second wall extends along an axis generally transverse to the longitudinal axis from a first end proximate the longitudinal axis to a second end distal to the longitudinal axis such that the cross-section of the first end, as viewed from the longitudinal axis, is less than the cross-section of the second end, as viewed from the longitudinal axis.

28. The fuel injector of claim 27, wherein the second distance comprises from 10% to 90% of the first distance.

29. A seat subassembly comprising:

a seat having a sealing surface, a seat orifice, a first surface contiguous to the seat orifice, and a longitudinal axis extending therethrough the seat orifice;

a metering orifice disc having a second surface confronting the first surface, the metering orifice disc having a plurality of metering orifices extending through the metering orifice disc, the metering orifices being located about the longitudinal axis outside a virtual projection of a sealing surface of the seat onto the second surface of the metering orifice disc; and

a divider interposed between the first and second surfaces and between each metering orifice and the seat orifice.

30. The seat subassembly of claim 29, wherein the divider comprises a first wall and a second wall disposed on the first surface of the seat, the divider defining at least two flow channels for each metering orifice.

31. The seat subassembly of claim 29, wherein the divider comprises a first wall and a second wall disposed on the second surface of the metering orifice disc, the first wall circumscribing a portion of the second wall.

32. The seat subassembly of claim 31, wherein the second wall extends along an axis generally transverse to the longitudinal axis from a first end proximate the longitudinal axis to a second end distal to the longitudinal axis to define a teardrop shape having a cross-section of the first end of the teardrop shape, as viewed from the longitudinal axis, being less than the cross-section of the second end of the teardrop shape, as viewed from the longitudinal axis.

33. The seat subassembly of claim 32, wherein the plurality of metering orifices includes at least two metering orifices diametrically disposed on a first virtual circle about the longitudinal axis.

34. The fuel injector of claim 32, wherein the plurality of metering orifices includes at least two metering orifices disposed at a first arcuate distance relative to each other on the first virtual circle.

35. The fuel injector of claim 32, wherein the plurality of metering orifices includes at least three metering orifices spaced at different arcuate distances on the first virtual circle.

36. A metering orifice disc for a fuel injector, comprising:
a generally planar surface having a longitudinal axis extending generally transversely through the surface of the metering orifice disc;
a plurality of metering orifices extending through metering orifice disc, the metering orifices being located radially outward of the longitudinal axis; and
a first wall and a second wall disposed on the generally planar surface of the metering orifice disc, the first wall circumscribing a portion of the second wall, the

second wall disposed between each metering orifice and the longitudinal axis so that the first and second walls define two flow channels that extend away from the longitudinal axis and converge towards each metering orifice.

37. The metering orifice disc of claim 36, wherein the flow channels are symmetric about the second wall.

38. The metering orifice disc of claim 36, wherein the first wall includes a first inner wall portion closest to the longitudinal axis and a first outer wall portion closest to the center of the metering orifice, the second wall having a second inner wall portion furthest from the center of the metering orifice and a second outer wall portion closest to the center of the metering orifice, the second wall confronting the first wall to define two channels that converge towards each metering orifice, each channel including a first distance between the first inner wall portion and second inner wall portion being greater than a second distance between the first outer wall portion and second outer wall portion.

39. A method of atomizing fuel flow through at least one metering orifice of a fuel injector, the fuel injector having an inlet and an outlet and a passage extending along a longitudinal axis therethrough the inlet and outlet, the outlet having a seat and a metering orifice disc, the seat having a seat orifice, a closure member that occludes a flow of fuel through seat orifice, the metering orifice disc being disposed between the seat and the outlet, the metering orifice disc including at least one metering orifice that extends along the longitudinal axis through the generally planar surface to define a centerline, the method comprising:

 flowing a first portion of fuel away from the longitudinal axis through a first channel;

 flowing a second portion of fuel away from the longitudinal axis through a second channel; and

 combining the first and second portions of fuel at the metering orifice.

40. The method of claim 39, wherein a portion of the fuel flow is divided and recombined symmetrically about an axis intersecting the centerline of the metering orifice.

41. The method of claim 40, wherein each flow path comprises a channel that includes:

- a first wall having a first inner wall portion closest to the longitudinal axis and a first outer wall portion closest to the center of the metering orifice; and
- a second wall having a second inner wall portion furthest from the center of the metering orifice and a second outer wall portion closest to the center of the metering orifice, the second wall confronting the first wall to define a channel that includes a first distance between the first inner wall portion and second inner wall portion being greater than a second distance between the first outer wall portion and second outer wall portion.

42. A fuel injector comprising:

- an inlet and an outlet and a passage extending along a longitudinal axis from the inlet to the outlet, the inlet communicable with a flow of fuel;

- a seat disposed in the passage proximate the outlet, the seat including a sealing surface that faces the inlet and a seat orifice extending through the seat from the sealing surface along the longitudinal axis;

- a closure member being reciprocally located between a first position displaced from the seat, and a second position contiguous the sealing seat surface of the seat to form a seal that precludes fuel flow past the closure member;

- a metering orifice disc disposed between the seat and the outlet, the metering orifice disc including:

- a generally planar surface;

- at least two metering orifices generally located along an axis extending radially away from the longitudinal axis and radially outward of the seat orifice; and

- at least one flow channel that extends radially away from the longitudinal axis towards each of the at least two metering orifices.

43. The fuel injector of claim 42, wherein the at least one flow channel comprises:

- a first wall having a first inner wall portion closest to the longitudinal axis and a first

outer wall portion closest to the center of the metering orifice; and
a second wall having a second inner wall portion furthest from the center of the metering orifice and a second outer wall portion closest to the center of the metering orifice, the second wall confronting the first wall to define two channels that converge towards each metering orifice, each channel including a first distance between the first inner wall portion and second inner wall portion being greater than a second distance between the first outer wall portion and second outer wall portion.

44. The fuel injector of claim 42, wherein the at least one flow channel comprises a plurality of cross-sectional areas generally perpendicular to the generally planar surface of the metering orifice disc, the plurality of cross-sectional areas reducing in magnitude as the at least one flow channel extends toward each of the at least two metering orifices, each of the at least two metering orifices having a center defined by the interior surface of the metering orifice extending through the disc, the respective centers of the at least two metering orifices being located on the axis extending radially away from the longitudinal axis.

45. The fuel injector of claim 43, wherein the plurality of metering orifices includes at least two metering orifices diametrically disposed on a first virtual circle about the longitudinal axis.

46. The fuel injector of claim 43, wherein the plurality of metering orifices includes at least two metering orifices disposed at a first arcuate distance relative to each other on the first virtual circle.

47. The fuel injector of claim 43, wherein the plurality of metering orifices includes at least three metering orifices spaced at different arcuate distances on the first virtual circle.

48. The fuel injector of claim 43, wherein the at least one flow channel comprises two flow channels for each metering orifice.

49. The fuel injector of claim 48, wherein the two flow channels are formed by a first wall and a second wall disposed on the generally planar surface of the metering orifice disc, the first wall circumscribing a portion of the second wall.

50. The fuel injector of claim 49, wherein the second wall extends along an axis generally transverse to the longitudinal axis from a first end proximate the longitudinal axis to a second end distal to the longitudinal axis such that the cross-section of the first end, as viewed from the longitudinal axis, is less than the cross-section of the second end, as viewed from the longitudinal axis.

51. The fuel injector of claim 50, wherein the second distance comprises from 10% to 90% of the first distance.

52. The fuel injector of claim 42, wherein the seat comprises a first surface contiguous to the seat orifice that confronts a second surface of the metering orifice disc, the metering orifice disc including a divider interposed between the first and second surfaces and between each metering orifice and the seat orifice such that the divider defines the at least one flow channel.

53. The fuel injector of claim 52, wherein divider defines at least two flow channels for each metering orifice.

54. The fuel injector of claim 53, wherein the divider comprises a first wall and a second wall disposed on the generally planar surface of the metering orifice disc, the first wall circumscribing a portion of the second wall.

55. The fuel injector of claim 54, wherein the second wall extends along an axis generally transverse to the longitudinal axis from a first end proximate the longitudinal axis to a second end distal to the longitudinal axis to define a teardrop shape having a cross-section of the first end of the teardrop shape, as viewed from the longitudinal axis, being less than the cross-section of the second end of the teardrop shape, as viewed from the longitudinal axis.

56. The fuel injector of claim 55, wherein the at least two metering orifices comprise a plurality of metering orifice pairs, each pair having an inner metering

orifice located on a first virtual circle about the longitudinal axis and an outer metering orifice located on a second virtual circle outside the first virtual circle, the plurality of metering orifice pairs includes two pairs of metering orifice diametrically disposed about the longitudinal axis.

57. The fuel injector of claim 56, wherein the plurality of metering orifice pairs includes at least two inner metering orifices of adjacent pairs disposed on the first virtual circle at a first arcuate distance relative to each other, and two outer metering orifices of adjacent pairs disposed on the second virtual circle at a second arcuate distance relative to each other.

58. The fuel injector of claim 57, wherein the plurality of metering orifice pairs includes at least at least inner three metering orifices of adjacent pairs disposed at different arcuate distances on the first virtual circle, and at least three outer metering orifices of adjacent pairs disposed at different arcuate distances on the second virtual circle.

59. A method of atomizing fuel flow through at least one metering orifice of a fuel injector, the fuel injector having an inlet and an outlet and a passage extending along a longitudinal axis therethrough the inlet and outlet, the outlet having a seat and a metering orifice disc, the seat having a seat orifice, a closure member that occludes a flow of fuel through seat orifice, the metering orifice disc being disposed between the seat and the outlet, the metering orifice disc including at least one metering orifice that extends along the longitudinal axis through the generally planar surface, the method comprising:

flowing fuel through the seat orifice away from the longitudinal axis towards at least one metering orifice; and

dividing the flow of fuel away from the longitudinal axis into a first flow path proximate a first metering orifice and a second flow path proximate a second metering orifice disposed outward of the first metering orifice.

60. The method of claim 59, wherein the dividing comprises splitting the flow of fuel into a first pair of fuel flow paths proximate the first metering orifice and a

second pair of fuel flow paths proximate the second metering orifice radially outward of the first metering orifice and the longitudinal axis.

61. The method of claim 60, wherein the splitting comprises combining the fuel flow paths proximate each metering orifice so that the fuel flow paths are atomized proximate the outlet of the fuel injector.

62. The method of claim 61, wherein each flow path comprises a channel that includes:

- a first wall having a first inner wall portion closest to the longitudinal axis and a first outer wall portion closest to the center of the metering orifice; and

- a second wall having a second inner wall portion furthest from the center of the metering orifice and a second outer wall portion closest to the center of the metering orifice, the second wall confronting the first wall to define two channels that converge towards each metering orifice, each channel including a first distance between the first inner wall portion and second inner wall portion being greater than a second distance between the first outer wall portion and second outer wall portion.

63. A method of making a metering orifice disc from a work piece having a first surface spaced apart from a second surface over a first distance along a longitudinal axis, the metering orifice disc having an outer diameter from 4 to 6 millimeters with at least one orifice disposed through the metering disc of about 75 to 150 microns in effective diameter, method comprising:

- removing material from one of the first and second surfaces of the work piece to define a recessed surface between first and second walls, the recessed surface being located between the first and second surfaces of the work piece; and

- forming an orifice in the recessed surface proximate a shortest distance between the first and second walls to define two channels that extend towards the longitudinal axis, the orifice extends through the recessed surface to one of the first and second surfaces.

64. The method of claim 63, wherein the removing comprises:

generating a two-dimensional image that defines the recessed surface area on a transfer medium;

applying a photographically resistant masking film onto one of the first and second surfaces;

transferring the image to the photographically resistant masking film disposed on the one surface; and

dissolving portions of the work piece having the image of the recessed surface area on the work piece to define the recessed surface between the wall structures.

65. The method of claim 64, wherein the forming of the orifice comprises forming an orifice from the recessed surface to the one of the first and second surfaces.

66. The method of claim 65, wherein the forming comprises electric-discharge-machining the orifice.

67. The method of claim 65, wherein the forming comprises laser machining the orifice.

68. The method of claim 64, wherein the forming comprises:

generating a two-dimensional image of a plurality of orifices disposed about a longitudinal axis on a virtual circle on a transfer medium;

applying a photographically resistant masking film onto the other of the first and second surfaces;

transferring the image to the photographically resistant masking film disposed on the one surface; and

dissolving portions of the work piece not protected by the photographically resistant masking film that embodied the image to form a plurality of orifices through the workpiece to the recessed surfaces, each of the plurality of orifices including a center defined by the internal wall surface of the orifice.

69. The method of claim 68, wherein the first wall comprises a first inner wall portion closest to the longitudinal axis and a first outer wall portion closest to the center of the orifice, and the second wall having a second inner wall portion furthest from the center of the orifice and a second outer wall portion closest to the center of the orifice, the second wall confronting the first wall to define a channel across the recessed surface that has a first distance between the first inner wall portion and second inner wall portion being greater than a second distance between the first outer wall portion and second outer wall portion.

70. The method of claim 68, wherein the first wall comprises an outer wall having a surface that defines first and second outer chords generally about the longitudinal axis, the first outer chord intersecting the second chord and having a length different than the length of the second outer chord; and the second wall comprises an inner wall having a surface that defines first and second inner chords that extend generally transverse to the longitudinal axis, the first inner chord intersecting the second inner chord, the first inner chord having a length different than the length of the second inner chord.

71. The method according to claim 70, wherein the first wall includes a first inner wall portion closest to the longitudinal axis and a first outer wall portion closest to the center of the metering orifice, the second wall having a second inner wall portion furthest from the center of the metering orifice and a second outer wall portion closest to the center of the metering orifice, the second wall confronting the first wall to define a channel that extends towards the metering orifice, the channel has a first distance between the first inner wall portion and second inner wall portion being greater than a second distance between the first outer wall portion and second outer wall portion.

72. The method of claim 68, wherein the first wall comprises an outer wall having a first outer wall portion closest to the longitudinal axis and a second outer wall portion closest to the center of the metering orifice; and the second wall comprises an inner wall having first and second inner wall portions, each of the first and second inner wall portions including a first portion furthest from the center of the

metering orifice and a second portion closest to the center of the metering orifice, each of the first and second inner walls confronting the outer wall to define a channel that extends towards the metering orifice, the channel has a first distance between the first outer wall portion and the first portion being greater than a second distance between the second outer wall portion and second portion, the first and second inner wall portions being spaced apart between respective first portions to define a third distance greater than a fourth distance between respective second portions, and wherein the recessed surface, inner and outer walls define three flow channels for each metering orifice, one of the three flow channels comprises a convergent linear flow channel and the other of the three flow channels comprises curved flow channels.

73. A method of making a valve seat from a work piece having a first surface spaced apart from a second surface over a first distance, the method comprising:

- providing a seat orifice extending through the work piece from the first surface along a longitudinal axis extending through the seat orifice to the second surface of the work piece; and

- removing material on the second surface of the work piece to define at least two flow channels extending generally transversely with respect to the longitudinal axis between first and second walls.

74. The method of claim 73, wherein the removing comprises:

- generating a two-dimensional image that defines recessed surfaces on a transfer medium;

- applying a photographically resistant masking film onto one of the first and second surfaces;

- transferring the image to the photographically resistant masking film disposed on the one surface; and

- dissolving portions of the work piece not protected by the photographically resistant masking film that embodied the image to define the recessed surface located between the first and second walls.

75. The method of claim 74, wherein the first wall comprises an outer wall having a surface that defines first and second outer chords generally about the longitudinal axis, the first outer chord intersecting the second chord and having a length different than the length of the second outer chord; and the second wall comprises an inner wall having a surface that defines first and second inner chords that extend generally transverse to the longitudinal axis, the first inner chord intersecting the second inner chord, the first inner chord having a length different than the length of the second inner chord.

76. The method of claim 74, wherein the first wall comprises an outer wall having a surface that defines first and second outer chords generally about the longitudinal axis, the first outer chord intersecting the second chord and having a length generally equal to the length of the second outer chord; and the second wall comprises an inner wall having a surface that defines first and second inner chords that extend generally transverse to the longitudinal axis, the first inner chord intersecting the second inner chord, the first inner chord having a length generally equal to the length of the second inner chord.

77. A fuel injector comprising:

- an inlet and an outlet and a passage extending along a longitudinal axis from the inlet to the outlet, the inlet communicable with a flow of fuel;

- a seat disposed in the passage proximate the outlet, the seat including a sealing surface that faces the inlet and a seat orifice extending through the seat from the sealing surface along the longitudinal axis;

- a closure member being reciprocally located between a first position displaced from the seat, and a second position contiguous the sealing seat surface of the seat to form a seal that precludes fuel flow past the closure member;

- a metering orifice disc disposed between the seat and the outlet, the metering orifice disc including:

- a generally planar surface;

- a plurality of metering orifices that extends through the generally planar surface, the metering orifices being located radially outward of the seat orifice, each of the metering orifices having a

center defined by the interior surface of the metering orifice through the disc;

a first wall having a first inner wall portion closest to the longitudinal axis and a first outer wall portion closest to the center of the metering orifice;

a second wall having a perimeter disposed about the longitudinal axis, the second wall including a plurality of projections that extend from the perimeter, each projection having a base and a free end, the base contiguous to the perimeter to define a second inner wall portion, the base confronting the first wall to define two channels that converge towards each metering orifice, each channel including a first distance between the first inner wall portion and second inner wall portion being greater than a second distance between the first outer wall portion and second outer wall portion.

78. The fuel injector of claim 77, wherein each projection comprises a transition portion disposed between the base and the free end.

79. The fuel injector of claim 78, wherein the at least one metering orifice comprises at least two metering orifices generally located along an axis extending radially away from the longitudinal axis and radially outward of the seat orifice, and the channel extends radially away from the longitudinal axis towards each of the at least two metering orifices.

80. The fuel injector of claim 79, wherein the channel comprises a plurality of cross-sectional areas generally perpendicular to the generally planar surface of the metering orifice disc, the plurality of cross-sectional areas reducing in magnitude as the channel extends toward each of the at least two metering orifices, each of the at least two metering orifices having a center defined by the interior surface of the metering orifice extending through the disc, the respective centers of the at least two metering orifices being located on the axis extending radially away from the longitudinal axis.

81. The fuel injector of claim 80, the plurality of metering orifices includes at least two metering orifices diametrically disposed on a first virtual circle about the longitudinal axis.

82. The fuel injector of claim 80, the plurality of metering orifices includes at least two metering orifices diametrically disposed on a second virtual circle about the longitudinal axis.

83. The fuel injector of claim 82, wherein the plurality of metering orifices includes at least two metering orifices disposed at a first arcuate distance relative to each other on the second virtual circle, the second virtual circle surrounding both the first virtual circle and a virtual projection of the seat orifice onto the metering orifice disc.

84. The fuel injector of claim 5, wherein the plurality of metering orifices includes at least two metering orifices disposed at a first arcuate distance relative to each other on the first virtual circle.

85. The fuel injector of claim 79, wherein the plurality of metering orifices includes at least three metering orifices spaced at different arcuate distances on the first virtual circle.

86. The fuel injector of claim 79, wherein the channel comprises two flow channels for each metering orifice.

87. The fuel injector of claim 86, wherein the two flow channels are formed by a first wall and a second wall disposed on the generally planar surface of the metering orifice disc, the first wall circumscribing a portion of the second wall.

88. The fuel injector of claim 87, wherein the second distance comprises from 10% to 90% of the first distance.

89. The fuel injector of claim 5, wherein the flow channels are symmetric about the axis extending from the longitudinal axis to the center of a metering orifice disposed on the first virtual circle.
90. The fuel injector of claim 82, wherein the flow channels are symmetric about the axis extending from the longitudinal axis to the center of a metering orifice disposed on the second virtual circle.
91. The fuel injector of claim 81, wherein the flow channels are asymmetric about the axis extending from the longitudinal axis to the center of a metering orifice disposed on the first virtual circle.
92. The fuel injector of claim 82, wherein the flow channels are asymmetric about the axis extending from the longitudinal axis to the center of a metering orifice disposed on the second virtual circle.
93. A method of atomizing fuel flow through at least one metering orifice of a fuel injector, the fuel injector having an inlet and an outlet and a passage extending along a longitudinal axis therethrough the inlet and outlet, the outlet having a seat and a metering orifice disc, the seat having a seat orifice, a closure member that occludes a flow of fuel through seat orifice, the metering orifice disc being disposed between the seat and the outlet, the metering orifice disc including at least one metering orifice that extends along the longitudinal axis through the generally planar surface to define a centerline, the method comprising:
- flowing a portion of the fuel to a first surface of the metering orifice disc closest to the closure member;
 - directing the portion of the fuel to the generally planar surface area spaced from the first surface and farther from the closure member; and
 - flowing the portion of fuel away from the longitudinal axis to the at least one metering orifice through two flow channels, each channel having a first cross-sectional area located proximate the longitudinal axis and a second cross-sectional area spaced farther away from the longitudinal axis, the second cross-sectional area being smaller than the first cross-sectional area.

94. The method of claim 93, wherein the directing comprises providing a generally circular member between the seat orifice and the generally planar surface of the metering orifice disc within a perimeter defined by a projection of the seat orifice onto the metering orifice disc.
95. The method of claim 94, wherein the flowing comprises dividing a flow of fuel through the seat orifice into at least two fuel flow paths that extend away from the longitudinal axis.
96. The method of claim 95, wherein the flowing comprises combining the flow paths proximate each metering orifice located outward of the seat orifice so that the fuel flow paths are atomized proximate the outlet of the fuel injector.
97. The method of claim 96, wherein a portion of the fuel flow is divided and recombined symmetrically about an axis intersecting the centerline of the metering orifice.
98. The method of claim 94, wherein the flowing comprises dividing the flow of fuel away from the longitudinal axis into a first flow path proximate a first metering orifice and a second flow path proximate a second metering orifice disposed outward of the first metering orifice.
99. The method of claim 98, wherein the dividing comprises splitting the flow of fuel into a first pair of fuel flow paths proximate the first metering orifice and a second pair of fuel flow paths proximate the second metering orifice radially outward of the first metering orifice and the longitudinal axis.
100. The method of claim 99, wherein the splitting comprises combining the fuel flow paths proximate each metering orifice so that the fuel flow paths are atomized proximate the outlet of the fuel injector.
101. The method of claim 100, wherein each flow path comprises a channel having a flow divider unitary with the member.
102. A fuel injector comprising:

an inlet and an outlet and a passage extending along a longitudinal axis from the inlet to the outlet, the inlet communicable with a flow of fuel;

a seat disposed in the passage proximate the outlet, the seat including a sealing surface that faces the inlet and a seat orifice extending through the seat from the sealing surface along the longitudinal axis;

a closure member being reciprocally located between a first position displaced from the seat, and a second position contiguous the sealing seat surface of the seat to form a seal that precludes fuel flow past the closure member;

a metering orifice disc disposed between the seat and the outlet, the metering orifice disc including:

a generally planar surface;

a plurality of metering orifices that extends through the generally planar surface, the metering orifices being located radially outward of the seat orifice, each metering orifice including an internal wall surface that defines a center of the metering orifice;

an outer wall having a surface that defines first and second outer chords generally about the longitudinal axis, the first outer chord intersecting the second chord and having a length different than the length of the second outer chord; and

an inner wall having a surface that defines first and second inner chords that extend generally transverse to the longitudinal axis, the first inner chord intersecting the second inner chord, the first inner chord having a length different than the length of the second inner chord.

103. The fuel injector of claim 102, wherein the plurality of metering orifices includes at least two metering orifices diametrically disposed on a first virtual circle about the longitudinal axis.

104. The fuel injector of claim 103, wherein the plurality of metering orifices includes at least two metering orifices disposed at a first arcuate distance relative to each other on the first virtual circle.

105. The fuel injector of claim 103, wherein the plurality of metering orifices includes at least three metering orifices spaced at different arcuate distances on the first virtual circle.

106. The fuel injector of claim 102, wherein the generally planar surface, inner and outer walls define two flow channels for each metering orifice.

107. The fuel injector of claim 106, wherein each of the two flow channels includes a surface of the seat that faces the generally planar surface of the metering orifice disc.

108. The fuel injector of claim 106, wherein the first wall includes a first inner wall portion closest to the longitudinal axis and a first outer wall portion closest to the center of the metering orifice, the second wall having a second inner wall portion furthest from the center of the metering orifice and a second outer wall portion closest to the center of the metering orifice, the second wall confronting the first wall to define two channels that converge towards each metering orifice, each channel including a first distance between the first inner wall portion and second inner wall portion being greater than a second distance between the first outer wall portion and second outer wall portion.

109. The fuel injector of claim 108, wherein the second distance comprises from 10% to 90% of the first distance.

110. A fuel injector comprising:

- an inlet and an outlet and a passage extending along a longitudinal axis from the inlet to the outlet, the inlet communicable with a flow of fuel;

- a seat disposed in the passage proximate the outlet, the seat including a sealing surface that faces the inlet and a seat orifice extending through the seat from the sealing surface along the longitudinal axis;

- a closure member being reciprocally located between a first position displaced from the seat, and a second position contiguous the sealing seat surface of the seat to form a seal that precludes fuel flow past the closure member;

a metering orifice disc disposed between the seat and the outlet, the metering orifice disc including:

a generally planar surface;

a plurality of metering orifices that extends through the generally planar surface, the metering orifices being located radially outward of the seat orifice, each of the metering orifices having a center defined by the interior surface of the metering orifice through the disc;

an outer wall having a first outer wall portion closest to the longitudinal axis and a second outer wall portion closest to the center of the metering orifice; and

an inner wall having first and second inner wall portions, each of the first and second inner wall portions including a first portion furthest from the center of the metering orifice and a second portion closest to the center of the metering orifice, each of the first and second inner walls confronting the outer wall to define a channel that has a first distance between the first outer wall portion and the first portion being greater than a second distance between the second outer wall portion and second portion, the first and second inner wall portions being spaced apart between respective first portions to define a third distance greater than a fourth distance between respective second portions.

111. The fuel injector of claim 110, wherein the plurality of metering orifices includes at least two metering orifices diametrically disposed on a first virtual circle about the longitudinal axis.

112. The fuel injector of claim 110, wherein the plurality of metering orifices includes at least two metering orifices disposed at a first arcuate distance relative to each other on the first virtual circle.

113. The fuel injector of claim 110, wherein the plurality of metering orifices includes at least three metering orifices spaced at different arcuate distances on the first virtual circle.

114. The fuel injector of claim 113, wherein the generally planar surface, inner and outer walls define three flow channels for each metering orifice.

115. The fuel injector of claim 114, wherein each of the three flow channels includes a surface of the seat that faces the generally planar surface of the metering orifice disc.

116. The fuel injector of claim 115, wherein one of the three flow channels comprises a convergent linear flow channel.

117. The fuel injector of claim 116, wherein the other of the three flow channels comprises curved flow channels.

118. A method of atomizing fuel flow through at least one metering orifice of a fuel injector, the fuel injector having an inlet and an outlet and a passage extending along a longitudinal axis therethrough the inlet and outlet, the outlet having a seat and a metering orifice disc, the seat having a seat orifice, a closure member that occludes a flow of fuel through seat orifice, the metering orifice disc being disposed between the seat and the outlet, the metering orifice disc including at least one metering orifice that extends along the longitudinal axis through the generally planar surface to define a perimeter having centerline, the method comprising:

flowing first and second portions of fuel generally simultaneously away from the longitudinal axis towards the at least one metering orifice ; and

directing one of the first and second portions of fuel along the first and second wall surfaces to arrive at the perimeter of the metering orifice at a different time interval than the other of the first and second portions of fuel.

119. The method of claim 118, wherein the flowing comprises dividing a flow of fuel through the seat orifice into at least two fuel flow paths that extend away from the longitudinal axis towards the metering orifice.

120. The method of claim 119, wherein the directing comprises combining the flow paths proximate each metering orifice located outward of the seat orifice so that the fuel flow paths are atomized proximate the outlet of the fuel injector.

121. The method of claim 118, wherein a portion of the fuel flow is divided into a first flow path along a first chord defined by a wall surface of the metering disc and a second flow path along a second chord defined by the wall surface.

122. The method of claim 119, wherein a portion of the fuel flow is divided into a third flow path along a linear path towards the metering orifice.

123. The method of claim 122, wherein the respective lengths of the first and second chord are generally equal.

124. The method of claim 123, wherein the respective lengths of the first and second chord are different.

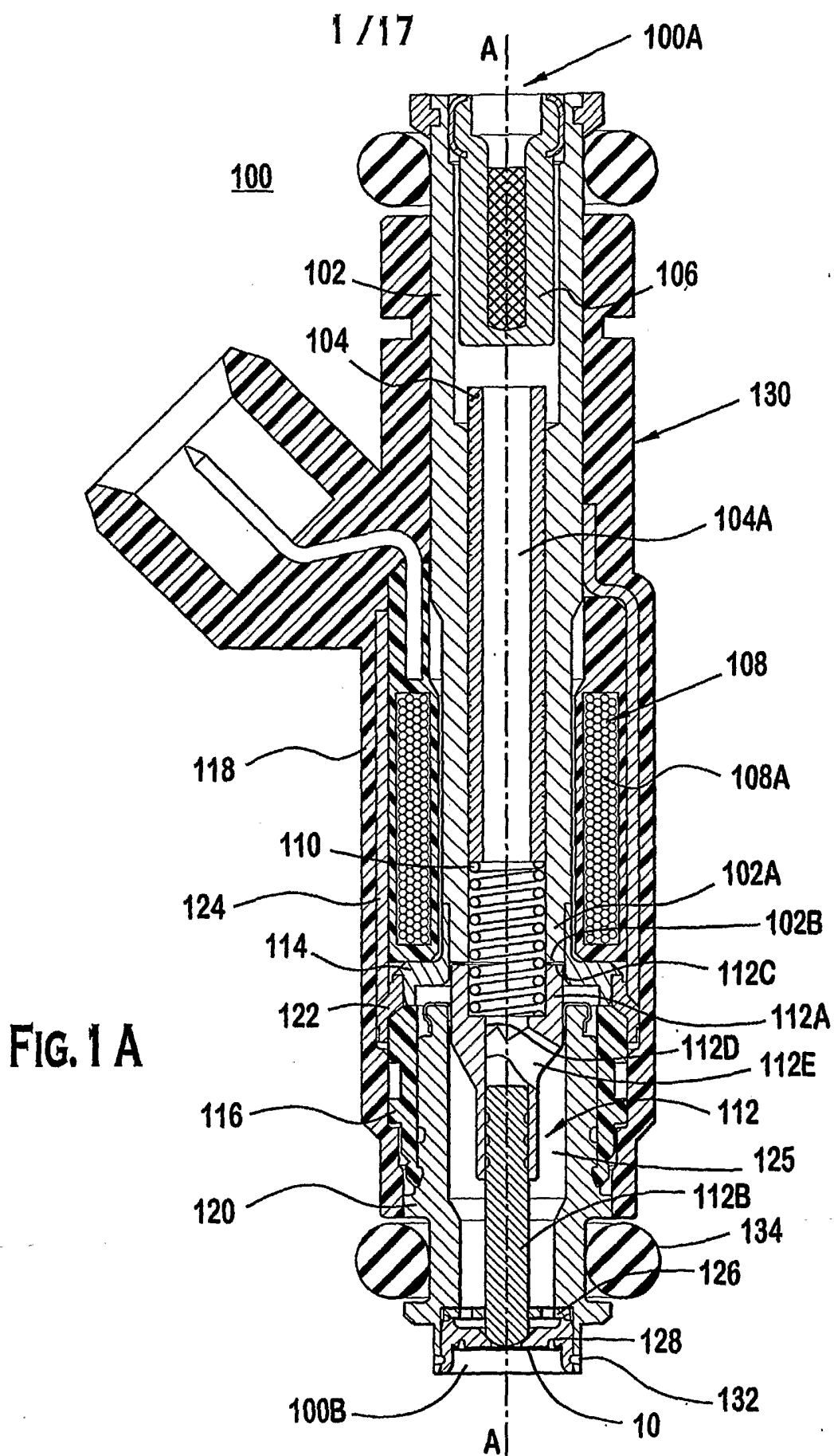
125. A method of spray targeting fuel flow through a metering orifice disc of a fuel injector, the fuel injector having an inlet and an outlet and a passage extending along a longitudinal axis therethrough the inlet and outlet, the outlet having a seat and a metering orifice disc, the seat having a seat orifice, a closure member that occludes a flow of fuel through seat orifice, the metering orifice disc being disposed between the seat and the outlet, the metering orifice disc including at least one metering orifice that extends along the longitudinal axis through the generally planar surface to define a centerline, the method comprising:

... impacting first and second portions of a fuel flow proximate the at least one metering orifice disposed outward of the seat orifice; and

... accelerating the first and second portions of the fuel flow through the at least one metering orifice to the outlet of the fuel injector at an oblique angle with respect to the longitudinal axis.

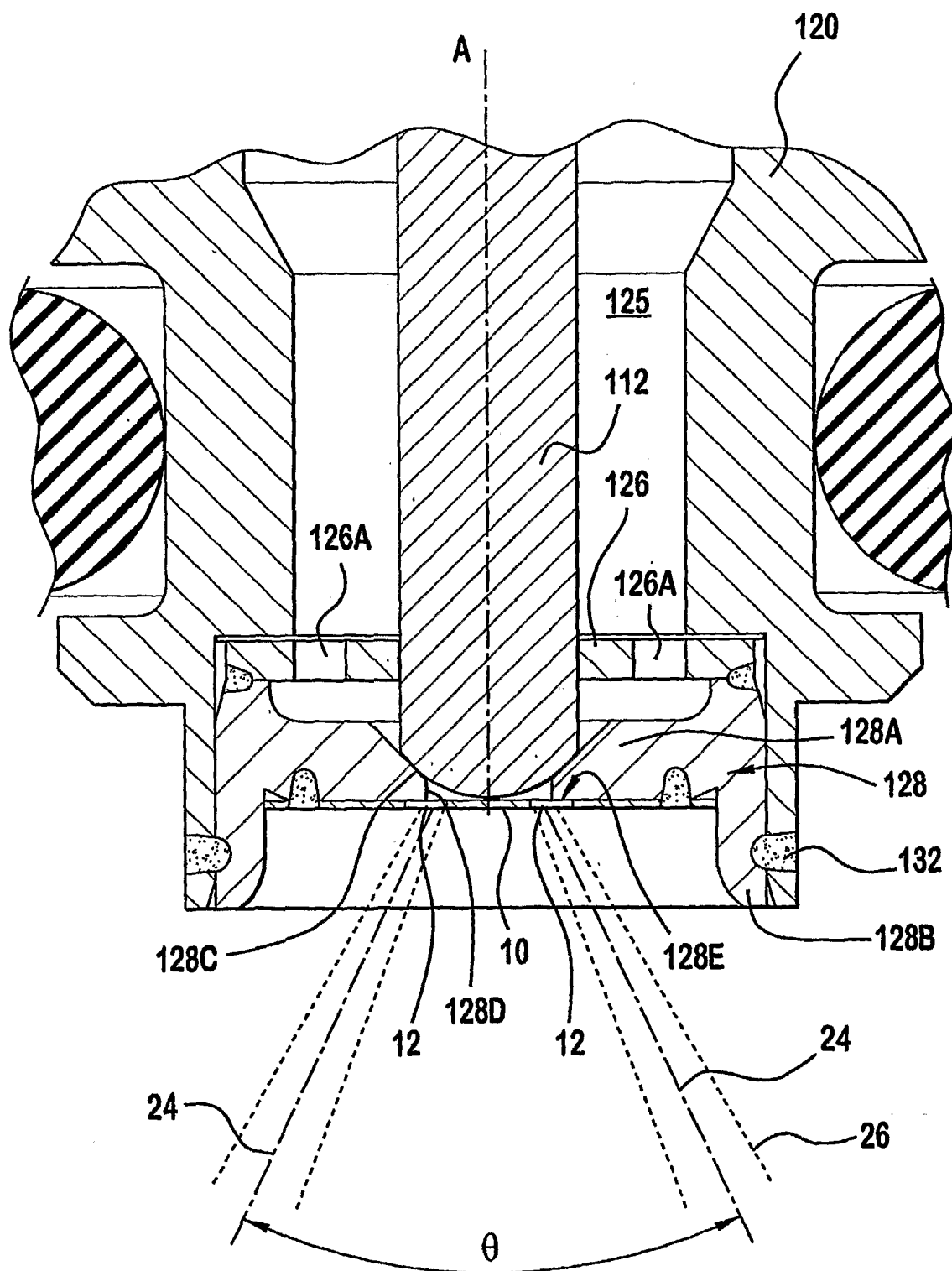
126. The method of claim 125, wherein the accelerating comprises flowing a third portion of the fuel flow along an axis generally transverse to the longitudinal axis.

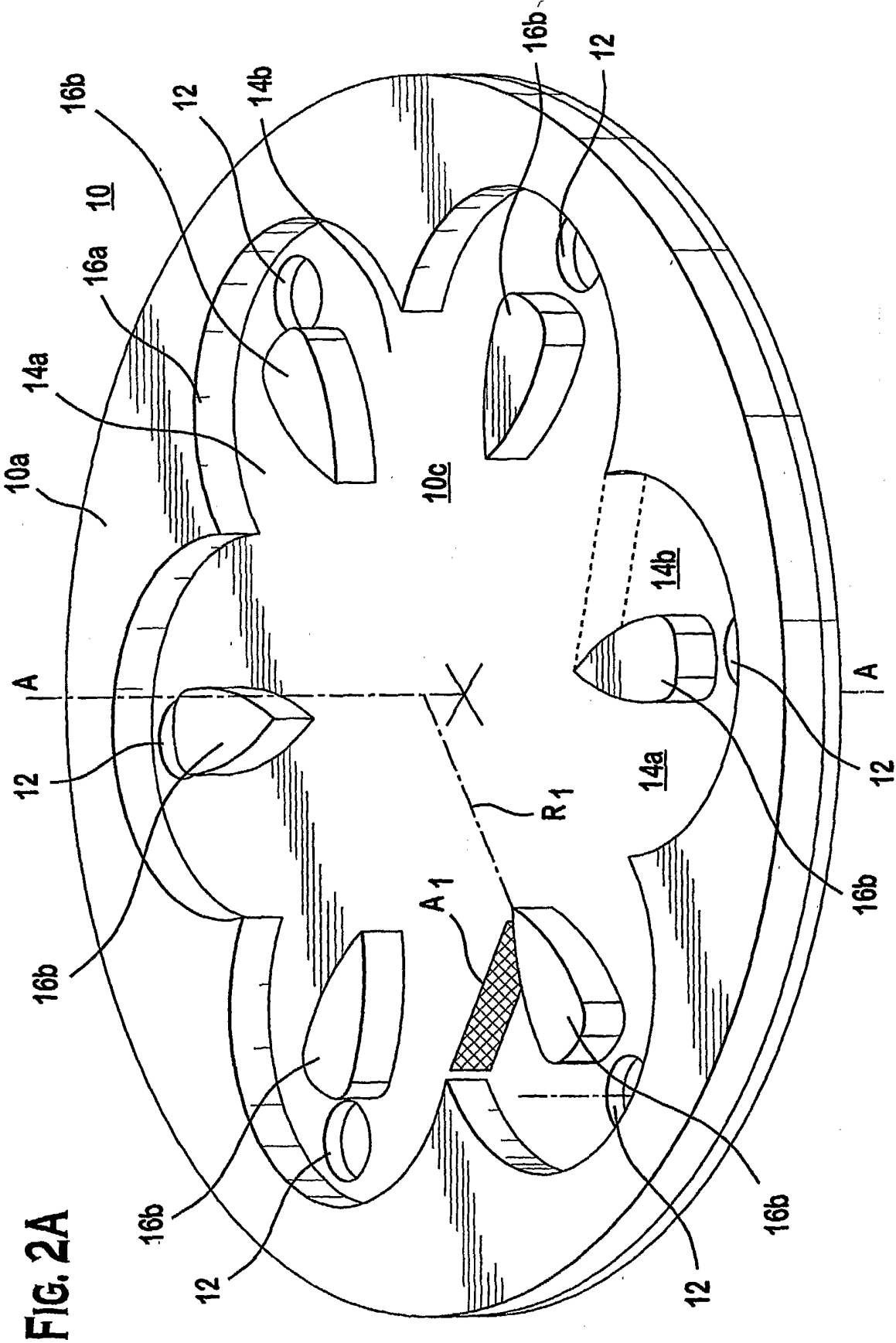
127. The method of claim 126, wherein the oblique angle comprises an angle of about 10 degrees.



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FIG. 1B





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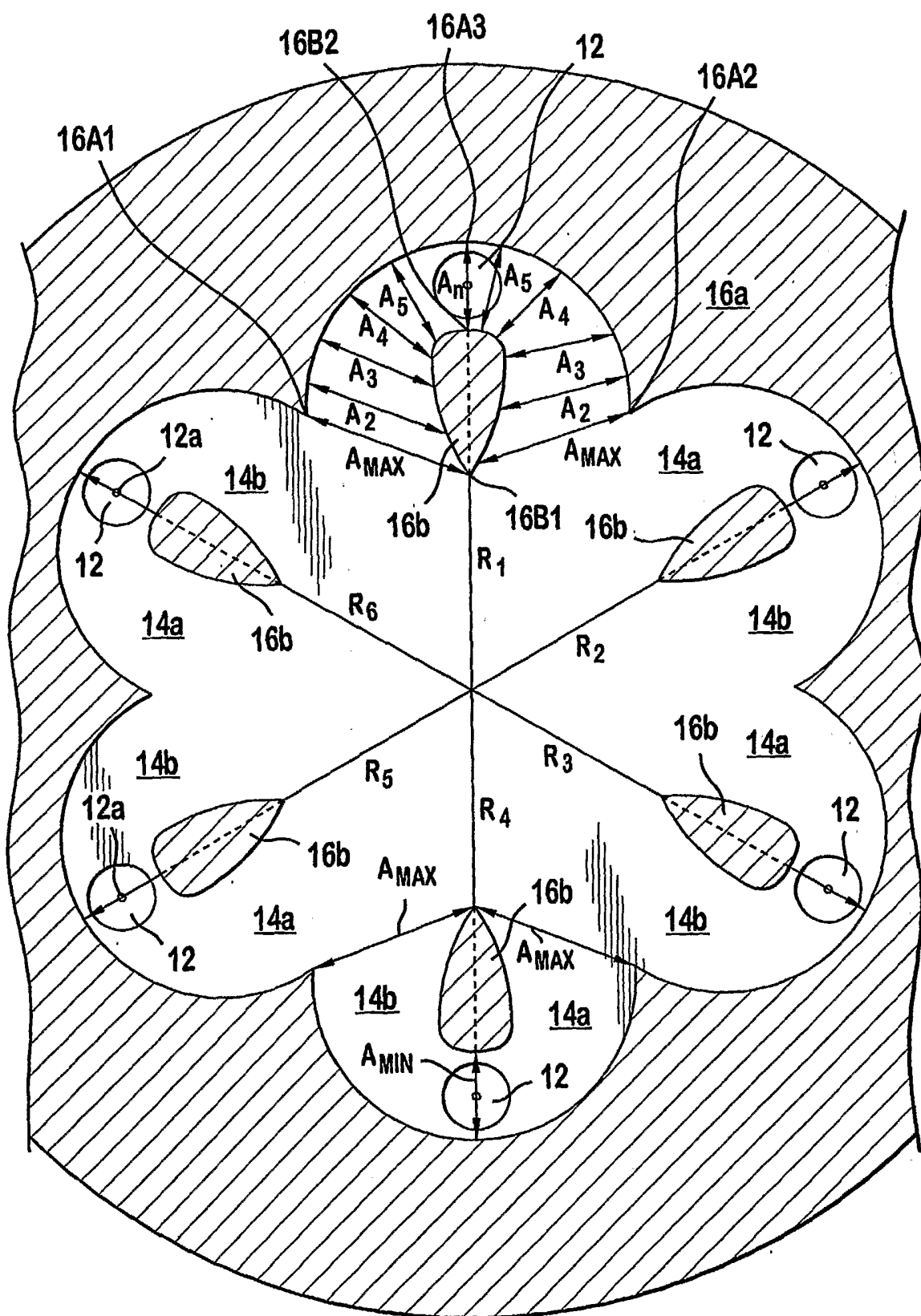


FIG. 2B

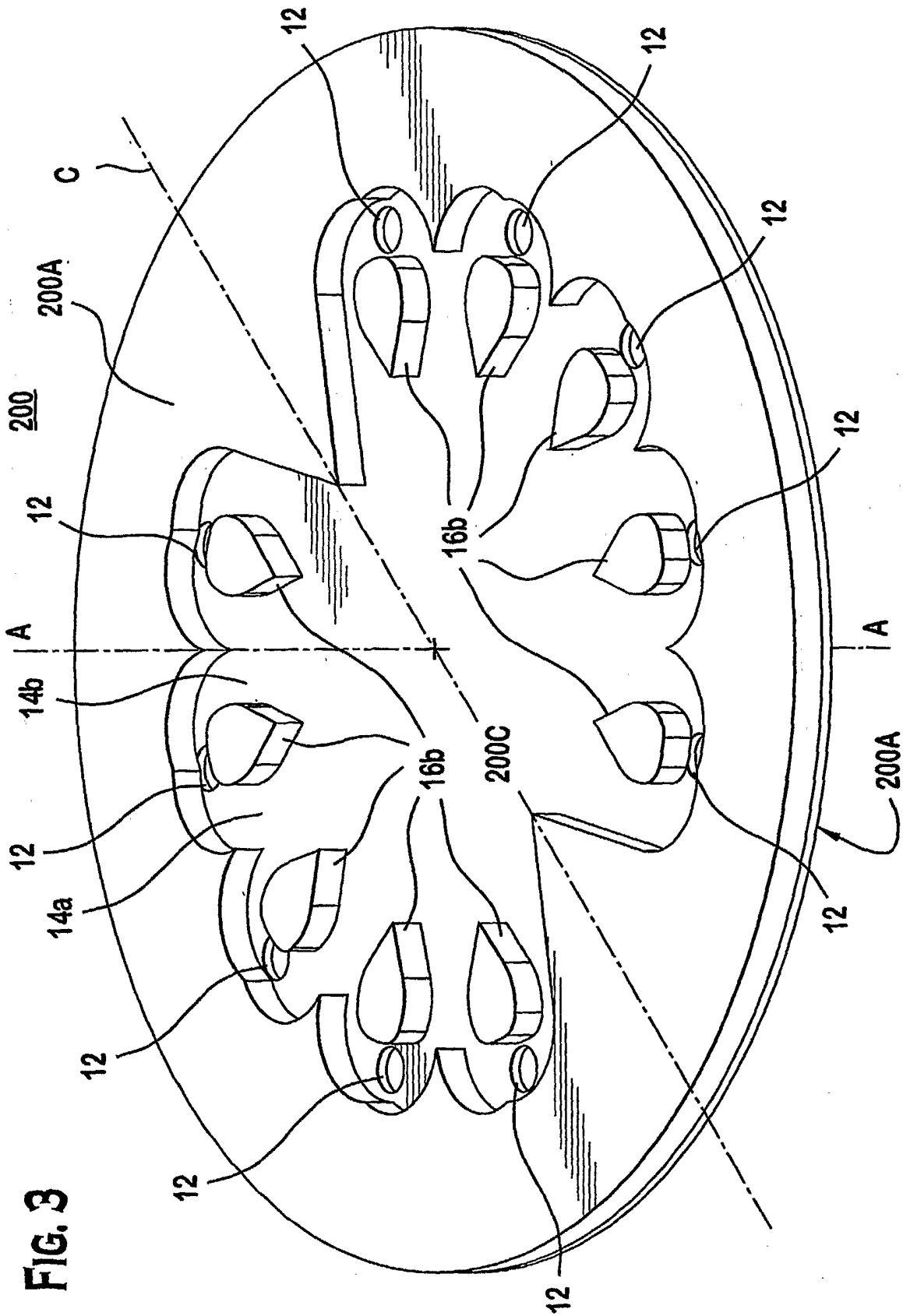


FIG. 3

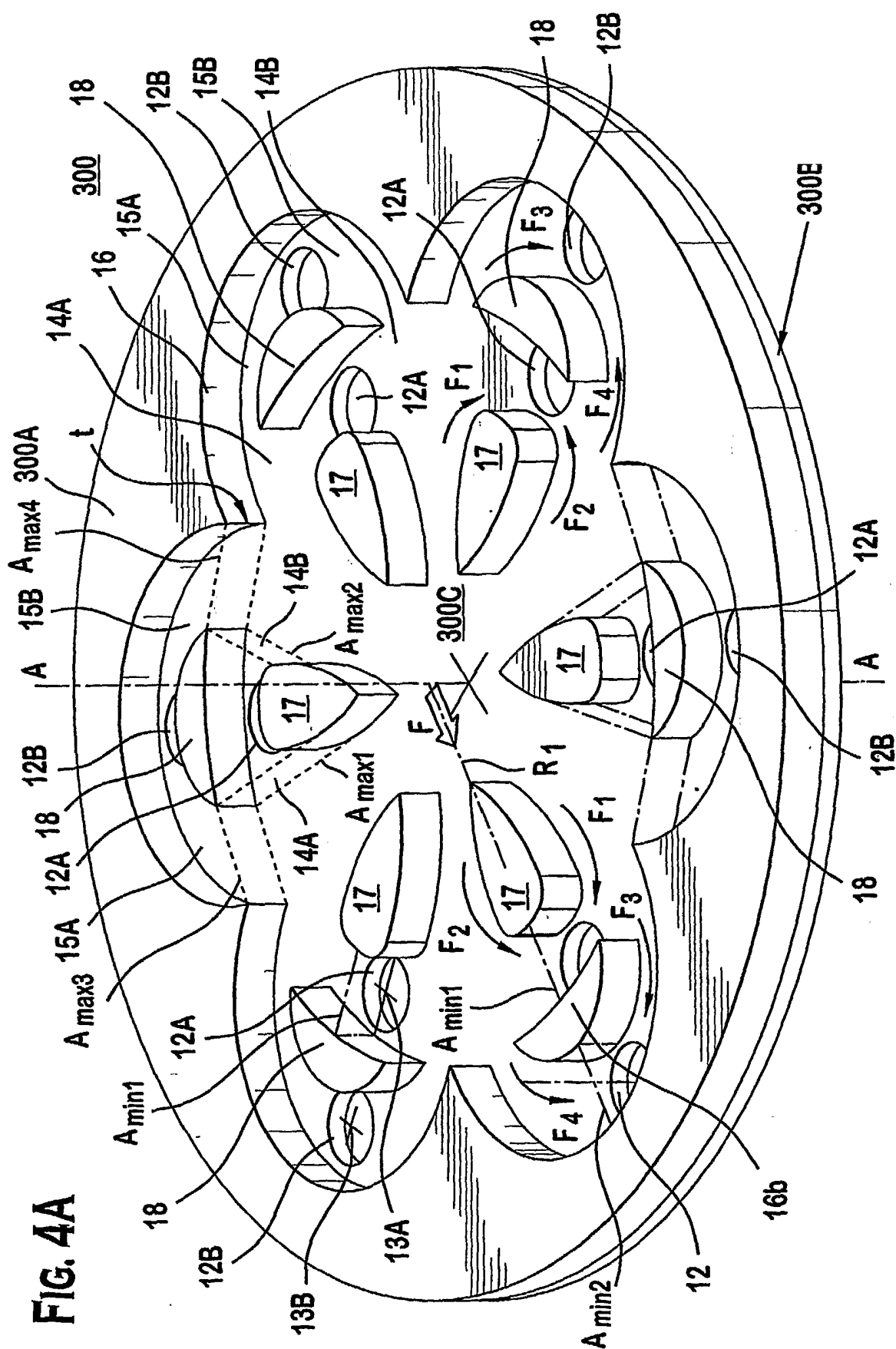


FIG. 4A

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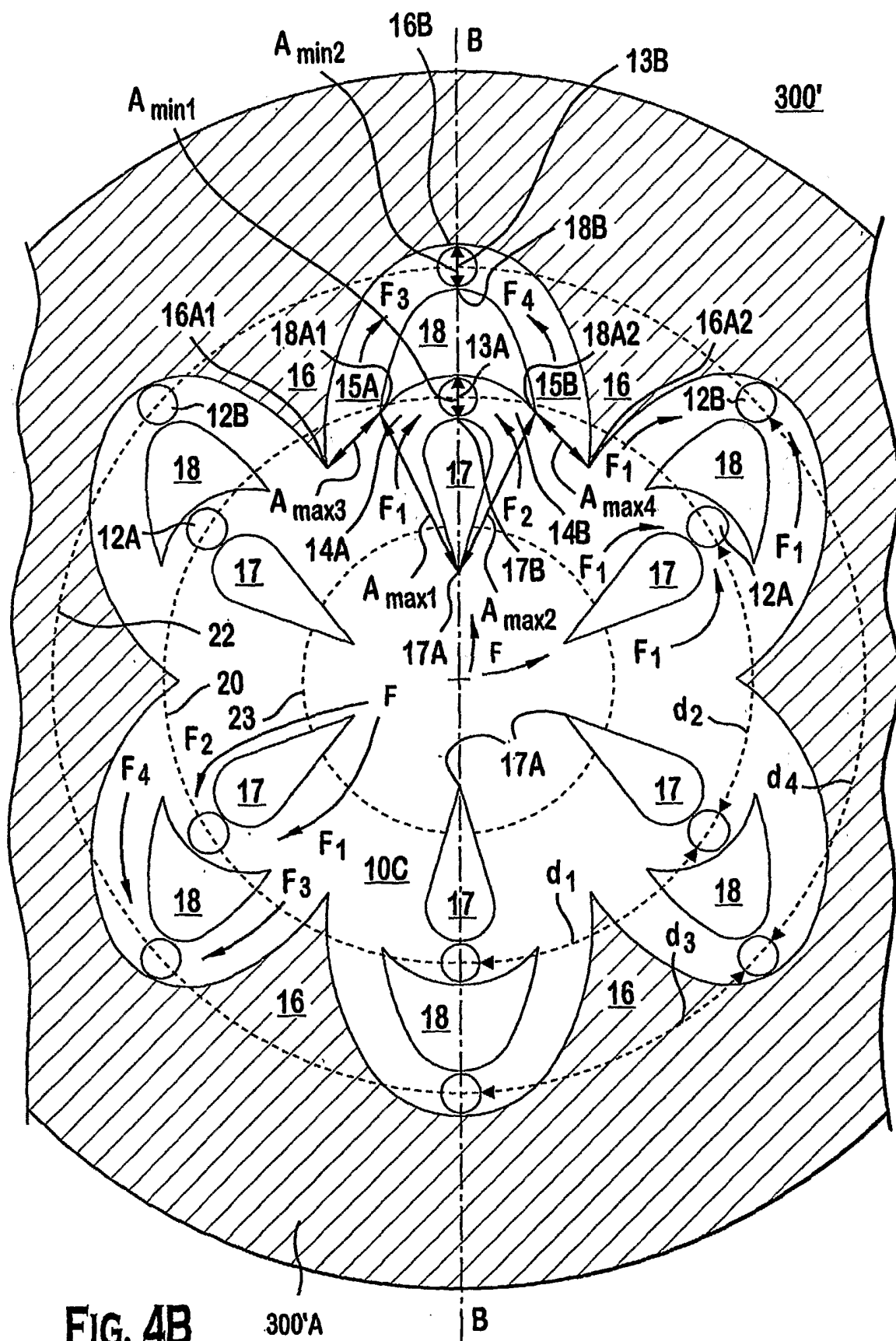


FIG. 4B

300'A

B

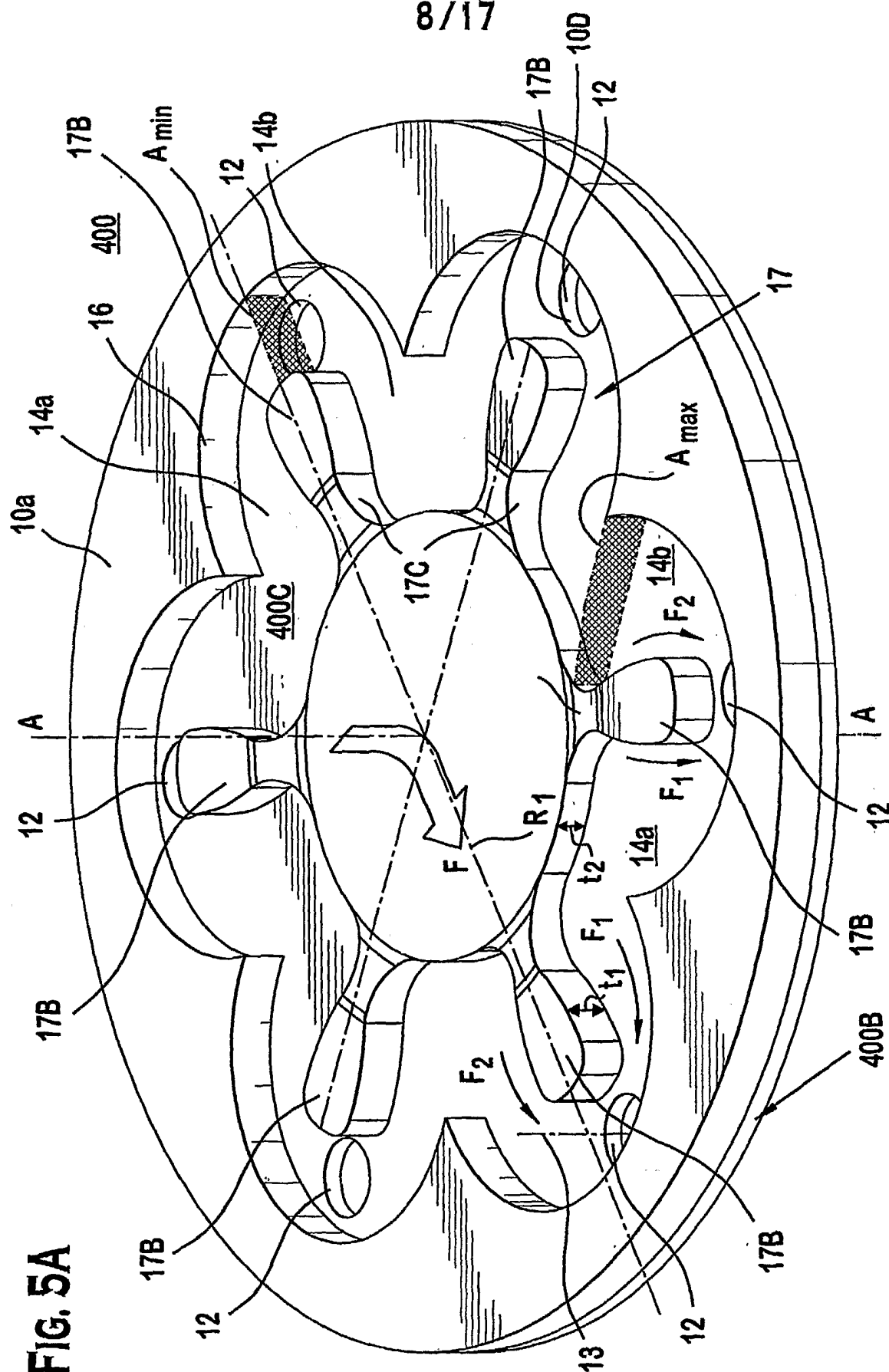


FIG. 5A

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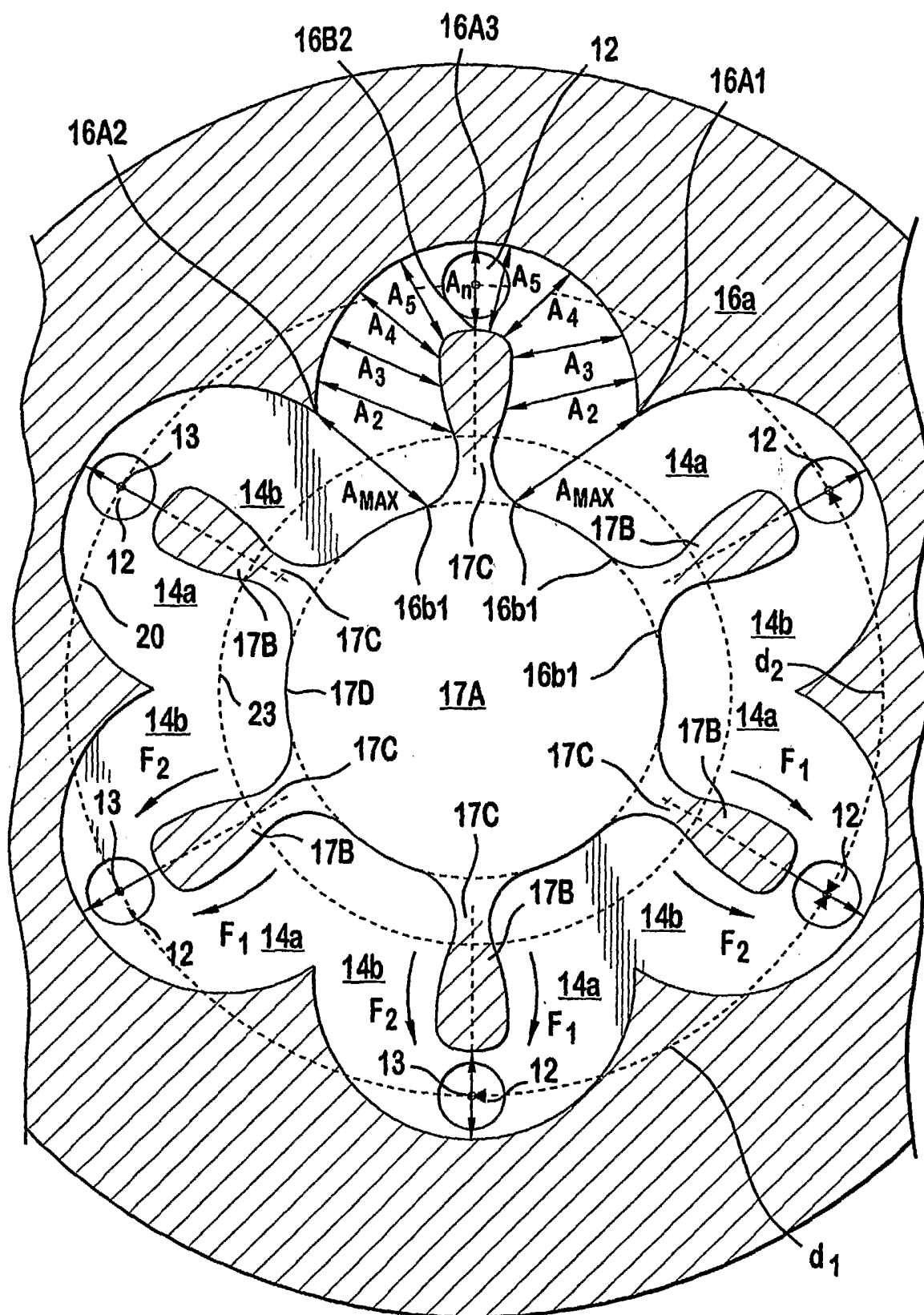
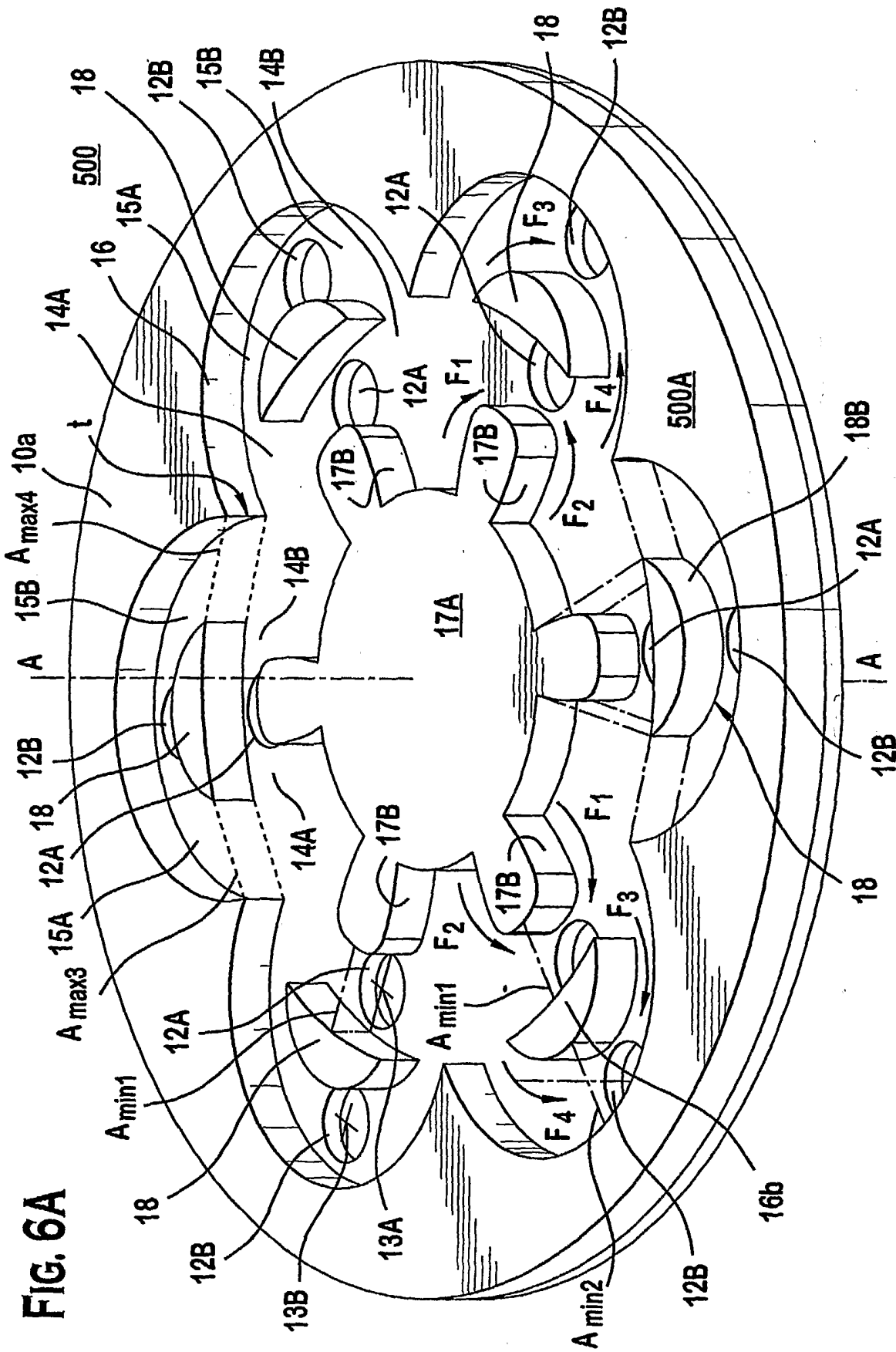


FIG. 5B

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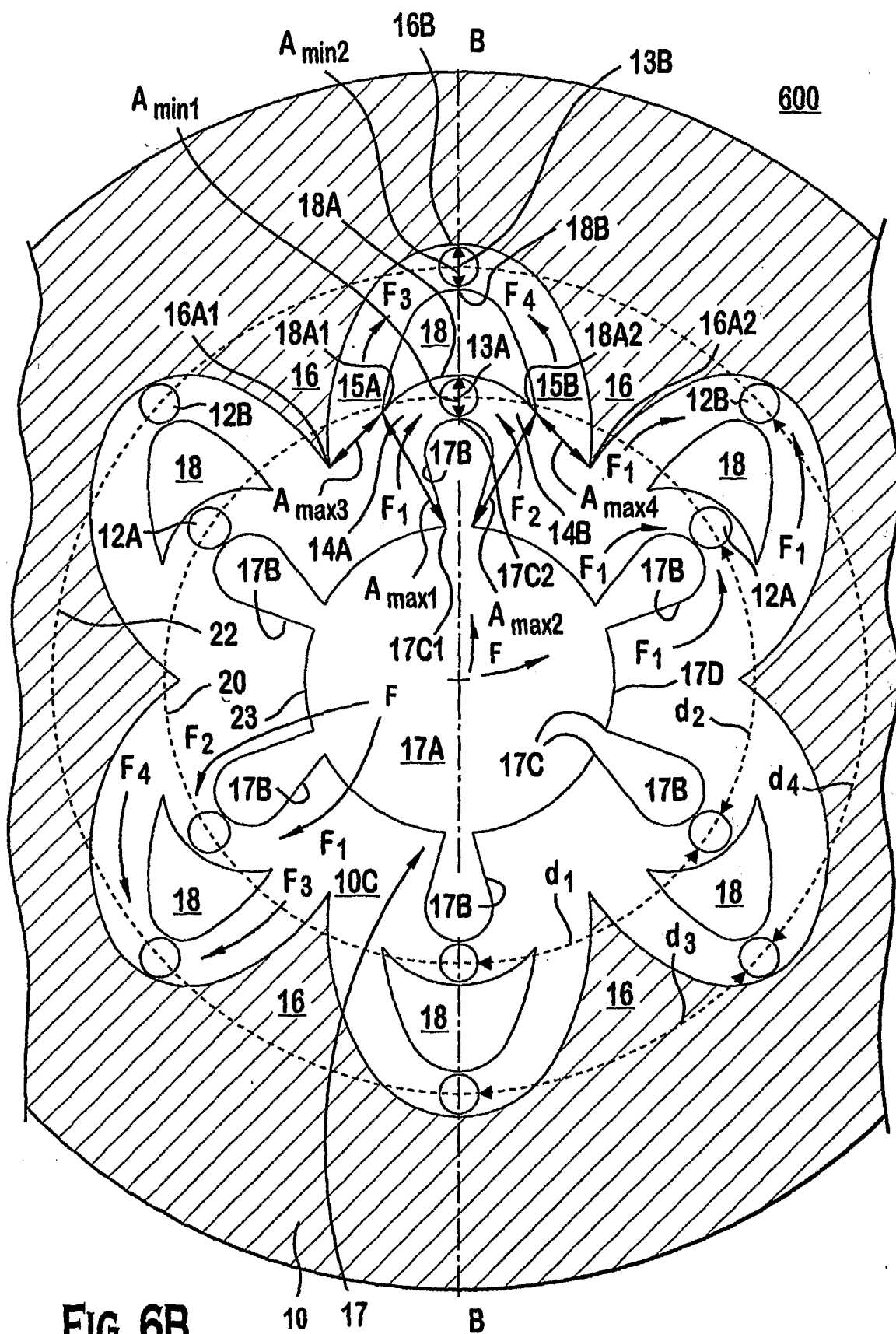


FIG. 6B

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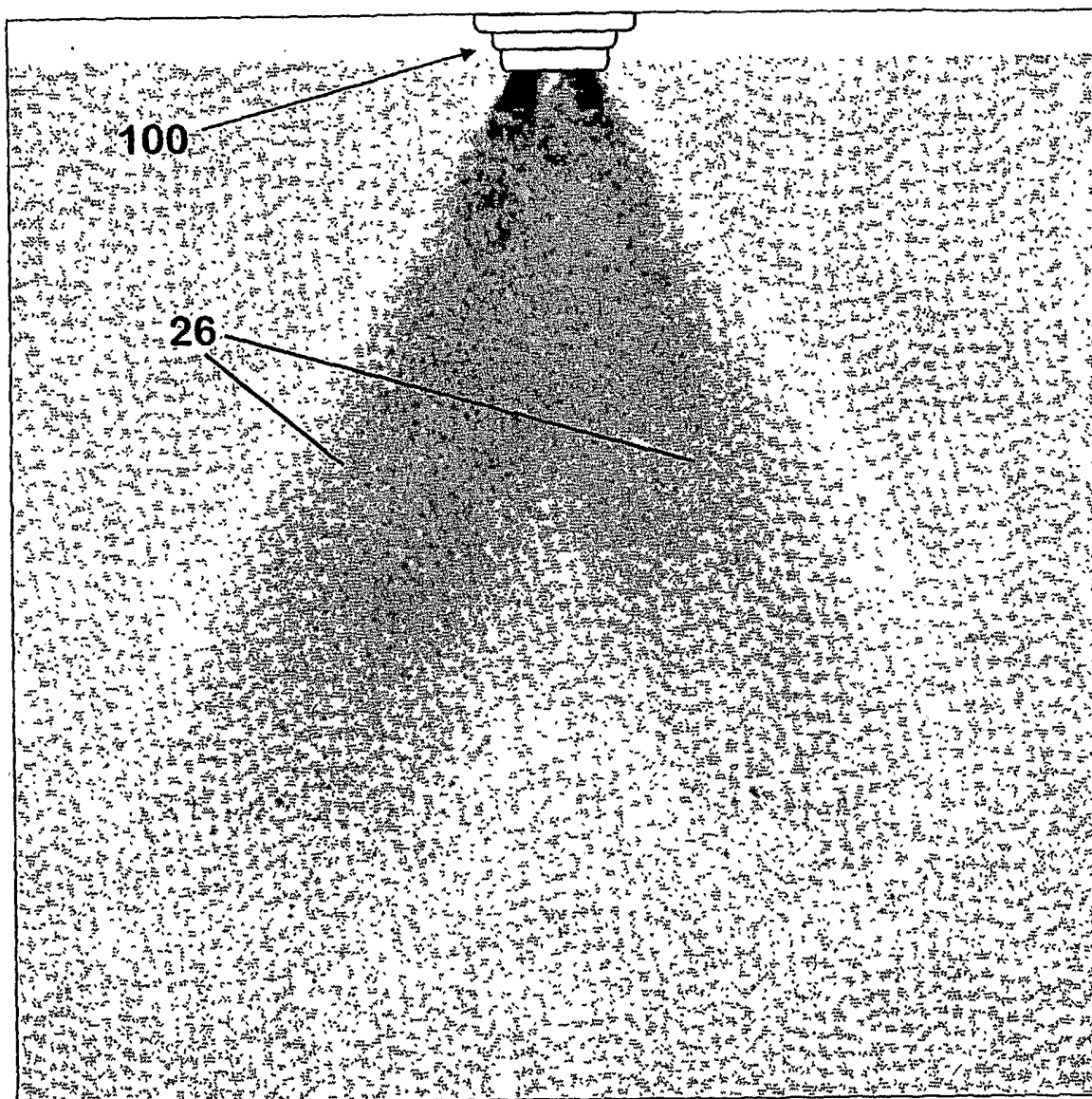
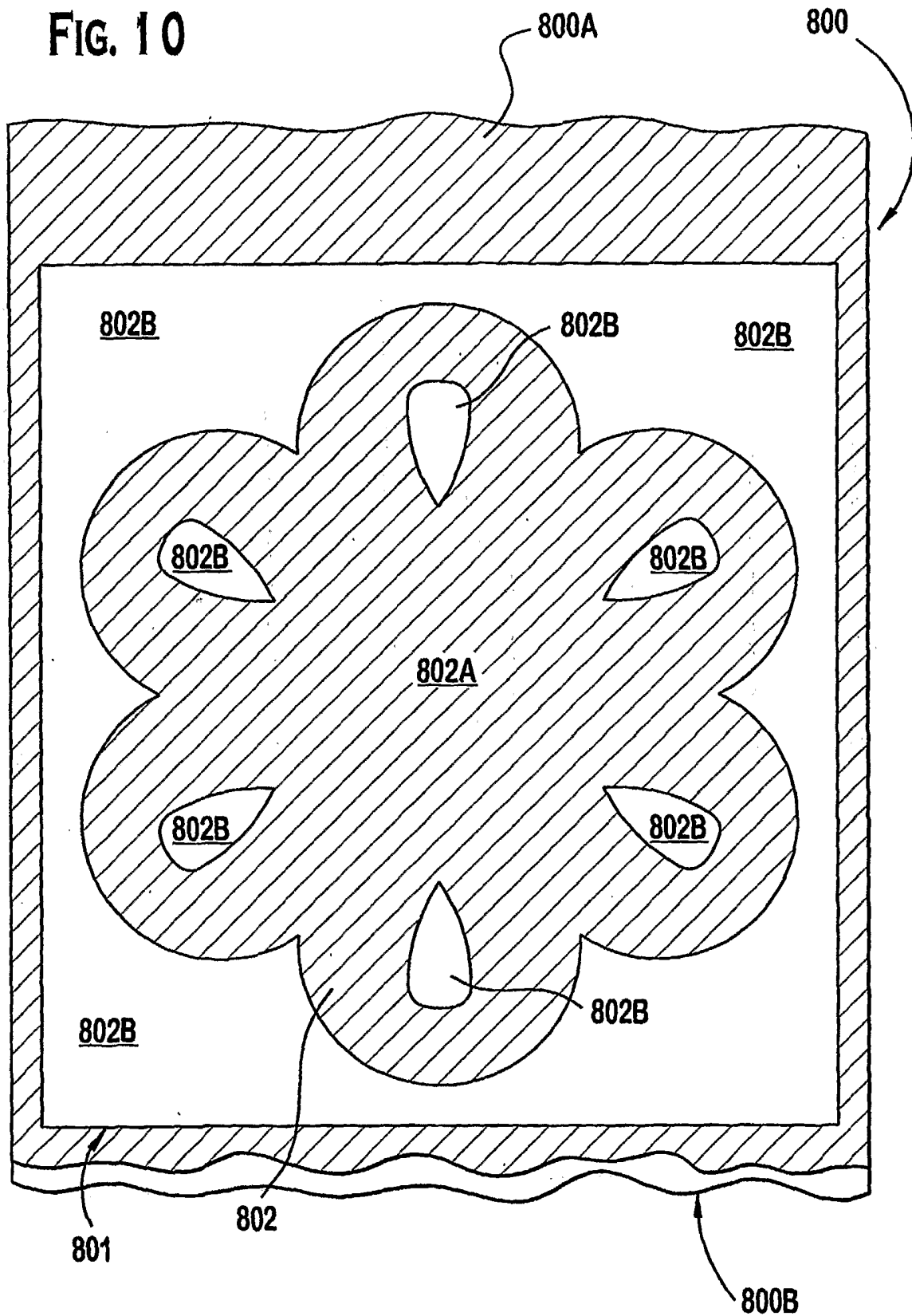


FIG. 9

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FIG. 10



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FIG. 11 A

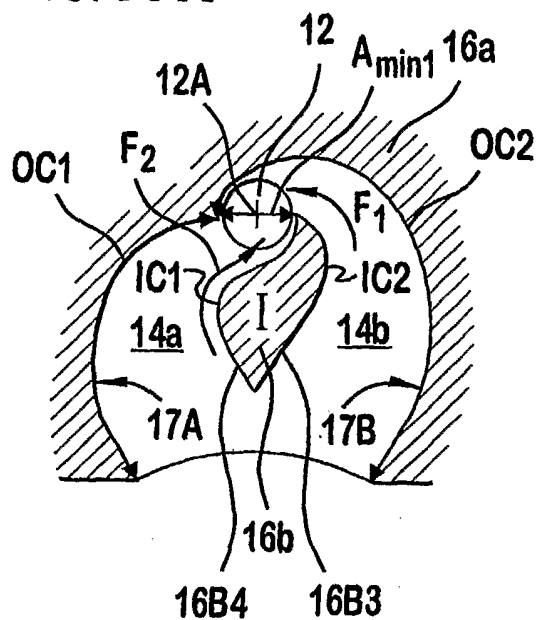


FIG. 11 B

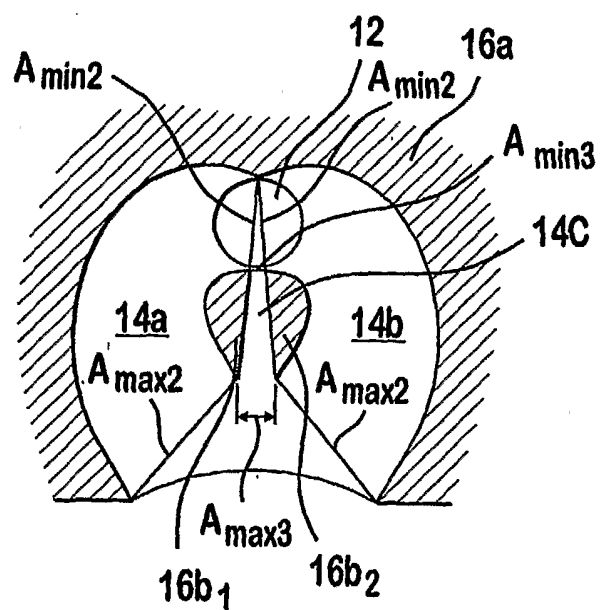
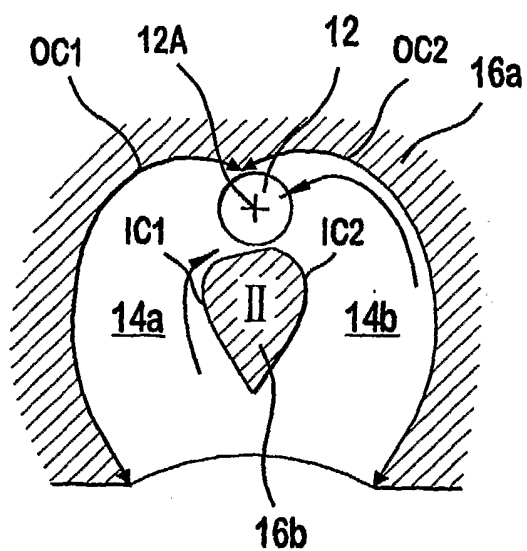
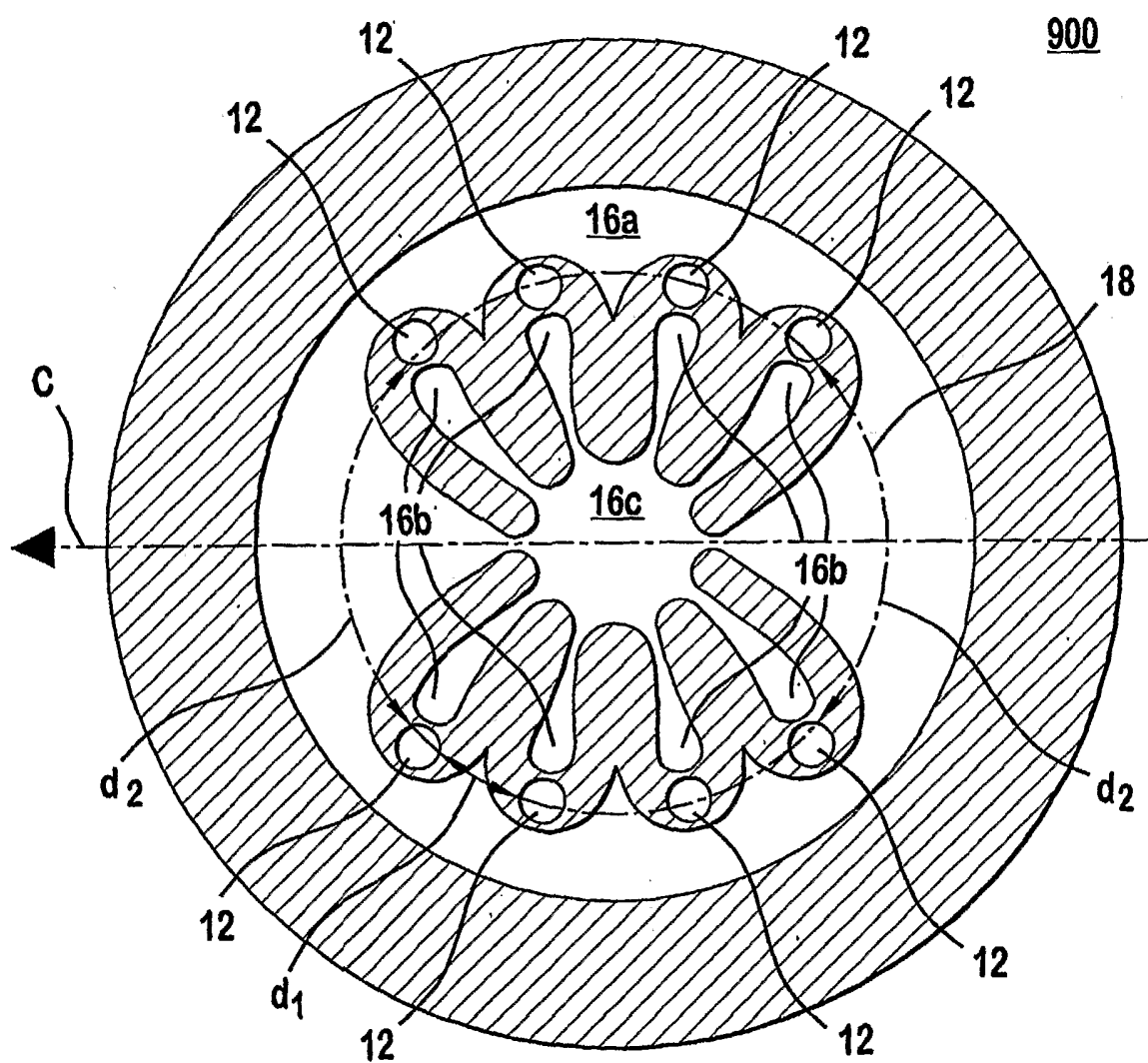


FIG. 11 C

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FIG. 12



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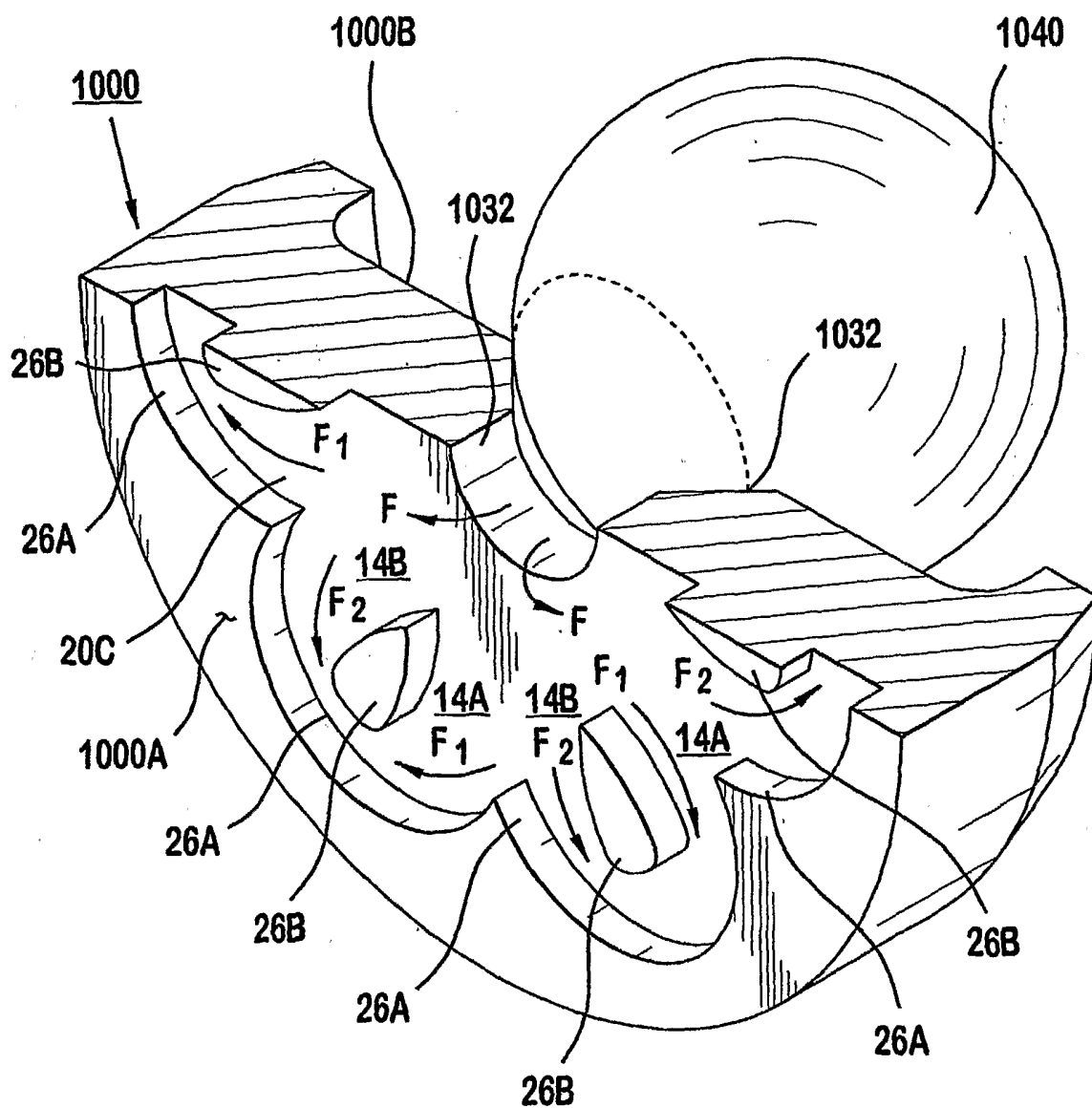


FIG. 13