A tool and apparatus to refurbish a valve seat having a compound geometry, such as a valve seat in a valve body for a common rail fuel injector is disclosed. The tool includes a body with a head portion having substantially the same geometry as the valve seat to be refurbished. The tool further includes a radiused portion located between two angled surfaces of the tool that functions to provide a chamfered cut at the intersection of the valve seat and diffuser passage to be refurbished. The apparatus includes a collet to secure the tool, and the collet may be mounted or secured to a fixture which is in turn mounted on a preloaded biased base so movement of the tool in the Z axis is controllable. The apparatus also comprises a slide movable in an X and Y axis for adjustment of the tool.
COMMON RAIL VALVE SEAT
REFURBISHING TOOL AND APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

The following continuation application claims the benefit of U.S. patent application Ser. No. 13/433,481, filed on Mar. 29, 2012, which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

In a common rail fuel injector, a high pressure valve seat is used to control injector firing. When a magnetic energizer energizes an armature lift and a ball lifts from its seat. High pressure fuel (up to 2000 bar) spills out of a control chamber at elevated velocities between the ball and the value seat. The lift of the ball is only in the order of about fifty (50) microns, and this creates extreme fuel velocities which make the area prone to cavitation. To address this issue, manufacturers have provided a small relief angle called a diffuser angle below the valve seat to help smooth the fluid flow past the ball valve seat while the injector is firing.

It has been a challenge in the manufacturing of valve seats of common rail fuel injectors to provide for consistent stock removal between the valve seat and the diffuser angle. Typical approaches included lapping the valve seat, which only serves to reduce the effective diffuser diameter, which in turns increases the rate of cavitation. Lapping the valve seat and the diffuser angle separately presents extreme challenges in maintaining the diffuser diameter within acceptable tolerances.

Thus, there is a need for a tool and an apparatus to lap the valve seat and maintain the diffuser diameter within acceptable tolerances in refurbishment of common rail fuel injectors.

SUMMARY

In one embodiment, the disclosure relates to a lapping tool to refurbish a valve seat having a compound geometric profile. The tool includes a body having a length and a width wherein the length may be greater than the width. The tool is defined with a first end and a second end in opposed relation to each other. The first end is insertable into a unit for lapping tool motion in an X axis, a Y axis and a Z axis. The second end terminates in a head portion. The head portion may be equipped with an abrasive surface and has a compound geometric profile substantially the same as the compound geometric profile of the valve seat and also includes a radiused portion at the intersection of the compound geometric profile to create a chamfered surface. The tool is rotated at various speeds to facilitate refurbishing of the valve seat in a single action.

In another embodiment, the disclosure relates to a lapping tool to refurbish a valve having a valve seat angle and a diffuser angle. The tool includes a body having a length greater than a width and opposed first and second ends. The first end is configured to be insertable in a lapping unit for motion of the tool in an X axis, a Y axis and a Z axis. The second end is equipped with a head portion having an abrasive surface. The head portion is configured to have a head valve seat angle and a head diffuser angle separated by a radiused portion. The head portion valve seat angle is of substantially the same angle as the valve seat angle, and the head portion diffuser angle is of substantially the same angle as said valve seat diffuser angle. The head radiused portion forms a chamfered intersection between said valve seat angle and said valve seat diffuser angle to maintain the diameter of the refurbished diffuser.

In another embodiment, the disclosure relates to an apparatus to refurbish a ball check valve in a single operation. The apparatus may be a computer numerically controlled machining center, including a fixture configured to accept a ball check valve. The fixture is mountable in a precision slide machining apparatus for movement of the fixture in an X axis and a Y axis, and the fixture is supported by a preloaded bias, such as, for example a spring, to control movement of the fixture in a Z axis. The apparatus may also include a rotary power unit suitable to rotate a lapping tool at various speeds. The lapping tool may be equipped with a body having a length greater than a width and opposed first and second ends. The first end is insertable in a lapping unit for motion of the tool in an X axis, a Y axis and a Z axis, and the second end is equipped with a head portion having an abrasive surface. The head portion has a valve seat angle and a diffuser angle separated by a radiused portion. The head portion valve seat angle of substantially the same angle as the valve seat angle, and the head portion diffuser angle of substantially the same angle as said valve seat diffuser angle. The head portion also includes a radiused portion forming a chamfered intersection between said head portion valve seat angle and said head portion valve seat diffuser angle.

These and other aspects of the disclosure will be apparent upon a reading of the specification and consideration of the drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic representation of a common rail fuel injector comprising a ball check valve;
Fig. 2A is a detailed view of Section 2A of Fig. 1 illustrating the ball check valve in the common rail fuel injector;
Fig. 2B is a cut away side view of the ball check valve of Fig. 2A showing its construction;
Fig. 2C is a detailed view of Section 2C of Fig. 2B illustrating the valve seat of the ball check valve;
Fig. 2D is a detailed view of Section 2C of Fig. 2B detailing the diffuser passage, diffuser distance, and diffuser angle of the ball check valve;
Fig. 3A is a side view of one embodiment of a lapping tool according to the disclosure;
Fig. 3B is a detailed view of Section 3B of Fig. 3A illustrating the head portion of the lapping tool;
Fig. 3C is a detailed view of Section 3B of Fig. 3A illustrating the angled surfaces of the lapping tool;
Fig. 4 is a sectional representation of one apparatus according to the disclosure; and
Figs. 5 through 9 are photomicrographs showing the machined valve seat and diffuser surfaces after various test times to simulate actual use wear.

DETAILED DESCRIPTION

Turning now to the drawings wherein like numbers refer to like structures, Fig. 1 is a representation of a common rail fuel injector 10. While there are many parts and assemblies that comprise the common rail fuel injector 10, the description will be only to those portions of the common rail
fuel injector 10 that are relevant to the inventive concepts of the present application, inasmuch as common rail fuel injectors are well known to those skilled in the art and need not be described in great detail here.

[0020] Referring still to FIG. 1, the common rail fuel injector 10 has a body portion 12 upon which is situated a nozzle portion 14 at one end thereof, and a magnetic energizer 16 at the opposite end. The energizer 16 is electronically connected to an Electronic Control Unit (ECU) (not shown) and energized as per fueling instructions held in memory of the ECU to permit fuel to pass through the injector and out of the nozzle 14. In this regard, fuel is introduced under pressure through intake fuel passage 18, where it encounters ball check valve 30 in valve body 20. The ball check valve body 20 has a valve seat 22 and a diffuser passage 38. A bearing 24, which may be a ball for example, sits on a bearing seat 32 and obstructs diffuser passage 38. The valve body 20 is composed at least partially of a magnetic material such that when the magnetic energizer 16 is energized, ball check valve 30 is attracted out of engagement from the surface of the valve seat 22. When the ball check valve 30 is disengaged from its valve seat 22, the pressurized fuel displaces bearing 24 from its bearing seat 32, permitting the pressurized fuel to enter the diffuser passage 38 and flow to the high pressure fuel passage 28. The fuel flowing through the high pressure fuel passage 28 causes needle 15 in the nozzle 14 to lift, thereby allowing fuel to be injected into the engine through apertures (not shown).

[0021] Turning now to FIG. 2A, there is shown a detailed view of Section 2A of FIG. 1 illustrating the ball check valve 30 in the common rail fuel injector 10. With greater reference to valve body 20, magnetic energizer 16 is in close proximity to ball check valve 30. The valve body 20 has a compound geometry, with a first surface being a valve seat 22 having a valve seat angle θ. Bearing 24 is seated atop diffuser passage 38 at bearing seat 32. At the intersection of the diffuser passage 38 and the bearing seat 32, valve body 20 has a second surface having a diffuser angle Φ.

[0022] FIG. 2B is a cutaway view of the valve body 20 of FIG. 2A. Specifically, the ball check valve 30 sits in a valve seat 22, which has a compound geometric profile of a first inclined surface at a valve seat angle θ and a second inclined surface at a diffuser angle Φ. As previously noted, the bearing 24 is seated atop a diffuser passage 38 at bearing seat 32. When the ball check valve 30 is attracted by the magnetic energizer 16, highly pressurized fuel travels into the valve body 20 along the valve seat 22 and displaces the bearing 24 from bearing seat 32 to permit the flow of high pressure fuel into the diffuser passage 38 and then into the high pressure fuel passage 28. It should be understood that the bearing 24 is displaced from the bearing seat 32 only a slight amount, on the order of about fifty (50) microns, and the fuel is under such high pressure that, as the fuel travels along the valve seat 22 and into diffuser passage 38, cavitation occurs along those surfaces such that accuracy of the injection event is eventually compromised. Refurbishing of these surfaces is necessary to restore the common rail fuel injector 10 to its operating specification.

[0023] Turning now to FIGS. 2C and 2D, there is shown a detail of Section 2C from FIG. 2B of the valve body 20. Specifically, valve seat 22 is shown at a valve seat angle θ, and diffuser passage 38 is shown at a diffuser angle Φ. The diffuser angle Φ surrounds and intersects the diffuser passage 38 to define the ball or bearing seat 32. It is the bearing seat 32 that suffers most from cavitation as the fuel passes along the valve seat 22 through the diffuser passage 38 and into the high pressure fuel passage 28 of the common rail fuel injector 10. It is understood that the sharp angled intersection between the diffuser passage 38 and the valve seat 22 causes especially high pressure flow that contributes to cavitation.

[0024] FIG. 3A is a side view of a lapping tool 42 according to one aspect of the disclosure. The lapping tool 42 has a body 44 having a length 46 and a width 47 through which an axis of rotation 48 may extend. The length 46 of the lapping tool 42 is shown greater than its width 47. The body 44 has opposing first and second ends 45 and 49 respectively. The first end 45 is insertable into a rotary power unit 66 for rotary motion of the lapping tool 42 along its axis of rotation 48. The second end 49 comprises a head portion 50, which is better understood with reference to FIGS. 3B and 3C.

[0025] Referring now to FIGS. 3B and 3C, detailed views of Section 3B of FIG. 3A are shown illustrating the head portion 50 of the lapping tool 42. A tapered portion 52 separates the body 44 of the lapping tool 42 from the head portion 50. The head portion 50 comprises an angled work portion 54 that extends at a first angle θ1, which may be conical, parabolic, semi-spherical, or any other shape desired to refurbish the valve seat 22 of the valve body 20. The angled work portion 54 includes a work surface 60, which may be equipped with abrasive material 62 to remove material from the valve seat 22 of the valve body 20 during a lapping motion. The abrasive material 62 may be at least one of diamond, cubic boron or silicon carbide, or any other suitable abrasive, and has a grit sufficient to refurbish the valve seat 22 of the valve body 20. In one embodiment, the grit may be on the order of thirty (30) microns.

[0026] Concentric on head portion 50 at its distal end 59 is angled end diameter portion 58, which extends a sufficient distance 56 to machine the diffuser passage 38. The angled end diameter portion 58 has a work surface 61 that extends in a second angle θ2. Angled end diameter portion 58 extends at second angle θ2 from proximal diameter 90 to distal diameter 92. The first angle θ1 of the angled work portion 54 is substantially the same angle as the valve seat angle θ of valve seat 22, and the second angle θ2 of the angled end diameter portion 58 of lapping tool 42 is substantially the same angle as the diffuser angle Φ of the diffuser passage 38. It is important to note that a radiused portion 63 exists at the intersection between the angled work portion 54 and the angled end diameter 58. Radiused portion 63 is slightly radiused. Accordingly, it can be readily understood that the angled work portion 54 and the angled end diameter portion 58 of the head portion 50 do not intersect each other, but rather each one intersects the radiused portion 63.

[0027] Abrasive material 62 may be deposited on the head portion 50 by mixing the abrasive with a plating material, such as nickel, and overlaying the head portion 50. This plating will also form the radiused portion 63. The radiused portion 63 can also be formed by forming it when the head portion 50 is formed, and then overlaying it with the abrasive, or in any other way that may be apparent to those skilled in the art.

[0028] FIG. 4 is a schematic representation of an apparatus 64 to refurbish valve seats according to one aspect of this disclosure. Specifically, the lapping tool 42 is fixed or inserted at its first end 45 into rotary power unit 66 for variable speed rotation of the lapping tool 42. A collet 72 or a suitable chuck secures the valve body 20 in place. The collet 72 is in turn mounted or secured to a fixture, or floating assembly 68.
Floating assembly 68 is floatably mounted on a preloaded biaser 78, such as a coil spring, leaf springs, resilient material, a hydraulic or pneumatic cylinder arrangement, or any other arrangement that may control the movement of the floating assembly 68 in the Z axis direction. The floating assembly 68 is mounted on a slide 67 for movement of the collet 72 and floating assembly 68 in the X axis and the Y axis. When it is desired to refinish a valve seat having a compound geometric profile (as described above) the valve body 20 is mounted in the collet 72 which is then placed in the floating assembly 68. The lapping tool 42 may be inserted into rotary power unit 66 for rotary motion at various speeds to provide lapping of the valve seat in a single operation. The rotary power unit 66 is lowered until the lapping tool 42 contacts the valve seat 22. The lapping tool 42 is then rotated at a relatively high speed for stock removal of the valve seat 22 for a time sufficient to remove sufficient stock to remove traces of cavitation, and then at a low speed to improve valve seat roundness. Because the head portion 50 of the lapping tool 42 includes the radiused portion 63 that finishes the diffuser passage 38, the valve seat 22 and the diffuser passage 38 may be refinished in a single action. The preloaded biaser 78 prevents over machining in the Z axis, as it is preloaded and will only permit the correct force be applied in the Z axis, as it will bias the lapping tool 42 in the opposite Z axis direction if the tool is plunged too deeply into the valve body 20. The slide 67 is adapted to provide movement of the floating assembly 68 and collet 72 in the X axis and the Y axis, to allow for lapping of the valve seat 22 to ensure complete removal of stock that may have been affected by cavitation. Generally, the valve seat 22 is subjected to stock removal at tool rotary speeds up to about 2000 RPM until cavitation is removed, and then it is subjected to valve seat rounding at tool rotary speed of up to about 150 RPM. All machining aspects described above, such as the lowering of the rotary power unit 66 to contact the valve seat 22, activation of the lapping tool 42 for lapping, and adjustment of tool speed, may be controlled by a Computer Numerically Controlled (CNC) machine center 79.

Table 1 shows the refinished injectors were tested for four points according to Original Equipment Manufacturer (OEM) specifications. The table contains data that is illustrative, but not limiting, of the concepts in this disclosure. Table 1 shows several test examples of valve seat bodies refinished with one embodiment of the described lapping tool 42 in one embodiment of the apparatus 64 as described above.

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<th>Part Type</th>
<th>Model</th>
<th>Date</th>
<th>Time After 512 Hours</th>
<th>Part No.</th>
<th>PASS Cycle Time</th>
<th>2VolumeHE Emissions</th>
<th>2SplitFlow</th>
<th>2RailPress</th>
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AVG Field Tolerance (+/-)

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<th>Model</th>
<th>Date</th>
<th>Time After 512 Hours</th>
<th>Part No.</th>
<th>PASS Cycle Time</th>
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</table>
FIGS. 5-9 are photomicrographs showing the bearing seat 32 of the several refurbished valve seat bodies after various lengths of service, as described in Table 1. In each instance, as described in the data of Table 1, cavitation at the bearing seat 32 is substantially diminished and practically nonexistent. The bearing seat 32 remains functional within specification and the radiused portion clearly demonstrates the advantage of reduced fuel flow velocities with resultant decreased cavitation. In addition, the valve body 20 has an increased service life between refurbishments, resulting in substantial savings to an operator.

Specifically, FIG. 5 is a photomicrograph of sample 1, machined and tested as set forth in Table 1. FIG. 5 shows light cavitation at the chamfer (radiused portion)/seat intersection. There was no progression of cavitation into the ball sealing area 57 of bearing seat 32. There is also exhibited a very consistent wear pattern with the core material. The ball sealing area 57 shows normal wear after more than 512 hours of testing.

FIG. 6 is a photomicrograph of sample 2, machined and tested as test forth in Table 1. The figure shows heavier cavitation at the chamfer/seat intersection. However, there is no progression of cavitation into the ball sealing area 57, and the core material shows very consistent wear pattern. In addition, the ball sealing area 57 shows normal wear, after being machined and tested as set forth in Table 1.

FIG. 7 is a photomicrograph of Sample 3, machined and tested as set forth in Table 1. It can be seen that light cavitation occurred at the chamfer/seat intersection, with no progression into the ball sealing area 57. The core material also showed very consistent wear pattern, and the ball seating area 57 shows normal wear, after machining and testing as set forth in Table 1.

FIG. 8 is a photomicrograph of sample 4, machined and tested as set forth in Table 1. Again, there is no progression of cavitation into the ball sealing area 57, and the core material shows very consistent wear pattern. The ball sealing...
area 57 shows higher than average wear, but that wear is still consistent with the core material.

[0036] FIG. 9 is a photomicrograph of sample 5, machined and tested as set forth in Table 1. The sample shows a light cavitation at the chamfer/seat intersection, with no progression of cavitation into the ball sealing area 57. The core material shows a very consistent wear pattern and the ball sealing area 57 shows normal wear.

[0037] Many modifications and variations of the invention as described are possible in light of the above teachings. In addition, the words used in the specification are of description, not limitation. Within the scope of the appended claims, the invention may be practiced other than as specifically described.

What is claimed as new and desired to be protected by Letters Patent of the United States is:

1. A lapping tool to refurbish a valve seat having a compound geometric profile, said lapping tool comprising:
   - a body having a length and a width;
   - said length longer than said width;
   - said body having a first end and a second end, said first and second ends opposed to each other;
   - said first end insertable into a unit for lapping tool motion in an X axis, a Y axis and a Z axis;
   - said second end terminating in a head portion, said head portion equipped with an abrasive surface; and
   - said head portion comprising:
     - an angled work portion extending at a first angle, said first angle substantially complimentary to said compound geometric profile of said valve seat;
     - an angled end diameter portion protruding outward from said angled work portion at a second angle, said angled end diameter having a proximal diameter and a distal diameter, said distal diameter shorter than said proximal diameter, said angled end diameter portion extending at said second angle from said proximal diameter to said distal diameter; and
   - a raduisued head portion separating and contiguous with said angled work portion and said angled end diameter portion.

2. The lapping tool of claim 1, wherein said body and said head portion are separated by a tapered portion.

3. The lapping tool of claim 1, wherein said abrasive surface includes at least one of diamond, cubic boron, or silicon carbide abrasive having a grit in the range of about 30 microns.

4. The lapping tool of claim 3, wherein said head portion comprises a nickel plated layer with said grit impregnated in said nickel plated layer.

5. A lapping tool to refurbish a valve, said valve comprising a valve seat having a valve seat angle and a diffuser passage having a diffuser angle, said lapping tool comprising:
   - a body having a length greater than a width;
   - said body having opposed first and second ends;
   - said first end insertable in a lapping unit for motion of the tool in an X axis, a Y axis and a Z axis, said second end equipped with a head portion having an abrasive surface; said head portion having an angled work portion having a first angle, and an angled end diameter portion having a second angle, said angled work portion and said angled end diameter portion separated by and contiguous with a radiusued portion; said first angle of said head portion substantially the same angle as said valve seat angle, and said second angle of said head portion substantially the same angle as said diffuser angle; and
   - said raduisued portion forming a raduisued intersection between said angled work portion and said angled end diameter portion, said raduisued intersection configured to facilitate a chamfered cut at an intersection of said valve seat angle and said diffuser angle of said valve.

6. The lapping tool of claim 5, wherein said body and said head portion are separated by a tapered portion.

7. The lapping tool of claim 5, wherein said abrasive surface includes at least one of diamond, cubic boron, or silicon carbide abrasive having a grit in the range of about 30 microns.

8. The lapping tool of claim 7, wherein said head portion comprises a nickel plated layer with said grit impregnated in said nickel plated layer.

9. An apparatus to refurbish a ball check valve in a single operation, said ball check valve comprising a valve seat having a valve seat angle and a diffuser passage having a diffuser angle, said apparatus comprising:
   - a fixture configured to accept said ball check valve;
   - said fixture mountable in a precision slide machining apparatus for movement of said fixture in an X axis and a Y axis;
   - said fixture supported by a preloaded biaser to control movement of the fixture in a Z axis;
   - a rotary power unit suitable to rotate a lapping tool at various speeds;
   - said lapping tool equipped with a body having a length greater than a width;
   - said body having opposed first and second ends;
   - said first end insertable in a rotary power unit for motion of said lapping tool in an X axis, a Y axis and a Z axis, said second end equipped with a head portion having an abrasive surface;
   - said head portion further comprising:
     - an angled work portion having a first angle;
     - an angled end diameter portion having a second angle and protruding outward from said angled work portion, said angled end diameter portion having a proximal diameter and a distal diameter, said distal diameter shorter than said proximal diameter, said angled end diameter extending at said second angle from said proximal diameter to said distal diameter;
   - said head portion further comprising:
     - said first angle of substantially the same angle as said valve seat angle, and said second angle of substantially the same angle as said diffuser angle; and
     - said angled work portion and said angled end diameter portion separated by and contiguous with a radiusued portion, said radiusued portion configured to form a chamfered intersection between said valve seat angle and said diffuser angle.

10. The apparatus of claim 9, wherein said apparatus is a Computer Numerically Controlled (CNC) machine center.

11. The apparatus of claim 9, wherein said lapping tool further comprises a tapered portion separating said body and said head portion.

12. The apparatus of claim 9, wherein said abrasive surface includes at least one of diamond, cubic boron, or silicon carbide abrasive having a grit in the range of about 30 microns.
13. The apparatus of claim 12, wherein said head portion comprises a nickel plated layer with said grit impregnated in said nickel plated layer.