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Tassone et al.

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(54) **METHOD AND SYSTEM FOR INTRODUCING FLUID INTO AN AIRSTREAM**

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(22) Filed: **Jun. 9, 2005**

Related U.S. Application Data

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(51) **Int. Cl.**
F02C 1/00 (2006.01)
F02C 3/30 (2006.01)

(52) **U.S. Cl.** **60/772**; 60/772; 60/775

(58) **Field of Classification Search** .... 60/775; 134/169, 169 A
See application file for complete search history.

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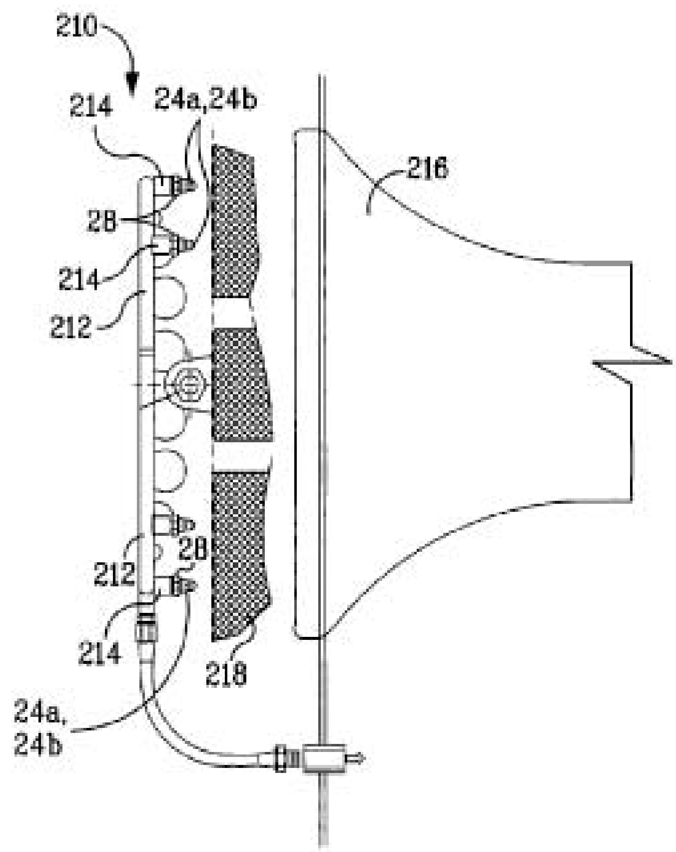
(57) **ABSTRACT**

A preferred of operating a gas turbine engine having an inlet for receiving a stream of air to be compressed includes providing a first and a second set of interchangeable spray nozzles. Each of the nozzles in the first set is capable of discharging fluid supplied to the nozzle at a first pressure at a first flow rate. Each of the nozzles in the second set is capable of discharging fluid supplied to the nozzle at the first pressure at a flow rate that is different from the first flow rate.

8 Claims, 12 Drawing Sheets



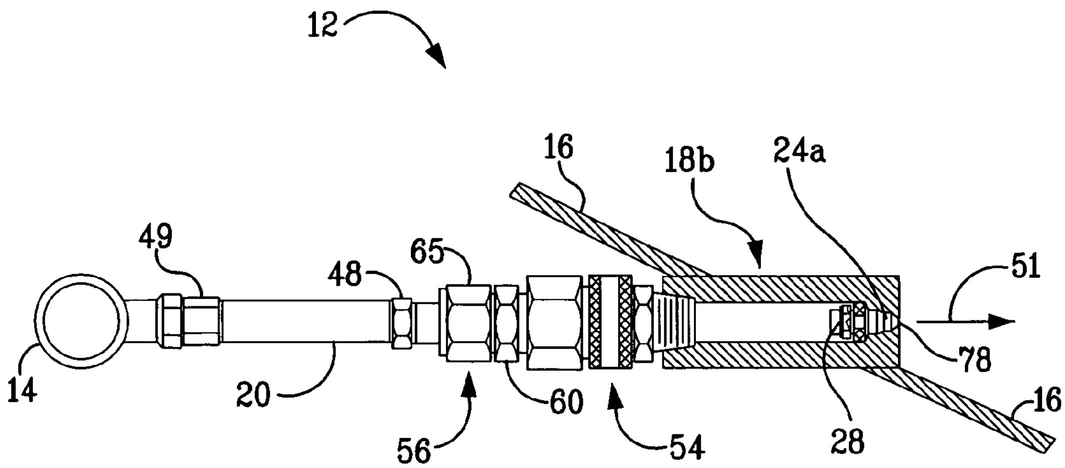

12
16
18b
24a
49
48
65
51
78
14
20
60
16
56
54
28

FIG. 1A

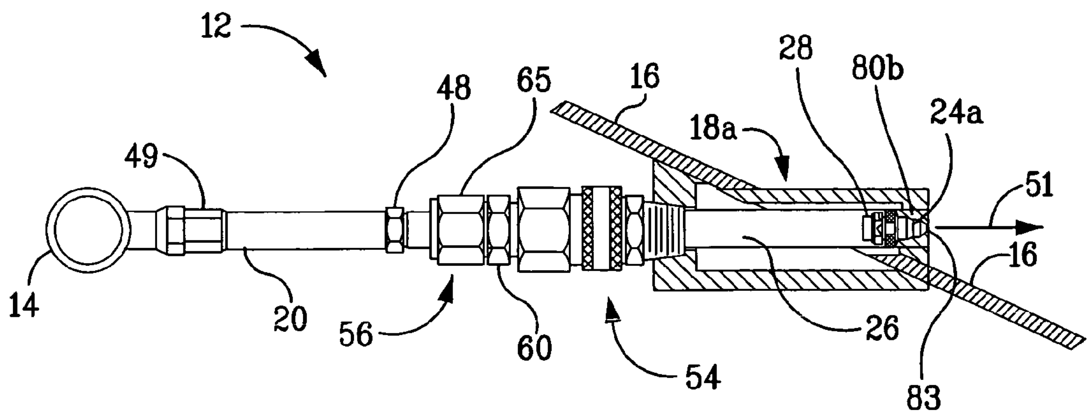

12
28
80b
16
65
48
18a
24a
49
51
16
14
20
56
60
26
54
83

FIG. 1B

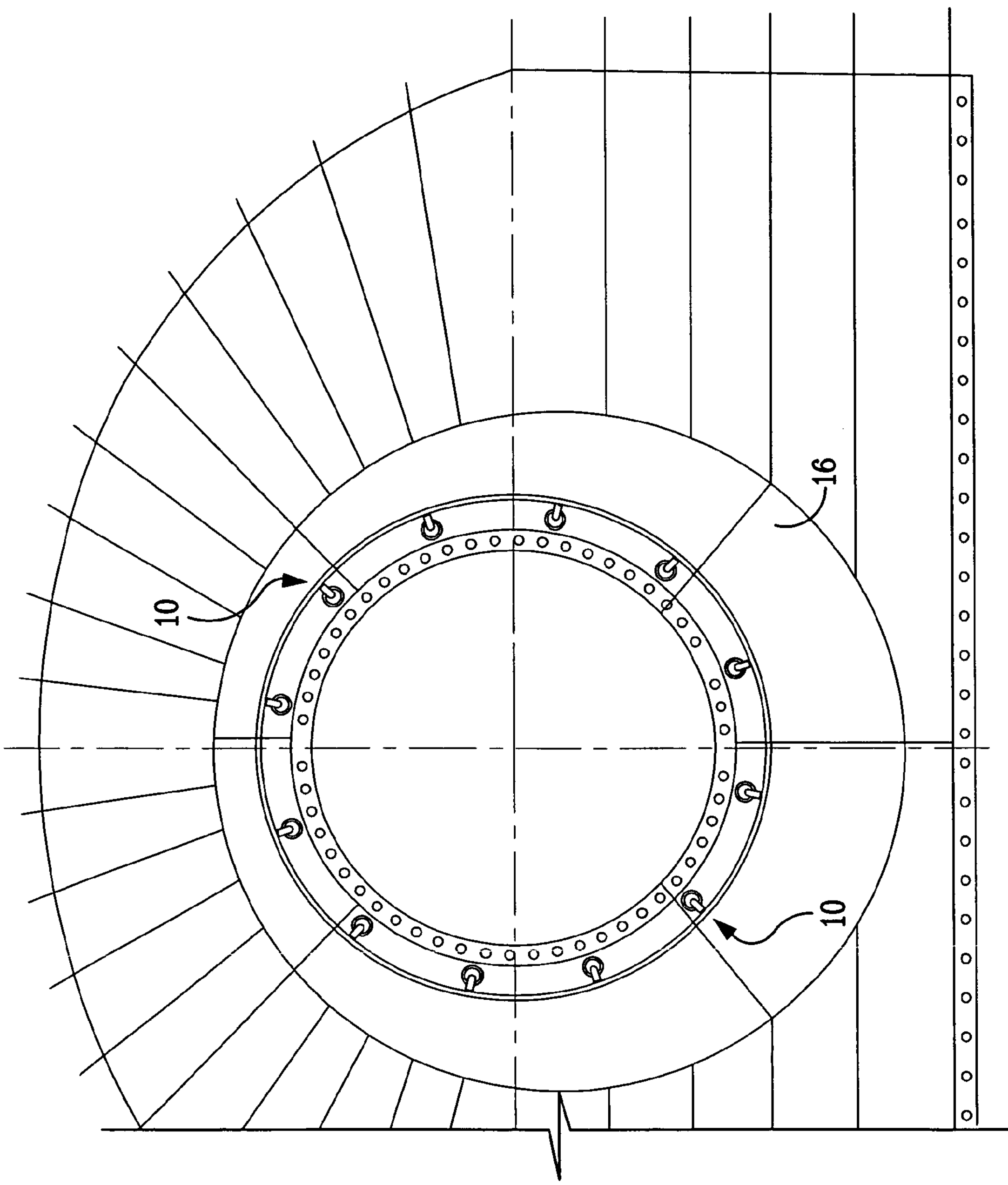


FIG. 2

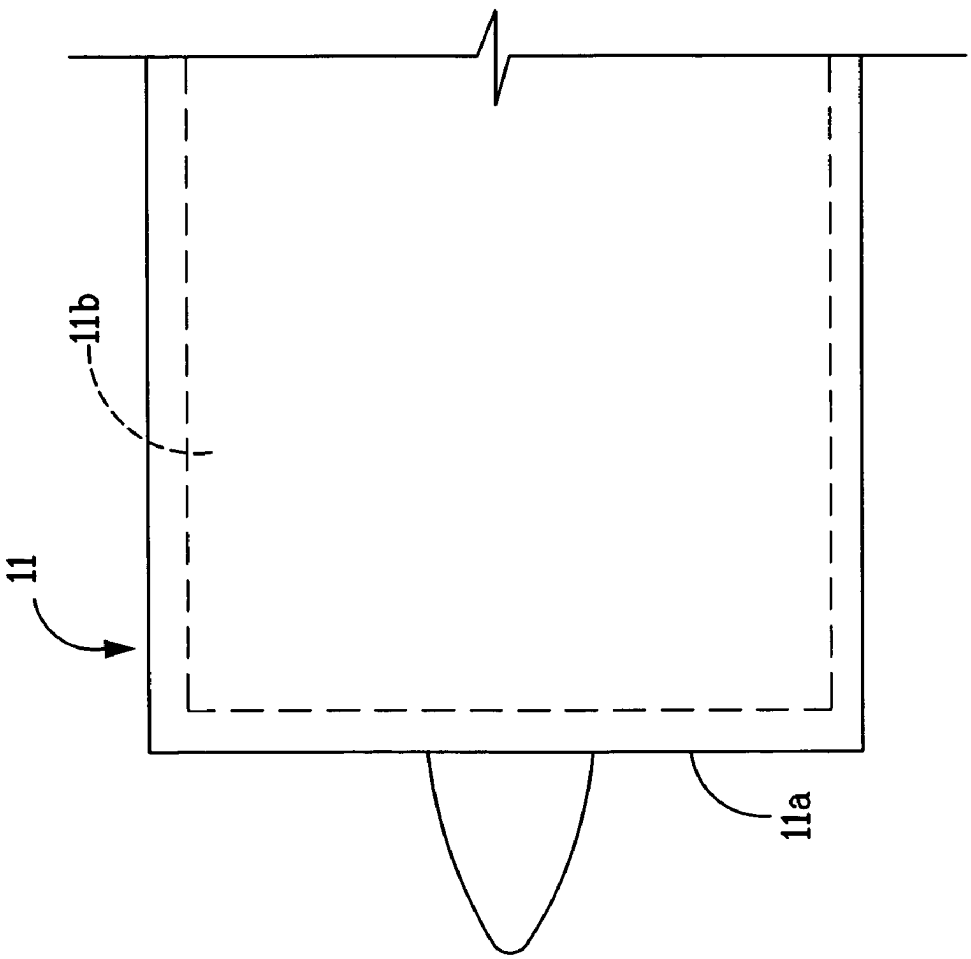


FIG. 3B

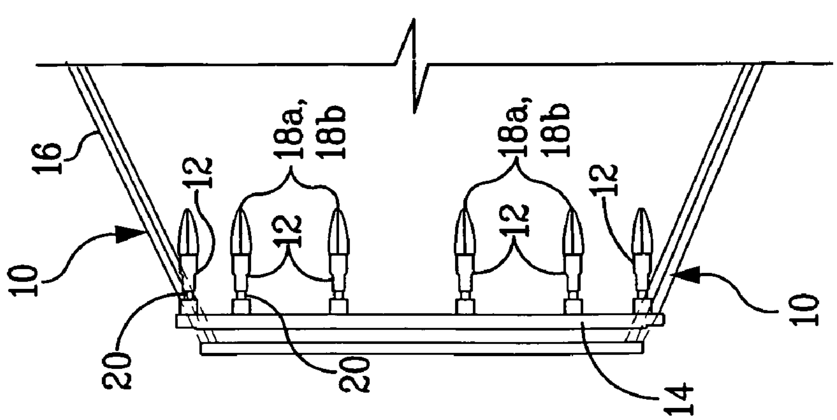


FIG. 3A

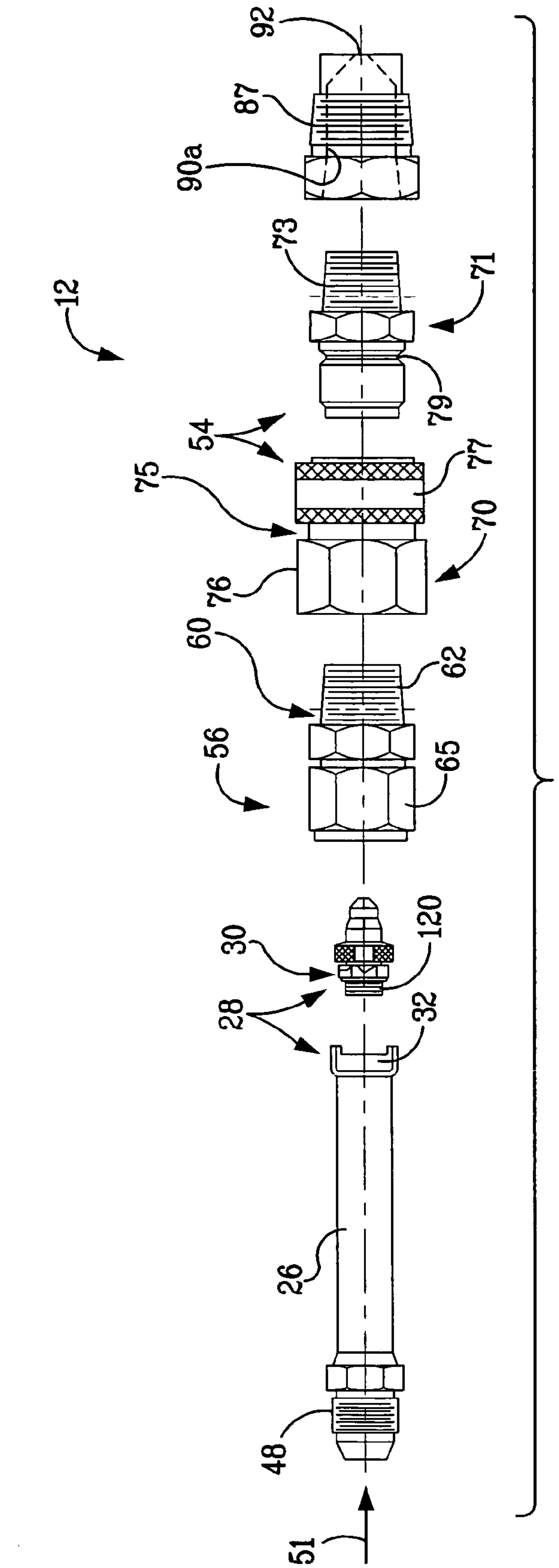


FIG. 4

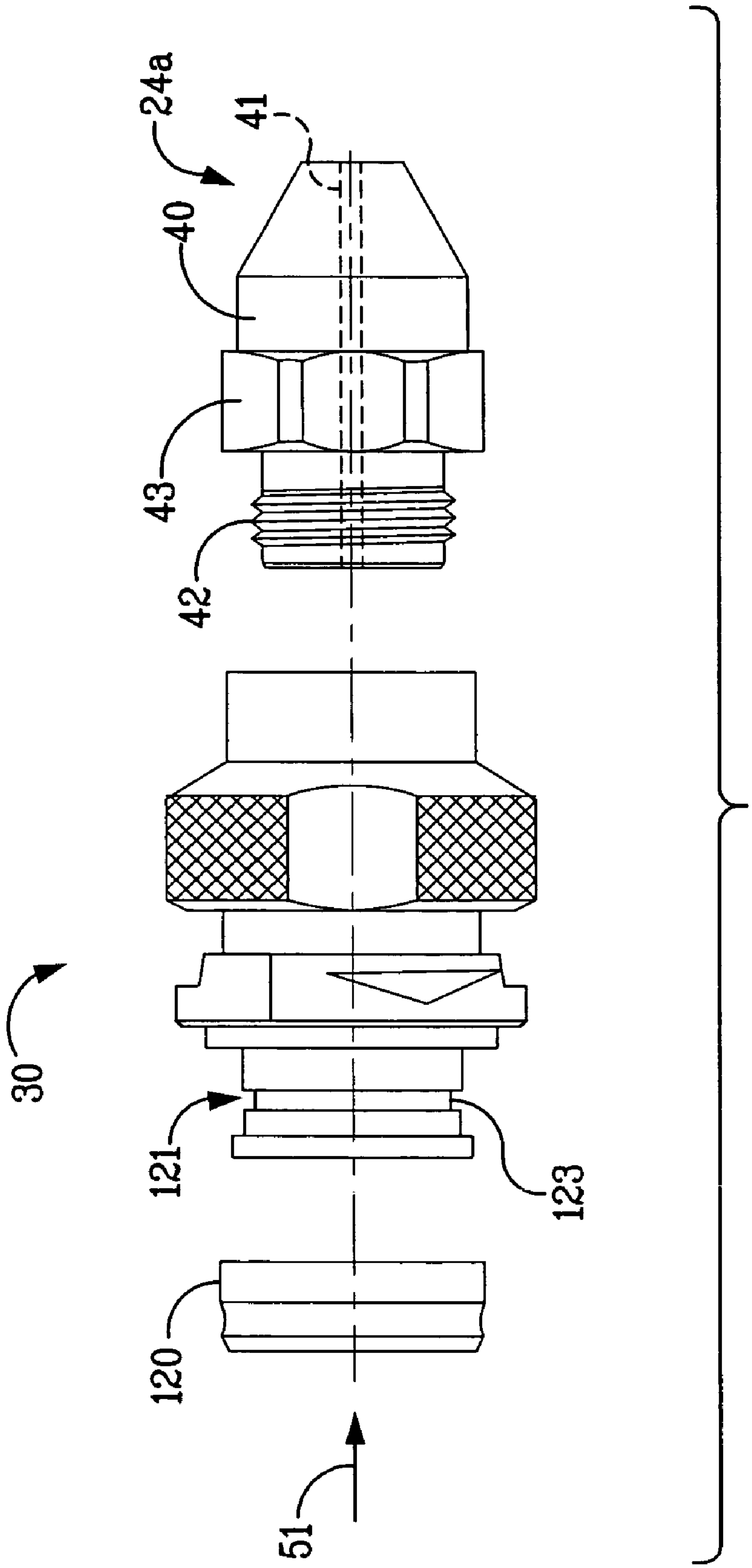


FIG. 5

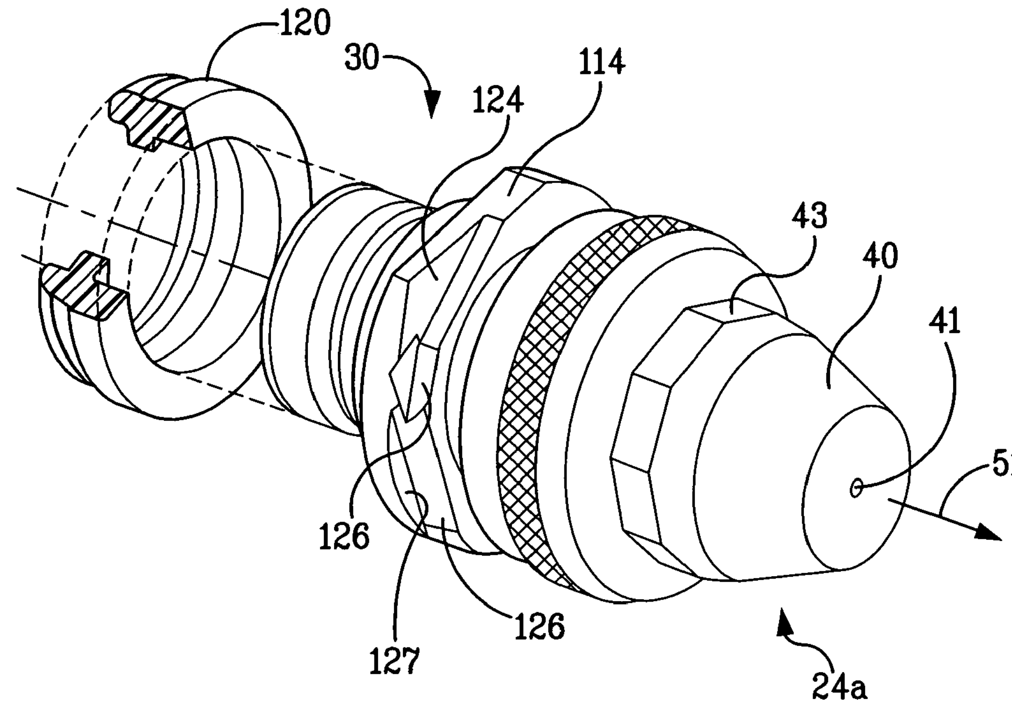

120
30
124
114
43
40
41
51
126
126
127
24a

FIG. 6

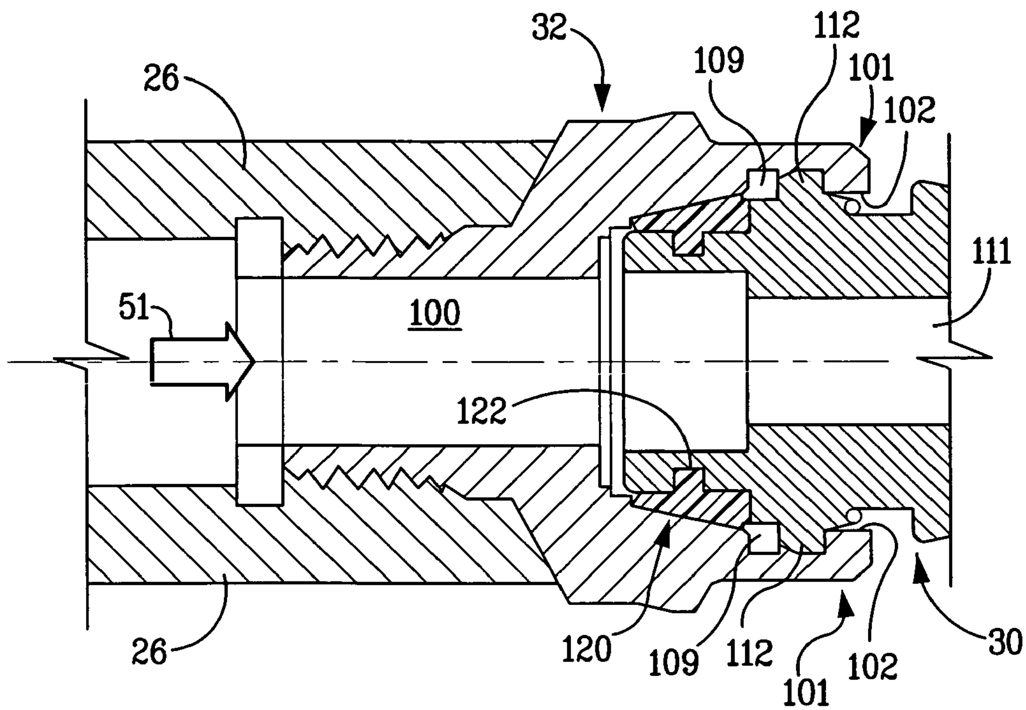

32
26
109
112
101
102
111
51
100
122
26
120
109
112
101
102
30

FIG. 7

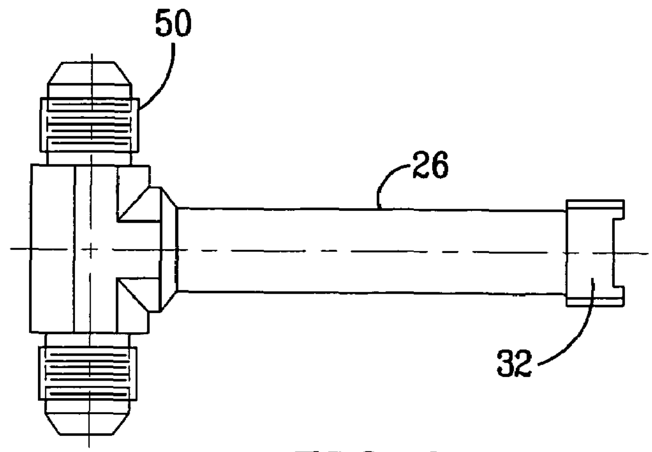


FIG. 8

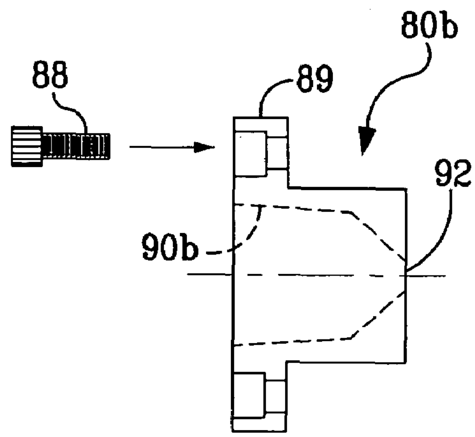


FIG. 9

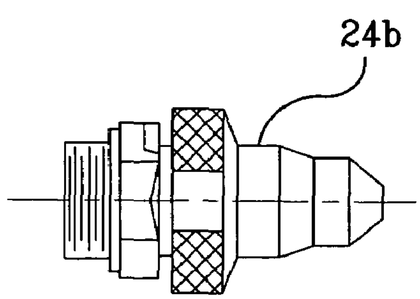


FIG. 10

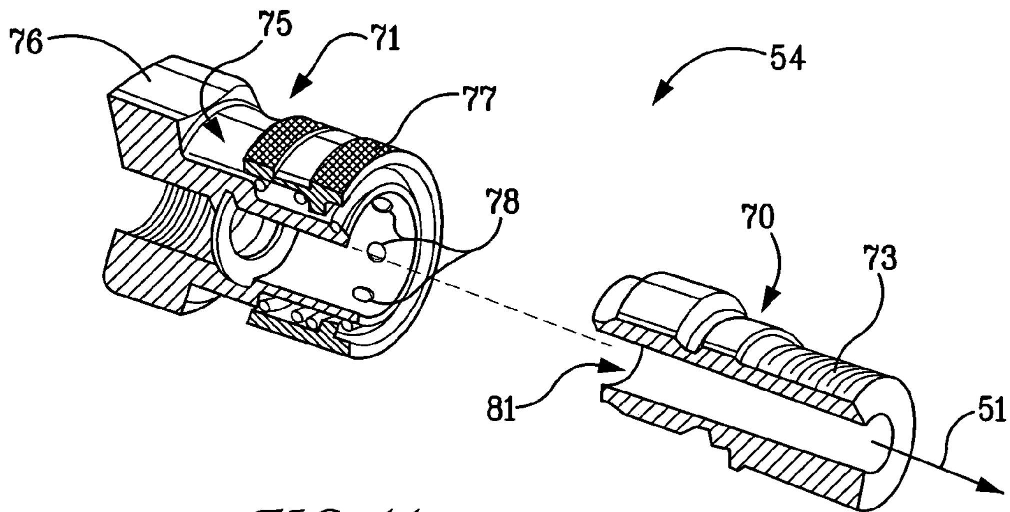


FIG. 11

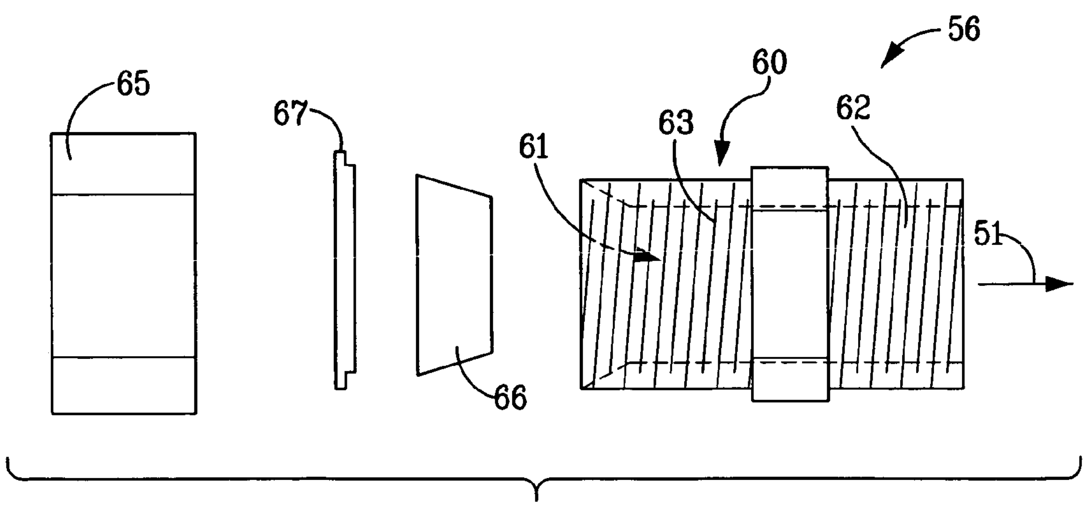


FIG. 12

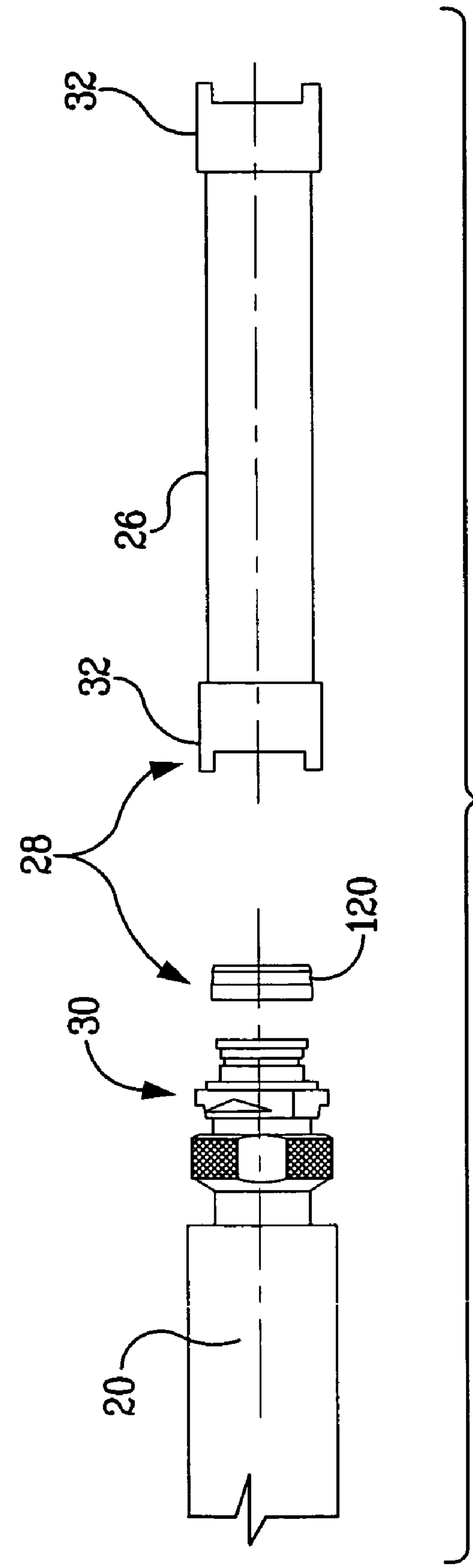


FIG. 13

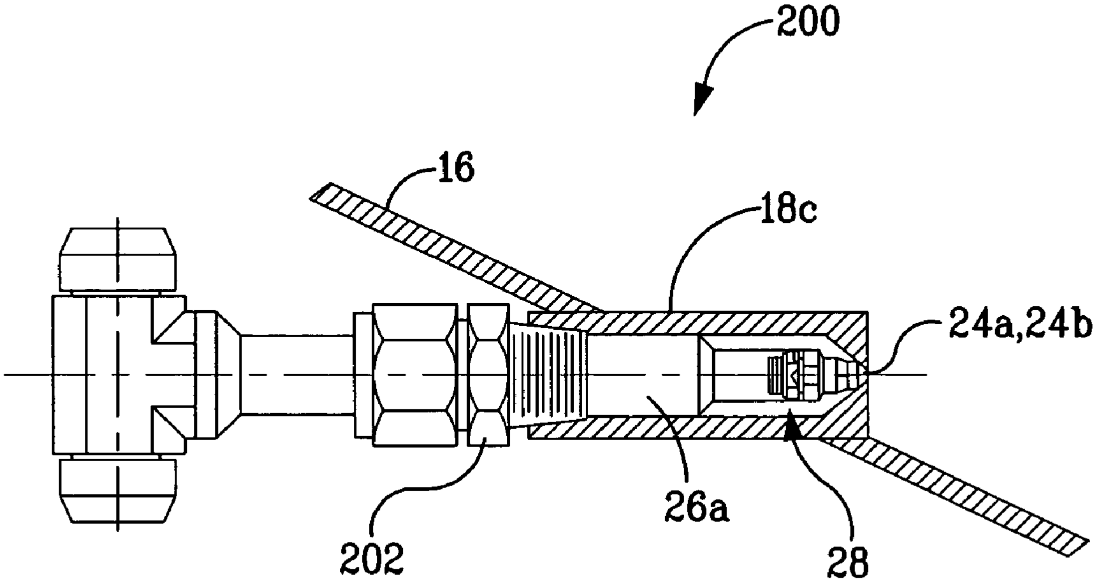


FIG. 14

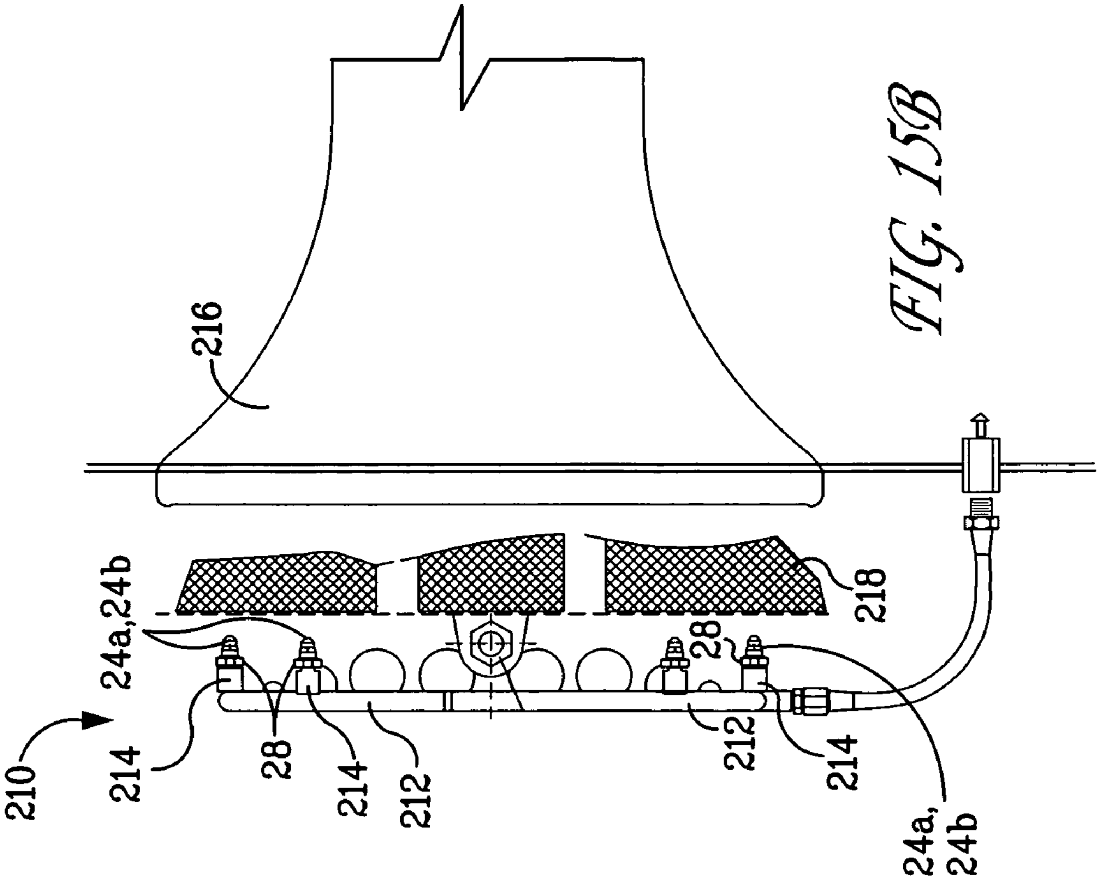


FIG. 15B

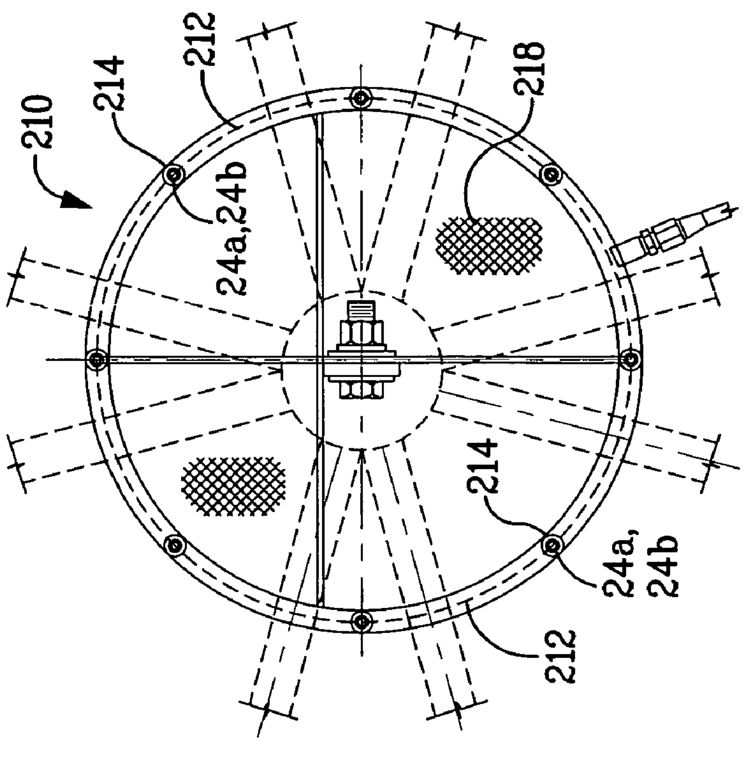


FIG. 15A

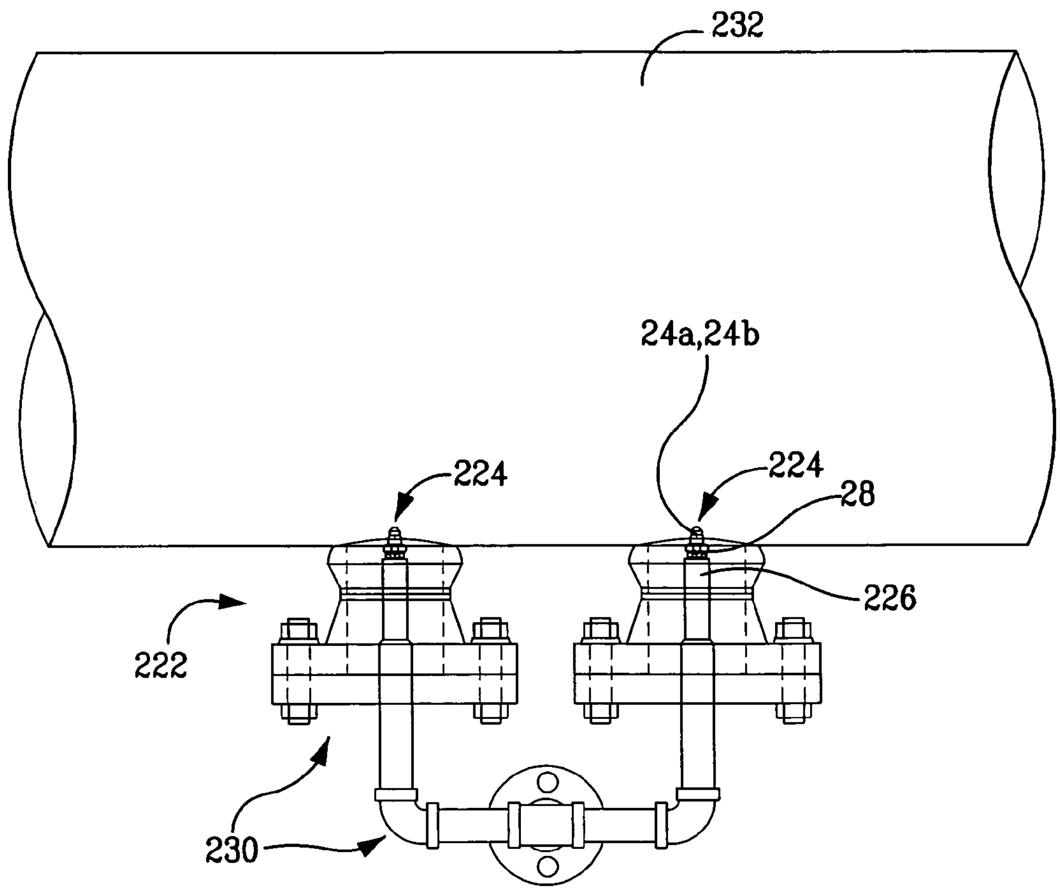


FIG. 16A

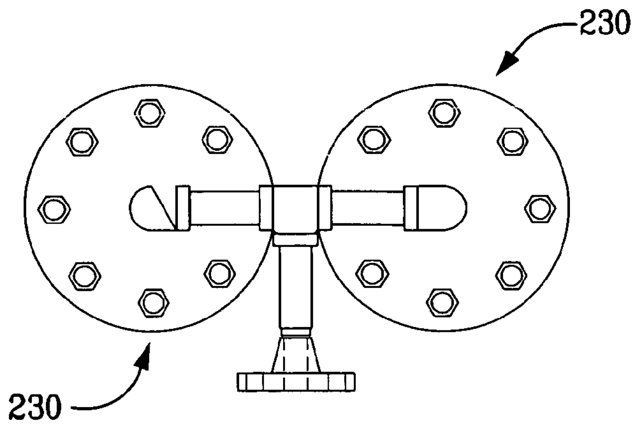


FIG. 16B

METHOD AND SYSTEM FOR INTRODUCING FLUID INTO AN AIRSTREAM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority under 35 U.S.C. § 119(e) to U.S. provisional application No. 60/675,993, filed Apr. 29, 2005, the contents of which is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

The present invention relates to systems used to introduce fluid into an inlet airstream of rotating machinery such as gas turbine engines, for purposes such as washing, power augmentation, etc.

BACKGROUND OF THE INVENTION

Rotating machinery, such as gas turbine engines, centrifugal compressors, steam turbines, etc., typically requires washing on a periodic basis. Washing is usually performed to remove dirt, dust, and other contaminates that collect along the flow path of the machine. Washes are usually conducted by injecting water or a liquid cleaning agent into the inlet airstream of the machine, so that the water or cleaning agent is ingested by the machine upon reaching the inlet thereof. Alternatively, the water or cleaning agent can be injected directly into the flow path within the machine.

Washes may be performed on an on-line basis, i.e., while the machine is operating. Alternatively, washes can be performed on an off-line basis, i.e., while the rotating components of the machine are spun at relatively low speed using the machine's starter or other suitable means; this type of wash is commonly referred to as a "crank wash."

Moreover, water or other types of heat-transfer media can be introduced into the inlet airstream of the machine, to increase the density of the inlet air and thereby augment the power of the machine.

The water or other fluid is usually introduced using a series of spray nozzles mounted upstream of the machine, on the bellmouth, inlet scroll, or other inlet structure. Spray nozzles can also be mounted on one or more casings of the machine itself, so that the spray nozzles extend into the flow path within the machine.

The spray nozzles and their associated mounting hardware are usually secured in place using welds, or other permanent or semi-permanent attachment means, to minimize the potential for the spray nozzles and mounting hardware to become detached. Detachment of a spray nozzle or its mounting hardware can result in catastrophic damage to the machine as the spray nozzle or mounting hardware travel downstream through the machine.

Mounting the spray nozzles and their associated mounting hardware using welds, or other permanent or semi-permanent connecting means, can make it difficult to remove and replace/reinstall the spray nozzles. Removal and replacement/reinstallation may be necessary when a nozzle requires cleaning or preventive maintenance, or when a different type of nozzle is required for a particular task.

For example, the disparate fluid pressures and flow rates associated with on-line and off-line washes usually necessitate the use of different spray nozzles for on-line and off-line washes. Switching between on-line and off-line nozzles can necessitate the time-consuming and labor-intensive process of breaking and subsequently re-forming welded connections. Alternatively, an installation may be configured to accommodate two separate sets of spray nozzles at the same time. The addition of a second set of spray nozzles requires additional space within the installation. The additional set of spray nozzles also requires an additional manifold or other means for delivering fluid to the additional spray nozzles, and additional mounting hardware.

SUMMARY OF THE INVENTION

A preferred method for operating a gas turbine having an inlet for receiving a stream of air to be compressed comprises providing a first set of spray nozzles. Each of the nozzles in the first set is capable of discharging fluid supplied to the nozzle at a first pressure at a first flow rate. Each of the nozzles in the first set has a first portion of a quick-connect fitting coupled thereto.

The method also comprises providing a second set of spray nozzles. Each of the nozzles in the second set is capable of discharging fluid supplied to the nozzle at the first pressure at a flow rate that is different from the first flow rate. Each of the nozzles in the second set has a first portion of a quick-connect fitting coupled thereto.

The method also comprises mounting the first set of spray nozzles on a manifold located proximate the air inlet of the gas turbine. The manifold has mounted thereon a plurality of second portions of the quick-connect fittings that are coupled to the nozzles of the first and second sets. The first set of spray nozzles is mounted on the manifold by mating the first portion of the quick-connect fittings on the spray nozzles of the first set to the second portions of the quick-connect fittings on the manifold.

The method further comprises supplying a first fluid to the manifold so as to distribute the first fluid to each of the spray nozzles in the first set, whereby each of the spray nozzles of the first set discharge the first fluid into the air inlet of the gas turbine at the first flow rate, and removing the first set of nozzles from the manifold by separating the first and second portions of the quick-connect fittings.

The method further comprises mounting the second set of spray nozzles on the manifold by mating the first portion of the quick-connect fittings on the spray nozzles of the second set to the second portions of the quick-connect fittings on the manifold, and supplying a second fluid to the manifold so as to distribute the second fluid to each of the spray nozzles in the second set, whereby each of the spray nozzles of the second set discharge the second fluid into the air inlet of the gas turbine at a flow rate that is different from the first flow rate at which the spray nozzles from the first set discharged the first fluid.

A preferred embodiment of a kit for introducing a fluid into an inlet airstream of a gas turbine engine comprises a first spray nozzle configured to discharge the fluid at a first flow rate, and a second spray nozzle configured to discharge the fluid at a second flow rate different than the first flow rate. The kit also comprises a manifold capable of being mounted on an inlet structure upstream of the machine for directing the fluid to the first and second spray nozzles. The first and second spray nozzles can be interchangeably coupled to the manifold.

A preferred embodiment of a system for introducing a liquid into the inlet airstream of a gas turbine comprises a first set of spray nozzles. Each of the nozzles in the first set is configured to discharge the liquid at a first flow rate. The system also comprises a second set of spray nozzles. Each of the nozzles in the second set is configured to discharge the liquid at a second flow rate different than the first flow rate.

The system further comprises a manifold capable of directing the liquid to either one of the first and second sets of spray nozzles, and means for interchangeably coupling the first and second spray nozzles to the manifold, whereby the first set of nozzles can be readily replaced by the second set of nozzles if a different flow rate of liquid is desired.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing summary, as well as the following detailed description of a preferred embodiment, are better understood when read in conjunction with the appended diagrammatic drawings. For the purpose of illustrating the invention, the drawings show an embodiment that is presently preferred. The invention is not limited, however, to the specific instrumentalities disclosed in the drawings. In the drawings:

FIG. **1**A is a side view of a spray nozzle assembly of a preferred embodiment of a system for injecting fluid into an inlet airstream of rotating machinery, depicting the spray nozzle assembly mounted on a mounting boss on an inlet scroll;

FIG. **1**B depicts an alternative mounting configuration for the spray nozzle assembly shown in FIG. **1**A;

FIG. **2** is a front view of the system comprising the spray nozzle assembly shown in FIGS. **1**A and **1**B;

FIG. **3** is a side view of the system shown in FIG. **2**;

FIG. **4** is an exploded side view of the spray nozzle assembly shown in FIGS. **1**A thru **3**;

FIG. **5** is an exploded side view of a spray nozzle, and a male portion of a quick-connect fitting of the spray nozzle assembly shown in FIGS. **1**A thru **4**;

FIG. **6** is a perspective view of the spray nozzle and male portion of the quick-connect fitting of the spray nozzle assembly shown in FIGS. **1**A thru **5**;

FIG. **7** is a cross-sectional side view of the male portion and a female portion of the quick-connect fitting, and a nozzle body of the spray nozzle assembly shown in FIGS. **1**A thru **6**;

FIG. **8** is a side view of an the nozzle body of the spray nozzle assembly shown in FIGS. **1**A thru **7**, depicting an alternative mounting arrangement for the nozzle body;

FIG. **9** is a side view of an alternative embodiment of a retainer used to mount the spray nozzle assembly shown in FIGS. **1**A thru **7**;

FIG. **10** is a side view of an alternative embodiment of a spray nozzle of the spray nozzle assembly shown in FIGS. **1**A thru **7**;

FIG. **11** is a perspective view of a coupling of the spray nozzle assembly shown in FIGS. **1**A thru **7**, showing a plug of the coupling in cross-section;

FIG. **12** is a side view of a compression fitting of the spray nozzle assembly shown in FIGS. **1**A thru **7** and **11**, showing a plug of the coupling in cross-section;

FIG. **13** is a side view of an alternative mounting configuration for the spray nozzle assembly shown in FIGS. **1**A thru **7**, **11**, and **12**;

FIG. **14** is a side view of an alternative embodiment of the spray nozzle assembly shown in FIGS. **1**A thru **7**, **11**, and **12**;

FIG. **15**A is a front view of an alternative embodiment of the system shown in FIGS. **2** and **3**;

FIG. **15**B is a side view of the alternative embodiment shown in FIG. **15**A;

FIG. **16**A is a side view of another alternative embodiment of the system shown in FIGS. **2** and **3**; and

FIG. **16**B is a front view of a manifold of the alternative embodiment shown in FIG. **16**A.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The figures depict a preferred embodiment of a system **10** for injecting fluid into the inlet airstream of rotating machinery. The system **10** can be used, for example, to inject wash solution into the inlet airstream of rotating machinery such as a gas turbine engine **11**, to perform engine washes. The system **10** can also be used to inject water into the inlet airstream of the engine **11**, to augment the power of the engine **11**. It should be noted that the use of the system **10** in connection with a rotating machine such as the gas turbine engine **11** is disclosed for exemplary purposes only. The system **10** can be used in connection with other types of rotating machinery, including centrifugal compressors, steam turbines, etc. The system **10** can also be used to direct fluid to the inlet airstream of the engine **11** (or other types of machinery) for purposes other than washing and power augmentation.

The system **10** includes a plurality of nozzle assemblies **12**, and a manifold **14** (see FIGS. **2** and **3**; the manifold **14** is not depicted in FIG. **2**, for clarity). The nozzle assemblies **12** and the manifold **14** can be mounted on an inlet scroll **16** that helps guide the inlet airstream toward an inlet **11***a* of the engine **11**. The inlet airstream enters a compressor **11***b* of the engine **11**, after reaching the inlet **11***a*. The compressor **11***b* compresses the air. The air subsequently enters a combustor (not shown) of the engine **11**, where the air is mixed with fuel and burned. The resulting combustion gases enter a turbine (also not shown). The turbine **11***d* is coupled to the compressor **11***b* by a shaft. The turbine **11***d* extracts energy from the combustion gases, and drives the compressor by way of the shaft.

Each nozzle assembly **12** is accommodated by an associated mounting boss **18***a* (FIG. **1**B) or, alternatively, a mounting boss **18***b* (FIG. **1**A). The mounting bosses **18***a*, **18***b* are mounted on the inlet scroll **16** by a suitable means such as welding. The differences between the mounting bosses **18***a*, **18***b* are discussed below.

The system **10** is described in connection with the inlet scroll **16** for exemplary purposes only. The system **10** can be used with other types of inlet structures, such as an inlet plenum or a bellmouth. In other words, the mounting bosses **18***a*, **18***b* can be mounted on other types of inlet structures in other applications of the system **10**.

Each nozzle assembly **12** is in fluid communication with the manifold **14** by way of an associated section of tubing **20** coupled to the manifold **14** and the nozzle assembly **12**. Pressurized fluid is supplied the manifold **14** by a pump (not shown). The fluid flows through the manifold **14**, and reaches each nozzle assembly **12** by way of the tubing **20**. The nozzle assemblies **12** discharge the fluid into the inlet airstream, so that the fluid can be carried downstream, into the engine **11**.

The fluid supplied to the manifold **14** can be a suitable engine wash solution or water, when the system **10** is used to perform engine washes. For example, the fluid can be R-MC, POWERBACK, or RELION engine wash solution, available from ECT, Inc. of Bridgeport, Pa. Water or other suitable fluid can be supplied to the manifold **14** when the system **10** is used for power augmentation.

Each nozzle assembly **12** comprises a first spray nozzle (spray tip) **24***a*, and a substantially cylindrical nozzle body **26**. Each nozzle assembly **12** optionally can include a second spray nozzle **24***b* configured for operation at a different fluid pressure and flow-rate than the first spray nozzle **24***a* (see FIG. **10**). For example, the first spray nozzle **24***a* can be configured for the flow rate and pressure required during an on-line wash, i.e., a wash performed while the engine **11** is operating. The second spray nozzle **24***b* can be configured for the lower flow rate and pressure associated with an off-line, or crank wash. A crank wash typically is performed while the engine **11** is not operating, and while the rotating components of the engine **11** are rotated at a relatively low velocity by, for example, the engine starter. The first and second spray nozzles **24***a*, **24***b* are interchangeable, as discussed below.

The system **10** can include additional spray nozzles (not shown) configured for operation at a different fluid pressure and flow-rate than the first and second spray nozzles **24***a*, **24***b*. The additional spray nozzles can be configured, for example, to operate at the pressure and flow rate associated with water injection used for power augmentation. The additional spray nozzles can be configured to be interchangeable with the first and second spray nozzles **24***a*, **24***b*. The following comments regarding the first and second spray nozzles **24***a*, **24***b* apply equally to any additional spray nozzles included with the nozzle assemblies **12**, unless otherwise noted.

The first and second spray nozzles **24***a*, **24***b* can be any suitable spray nozzles capable of producing the required spray pattern in the inlet airstream, and capable of operating at the required flow rate and pressure for a particular application. For example, spray nozzles suitable for use as the first and second spray nozzles **24***a*, **24***b* can be obtained from Spraying Systems Co. of Wheaton, Ill. as the QUICKJET spray nozzle. The optimal spray pattern for the first and second spray nozzles **24***a*, **24***b* is application dependent, and can vary with factors such as the flow rate and velocity of the inlet airstream, the distance between the first and second spray nozzles **24***a*, **24***b* and the inlet **11***a*, etc. A particular spray pattern therefore is not specified herein.

The first and second spray nozzles **24***a*, **24***a* are substantially identical, with the exception discussed below. The following description therefore applies equally to the second spray nozzle **24***b*, unless otherwise stated.

The first spray nozzle **24***a* comprises a body **40** (see FIGS. **5** and **6**). The body **40** has an axial bore, or orifice **41** formed therein for directing fluid through spray nozzle **24***a*. The orifice **41** of the second spray nozzle **24***b* is sized differently than the orifice **41** of the first spray nozzle **24***a*, to accommodate the different fluid pressure and flow rate associated with the second spray nozzle **24***b*.

The first spray nozzle **24***a* also includes a threaded portion **42** and a hexagonal portion **43** that each adjoin the body **40**. The threaded portion **42** facilitates mounting of the first spray nozzle **24***a*. The hexagonal portion **43** facilitates tightening of the first spray nozzle **24***a* during mounting, using a wrench or other suitable means.

Preferably, the first and second spray nozzles **24***a*, **24***b* are coupled to the nozzle body **26** by a quick-connect fitting **28** comprising a male portion **30** and a female portion **32** (see FIGS. **4** thru **7**). A quick-connect fitting suitable for use as the quick-connect fitting **28** can be obtained, for example, from Spraying Systems Co.

The male portion **30** of the quick-connect fitting **28** can be secured to the first spray nozzle **24***a* by a suitable means such as internal threads formed on the male portion **30** (not shown), for engaging the threaded portion **42** of the first spray nozzle **24***a*.

The first spray nozzle **24***a* and the male portion **30** can be further secured by welding or other suitable means, to help ensure that the first spray nozzle **24***a* does not separate from the male portion **30**. Another male portion **30** can be secured to the second spray nozzle **24***b*, in a substantially identical manner.

The female portion **32** can be secured to the nozzle body **26**, proximate a first end thereof, by a suitable means such as external threads formed on the female portion **32**, and complementary threads on the nozzle body **26** (see FIG. **7**). The female portion **32** and the nozzle body **26** can be further secured by welding or other suitable means, to help ensure that the female portion **32** does not separate from the nozzle body **26**.

The relative positions of the male and female portions **30**, **32** can be reversed in alternative embodiments. In other words, a male portion **30** can be secured to the nozzle body **26**, and respective female portions **32** can be secured to the first and second spray nozzles **24***a*, **24***b* in the alternative.

The female portion **32** of the quick-connect fitting **28** has a bore **100** formed therein. The bore **100** is defined, in part, by two diametrically-opposed flanges **101**. Each flange **101** has a substantially planar, inwardly-facing surface **102**. The surfaces **102** help to define a downstream end of the bore **100**. (The direction of flow through the various components of the system **10** is denoted by the arrows **51** in the figures.) Each flange **101** has a circumferentially-extending, inwardly-facing slot **109** formed therein. The bore **100** helps to facilitate mating of the male and female portions **30**, **32**. The bore **100** also facilitates the flow of fluid through the female portion **32**.

The male portion **30** of the quick-connect fitting **28** can include a body **110**, and two diametrically-opposed lugs **112** formed on the body **110**. The body **110** has a bore, or orifice **111** formed therein for directing fluid from the bore **100** of the female portion **32**, to the orifice **41** of the associated spray nozzle **24***a*, **24***b*.

Each lug **112** includes an outwardly-facing, substantially planar surface **114**. The surfaces **114** are spaced so that the lugs **112** can be inserted between the surfaces **102** and into the bore **100**, so that each lug **112** substantially aligns with a corresponding slot **109**.

The quick-connect fitting **28** can include a biasing seal member **120**. The biasing seal member **120** can be mounted on a shoulder **121** of the male portion **30**. The biasing member **120** has a rib **122** formed thereon (see FIG. **7**). The shoulder **121** has a groove **123** formed therein for receiving the rib **122** (see FIG. **5**). The rib **122** helps to retain the biasing member **120** on the shoulder **121**.

Each lug **112** preferably includes a pair of diametrically-substantially planar camming surfaces **124** (see FIG. **6**). Each camming surface **124** extends radially outward, i.e., away from the axial centerline of the male portion **30**. Each camming surface **124** also extends at an acute angle, e.g., 30°, in relation the axis of the male portion **30**. The camming surfaces **124** each have a substantially triangular shape. Rotating the male portion **30** in the clockwise direction (from the perspective of FIG. **6**) once lugs **112** have been aligned with the slots **109** causes the portions of the camming surfaces **124** adjacent the outer ends of the camming surfaces **124** to come into contact with an associated one of the flanges **101**. Continued rotation of the male portion **30**, through an angular displacement of approximately 60°, causes the camming surfaces **124** to draw the male portion **30** toward the female portion **32**.

The biasing seal member **120** is positioned so the movement of the male portion **30** toward the female portion **32** compresses the biasing seal member **120**. The biasing seal member **120** helps to seal the interface between the male and female portion **30**, **32**. Moreover, the resilient deflection of the biasing seal member **120** causes the biasing seal member to exert an axial biasing force that acts on the male and female portions **30**, **32**, in opposing directions.

The lugs **112** preferably have substantially planar detent surfaces **126** formed thereon (see FIG. **6**). The detent surfaces **126** are positioned at a common axial location with a first, or inner side **126** of the associated camming surface **124**. Rotation of the male portion **30** in relation to the female portion **32** by approximately 60° causes the detent surfaces **126** to engage the flanges **101**, thereby establishing the further extent of inward movement of the male portion **30** into the female portion **32**, against the bias of the biasing seal member **120**.

The lugs **112** can also include locking surfaces **128**. The locking surfaces **128** are axially offset from the detent surfaces **126**. Rotation of the male portion **30** in relation to the female portion **32** by approximately 90° causes the detent surfaces **126** to pass completely over the flanges **101**, so that the locking surfaces **128** can drop into engagement with the associated flanges **101** with a snap action. Walls **127** associated with each locking surface **128** contact associated ones of the flanges **101** at this point, thereby preventing further rotation of the male portion **30**. As the locking surfaces **128** are axially offset from the detent surfaces **126** at this point, contact between the flanges **101** and the associated detent **126** can prevent rotation of the male portion **30** in the reverse direction, thereby securing the male portion **30** to the female portion **32**.

The quick-connect fitting **28** thus permits the first and the second spray nozzles **24***a*, **24***b* to be securely mated to the nozzle body **26** with relative ease, without a need for threaded or welded connections. Moreover, the quick-connect fitting **28** facilitate removal of the first and the second spray nozzles **24***a*, **24***b* from the nozzle body **26** without a need to break any threaded or welded connections.

Further details of a quick-connect fitting suitable for use as the quick-connect fitting **28** can be found in U.S. Pat. No. 6,244,527, the contents of which is incorporated by reference herein in its entirety.

It should be noted that other types of quick-connect fittings can be used in lieu of the quick-connect fitting **28**. For example, quick-connect fittings that utilize springs to bias a male and a female portion into engagement can be used instead of the quick-connect fitting **28**. As a further example, quick-connect fittings that incorporate configurations of camming surfaces and/or biasing seal members different than those of the quick-connect fitting **28** can also be used in the alternative.

Each nozzle assembly **12** also comprises a fitting **48** (see FIGS. **1**A, **1**B, and **4**). The fitting **48** is secured to a second end of the nozzle body **26** by a suitable means such as welding. The fitting **48** can be, for example, a ½-inch NPT or JIC fitting (the fitting **48** is depicted as a JIC fitting in the figures for exemplary purposes only). The fitting **48** can be used to couple the nozzle assembly **12** to its associated length of tubing **14** by way of a complementary fitting **49** on the tubing **14**.

A suitable quick-connect fitting, such as the quick-connect fitting **28**, can be used in lieu of the fitting **48** and the associated fitting on the tubing **14** in alternative embodiments of the system **10**, as shown in FIG. **13**.

It should be noted that dimensions of the various components of the system **10** are application dependent, and can vary with factors such as the required flow rate and pressure of the fluid being injected by the system **10**; specific dimensions are presented herein for exemplary purposes only.

Each nozzle assembly **12** can have a fitting **50** secured thereto in lieu of the fitting **48** in alternative embodiments of the system **10** (see FIG. **8**). The fitting **50** can accommodate two lengths of tubing that couple the nozzle assembly **12** to its adjacent nozzle assemblies **12**. The use of the fittings **50** and associated tubing can obviate the need for the manifold **14** to direct the pressurized fluid to the nozzle assemblies **12**. In other words, the lengths of tubing between each adjacent pair of fittings **50** collectively can form a manifold, in lieu of the manifold **14**.

The nozzle assembly **12** also comprises a quick-connect fitting in the form of a coupling **54**, and a compression fitting **56**. The compression fitting **56** secures the coupling **54** to the nozzle body **26**. The coupling **54** removably couples the compression fitting **56**, the nozzle body **26**, and the attached spray nozzle **24***a*) to the mounting boss **18***a* or **18***b*.

The compression fitting **56** includes a body **60** having a bore **61** formed therein (see FIGS. **1**A, **1**B, **4**, and **12**). The bore **61** is sized so that the nozzle body **26** can fit within the bore **61** with minimal clearance between the outer surface of the nozzle body **26**, and the circumference of the bore **61**. The body **60** has a first and a second set of external threads **62**, **63** formed thereon.

The compression fitting **56** also includes a nut **65**, and ferrule **66**, and an annular seat **67**. The nut **65** has internal threads (not shown) that engage the threads **63** on the body **60**. The ferrule **66** is positioned within the nut **65** so that a first end of the ferrule **66** contacts the upstream end of the body **60**. The seat **67** is disposed between a second end of the ferrule **66** and the nut **65**, so that tightening of the nut **65** on the body **60** urges the ferrule toward the body **60**.

The surface of the body **60** that defines the upstream end of the bore **61** is tapered. The ferrule **66** has a frustoconical shape, so that the outer surface of the ferrule **66** substantially matches the taper of the bore **61**. The ferrule **66** therefore is compressed radially inward, toward the nozzle body **26**, as the nut **65** is tightened. The compression of the ferrule **66** between the body **60**, nut **65**, and nozzle body **26** secures the body **60** to the nozzle body **26**.

Specific details of the compression fitting **56** are presented for exemplary purposes only. Other types of compression fittings, including single-piece compression fittings, can be used in lieu of the compression fitting **56** in alternative embodiments.

The coupling **54** comprises a plug **70**, and a socket **71** for receiving the plug **70** (see FIGS. **1**A, **1**B, **4**, and **11**). The plug **70** has an axially-extending passage **81** formed therein for receiving the nozzle body **26**. The plug **71** mates with a corresponding mounting boss **18***a* or **18***b* on the inlet scroll **16**. In particular, the plug **70** preferably has NPT threads **73** formed on an exterior thereof. The mounting boss **18***a*, **18***b* has a through hole formed in a rearward end thereof. The though hole has complementary threads formed along a circumference thereof for engaging the threads **73** on the plug **70**, thereby securing the plug **71** on the mounting boss **18***a* or **18***b*.

The socket **71** comprises a body **75**. The body **75** includes a hexagonal portion **76** having internal threads (not shown) formed therein. The threads within the hexagonal portion **76** engage the threads **62** on the body **60** of the compression fitting **54**, to secure the compression fitting **54** to the socket **71**.

The socket **71** also includes a collar **77**. The collar **77** is positioned around the body **75**, downstream of the hexagonal portion **76**. The collar **77** can move axially in relation to the body **75**, between a first (downstream) position shown in the figures, and a second position. The collar **77** is biased toward the first position by a spring (not shown).

The socket also includes a plurality of ball bearings **78** (see FIG. **11**). The ball bearings **78** are disposed corresponding bores formed in the body **75**. The bores are formed beneath the collar **77**, so that the collar **77** contacts the ball bearings **78** and urges the ball bearings **78** radially inward when the collar **77** is in its first position.

The plug **70** has a circumferentially-extending groove **79** formed therein (see FIG. **4**). The groove **79** substantially aligns with the ball bearings **78** when the plug **70** is inserted in the socket **71**. The collar **77** urges the ball bearings **78** into the groove **79** when the collar **77** is in its first position. Contact between the ball bearings **78** and the surface of the groove **79** prevents separation of the plug **70** and the socket **71**. The collar **77** releases the ball bearings **78** when the collar **77** is moved to is second position, so that the plug **70** and the socket **71** can be separated by pulling the socket **71** away from the plug **70** in the axial direction. The plug **70** and the socket **71** thus can be separated with relative ease, without a need to unscrew any threaded fittings. The plug **70** can be mated with the socket **71** by retracting the collar **77** to the second position, inserting the plug **70** into the socket, and releasing the collar **77**.

A coupling suitable for use as the coupling **52** can be obtained, for example, from Parker Hannefin Corp. Specific details of the coupling **52** are presented for exemplary purposes only. Other types of quick-connect fittings can be used in lieu of the coupling **52** in alternative embodiments.

The socket **71** of the coupling **54**, the compression fitting **56**, the nozzle body **26**, the fitting **48**, and the first or second spray nozzles **24***a*, **24***b* form an assembly that can be secured to and removed from an associated mounting boss **18***a* or **18***b* as a single unit, as discussed below.

A retainer **80***a* can be installed on the mounting boss **18***a* (see FIG. **4**). Alternatively, a retainer **80***b* can be installed on the mounting boss **18***a* (see FIGS. **1**B and **9**). The retainers **80***a*, **80***b* can receive either of the nozzle tips **24***a* or **24***b*.

The mounting boss **18***a* has a penetration **83** formed in a forward end thereof, for receiving the retainer **80***a* or, alternatively, the retainer **80***b*. The surface of the mounting boss **18***a* that defines the penetration **83** is shaped to substantially match the exterior profile of the retainer **80***a* or, alternatively, the retainer **80***b*.

Threads **87** can be formed around the circumference of the penetration **83**, when the mounting boss **18***a* is configured to receive the retainer **80***a*. The threads **87** can engage complementary threads **86** formed on the exterior of the retainer **80***a*, to mate the retainer **80***a* with the mounting boss **18***a*.

The circumference of the penetration **83** can be formed without threads when the mounting boss **18***a* is configured to accommodate the retainer **80***b*, as shown in FIG. **1**B. The retainer **80***b* has a flange **89** formed thereon that permits the retainer **80***b* to be secured to the mounting boss **18***a* by bolts **88**. The forward end of the mounting boss **18***a* can include threaded holes that accommodate the bolts **88** used to secure the retainer **80***b* to the mounting boss **18***a*.

Alternative embodiments of the retainers **80***a*, **80***b* (not shown) can be secured to the mounting boss **18***a* by welding or other suitable means.

The retainers **80***a*, **80***b* have respective interior surfaces **90***a*, **90***b* (see FIGS. **4** and **9**). The interior surfaces **90***a*, **90***b* each have a shape that substantially matches the shape of the respective first and second spray nozzles **24***a*, **24***b*. Each retainer **80***a*, **80***b* has a hole **92** formed in a forward end thereof, to provide an outlet for the fluid discharged by the first and second spray nozzles **24***a*, **24***b*.

The mounting boss **18***b* can be used in the alternative to the mounting boss **18***a* (see FIG. **1**A). The mounting boss **18***b* facilitates mounting of the nozzle assembly **12** without the use of retainers such as the retainers **80***a*, **80***b*. A forward end of the mounting boss **18***b* has a penetration **78** formed therein. The surface of the penetration **78** is shaped to substantially match the exterior profile of the first and second spray nozzles **24***a*, **24***b*.

The penetrations **83**, **78** formed in the respective mounting bosses **18***a*, **18***b* are shaped to prevent the nozzle assembly **12**, or any of the individual components thereof, from accidentally traveling downstream past the inlet scroll **16** and entering the inlet airstream.

Each nozzle assembly **12** can be installed on the inlet scroll **16** as follows. The retainers **80***a*, **80***b*, or another type of retainer can be mounted on the forward end of the mounting boss **18***a*. (The system **10** can be used without a retainer, as discussed above.) The plug **70** of the coupling **54** can be mated with the rearward end of the mounting boss **18***a* or **18***b*.

The socket **71** of the coupling **54**, the compression fitting **56**, the nozzle body **26**, the fitting **48**, and the first or second spray nozzles **24***a*, **24***b* can be mated to form an assembly that can be secured to and removed from an associated mounting boss **18***a*,**18***b* and retainer **80***a*, **80***b* as a single unit. The assembly can be mounted on an associated mounting boss **18***a*, **18***b* and retainer **80***a*, **80***b* by inserting the nozzle body **26** and the first or second spray nozzles **24***a*, **24***b* of the assembly **68** into the mounting boss **18***a* or **18***b*, by way of the through hole formed in the rearward end of the mounting boss **18***a*, **18***b*. The socket **71** of the coupling **54** (and the remainder of the assembly **68**) can be secured to the mounting boss **18***a* or **18***b* by mating the socket **71** with the plug **70** in the above-noted manner. As discussed above, the use of a quick-connect fitting such as the coupling **54** permits the assembly to be securely mounted with relative ease, without a need to break any threaded, flanged, welded, or other connections.

The first and second spray nozzles **24***a*, **24***b* therefore can be accessed with relative ease, and without a need to break any threaded, flanged, welded, or other connections besides the connection between the socket **71** and the plug **70**. The quick-connect fitting **28** that couples each of the first and second spray nozzles **24***a*, **24***b* permits the first and second spray nozzles **24***a*, **24***b* to be removed from the nozzle body **26** and replaced without the need to break any threaded or welded connections. Hence, the first and second spray nozzles **24***a*, **24***b* can be removed for cleaning, repair, or maintenance, and can be reinstalled or replaced with a substitute, with a minimal outlay of time and effort.

Moreover, the first and second spray nozzles **24***a*, **24***b* are each equipped with the male portion **30** of the quick-connect fitting **28**, and therefore are interchangeable. Hence, the first and second spray nozzles **24***a*, **24***b* can be swapped with a minimal outlay of time and effort, to reconfigure the system **10** for on-line and off-line washes, power augmentation, etc. The interchangeability of the first and second spray nozzles **24***a*, **24***b*, and the relative ease with which the first and second spray nozzles **24***a*, **24***b* can be changed, can obviate the need for separate manifolds for on-line and off-line washes.

The foregoing description is provided for the purpose of explanation and is not to be construed as limiting the invention. While the invention has been described with reference to preferred embodiments or preferred methods, it is understood that the words which have been used herein are words of description and illustration, rather than words of limitation. Furthermore, although the invention has been described herein with reference to particular structure, methods, and embodiments, the invention is not intended to be limited to the particulars disclosed herein, as the invention extends to all structures, methods and uses that are within the scope of the appended claims. Those skilled in the relevant art, having the benefit of the teachings of this specification, may effect numerous modifications to the invention as described herein, and changes may be made without departing from the scope and spirit of the invention as defined by the appended claims.

For example, FIG. **14** depicts an alternative embodiment of the spray nozzle assembly **12**, in the form of a spray nozzle assembly **200**. The spray nozzle assembly **200** can include one of the first spray nozzles **24***a* and, optionally, one of the second spray nozzles **24***b*. The spray nozzle assembly **200** can also include a nozzle body **26***a*, and a quick-connect fitting such as the quick-connect fitting **28**, for removably securing the first and second spray nozzles **24***a*, **24***b* to the nozzle body **26***a*. The spray nozzle assembly **200** can be mounted on a mounting boss **18***c*. The spray nozzle assembly **200** can include a JIC or other suitable fitting **202** for securing the nozzle assembly **200** to the boss **18***c*.

FIGS. **15**A and **15**B depict an alternative embodiment of the system **10** in the form of a system **210**. The system **210** comprises a manifold **212** having bosses **214** formed thereon for mounting the first spray nozzles **24***a* and, optionally, the second spray nozzle **24***b*. The manifold **102** is mounted upstream of an inlet bellmouth **216** that directs airflow to the inlet of rotating machinery such as the engine **11**. A FOD screen **218** can be positioned between the manifold **212** and the inlet bellmouth **216** (only selected portions of the FOD screen are depicted in FIGS. **15**A and **15**B, for clarity).

The first and second spray nozzles **24***a*, **24***b* can be mounted on the manifold **102** using quick-connect fittings such as the quick-connect fittings **28**. In particular, the female portion **32** of a quick-connect fitting **28** can be secured to each boss **214** by a suitable means such as welding. Respective male portions **30** of the quick-connect fitting **28** can be mounted on the first and second spray nozzles **24***a*, **24***b*. (The male portion **32** can be mounted on the boss **214**, and respective female portions **32** can be mounted on the first and second spray nozzles **24***a*, **24***b* in alternative embodiments.)

As the FOD screen **218** is located between the first and second spray nozzles **24***a*, **24***b* and the inlet bellmouth **216**, the system **210** does not include structures, such as the mounting bosses **18***a* or **18***b* of the system **10**, that can help retain the first or the second spray nozzles **24***a*, **24***b* in the event the first or second spray nozzles **24***a*, **24***b* become liberated from their mounts during operation.

FIGS. **16**A and **16**B depict another alternative embodiment of the system **10**, in the form of a system **222**. The system **222** comprises a plurality of nozzle assemblies **224**. Each nozzle assembly **224** comprises a nozzle body **226**, one of the first spray nozzles **24***a* and, optionally, one of the second spray nozzles **24***b*. The first and second spray nozzles **24***a*, **24***b* can be mounted on the associated nozzle body **226** using the quick-connect fittings **28**. In particular, the female portion **32** of a quick-connect fitting **28** can be secured to each nozzle body **226** by a suitable means such as welding. Respective male portions **30** of the quick-connect fitting **28** can be mounted on the first and second spray nozzles **24***a*, **24***b*. (The male portion **30** can be mounted on the nozzle body **226**, and respective female portions **32** can be mounted on the first and second spray nozzles **24***a*, **24***b* in alternative embodiments.)

Each nozzle assembly **224** is supplied with pressurized fluid by a manifold **230**. The nozzle assemblies **224** can be positioned so that the tip of each spray nozzle **24***a*, **24***b* extends into an inlet plenum **232** by way of a respective hole formed in the inlet plenum **232**. Each hole is large enough to permit the associated nozzle first and second **24***a*, **24***b* to discharge fluid into the airstream within the inlet plenum **232**, and to permit the first and second nozzle **24***a*, **24***b* to be removed from the nozzle body **226**. Each hole preferably is small enough, however, to prevent the first or second spray nozzle **24***a*, **24***b* from entering the airstream if the first or second spray nozzle **24***a*, **24***b* becomes liberated during operation.

What is claimed is:

1. A method of operating a compressor having an inlet for receiving a stream of air to be compressed, comprising:

(a) providing a first set of spray nozzles, each of the nozzles in the first set capable of discharging fluid supplied to the nozzle at a first pressure at a first flow rate, each of the nozzles in the first set having a first portion of a quick-connect fitting coupled thereto;

(b) providing a second set of spray nozzles, each of the nozzles in the second set capable of discharging fluid supplied to the nozzle at the first pressure at a flow rate that is different from the first flow rate, each of the nozzles in the second set having a first portion of a quick-connect fitting coupled thereto;

(c) mounting the first set of spray nozzles on a manifold located proximate the air inlet of the compressor, the manifold having mounted thereon a plurality of second portions of the quick-connect fittings that are coupled to the nozzles of the first and second sets, the first set of spray nozzles mounted on the manifold by mating the first portion of the quick-connect fittings on the spray nozzles of the first set to the second portions of the quick-connect fittings on the manifold,

(d) supplying a first fluid to the manifold so as to distribute the first fluid to each of the spray nozzles in the first set, whereby each of the spray nozzles of the first set discharge the first fluid into the air inlet of the compressor at the first flow rate;

(e) removing the first set of nozzles from the manifold by separating the first and second portions of the quick-connect fittings;

(f) mounting the second set of spray nozzles on the manifold by mating the first portion of the quick-connect fittings on the spray nozzles of the second set to the second portions of the quick-connect fittings on the manifold,

(g) supplying a second fluid to the manifold so as to distribute the second fluid to each of the spray nozzles in the second set, whereby each of the spray nozzles of the second set discharge the second fluid into the air inlet of the compressor at a flow rate that is different from the first flow rate at which the spray nozzles from the first set discharged the first fluid.

2. The method according to claim **1**, wherein step (d) is performed while the compressor is in operation and step (g) is performed under cranking conditions.

3. The method according to claim **1**, wherein step (d) is performed under cranking conditions and step (g) is performed while the compressor is in operation.

4. The method according to claim **1**, wherein the first and second fluids are the same type of fluid.

5. The method according to claim **4**, wherein the first and second fluids consist essentially of water.

6. The method according to claim **1**, wherein at least one of the first and second fluids comprises a solution of water and a cleaning detergent.

7. The method according to claim **1**, wherein the compressor is a centrifugal compressor.

8. The method according to claim **1**, wherein the compressor forms a portion of a gas turbine engine.

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