Title: SINGLE SCREW EXPANDER/COMPRESSOR APPARATUS

Abstract: An apparatus that can be configured to operate as a single screw expander, or a single screw compressor, is disclosed. The apparatus includes a housing having a cylindrical bore; one or more bearing assemblies; a pair of gate rotors mounted for rotation in the housing; a main rotor rotatably mounted at least partially within the cylindrical bore; a plurality of gas chambers; and a high pressure sealing structure situated within the housing and including at least one channel formed therein for injecting a flow of lubricant into a space formed by at least a portion of the high pressure seal and a running surface of the main rotor. In one aspect, the high pressure sealing structure can include a conventional labyrinth seal that has been modified in accordance with embodiments of the present disclosure. Methods of using and operating the apparatus are also disclosed.
SINGLE SCREW EXPANDER/COMPRESSOR APPARATUS

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 61/562,749, filed November 22, 2011, the disclosure of which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates generally to expanders and compressors. In one aspect, the present invention relates to lubrication of a sealing structure in screw compressors or screw expanders. In another aspect, the present invention relates to injected or forced lubrication of or into a high pressure seal or sealing structure so as to allow oil to lubricate the seal and decrease the leakage rate of the seal, as well as to lubricate one or more components of the expander or compressor.

BACKGROUND OF THE INVENTION

[0003] Compressors are used, for example, in compression systems, such as refrigeration systems, to compress a gas, such as refrigerant gas, for example "Freon," ammonia, natural gas, or the like. One type of compressor is a single screw gas compressor. This type of compressor employs a housing in which a motor-driven single main rotor having helical grooves thereon meshes with a pair of gate or star-shaped rotors on opposite sides of the rotor to define gas compression chambers. The housing is provided with two gas suction ports (one near each gate rotor) and with two gas discharge channels (one near each gate rotor). Two dual slide valve assemblies are provided on the housing (one assembly near each gate rotor) and each slide valve assembly comprises a suction (also referred to as a "capacity slide valve") and a discharge slide valve (also referred to as a "volume slide valve") for controlling an associated intake channel and an associated discharge channel, respectively.
Farmer, a single screw compressor in particular provides several specific benefits over various other compressors. For example, since the dual gate rotors are situated opposite each other with respect to the main rotor, their rotational forces substantially cancel each other, thereby providing a more balanced load at the bearings that support the main rotor. The balanced load in turn results in less vibration about the compressor and a lower load on the bearings. In addition, the single screw compressor typically utilizes a metallic main rotor and non-metallic gate rotors, thereby reducing the operational wear between these components and therefore reducing the overall lubrication requirements.

In general, a person of skill in the art will recognize that at least some types of compressors, including single screw compressors, can be configured to run in reverse so that it can operate as an expander. Still, a person of skill in the art will recognize that, in order to accomplish such reverse operation, certain modifications are typically be made to a given compressor. A compressor generally uses a drive source to output compressed gas. In contrast, an expander can use an input of compressed gas to operate as a drive source for another machine. Even so, it would be desirable to provide a single screw expander apparatus and a single screw compressor apparatus, with such apparatuses having greater reliability and increased overall efficiency, at least during certain operating conditions.

SUMMARY OF THE INVENTION

In one aspect, an apparatus that can be configured to operate as a single screw expander, or a single screw compressor, is disclosed. The apparatus includes a housing having a cylindrical bore; one or more bearing assemblies, wherein the one or more bearing assemblies are mounted to the housing; a pair of gate rotors mounted for rotation in the housing, each having a plurality of gate rotor teeth; a main rotor rotatably mounted at least partially within the cylindrical bore, the main rotor including a plurality of grooves that meshingly engage at least one of the plurality of gear teeth from each gate rotor; a plurality of gas chambers, each of the gas chambers formed by a respective portion of one of the plurality of gate rotors, a respective portion of one of the plurality of main rotor grooves, and a portion of the cylindrical bore, wherein each of the plurality of gas expansion chambers; and a high pressure sealing structure situated within the housing and including at least one channel formed therein for injecting a flow.
of lubricant into a space formed by at least a portion of the high pressure seal and a running surface of the main rotor. In one aspect, the high pressure sealing structure can include a conventional labyrinth seal that has been modified in accordance with embodiments of the present disclosure. Methods of using and operating the apparatus are also disclosed.

In another aspect, a method of generating power from a single screw expander is disclosed. The method comprises: flowing compressed gas from at least one intake channel into the intake side of at least one gas expansion chamber, the gas expansion chamber including at least a portion of a grooved main rotor and a plurality of teeth from at least one gate rotor; expanding the gas in the at least one gas expansion chamber as the gas moves from the higher pressure intake side of the gas expansion chamber to a lower pressure discharge side of the gas expansion chamber, thereby rotating the at least one gate rotor and the grooved main rotor, wherein the main rotor thereby is configured to operate as a rotational drive source; and injecting a flow of lubricant into a space formed by a surface of high pressure sealing structure and a running surface of the main rotor using a channel formed in the high pressure sealing structure, which at least partially prevents leakage of the gas.

In still another aspect, a single screw expander is disclosed that comprises: a housing including a cylindrical bore; a plurality of bearing assemblies mounted to the housing; a pair of gate rotors mounted for rotation in the housing, each having a plurality of gate rotor teeth; a main rotor rotatably mounted at least partially in the cylindrical bore, wherein the main rotor has one or more grooves that meshingly engage at least one of the plurality of gate rotor gear teeth from each of the pair of gate rotors; a pair of gas expansion chambers each at least partially created by a portion of a respective one of the pair of gate rotors, a portion of the main rotor groove, and a portion of the cylindrical bore, wherein each of the respective one of the pair of gas expansion chambers includes an intake side and a discharge side to provide, associated with each gate rotor; and a high pressure sealing structure situated at least partially between the housing and the bearing assemblies, and at least partially between the housing and the main rotor, and including one or more channels formed therein, the one or more channels configured to inject a flow of lubricant from one or more desired locations in the housing and into a space formed by a portion of the high pressure seal and a running surface of the main rotor, so as to at least partially prevents leakage of the gas.
In another aspect, a method of operating a single screw compressor as a single screw expander is disclosed. The method comprises: flowing compressed gas into a discharge end of the compressor; expanding a higher pressure compressed gas as it passes through a gas compression chamber to a lower pressure suction end, the expansion of the gas thereby rotating a main rotor situated at least partially in the compression chamber; and injecting oil into a space between a high pressure seal and a running surface of the main rotor via at least one channel formed or otherwise provided in a high pressure seal; and discharging the gas through the suction end.

Other embodiments, aspects, features, objectives and advantages of the present invention will be understood and appreciated upon a fall reading of the detailed description and the claims that follow.

DESCRIPTION OF THE DRAWINGS

Features of the present invention, which are believed to be novel, are set forth with particularity in the appended claims. Embodiments of the invention are disclosed with reference to the accompanying drawings and are for illustrative purposes only. The invention is not limited in its application to the details of construction or the arrangement of the components illustrated in the drawings. The invention is capable of other embodiments or of being practiced or carried out in other various ways. Like reference numerals are used to indicate like components. In the drawings:

FIG. 1 is a top view, partly in cross-section and with portions broken away, of an exemplary apparatus representative of an expander and a compressor employing a single screw rotor, a pair of gate rotors and having dual slide valves (not visible) in accordance with at least some embodiments of the present invention;

FIG. 2 is an enlarged cross-sectional view taken along line 2-2 of FIG. 1;

FIG. 3 is a schematic view of the apparatus of FIG. 1, particularly when the apparatus is configured to operate as an expander, and illustrating i) exemplary intake and discharge flow paths, ii) exemplary intake and discharge sides, and iii) exemplary intake and discharge channels, in accordance with at least some embodiments of the present disclosure;
[0016] FIG. 4 is a Mollier diagram depicting a theoretical expansion process for an expander apparatus in accordance with embodiments of the present disclosure;

[0017] FIG. 5 shows a schematic view of a portion of the apparatus shown in FIG. 3, when the apparatus is configured to operate as an expander, and further illustrating i) exemplary intake and discharge flow paths, and ii) exemplary intake and discharge sides, but utilizing a conventional sealing arrangement;

[0018] FIG. 6A shows an enlarged schematic view of a portion of the apparatus shown in FIG. 3 and similar to FIG. 5, with the apparatus again configured to operate as an expander, and illustrating a sealing arrangement in accordance with alternative embodiments of the present invention;

[0019] FIG. 6B shows an enlarged schematic view of a portion of the apparatus shown in FIG. 3 and similar to FIG. 6a, with the apparatus configured to operate as a compressor, and illustrating the sealing arrangement, again in accordance with alternative embodiments of the present invention;

[0020] FIG. 7 is a partially schematic cross-sectional view with portions broken away taken along line 7-7 of FIG. 3;

[0021] FIG. 8 is a partially schematic cross-sectional view of a portion of a main rotor of a conventional single screw compressor; and

[0022] FIG. 9 is a partially schematic cross-sectional view of a portion of a main rotor of a single screw expander in accordance with alternative embodiments of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0023] Referring to FIGS. 1 and 2, numeral 10 designates an exemplary embodiment of an apparatus 10, that can be configured for use as a single screw gas compressor, or a single screw gas expander that can be used as a drive source. Apparatus 10 generally comprises an housing 12, a single main rotor 14 mounted for rotation in housing 12, and a pair of gate rotors 16 and 18 mounted for rotation in housing 12 and engaged with main rotor 14.

[0024] In accordance with at least some embodiments of the present disclosure, housing 12 includes a cylindrical bore 24 in which a main rotor 14 is rotatably mounted. Bore 24 is open at its end 27 and is closed by an end wall 29. The end 27 is a discharge end and the end wall 29 is
an intake end wall when the apparatus is configured to operate as an expander (and as an intake end and discharge end wall respectively, when the apparatus is configured to operate as a compressor). Main rotor 14, which is generally cylindrical and has a plurality of helical grooves 25 formed therein defining gas chambers 35, is provided with a rotor shaft 26 which is rotatably supported at opposite ends on the bearing assemblies 28 mounted on housing 12. The gas chambers 35 are gas expansion chambers when the apparatus is configured to operate as an expander (and are compression chambers when the apparatus is configured to operate as a compressor). The apparatus 10 includes two exemplary slide valve assemblies 20 (one of which is shown), each of which are mounted within, or at least substantially within, housing 12, and which are positioned axially opposite one another, and which cooperate with the main rotor 14 to control gas flow into and from the gas chambers 35 of the main rotor.

[0025] Apparatus housing 12 includes spaces 30 in which the gate rotors 16 and 18 are rotatably mounted and are located on opposite sides of, and 180 degrees apart from one another and about, the main rotor 14. Each of the gate rotors 16 and 18 has a plurality of gear teeth 32 and is provided with a gate rotor shaft 34 which is rotatably supported at opposite ends on bearing assemblies 34A and 34B (FIG. 2) mounted on housing 12. Each of the gate rotors 16 and 18 rotate on an axis that is perpendicular to and spaced from the axis of rotation of main rotor 14 and its teeth 32 extend through an opening 36 communicating with bore 24. Each tooth 32 of each of the gate rotors 16 and 18 successively engages a groove 25 in main rotor 14 and, in cooperation with the wall of bore 24 and specifically its end wall 29, defines one of the gas chambers 35. The aforementioned engagement allows the gate rotors 16 and 18 to drive the main rotor 14, and subsequently the rotor shaft 26. When the apparatus is configured to operate as an expander, the rotor shaft 26 can be coupled with another machine (not shown) to thereby provide a drive source, and thus can be configured to operate as an output shaft or rotor output shaft. Apparatus 10 further includes a high pressure seal or sealing structure 1 situated at least partially between the housing 12 and bearing assemblies 28, and at least partially between the housing 12 and the main rotor 14. As described further below, the high pressure sealing structure 1 can take the form of a conventional labyrinth seal modified in accordance with embodiments of the present disclosure.

[0026] Referring now to FIG. 3, a schematic view of FIG. 1 is provided to further illustrate the operation of the apparatus 10 when the apparatus is particularly configured to operate as an
expander in accordance with embodiments of the present disclosure. More particularly, the apparatus 10 is configured to receive compressed gas at channels 40 (configured as intake channels when the apparatus is configured to operate as an expander), from an outside source, such as a condenser (not shown). The compressed gas travels along flow paths 42, namely intake flow paths, passing the high pressure seal 1, to the sides 44, of the gas chambers 35. The sides 44 are intake sides and the gas chambers 35 are gas expansion chambers when the apparatus is configured to operate as an expander (and as discharge sides and compression chambers, respectively, when the apparatus is configured to operate as a compressor). The compressed gas meets resistance at the sides 44 of the gas chambers 35 where the gear teeth 32 and the groove 25 are engaged. As the pressure continues to build at the sides 44 of the gas chambers 35, the pressure at the sides 44 exceeds the pressure at sides 48 of the gas chambers 35. The sides 44 are intake sides when the apparatus 10 is configured to operate as an expander (and the sides are discharge sides when the apparatus is configured to operate as a compressor). To relieve this pressure, the main rotor 14 and the gate rotors 16 and 18 begin to rotate to allow the compressed gas to expand in the gas chambers 35, and then released at sides 48 of the gas chambers 35. The now expanded gas is relieved through channels 50 and exits the housing 12, as shown along paths 52. The channels 50 are discharge channels and the paths 52 are discharge paths when the apparatus 10 is configured to operate as an expander (and as intake channels and intake paths when the apparatus is configured to operate as a compressor). The expansion of the compressed gas results in the rotation of the main rotor 14 and subsequently the rotor shaft 26. The rotor shaft 26 provides a rotating output that can be coupled to the input of other machines. In this manner, the apparatus 10, when configured to operate as an expander, can be used to drive various other machines.

FIG. 3 illustrates the flow path of the compressed gas as it enters the apparatus 10, configured to operate as an expander, and proceeds through the channels 40. The gas then proceeds into the sides 44 (intake sides at high pressure) of the gas chambers 35, wherein the gas expands as it passes to the sides 48 (discharge sides at low pressure), providing a rotational motion of the main rotor 14. The injected oil provides lubrication and sealing between the gear teeth 32 and the main rotor 14 during the expansion process. The gas then proceeds through the discharge channels 50 to exit the expander.
In accordance with at least some embodiments of the present disclosure, during operation of the apparatus when configured to operate either as an expander or as a compressor, oil injection ports 54 are situated within close proximity to the channels 40, and the high pressure seal. This allows the oil to be directed to a space formed by the high pressure seal and the main rotor 14, which in turn limits leakage of the gas. In another embodiment, oil injection ports 54 are located adjacent to each of the sides 44 of the gas chambers 35. To conserve the use of oil, oil that exits gas chambers 35 and flows out of the channels, such as channels 50, and is recovered and recirculated. Further, to facilitate proper injection of oil at injection ports 54, the oil can be pressurized to exceed the pressure of the gas in the channels 40.

FIG. 4 is a Mollier diagram depicting a theoretical expansion process for an expander. Line A indicates a wet-wet condition, line B indicates a dry-wet condition, and line C indicates a dry-dry condition. Desirably, a single screw expander, in accordance with at least some embodiments of the present invention, is capable of maintaining the compressed gas in a wet-wet condition inside the gas expansion chambers. In such cases, the expander requires less cooling than when the compressed gas is in a dry-wet or dry-dry condition.

FIG. 5 shows a schematic view of a portion of the apparatus shown in FIG. 3, when the apparatus is configured to operate as an expander, and further illustrating i) exemplary intake and discharge flow paths, and ii) exemplary intake and discharge sides, but utilizing a conventional sealing arrangement. FIG. 6A shows an enlarged schematic view of a portion of the apparatus shown in FIG. 3 and similar to FIG. 5, with the apparatus again configured to operate as an expander, and illustrating a sealing arrangement in accordance with alternative embodiments of the present invention.

With reference to FIGS. 5 and 6A, it can be seen that compressed gas flows through the portion of the apparatus 10 (FIGS. 1-3), configured to operate as an expander (FIG. 3), and more specifically, through the channels 40 (one of which is shown) which are located opposite each one another in the apparatus 10. In FIG. 5, the gas flowing in the illustrated channel 40 follows and diverges among at least two possible paths 42a and 68. One of these paths (the path 42a in particular) is merely a portion of the path 42. The other mentioned flow of gas moves through the leakage path 68 via a labyrinth space 74 that is created by a combination of a conventional labyrinth seal 1', teeth 1a' of the conventional labyrinth seal, and a running surface of the rotor 14a. Further, the leakage path 68 provides a pathway for leakage of compressed gas.
to the discharge channels 50; and thus reducing efficiency of the operation of the apparatus 10 when configured to operate as an expander. Oil (or other lubricant) is injected by the oil (lubricant) injection ports 54 into the gas flowing in channel 40. It will be appreciated that oil (lubricant) would similarly be injected into the channel 40 located on the opposite side of the expander.

[8832] In FIG. 6A, however, conventional labyrinth seal is now replaced with the high pressure seal or sealing structure 1 configured to provide forced lubrication within the apparatus 10 (FIG. 1). More particularly, and in accordance with at least some embodiments of the present disclosure, the seal oil is injected by the oil injection ports 54 in to channels 40 and is further directed and forced, by one or more forced oil or lubrication injection channels 56, into the space 74, which reduces the leakage of compressed gas. In accordance with at least some embodiments of the present disclosure, high pressure oil seating structure 1 comprises a conventional labyrinth seal 1', but with the structure modified to include one more oil (lubricant) injection channels formed therein.

[0833] When the apparatus 10 is configured to operate as an expander, the high pressure seal 1 is used to seal the low-pressure side, for example, on a side adjacent to or near the channels 50 (discharge channels), from the high-pressure side, for example, on a side adjacent to or near the channels 40 (intake channels). Further, the high pressure seal 1 has many grooves and threads 1a and it encircles the main rotor 14 with a small gap between the grooves and threads 1a and the running surface of the main rotor 14. The high pressure seal 1 is fixed in relation to the housing 12 and is held in place by the bearing assemblies 28. The bearing assemblies 28 house bearings 55a and 55b that connect the rotor shall 26 and facilitate rotation of the main rotor 14 that rotates in between, at least partially, the high pressure seal 1. As shown in FIG. 5, the high pressure seal 1 leaks, by way of the path 68, compressed gas to the low-pressure area 50, typically by way of the channels 51, of which one is shown. Further description regarding embodiments of the high pressure seal 1 is provided with respect to FIGS. 6B and 7 and associated description which follows.

[9934] In accordance with embodiments of the present disclosure leakage is addressed, remedied, or is at least reduced, by injecting, and as such forcing, an amount of oil into the space 74. As shown in FIG. 6A, an amount of oil (or other lubricant) is injected or forced into the space 74 and such oil injection creates a film or cushion, schematically represented by arrows 76,
that substantially limits the leakage depicted by flow of gas along the path 68. In addition to limiting the leakage of the gas, the cushioning effect of oil 76 also lubricates the naming end of the main rotor 14a and, in so doing, serves at least in part to decrease wear to the rotor 14. Another benefit cushioning effect 76 provided by the oil (or other lubricant) injection into the space by way of the lubrication injection channels 56, is a decrease in thermal shock during startup and transition periods of running the apparatus 10. One of skill in the art may appreciate that the apparatus, during such periods and when configured to operate as an expander, permits hot (or warmer) gas to enter the apparatus and cold (or cooler) gas to be discharged from the apparatus. Since the main rotor 14 is constructed from a different material than the labyrinth seal, it may to expand faster than the labyrinth seal 1. Injecting oil, as described above, reduces the differential of expansion rate between the parts, and therefore can serve to reduce leakage further. Temperature differentials are also a concern when the apparatus is configured to operate as a compressor, but it is understood that cold (or cooler) gas would typically enter the compressor, while hot (or warmer) gas would be discharged. Another advantage, particularly in regard to application of oil (lubricant) injection via the high pressure seal to expander configurations is that, the associated lubrication of the high pressure seal without adding any lubrication into the internal expansion process taking place using the main rotor.

[0035] FIG. 6B shows an enlarged schematic view of a portion of the apparatus shown in FIG. 3 and similar to FIG. 6A, with the but with apparatus 10 (FIGS. 1 and 2) configured to operate as a single screw compressor, in which it cold (or cooler) gas typically enters the compressor and hot (or warmer) gas is typically discharged from the compressor. The high pressure sealing arrangement previously described with reference to FIG. 6A is again illustrated. In accordance with embodiments of the present disclosure in which injection of oil by way of high pressure seal 1, particularly by way of lubrication injection channels 56 from oil injection ports 54 and into space 74, is accomplished in a compressor, such as a single screw compressor, the same or similar benefit is achieved as in an expander. Here again, with oil or other lubricant introduced into space 74, a firm and associated cushion effect is provided, which serves to reduce leakage that is caused by the dynamic nature of the high pressure seal and associated return of gas to an intake (suction) side of the compressor. Additionally, in FIG. 6B, the high pressure seal 1 leaks, by way of the path 68, gas to a low pressure area, 50, typically by way of the channels 51, one of which is again shown. Thermal shock, as previously described, is lessened or
alleviated due to the forced or injected lubrication, which can reduce differential expansion rates and between parts. Wear rates are also reduced.

[W 36] FIG. 7 is a partially schematic cross-sectional view taken along line 7-7 of FIG. 3, and provides for a view of desired angular locations, generally referred to as numerals 72 and 82, of lubricant flow into the injection passages of high pressure sea! 1 when the apparatus is configured to operate either as a compressor or as an expander. In accordance with at least some embodiments, oil or other lubricant is provided, as noted before, from passages 54 (FIGS. 6A and 6B) and is injected, or otherwise forced, into the oil or lubrication injection channels 56 of the seal 1, which is shown to comprise an generally annular body that completely or at least substantially entirely encircles or surrounds the main rotor 14. Channels 40 are shown for reference purposes. It is again noted that channels 40 are intake channels when the apparatus 10 (FIG. 1) is configured for operation as an expander and as discharge channels when apparatus 10 is configured for operation as a compressor. The angular locations 72 and 82 of injection passages 56 are adjacent to, but not within, the respective channels 40. For these and other reasons, in general, it will be appreciated that many, if not most, of the techniques and structures described herein apply to both screw compressors and screw expanders and particularly single screw compressors and expanders.

[β037] In another aspect of the invention and referring to FIGS. 8 and 9, depicted are cross-sectional views of a portion of a main rotor of an apparatus, such as the apparatus 10 (FIG. 1) which can comprise, by way of example, a single screw compressor or single screw expander. With respect to FIG. 8 in particular, in operating a single screw compressor, a groove, for example, a groove 804, of a main rotor 805, facilitates compression of gas, which follows a path 806 from a low-pressure side of the compressor to a high-pressure side of the compressor, generally referenced by numerals 807 and 808. When the apparatus 10 is configured to operate as an expander, the compressor, and particularly the rotor 80S, mns in reverse and, in the case of an expander having the rotor 806 of FIG. 8, the gas, such as air, follows a path opposite to that of 806. In following the path opposite to that of path 806, the gas partially recompresses as it approaches a discharge portion 809 (which corresponds to an intake portion when the apparatus is configured to be run and/or is running as a compressor) of the groove 804. Such recompression greatly reduces efficiency of the expander. As shown, main rotor portion includes a discharge angle (when the rotor is used with an expander), indicated by angle 802, as
measured from the edge or surface of the main rotor (or main rotor portion) to a main rotor axis of rotation 803. In accordance with at least some embodiments the discharge angle can comprise thirty-nine (39) degrees, however, other discharge angles are contemplated.

In contrast, such recompression does not occur in the embodiment of the main rotor portion depicted in FIG. 9. As shown in FIG. 9, a discharge angle, indicated by reference numeral 902, is reduced when compared to the discharge angle 802 (when the rotor of FIG. 8 is utilized in an apparatus configured for use as an expander). Relatedly; a discharge portion 90S of a groove 904 (and potentially across a plurality of discharge portions of a respective plurality, or all of such grooves provided in a main rotor) is reduced, and is particularly reduced in comparison to the discharge portion 809 of FIG. 8. For example, in accordance with at least some embodiments the reduced discharge angle can comprise twenty-six (26) degrees, although again other discharge angles are contemplated, to provide an angled main rotor structure in which recompression is substantially reduced, or eliminated. In other words, by having a shortened groove, for example, the groove 904 (or a shortened plurality of grooves), and/or a narrower discharge angle, such as the angle 902, the recompression is reduced or eliminated. Therefore, when gas travels along the path 906 from the intake channels 40 to the discharge channels 50 of an apparatus, for example the apparatus 10 configured to operate as a an expander, potential recompression of the gas is at least substantially reduced, or possibly even eliminated, at the discharge portion 908 of the groove 904.

In general, and in accordance with embodiments of the present disclosure, apparatuses configured to operate as expanders provide a versatile energy converter that can be powered by a multitude of heat sources and provides a rotating drive source that can power various machines. Additionally, one example of a heat source that can be used to create the compressed gas is the exhaust of an electric generator. This generator exhaust may be used to heat a liquid such as ammonia in a condenser unit, thereby creating the pressurized/compressed gas. Although the pressure of the compressed gas can vary depending on the heat source, the size of the condensing unit, etc., a typical 240 millimeter size expander can provide enough rotational power at the rotor output shaft 26 to drive sufficiently a 300-kilowatt electric generator. Further, the rotor shaft 26, when configured to operate as an output shaft, can drive various machines that are capable of utilizing a rotational input drive source, for example, an electric generator. In a more specific example, the apparatuses configured to operate as an
expander as disclosed herein can utilize compressed gas generated from the exhaust of an electric
generator to provide an output to drive another electric generator. Therefore, at least some of the
wasted energy of driving one power generation source is recycled to provide the driving force for
another power source.

In one aspect, an apparatus that can be configured to operate as a single screw expander, or a single screw compressor, is disclosed. The apparatus includes a housing having a
cylindrical bore; one or more bearing assemblies, wherein the one or more bearing assemblies
are mounted to the housing; a pair of gate rotors mounted in the housing, each having
a plurality of gear teeth; a main rotor rotatably mounted at least partially within the
cylindrical bore, the main rotor including a plurality of grooves that meshingy engage at least
one of the plurality of gear teeth from each gate rotor; a plurality of gas chambers, each of the
gas chambers formed by a respective portion of one of the plurality of gate rotors, a respective
portion of one of the plurality of main rotor grooves, and a portion of the cylindrical bore,
wherein each of the plurality of gas expansion chambers; and a high pressure sealing structure
situated within the housing and including at least one channel formed therein for injecting a flow
of lubricant into a space formed by at least a portion of the high pressure seal and a running
surface of the main rotor. In one aspect, the high pressure sealing structure can include a
conventional labyrinth seal that has been modified in accordance with embodiments of the
present disclosure. Methods of using and operating the apparatus are also disclosed.

In at least some embodiments of the present disclosure, the apparatus is configured to
operate as one of a single screw expander or a single screw compressor. In at least some
embodiments, the high pressure sealing structure includes an arcuate structural body that at least
partially surrounds a portion of the main rotor and includes a plurality of channels formed in the
body and spaced about the body for injection of lubricant into the space at a plurality of
locations. In at least some embodiments, the high pressure sealing structure is a labyrinth seal
that has been modified and the space is a labyrinth space. Still further, in at least some
embodiments, the high pressure sealing structure includes an arcuate structural body that at least
partially surrounds a portion of the main rotor and includes a plurality of channels formed in the
body and spaced about the body for injection of lubricant into the space at a plurality of
locations. In at least some embodiments, the high pressure sealing structure is a labyrinth seal
that has been modified and the space is a labyrinth space. In at least some embodiments, the
apparatus is configured to operate as a single screw expander, and wherein, where so configured, at least a portion of at least one of the plurality of grooves of the main rotor is shaped to prevent gas that expands within one or more of the plurality of gas chambers from recompressing within the one or more of the plurality of gas chambers. Still further, in at least some embodiments, at least a portion of each of the plurality of grooves of the main rotor is shaped to prevent gas that expands within each of the plurality of gas chambers from recompressing within each of the plurality of gas chambers. And in at least some embodiments, the injecting of a flow of lubricant into the space provides lubrication of the high pressure seal without adding any lubrication into an internal expansion process taking place using, or by way of, the main rotor.

[0042] In another aspect, a method of generating power from a single screw expander is disclosed. The method comprises: flowing compressed gas from at least one intake channel into the intake side of at least one gas expansion chamber, the gas expansion chamber including at least a portion of a grooved main rotor and a plurality of teeth from at least one gate rotor; expanding the gas in the at least one gas expansion chamber as the gas moves from the higher pressure intake side of the gas expansion chamber to a lower pressure discharge side of the gas expansion chamber, thereby rotating the at least one gate rotor and the grooved main rotor, wherein the main rotor thereby is configured to operate as a rotational drive source; and injecting a flow of lubricant into a space formed by a surface of high pressure sealing structure and a running surface of the main rotor using a channel formed in the high pressure sealing structure, which at least partially prevents leakage of the gas.

[0043] In at least some embodiments, the lubricant includes an amount of oil and the injecting takes place via a plurality of channels positioned in relation to, but not within, discharge areas of the expander. Further, in at least some embodiments, the method further includes discharging an expanded gas via a discharge portion of a groove of the at least a portion of the grooved main rotor, and wherein discharge portion is shaped to prevent the expanded gas from recompressing in the at least one gas expansion chamber.

[0044] In still another aspect, a single screw expander is disclosed that comprises: a housing including a cylindrical bore; a plurality of bearing assemblies mounted to the housing; a pair of gate rotors mounted for rotation in the housing, each having a plurality of gate rotor teeth; a main rotor rotatably mounted at least partially in the cylindrical bore, wherein the main rotor has one or more grooves that meshmgiy engage at least one of the plurality of gate rotor gear
teeth from each of the pair of gate rotors; a pair of gas expansion chambers each at least partially created by a portion of a respective one of the pair of gate rotors, a portion of the main rotor groove, and a portion of the cylindrical bore, wherein each of the respective one of the pair of gas expansion chambers includes an intake side and a discharge side to provide, associated with each gate rotor; and a high pressure sealing structure situated at least partially between the housing and the bearing assemblies, and at least partially between the housing and the main rotor, and including one or more channels formed therein, the one or more channels configured to inject a flow of lubricant from one or more desired locations in the housing and into a space formed by a portion of the high pressure seal and a running surface of the main rotor, so as to at least partially prevents leakage of the gas.

[0045] In accordance with at least some embodiments, the one or more channels formed or otherwise provided in the high pressure seal is or are situated adjacent to an intake side of the at least one of the gas expansion chambers. Further, in at least some embodiments, the rotor shaft is configured to serve as a drive source of a machine. Still further, in at least some embodiments, at least a portion of each of the plurality of grooves of the main rotor is shaped to prevent gas that expands within each of the plurality of gas chambers from recompressing within the each of the plurality of gas chambers. In addition, in at least some embodiments, lubrication of the high pressure seal occurs without adding any lubrication into an internal expansion process taking place using the main rotor. An in at least some embodiments, the high pressure sealing structure is a labyrinth seal that has been modified and the space is a labyrinth space.

[0046] In another aspect, a method of operating a single screw compressor as a single screw expander is disclosed. The method comprises; flowing compressed gas into a discharge end of the compressor; expanding a higher pressure compressed gas as it passes through a gas compression chamber to a lower pressure suction end, the expansion of the gas thereby rotating a main rotor situated at least partially in the compression chamber; and injecting oil into a space between a high pressure seal and a running surface of the main rotor via at least one channel formed or otherwise provided in a high pressure seal; and discharging the gas through the suction end. In at least some embodiments, the injecting of oil into the space provides lubrication of the high pressure seal and such lubrication occurs without adding any lubrication into an internal expansion process taking place using, or by way of, the main rotor.
It is specifically intended that the present invention not be limited to the embodiments and illustrations contained herein, but include modified forms of those embodiments including portions of the embodiments and combinations of elements of different embodiments as come within the scope of the following claims.
CLAIMS

WE CLAIM:

1. An apparatus comprising:

   a housing having a cylindrical bore:

   one or more bearing assemblies, wherein the one or more bearing assemblies are
   mounted to the housing;

   a pair of gate rotors mounted for rotation in the housing, each having a plurality of
gate rotor teeth;

   a main rotor rotatably mounted at least partially within the cylindrical bore, the
   main rotor including a plurality of grooves that respectively engage at least one of the plurality of
   gear teeth from each gate rotor;

   a plurality of gas chambers, each of the gas chambers formed by a respective
   portion of one of the plurality of gate rotors, a respective portion of one of the plurality of main
   rotor grooves, and a portion of the cylindrical bore, wherein each of the plurality of gas
   expansion chambers;

   a high pressure sealing structure situated within the housing and including at least
   one channel formed therein for injecting a flow of lubricant into a space formed by at least a
   portion of the high pressure seal and a running surface of the main rotor.

2. The apparatus of claim 1, wherein the apparatus is configured to operate as one of a
   single screw expander or a single screw compressor.

3. The apparatus of claim 2, wherein the high pressure sealing structure includes an arcuate
   structural body that at least partially surrounds a portion of the main rotor and includes a
   plurality of channels formed in the body and spaced about the body for injection of lubricant into
   the space at a plurality of locations.

4. The apparatus of claim 3, wherein the high pressure sealing structure is a labyrinth seal
   that has been modified and the space is a labyrinth space.
5. The apparatus of claim 1, wherein the high pressure sealing structure includes an arcuate structural body that at least partially surrounds a portion of the main rotor and includes a plurality of channels formed in the body and spaced about the body for injection of lubricant into the space at a plurality of locations.

6. The apparatus of claim 5, wherein the high pressure sealing structure is a labyrinth seal that has been modified and the space is a labyrinth space.

7. The apparatus of claim 1, wherein the apparatus is configured to operate as a single screw expander, and wherein, when so configured, at least a portion of at least one of the plurality of grooves of the main rotor is shaped to prevent gas that expands within one or more of the plurality of gas chambers from recompressing within the one or more of the plurality of gas chambers.

8. The apparatus of claim 7, wherein at least a portion of each of the plurality of grooves of the main rotor is shaped to prevent gas that expands within each of the plurality of gas chambers from recompressing within the each of the plurality of gas chambers.

9. The apparatus of claim 1, wherein the injecting of a flow of lubricant into the space provides lubrication of the high pressure seal without adding any lubrication into an internal expansion process taking place using, or by way of, the main rotor.

10. A method of generating power from a single screw expander, the method comprising:

flowing compressed gas from at least one intake channel into the intake side of at least one gas expansion chamber, the gas expansion chamber including at least a portion of a grooved main rotor and a plurality of teeth from at least one gate rotor;

expanding the gas in the at least one gas expansion chamber as the gas moves from the higher pressure intake side of the gas expansion chamber to a lower pressure discharge side of the gas expansion chamber, thereby rotating the at least one gate rotor and the grooved main rotor, wherein the main rotor thereby is configured to operate as a rotational drive source; and

injecting a flow of lubricant into a space formed by a surface of high pressure sealing structure and a running surface of the main rotor using a channel formed in the high pressure sealing structure, which at least partially prevents leakage of the gas.
11. The Method of claim 10, wherein the lubricant includes an amount of oil and the injecting takes place via a plurality of channels positioned in relation to, but not within, discharge areas of the expander.

12. The method of claims 10, further comprising discharging an expanded gas via a discharge portion of a groove of the at least a portion of the grooved main rotor, and wherein discharge portion is shaped to prevent the expanded gas from recompressing in the at least one gas expansion chamber.

13. A single screw expander comprising:

   a housing including a cylindrical bore;

   a plurality of bearing assemblies mounted to the housing;

   a pair of gate rotors mounted for rotation in the housing, each having a plurality of gate rotor teeth;

   a main rotor rotatably mounted at least partially in the cylindrical bore, wherein the main rotor has one or more grooves that meshingly engage at least one of the plurality of gate rotor gear teeth from each of the pair of gate rotors;

   a pair of gas expansion chambers each at least partially created by a portion of a respective one of the pair of gate rotors, a portion of the main rotor groove, and a portion of the cylindrical bore, wherein each of the respective one of the pair of gas expansion chambers includes an intake side and a discharge side to provide, associated with each gate rotor; and

   a high pressure sealing structure situated at least partially between the housing and the bearing assemblies, and at least partially between the housing and the main rotor, and including one or more channels formed therein, the one or more channels configured to inject a flow of lubricant from one or more desired locations in the housing and into a space formed by a portion of the high pressure seal and a running surface of the main rotor, so as to at least partially prevents leakage of the gas.

14. The single screw expander of claim 13, wherein the one or more channels formed or otherwise provided in the high pressure seal is or are situated adjacent to an intake side of the at least one of the gas expansion chambers.
15. The single screw expander of claims 13, wherein the rotor shaft is configured to serve as a drive source of a machine.

16. The single screw expander of claim 13, wherein at least a portion of each of the plurality of grooves of the main rotor is shaped to prevent gas that expands within each of the plurality of gas chambers from recompressing within the each of the plurality of gas chambers.

17. The single screw expander of claim 13, wherein lubrication of the high pressure seal occurs without adding any lubrication into an internal expansion process taking place using the main rotor.

18. The apparatus of claim 13, wherein the high pressure sealing structure is a labyrinth seal that has been modified and the space is a labyrinth space.

19. A method of operating a single screw compressor as a single screw expander, the method comprising:

   flowing compressed gas into a discharge end of the compressor;

   expanding a higher pressure compressed gas as it passes through a gas compression chamber to a lower pressure suction end, the expansion of the gas thereby rotating a main rotor situated at least partially in the compression chamber; and

   injecting oil into a space between a high pressure seal and a running surface of the main rotor via at least one channel formed or otherwise provided in a high pressure seal;

   discharging the gas through the suction end.

20. The method of claim 19, wherein the injecting of oil into the space provides lubrication of the high pressure seal and such lubrication occurs without adding any lubrication into an internal expansion process taking place using, or by way of, the main rotor.
FIG. 4
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F01 C 21/04 (2013.01)
USPC - 418/83

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

USPC 418/83

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

IPC(8): F01C 21/04 (2013.01)
USPC: 418/83, 84, 98, 201.1, 191, 206.8, 195, 201.2

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

Patbase, Google Scholar, Google Patents and Google: compressor, expander, screw, single, lubrication, oil, labyrinth, seal, gate, rotor, channel, pathway, duct, hole, aperture, opening, passage, conduit

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>US 2010/0260639 A1 (Hossain et al) 14 October 2010 (14.10.2010), entire document, especially Fig. 2-3; para (0055)-(0074)</td>
<td>1-6, 9, 18</td>
</tr>
<tr>
<td>Y</td>
<td>US 6,685,191 B2 (Tsai) 03 February 2004 (03.02.2004), entire document, especially Fig. 1-2; col 1, ln 64 to col 4, ln 37</td>
<td>1-20</td>
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<td>Y</td>
<td>US 2010/0166591 A1 (Murrow et al) 01 July 2010 (01.07.2010), entire document, especially Fig. 16-19; para [0060]-[0073]</td>
<td>1, 7-8 and 10-20</td>
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<td>A</td>
<td>US 7,891,955 B2 (Picouet) 22 February 2011 (22.02.2011), entire document, especially col 3, ln 32 to col 7, ln 20; Fig. 1-7B</td>
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<td>A</td>
<td>US 2010/0329918 A1 (Gotou et al) 30 December 2010 (30.12.2010), entire document, especially para [0047]-[0106]; Fig. 1-8</td>
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<td>A</td>
<td>US 2010/0284848 A1 (Fujisawa et al) 11 November 2010 (11.11.2010), entire document, especially para [0047]-[0107]; Fig. 1-6</td>
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<td>A</td>
<td>US 6,106,241 A (Zimmern) 22 August 2000 (22.08.2000), entire document, especially col 3, ln 46 to col 5, ln 7</td>
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<td>A</td>
<td>JP 2004/162540 A (Yoshimura) 14 November 2002 (11.11.2002), entire document, especially Abstract</td>
<td>1-20</td>
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</table>

Further documents are listed in the continuation of Box C.

* Special categories of cited documents:
  *A* document defining the general state of the art which is not considered to be of particular relevance
  *E* earlier application or patent but published on or after the international filing date
  *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
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T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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

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

& document member of the same patent family

Date of the actual completion of the international search
29 January 2013 (29.01.2013)

Date of mailing of the international search report
14 FEB 2013

Name and mailing address of the ISA/US
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450
Facsimile No. 571-273-3201

Authorized officer: Lee W. Young
PCT Helpdesk: 571-272-4000
PCT OSP: 571-272-7774

Form PCT/ISA/2 10 (second sheet) (July 2009)