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(54) **OIL-FREE COMPRESSOR CRANKCASE COOLING ARRANGEMENT**

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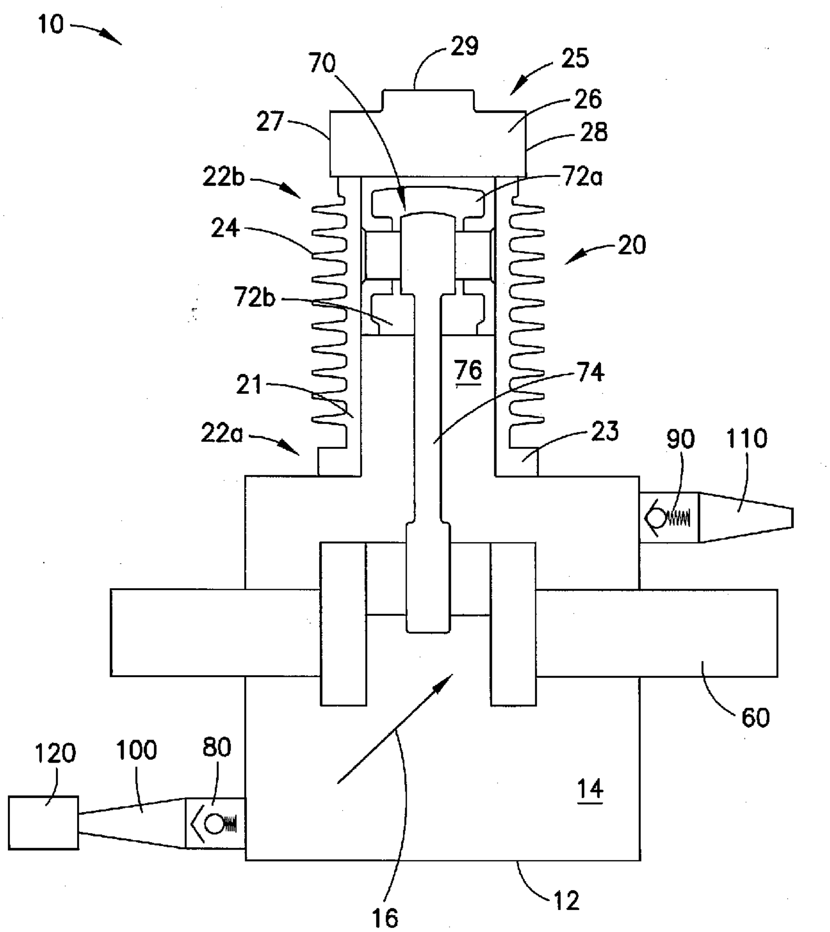
(57) **ABSTRACT**

An oil-free compressor crankcase cooling arrangement includes a compressor crankcase, at least one piston cylinder supported in the compressor crankcase, a crankshaft assembly supported by the compressor crankcase and linked to a piston of the at least one piston cylinder by a connecting rod, at least one inlet valve supported on and in fluid communication with the compressor crankcase, and at least one outlet valve supported on and in fluid communication with the compressor crankcase. A cooling cross-flow of air is established between the at least one inlet valve and the at least one outlet valve to cool the compressor crankcase. The at least one inlet valve and the at least one outlet valve include check valves. A first nozzle is positioned on the at least one inlet valve, and a second nozzle is positioned on the at least one outlet valve.



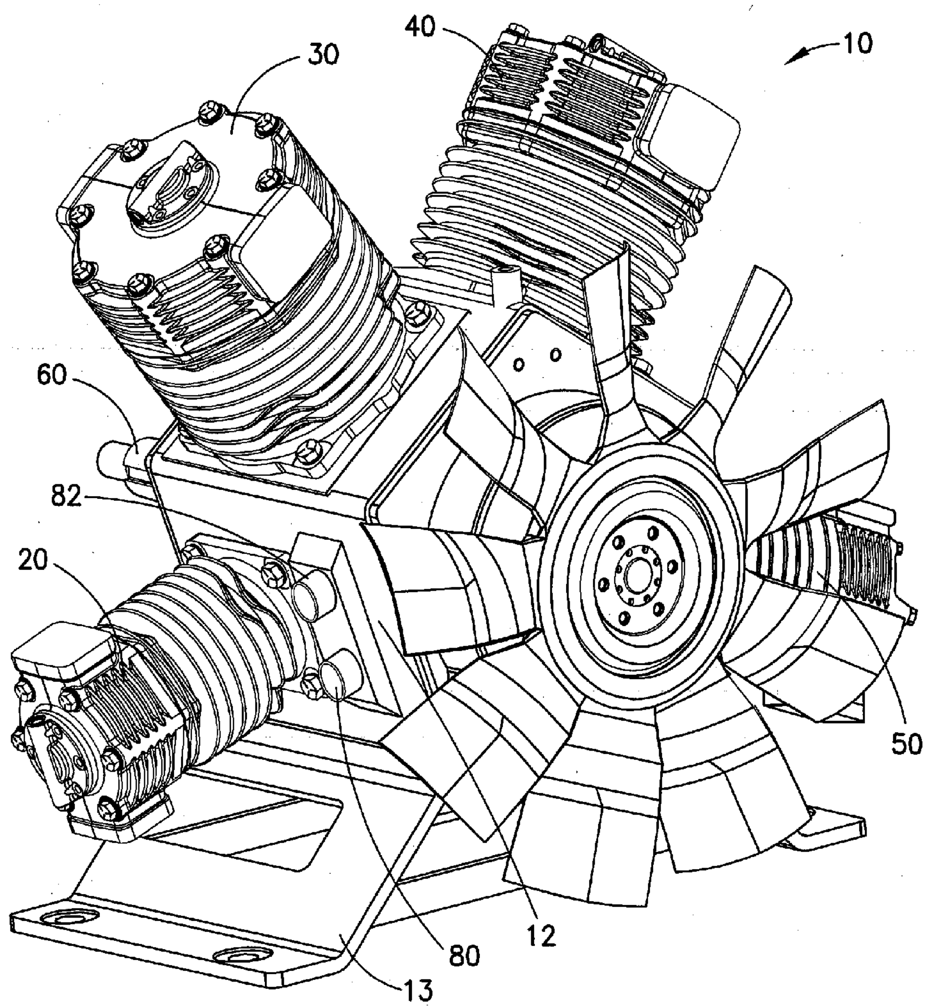


FIG.1

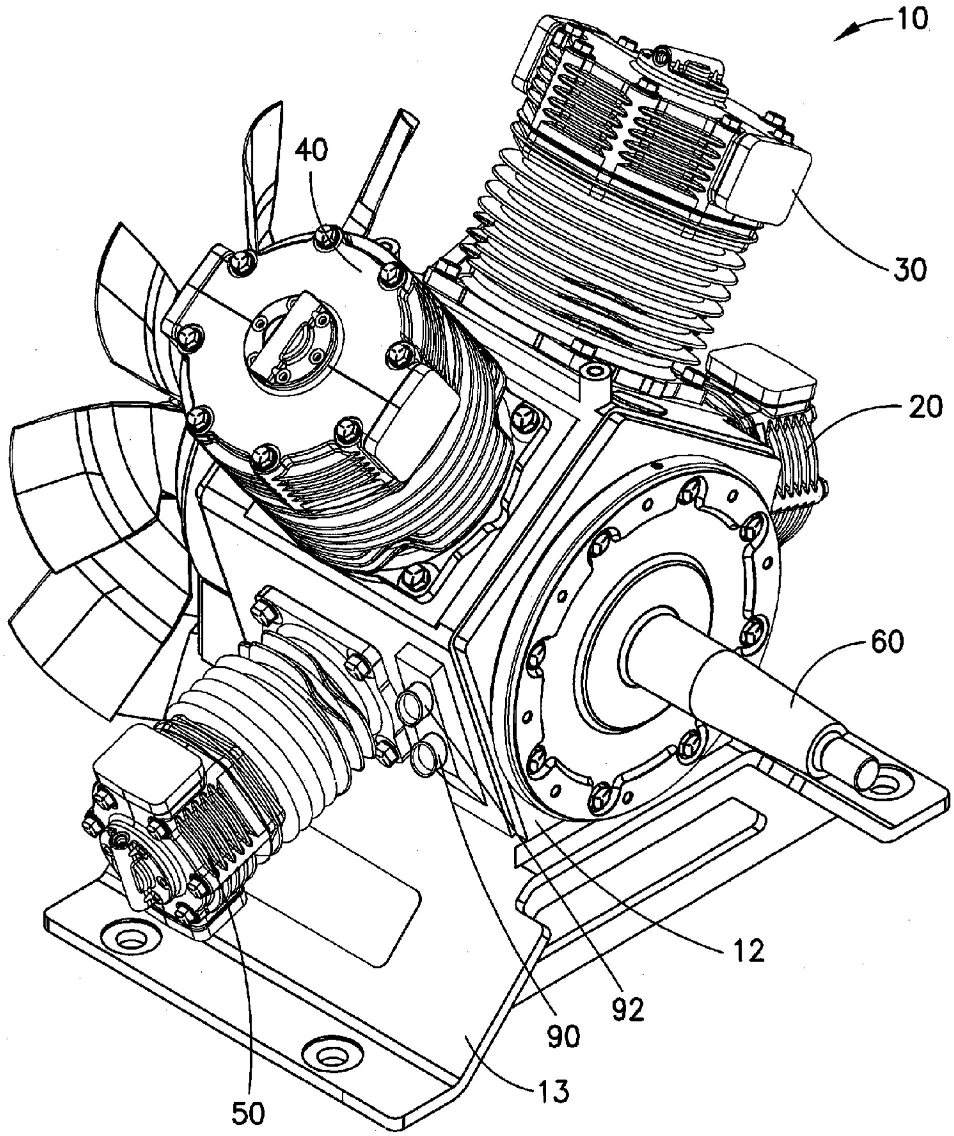
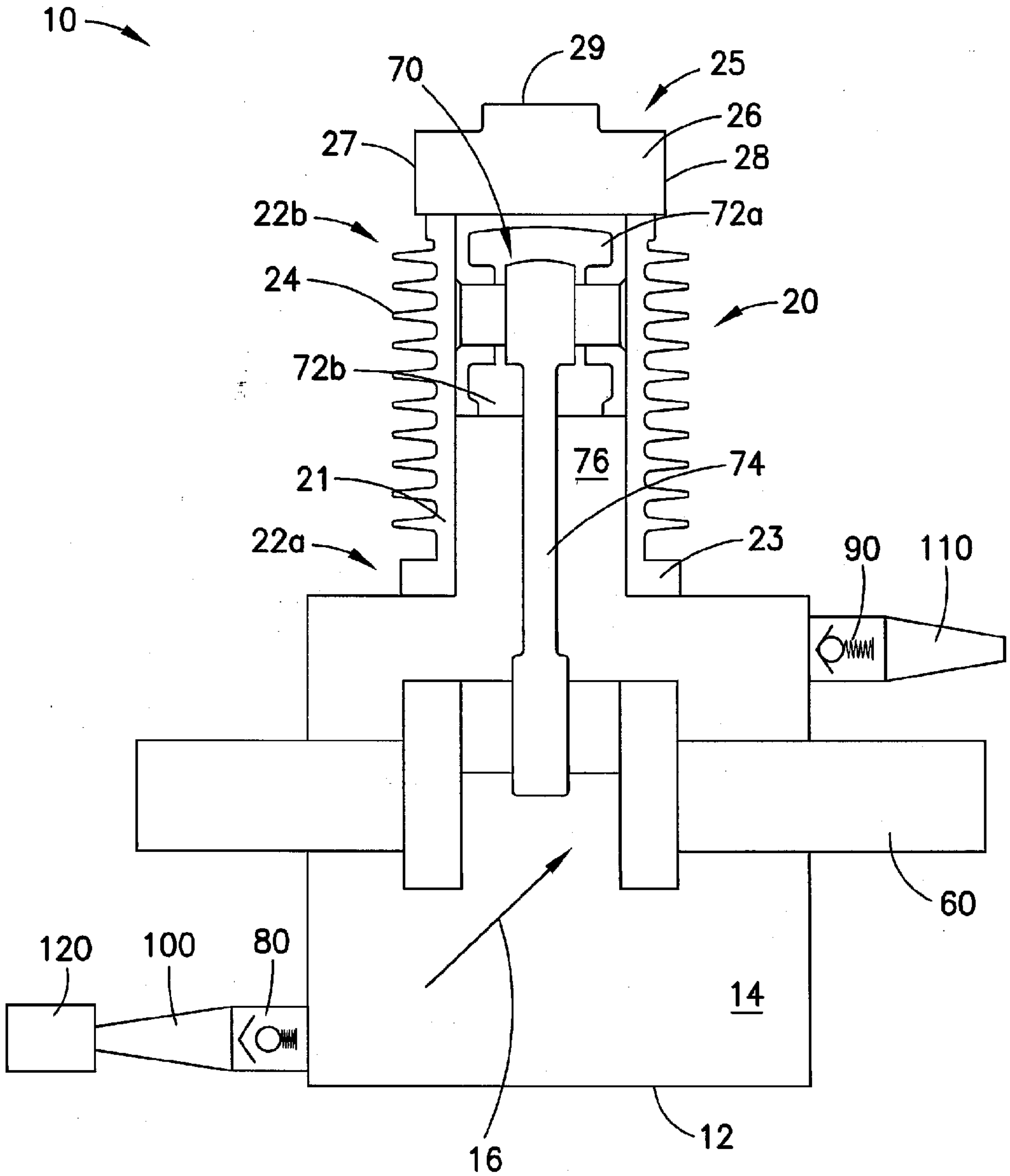


FIG.2


10
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70
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22b
72a
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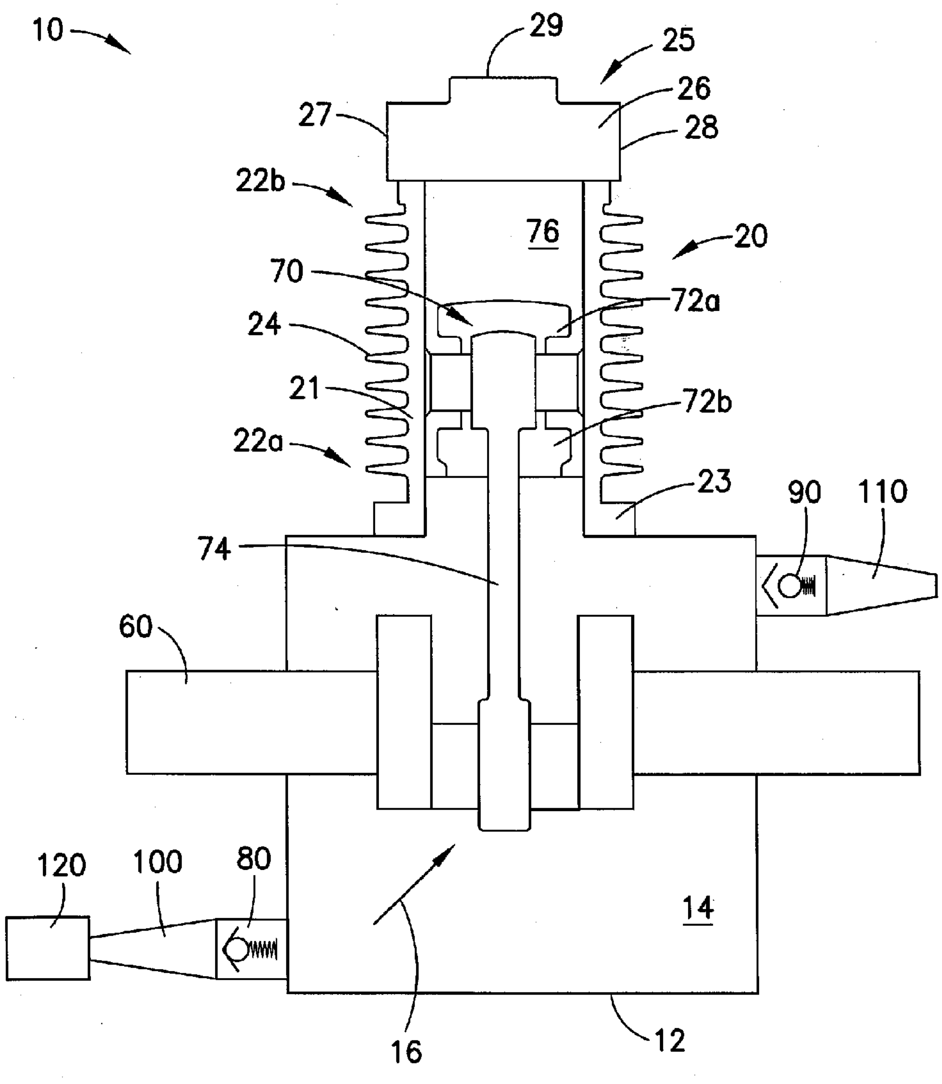
16
12

FIG.3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22b
76
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70
72a
24
21
72b
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120
100
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14
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12

FIG.4

OIL-FREE COMPRESSOR CRANKCASE COOLING ARRANGEMENT

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 61/990,934, filed May 9, 2014, the disclosure of which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present disclosure relates to the field of air compressors adapted for use on rail vehicles for supplying compressed air to pneumatic units associated with the rail vehicle and, in particular, to an oil-free compressor crankcase cooling arrangement for maintaining a safe operating temperature within the crankcase.

[0004] 2. Description of Related Art

[0005] By design, an oil-free compressor utilizes specially designed bearings and composite sealing materials to allow the air compressor to operate without lubrication. An example of one such oil-free air compressor for a rail vehicle is disclosed in U.S. patent application Ser. No. 14/030,588 to Kapadia et al. filed on Sep. 18, 2013, incorporated herein in its entirety. While the specialized components and materials allow the bearing surfaces to survive the internal loading within the air compressor without lubrications, they do not benefit from the cooling effects that are provided by a large sump of oil included in an oil-flooded air compressor. Therefore, internal cooling must be provided by alternative means.

[0006] There are two common preexisting methods for achieving improved cooling within the crankcase of an oil-free air compressor. The first method is to not seal the crankcase and allow air to naturally move into and out of the crankcase. The second method is to draw the compressor inlet air through the crankcase prior to being introduced into the low pressure cylinders for compression.

[0007] There are several deficiencies to using the first method of allowing air to naturally move into and out of the crankcase. By leaving the crankcase open to atmosphere, contamination and debris from the surrounding environment is easily pulled into the crankcase and increases the wear of the bearing surfaces, especially the piston ring and cylinder surface that are more prone to contamination. Further, the open crankcase does not create a cooling flow through the crankcase but, instead, creates a wafting-like effect where the same air is pulled in and pushed out of the crankcase. This fails to cool the internal components of the air compressor as efficiently as possible since the hot air pushed out of the air compressor is not moved away from the crankcase.

[0008] There are also several deficiencies in using the second method of drawing compressor inlet air through the crankcase prior to being introduced into the low pressure cylinders for compression. By pulling all of the inlet air through the crankcase before entering the first stage of compression, the second method does create a positive flow of fresh air through the crankcase that can be directed from a single inlet point to a single discharge point. However, when the air is routed through the crankcase prior to entering the first stage cylinder, the temperature of the air entering the compressor is higher than it would be if pulled directly into the cylinder. This has at least two effects on the air compressor. Firstly, any of the heat taken out of the crankcase is put back into the compressor within the primary compressing flow path resulting in a higher first stage component temperature. This will ultimately lead to a reduced life span for the inner air compressor components. Further, the increased temperature at the compressor inlet will result in a lower compressor efficiency as the inlet air temperature is inversely proportional to compressor efficiency. Secondly, another deficiency becomes apparent if the air compressor utilizes head unloaders that are a common means to operate an air compressor in an idle mode (not compressing air). In this cycle, the head unloaders typically act to mechanically hold the inlet valves open. By holding the inlet valves open, the air compressor continues to rotate but will not compress air, as the atmospheric air pulled in during the intake stroke is pushed back to atmosphere through the inlet valves during what is normally the compression stroke. As the same air is cycled in and out of the cylinder, the temperature of the air increases during the unloaded cycle. If the cylinder inlet air is routed through the crankcase prior to the atmospheric connection, then the air in the crankcase will be pulled into the first stage cylinder then pushed back into the case during the unloaded cycle. Therefore, the air temperature within the case will increase in temperature during the unloaded cycle similar to the air at the cylinder inlet that increases during the unloaded cycle in any common reciprocating air compressor with head unloaders. Lastly, pulling the inlet air through the crankcase prior to introducing the air into the first stage cylinder may result in contamination from the crankcase being spread into the first stage cylinder. This includes wear debris from the piston rings and excess grease released from the sealed bearings that are both typical occurrences in an oil-free compressor. This contamination will wear on the valves of the air compressor and reduce the life span of the valves.

[0009] There is a current need for an oil-free air compressor crankcase cooling arrangement that increases the cooling of the crankcase without increasing the contamination of the internal components of the crankcase. There is also a current need for an oil-free air compressor crankcase cooling arrangement that maximizes the life of the internal dynamic components while maintaining the crankcase at a safe operating temperature.

SUMMARY OF THE INVENTION

[0010] In one embodiment, an oil-free compressor crankcase cooling arrangement for a rail vehicle includes a compressor crankcase, at least one piston cylinder supported in the compressor crankcase, a crankshaft assembly supported by the compressor crankcase and linked to a piston of the at least one piston cylinder by a connecting rod, at least one inlet valve supported on and in fluid communication with the compressor crankcase, and at least one outlet valve supported on and in fluid communication with the compressor crankcase. A cooling cross-flow of air is established between the at least one inlet valve and the at least one outlet valve to cool the compressor crankcase.

[0011] The at least one inlet valve and the at least one outlet valve may include check valves. A first nozzle may be positioned on the at least one inlet valve, and a second nozzle may be positioned on the at least one outlet valve. An inlet air filter may be positioned on the at least one inlet valve. The inlet air filter may protect the compressor crankcase from contamination and debris. An inlet air filter may be positioned on the first nozzle of the at least one inlet valve. The inlet air filter may protect the compressor crankcase from contamination and debris. The compressor crankcase may define a cavity for housing the crankshaft assembly. The cooling cross-flow of air may be directed through the cavity of the compressor crankcase from a first side of the compressor crankcase to an opposing, second side of the compressor crankcase. The at least one inlet valve may be supported on a first side of the compressor crankcase and the at least one outlet valve may be supported on an opposing, second side of the compressor crankcase. The at least one inlet valve may be opened as air is pulled into the compressor crankcase during an upstroke of the at least one piston cylinder. The at least one outlet valve may be opened as air is pushed out of the compressor crankcase during a downstroke of the at least one piston cylinder. An inloader valve assembly may be positioned on the at least one piston cylinder and may be configured to exhaust pressurized fluid from the at least one piston cylinder.

[0012] In another embodiment, a method of cooling an oil-free compressor crankcase of a rail vehicle includes the steps of providing an oil-free compressor including a compressor crankcase, at least one piston cylinder supported in the compressor crankcase, a crankshaft assembly supported by the compressor crankcase and linked to a piston of the at least one piston cylinder by a connecting rod, at least one inlet valve supported on and in fluid communication with the compressor crankcase, and at least one outlet valve supported on and in fluid communication with the compressor crankcase; pulling air into the compressor crankcase via the at least one inlet valve; directing the air through the compressor crankcase; and pushing the air out of the compressor crankcase via the at least one outlet valve.

[0013] A further step of the method may include opening the at least one inlet valve during an upstroke of the at least one piston cylinder. Air may be pulled into the compressor crankcase through the open inlet valve. A further step of the method may include opening the at least one outlet valve during a downstroke of the at least one piston cylinder. Air may be pushed out of the compressor crankcase through the open outlet valve. A further step of the method may include establishing a cooling cross-flow of air that is directed from a first side of the compressor crankcase, over the crankshaft assembly, and out of an opposing, second side of the compressor crankcase. The at least one inlet valve may be supported on the first side of the compressor crankcase. The at least one outlet valve may be supported on the opposing, second side of the compressor crankcase. A first nozzle may be positioned on the at least one inlet valve and a second nozzle may be positioned on the at least one outlet valve. Still further steps of the method may include providing an inlet air filter on the at least one inlet valve; and filtering the air that is pulled into the compressor crankcase via the at least one inlet valve using the inlet air filter. Further steps of the method may include providing an inlet air filter on the first nozzle of the at least one inlet valve; and filtering the air that is pulled into the compressor crankcase via the at least one inlet valve using the inlet air filter. The at least one inlet valve and the at least one outlet valve may include check valves. The at least one inlet valve may be supported on the compressor crankcase on a first side of the at least one piston cylinder. The at least one outlet valve may be supported on the compressor crankcase on an opposing second side of the at least one piston cylinder. A further step of the method may include providing an unloader valve assembly on the at least one piston cylinder. Still a further step of the method may include exhausting fluid from the at least one piston cylinder via the unloader valve assembly.

[0014] Further details and advantages will be understood from the following detailed description read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. **1** is a front perspective view of an oil-free air compressor including a crankcase cooling arrangement in accordance with this disclosure.

[0016] FIG. **2** is a rear perspective view of the oil-free air compressor of FIG. **1**.

[0017] FIG. **3** is a cross-sectional view of an oil-free air compressor including a crankcase cooling arrangement in accordance with another embodiment of this disclosure.

[0018] FIG. **4** is another cross-sectional view of the oil-free air compressor of FIG. **3** in which a piston cylinder is on a downstroke.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0019] For purposes of the description hereinafter, spatial orientation terms, as used, shall relate to the referenced embodiment as it is oriented in the accompanying drawings, figures, or otherwise described in the following detailed description. However, it is to be understood that the embodiments described hereinafter may assume many alternative variations and configurations. It is also to be understood that the specific components, devices, features, and operational sequences illustrated in the accompanying drawings, figures, or otherwise described herein are simply exemplary and should not be considered as limiting.

[0020] The present disclosure is directed to, in general, an oil-free compressor crankcase cooling arrangement and, in particular, to an oil-free compressor crankcase cooling arrangement including at least two valves used to create a cross-flow of cooling air through the compressor crankcase. Certain preferred and non-limiting embodiments of the components of the cooling arrangement are illustrated in FIGS. **1-4**.

[0021] Referring to FIGS. **1-4**, an air compressor **10** according to one embodiment of the disclosure is shown. As shown, the air compressor **10** is a multi-cylinder air compressor **10** including a first piston cylinder **20**, a second piston cylinder **30**, a third piston cylinder **40**, and a fourth piston cylinder **50**. In one embodiment, the air compressor **10** is an oil-free air compressor for a rail vehicle (not shown). The first piston cylinder **20**, the second piston cylinder **30**, the third piston cylinder **40**, and the fourth piston cylinder **50** are supported by a compressor housing or crankcase **12** and each are driven by a crankshaft assembly **60** disposed within the compressor crankcase **12** and rotationally supported by the compressor crankcase **12**. The compressor crankcase **12** may define a cavity **14** therein for housing the crankshaft assembly **60**. The foregoing components of the air compressor **10** are described in detail herein. A method of cooling the compressor crankcase **12** is described in further detail hereinbelow. The air compressor **10** may have a pentagonal-shaped cross-section. A support member **13** may be fastened to a bottom surface of the air compressor **10**. The support member **13** may be used to mount the air compressor **10** on a locomotive or rail vehicle (not shown).

[0022] The first piston cylinder **20**, the second piston cylinder **30**, the third piston cylinder **40**, and the fourth piston cylinder **50** may be of substantially similar construction with the first piston cylinder **20** operating as the first cylinder, the second piston cylinder **30** operating as the second cylinder, the third piston cylinder **40** operating as the third cylinder, and the fourth piston cylinder **50** operating as the fourth cylinder in the multi-cylinder air compressor **10**. In one embodiment, the first piston cylinder **20**, the second piston cylinder **30**, the third piston cylinder **40**, and the fourth piston cylinder **50** may be radially configured about a longitudinal axis of the air compressor **10**. The piston cylinders **20**, **30**, **40**, **50** may interface with an outer circumference of the air compressor **10**.

[0023] As shown in FIGS. **3** and **4**, the first piston cylinder **20** includes a cylindrical housing **21** that has a first end **22***a* adapted to be inserted into a corresponding opening, as described herein, in the compressor crankcase **12** and a second end **22***b*. The cylindrical housing **21** is formed with a flange **23** located proximal the first end **22***a* for interfacing with the exterior of the compressor crankcase **12**. Heat-dissipating fins **24** may be provided about the cylindrical housing **21**, and the cylindrical housing **21** may be formed of any suitable material providing sufficient strength and heat-dissipating characteristics such as aluminum.

[0024] A cylinder head **25** is secured to the second end **22***b* of the cylindrical housing **21**. The cylinder head **25** generally comprises an air connecting unit **26** and an unloader cap **29** mechanically fastened to a top surface of the air connecting unit **26**. The air connecting unit **26** includes a first air channel **27** and a second air channel **28**. The air connecting unit **26** may be formed of any suitable material providing sufficient strength and heat transfer characteristics such as aluminum. The unloader cap **29** houses an unloader piston (not shown) that mechanically holds the inlet side of the valve assembly (not shown) open when a pneumatic signal is piloted to the valve assembly. It is also to be understood that an electric signal may be used to pilot the valve assembly. When activated, the air compressor **10** will continue to operate without compressing air, thereby cooling the cavity **14** of the air compressor **10**.

[0025] The first piston cylinder **20** may further include a first piston **70** that is reciprocally operable within the cylindrical housing **21**. The piston **70** includes a first end **72***a* and a second end **72***b*, and is made of any suitable material providing sufficient strength and heat transfer characteristics such as aluminum. The piston **70** is operatively connected to the crankshaft assembly **60** via a connecting rod **74**. A cavity **76** may be defined in the cylindrical housing **21** to hold the piston **70**. In operation, the piston **70** operates in a reciprocating movement which is generated via rotation of the crankshaft assembly **60**. Air is drawn into the cavity **76** of the cylindrical housing **21** of the first piston cylinder **20** via one of the air channels **27**, **28** as a result of the downward movement of the piston **70**. A valve assembly (not shown) may be associated with the cylinder head **25** and includes a portion that is opened during the downward movement of the piston **70**, drawing air into the cylindrical housing **21**, and closes during the upward movement. Further, the valve assembly may include another portion that closes during the downward movement of the piston **70** and opens during the upward movement of the piston **70**, whereby air in the cylindrical housing **21** is compressed and is guided out of the cylindrical housing **21**.

[0026] As noted previously, the second piston cylinder **30**, the third piston cylinder **40**, and the fourth piston cylinder **50** have a substantially similar construction to the first piston cylinder **20**.

[0027] Referring to FIGS. **1** and **2**, a first inlet valve **80** and a second inlet valve **82** are supported on a first side of the compressor crankcase **12**. A first outlet valve **90** and a second outlet valve **92** may be supported on an opposing, second side of the compressor crankcase **12**. The first inlet valve **80**, the second inlet valve **82**, the first outlet valve **90**, and the second outlet valve **92** may be in fluid communication with the compressor crankcase **12**. In one embodiment, the first inlet valve **80**, the second inlet valve **82**, the first outlet valve **90**, and the second outlet valve **92** may be check valves. In one embodiment, the first inlet valve **80**, the second inlet valve **82**, the first outlet valve **90**, and the second outlet valve **92** may be ball-type check valves. In another embodiment, the first inlet valve **80**, the second inlet valve **82**, the first outlet valve **90**, and the second outlet valve **92** may include an elastomer valve element (not shown) positioned between a seat (not shown) and guide member (not shown). This type of check valve is commonly known as a "flapper" style check valve. It is to be understood, however, that the use of alternative types of check valves are contemplated, such as a diaphragm check valve, a swing check valve, and a lift check valve, among others. In one embodiment, the first inlet valve **80**, the second inlet valve **82**, the first outlet valve **90**, and the second outlet valve **92** may be used to establish a cooling cross-flow of air **16** between one another to cool the compressor crankcase **12**. Although only two inlet valves and two outlet valves are shown in the drawings, it is contemplated that fewer or additional inlet valves and outlet valves may be supported on the compressor crankcase **12** to provide a reduced or greater amount of air for the cooling cross-flow **16** through the compressor crankcase **12**. As shown in FIGS. **1** and **2**, the first inlet valve **80** and the second inlet valve **82** may be positioned parallel to one another, and the first outlet valve **90** and the second outlet valve **90** may be positioned parallel to one another. It is also to be understood, however, that the first inlet valve **80** and the second inlet valve **82** may be positioned in series with one another, and the first outlet valve **90** and the second outlet valve **92** may be positioned in series with one another. The configuration of the valves may be used according to the capacity needed in the air compressor **10** and to provide redundancy.

[0028] In one embodiment, the first inlet valve **80** and the second inlet valve **82** may be supported on a lower portion of the compressor crankcase **12**. The first outlet valve **90** and the second outlet valve **92** may be supported on an opposing, lower portion of the compressor crankcase **12**. In one embodiment, the first inlet valve **80** and the second inlet valve **82** may be supported on the compressor crankcase **12** adjacent the first piston cylinder **20**. The first outlet valve **90** and the second outlet valve **92** may be supported on the compressor crankcase **12** adjacent the fourth piston cylinder **50**. Using this arrangement of the first inlet valve **80**, the second inlet valve **82**, the first outlet valve **90**, and the second outlet valve **92**, the cooling cross-flow of air **16** may be directed through the cavity **14** of the compressor crankcase **12** from the first side of the compressor crankcase **12** to the opposing, second side of the compressor crankcase **12**. The cooling cross-flow of air **16** is directed over the crankshaft assembly **60** to provide cooling for the components of the crankshaft assembly **60** and the compressor crankcase **12**. To establish this cooling cross-flow of air **16** in the compressor crankcase **12**, air is pulled into the compressor crankcase **12** via the first inlet valve **80** and the second inlet valve **82**. During an upstroke of the piston **70** in the cylindrical housing **21** of the first piston cylinder **20**, the first inlet valve **80** and the second inlet valve **82** are opened by the air that is pulled into the compressor crankcase **12**. The first inlet valve **80** and the second inlet valve **82** may be selected and/or adjusted according to the desired amount of air pressure that is necessary to open the first inlet valve **80** and the second inlet valve **82**. During the upstroke of the piston **70** in the cylindrical housing **21** of the first piston cylinder **20**, the first outlet valve **90** and the second outlet valve **92** are kept closed. In one embodiment, the cooling cross-flow of air **16** is then directed diagonally through the cavity **14** of the crankcase assembly **12** towards the first outlet valve **90** and the second outlet valve **92**. During a downstroke of the piston **70** in the cylindrical housing **21** of the first piston cylinder **20**, the cooling cross-flow of air **16** is pushed out of the first outlet valve **90** and the second outlet valve **92** to atmosphere. During the downstroke of the piston **70** in the cylindrical housing **21** of the first piston cylinder **20**, the first inlet valve **80** and the second inlet valve **82** are kept closed. The first outlet valve **90** and the second outlet valve **92** may be selected and/or adjusted according to the desired amount of air pressure that is necessary to open the first outlet valve **90** and the second outlet valve **92**. The total change of volume in the air compressor **10** is a summation of all of the piston movement within the air compressor **10**. Therefore, it is the total volume changed by reciprocating movement of the first piston cylinder **20**, the second piston cylinder **30**, the third piston cylinder **40**, and the fourth piston cylinder **50**, combined. This configuration and operation of the air compressor **10** ensures that the maximum amount of crankcase volume change is achieved without sacrificing other air compressor **10** characteristics. By combining the change in volume of all of the piston cylinders **20**, **30**, **40**, **50**, during rotation of the crankshaft assembly **60**, a maximum volume of air may be used to cool the air compressor **10**.

[0029] While FIGS. **1** and **2** depict the use of two inlet valves **80**, **82** and two outlet valves **90**, **92**, it is also to be understood that only one inlet valve **80** and one outlet valve **90** may be used, as shown in FIGS. **3** and **4**.

[0030] Referring now to FIGS. **3** and **4**, a first nozzle **100** may be positioned on the first inlet valve **80** and/or the second inlet valve **82**. The first nozzle **100** may be used to direct the flow of air into the first inlet valve **80** and/or the second inlet valve **82** during the upstroke of the piston **70** in the cylindrical housing **21** of the first piston cylinder **20**. A second nozzle **110** may be positioned on the first outlet valve **90** and/or the second outlet valve **92**. The second nozzle **110** may be used to direct the flow away from the compressor crankcase **12** to avoid directing the exhausted hot air back towards the compressor crankcase **12**. It is to be understood that different types of nozzles may be used in place of the first nozzle **100** and the second nozzle **110**, such as nozzles with a wider or narrower inlet or nozzles with a different cross-sectional shape. Further, although FIGS. **3** and **4** only depict the use of the first inlet valve **80** and the first outlet valve **90**, it is to be understood that the second inlet valve **82** and the second outlet valve **92** may be used as well. Nozzles may also be positioned on these valves as well.

[0031] With continued reference to FIGS. **3** and **4**, an inlet air filter **120** may be operatively connected to the first inlet valve **80** and/or the second inlet valve **82**. The inlet air filter **120** may be any standard inlet air filter commercially available that provides a screening function to remove contamination and debris from the air that is pulled into the compressor crankcase **12** through the first inlet valve **80** and/or the second inlet valve **82**. The inlet air filter **120** provides filtering capabilities to the air compressor **10** by removing debris and other contamination that may create wear on the crankshaft assembly **60** and components of the piston cylinders **20**, **30**, **40**, **50**. In one embodiment, the inlet air filter **120** may be positioned on an end of the first nozzle **100**. During use of the air compressor **10**, air is pulled into the cavity **14** of the compressor crankcase **12** first through the inlet air filter **120**, then through the first nozzle **100**, and finally through the first inlet valve **80** and/or the second inlet valve **82**.

[0032] Although a description of the first inlet valve **80** and the first outlet valve **90** being operatively positioned with the first piston cylinder **20** is provided, one of skill in the art will recognize that the first inlet valve **80** and the first outlet valve **90** may also be operatively positioned at different positions on the compressor crankcase **12**. The first inlet valve **80** and the first outlet valve **90** may be operatively positioned with another piston cylinder **30**, **40**, **50**. Further, the first inlet valve **80** and the first outlet valve **90** may be positioned adjacent the first piston cylinder **20** and the fourth piston cylinder **50**, respectively. The arrangement of the inlet valve **80** and the outlet valve **90** would be substantially similar to the arrangement described above in connection with the first piston cylinder **20**.

[0033] A method of cooling the compressor crankcase **12** is also described herein with reference to FIGS. **3** and **4**. In one embodiment, this method includes the step of providing an air compressor **10** as described hereinabove. During use of the cooling method, air from atmosphere is pulled into the cavity **14** of the compressor crankcase **12** via the first inlet valve **80**. The air is used as a cooling cross-flow of air **16** that is directed from the first inlet valve **80** to the first outlet valve **90**. The cooling cross-flow of air **16** is directed through the cavity **14** of the compressor crankcase **12**, thereby flowing over the components of the crankshaft assembly **60** and the piston cylinders **20**, **30**, **40**, **50**. After the cooling cross-flow of air **16** is directed through the cavity **14** of the compressor crankcase **12**, the air is pushed out of the compressor crankcase **12** via the first outlet valve **90**. As the air is directed over the crankshaft assembly **60** and the components of the piston cylinders **20**, **30**, **40**, **50**, the components are cooled by the air. The heat generated by the components is transferred to the cooling cross-flow of air **16** and carried out of the compressor crankcase **12**. In one embodiment, the first inlet valve **80** and the first outlet valve **90** may be check valves, as described hereinabove. The first inlet valve **80** may be supported on a first side of the compressor crankcase **12**. The first outlet valve **90** may be supported on an opposing, second side of the compressor crankcase **12**.

[0034] As the pistons **20**, **30**, **40**, **50** of the air compressor **10** move in and out of their respective piston cylinders, the total volume within the compressor crankcase **12** changes through a single rotation of the crankshaft assembly **60** provided the cylinders **20**, **30**, **40**, **50** are not perfectly out of phase and of the same diameter. In one embodiment, the first inlet valve **80** is opened during an upstroke of the piston **70** in the cylindrical housing **21** of the first piston cylinder **20**. The pressure exerted by the air that is pulled into the compressor crankcase **12** pushes open the first inlet valve **80**. In one embodiment, air may be pulled into the compressor crankcase **12** via the first inlet valve **80** until a maximum volume of the compressor crankcase **12** is filled. In one embodiment, the first outlet valve **90** may be opened during a downstroke of the piston **70** in the cylindrical housing **21** of the first piston cylinder **20**. The pressure exerted by the air that is pushed through and out of the cavity **14** of the compressor crankcase **12** pushes open the first outlet valve **90**, thereby allowing the air to vent to atmosphere. In one embodiment, air is pushed out of the compressor crankcase **12** via the first outlet valve **90** until a minimum volume of the compressor crankcase **12** remains. Using the described method, the cooling cross-flow of air **16** may be directed from a first side of the compressor crankcase **12**, over the crankshaft assembly **60**, and out of an opposing, second side of the compressor crankcase **12**. In this embodiment, the first inlet valve **80** is supported on the first side of the compressor crankcase **12** and the first outlet valve **90** is supported on the opposing, second side of the compressor crankcase **12**. Although the operation of the cooling method of the air compressor **10** is described in relation to the first piston cylinder **20**, it is to be understood that the cooling method is a cumulative effect of the reciprocating movement of all of the piston cylinders **20**, **30**, **40**, **50** that creates the cooling cross-flow of air **16**. The second piston cylinder **30**, the third piston cylinder **40**, and the fourth piston cylinder **50** operating in a similar manner to the first piston cylinder **20** to create the cross-flow of air **16**. It is also to be understood that the first inlet valve **80** and the first outlet valve **90** may be positioned near one of the second piston cylinder **30**, the third piston cylinder **40**, or the fourth piston cylinder **50** to provide the same cooling effect in the air compressor **10**.

[0035] In one embodiment of the method, the first nozzle **100** may be positioned on the first inlet valve **80** and the second nozzle **110** may be positioned on the first outlet valve **90**. The first nozzle **100** may be configured to direct the air from atmosphere into the first inlet valve **80**. The second nozzle **110** may be configured to direct the air from the first outlet valve **90** to atmosphere. The second nozzle **110** directs the air, whose temperature has risen due to the heat transferred from the compressor crankcase **12** components, away from the compressor crankcase **12** to atmosphere.

[0036] In another embodiment of the method, the inlet air filter **120** may be operatively connected to the first inlet valve **80**. The air that is pulled into the first inlet valve **80** may be filtered by the inlet air filter **120** to remove any contamination or debris from the air, so as not to contaminate or wear the inner components of the air compressor **10**. The inlet air filter **120** may also be positioned on an end of the first nozzle **100** connected to the first inlet valve **80**.

[0037] As explained hereinabove, although a description of a method of using the first inlet valve **80** and the first outlet valve **90** with the first piston cylinder **20** to cool the inner components of the compressor crankcase **12** is provided, one of skill in the art will recognize that the method may also be performed at different positions on the compressor crankcase **12**. The first inlet valve **80** and the first outlet valve **90** may be operatively positioned with another piston cylinder **30**, **40**, **50**. Alternatively, the first inlet valve **80** and the first outlet valve **90** may be positioned adjacent to the first piston cylinder **20** and the fourth piston cylinder **50**, respectively. It is also to be understood that the second inlet valve **82** and the second outlet valve **92** may be used to create a larger cooling cross-flow of air **16** through the compressor crankcase **12**. The arrangement and operation of the inlet valve **80** and the outlet valve **90** would be substantially similar to the arrangement described above in connection with the first piston cylinder **20**.

[0038] By using the method described hereinabove, there is no effect on the inlet air temperatures that are provided. Therefore, the first inlet valve **80** and the first outlet valve **90** are able to provide a directed positive flow through the compressor crankcase **12** without reducing the overall efficiency of the air compressor **10**, unlike if the inlet air was first routed through the compressor crankcase **12**. Further, the air at the first inlet valve **80** will not be pre-heated upon entering the compressor crankcase **12**, resulting in lower first stage temperatures. The air compressor **10** described hereinabove includes a multi-cylinder arrangement that maximizes the total change in the compressor crankcase **12** volume per revolution of the crankshaft assembly **60**, without sacrificing the dynamic balance of the air compressor **10**. In addition, the total crankshaft assembly **60** torque pulse per each revolution is reduced, while still maintaining a small overall size envelope for the air compressor **10**.

[0039] While an embodiment of an oil-free compressor crankcase cooling arrangement is shown in the accompanying figures and described hereinabove in detail, other embodiments will be apparent to, and readily made by, those skilled in the art without departing from the scope and spirit of the invention. Accordingly, the foregoing description is intended to be illustrative rather than restrictive. The invention described hereinabove is defined by the appended claims and all changes to the invention that fall within the meaning and the range of the equivalency of the claims are to be embraced within their scope.

The invention claimed is:

1. An oil-free compressor crankcase cooling arrangement for a rail vehicle, comprising:
- a compressor crankcase;
- at least one piston cylinder supported in the compressor crankcase;
- a crankshaft assembly supported by the compressor crankcase and linked to a piston of the at least one piston cylinder by a connecting rod;
- at least one inlet valve supported on and in fluid communication with the compressor crankcase; and
- at least one outlet valve supported on and in fluid communication with the compressor crankcase,
- wherein a cooling cross-flow of air is established between the at least one inlet valve and the at least one outlet valve to cool the compressor crankcase.

2. The crankcase cooling arrangement as claimed in claim **1**, wherein the at least one inlet valve and the at least one outlet valve comprise check valves.

3. The crankcase cooling arrangement as claimed in claim **1**, further comprising a first nozzle positioned on the at least one inlet valve, and a second nozzle positioned on the at least one outlet valve.

4. The crankcase cooling arrangement as claimed in claim **1**, further comprising an inlet air filter operatively connected to the at least one inlet valve,
- wherein the inlet air filter protects the compressor crankcase from contamination and debris.

5. The crankcase cooling arrangement as claimed in claim **3**, further comprising an inlet air filter positioned on the first nozzle of the at least one inlet valve,
- wherein the inlet air filter protects the compressor crankcase from contamination and debris.

6. The crankcase cooling arrangement as claimed in claim **1**, wherein the compressor crankcase defines a cavity for housing the crankshaft assembly, and

wherein the cooling cross-flow of air is directed through the cavity of the compressor crankcase from a first side of the compressor crankcase to an opposing, second side of the compressor crankcase.

7. The crankcase cooling arrangement as claimed in claim **1**, wherein the at least one inlet valve is supported on a first side of the compressor crankcase and the at least one outlet valve is supported on an opposing, second side of the compressor crankcase.

8. The crankcase cooling arrangement as claimed in claim **1**, wherein the at least one inlet valve is opened as air is pulled into the compressor crankcase during an upstroke of the at least one piston cylinder.

9. The crankcase cooling arrangement as claimed in claim **1**, wherein the at least one outlet valve is opened as air is pushed out of the compressor crankcase during a downstroke of the at least one piston cylinder.

10. The crankcase cooling arrangement as claimed in claim **1**,

further comprising an unloader valve assembly positioned on the at least one piston cylinder configured to exhaust pressurized fluid from the at least one piston cylinder.

11. A method of cooling an oil-free compressor crankcase of a rail vehicle, comprising the steps of:

a) providing an oil-free compressor, comprising:

a compressor crankcase;

at least one piston cylinder supported in the compressor crankcase;

a crankshaft assembly supported by the compressor crankcase and linked to a piston of the at least one piston cylinder by a connecting rod;

at least one inlet valve supported on and in fluid communication with the compressor crankcase; and

at least one outlet valve supported on and in fluid communication with the compressor crankcase;

b) pulling air into the compressor crankcase via the at least one inlet valve;

c) directing the air through the compressor crankcase; and

d) pushing the air out of the compressor crankcase via the at least one outlet valve.

12. The method of cooling a compressor crankcase as claimed in claim **11**, further comprising the step of opening the at least one inlet valve during an upstroke of the at least one piston cylinder,

wherein air is pulled into the compressor crankcase through the open inlet valve.

13. The method of cooling a compressor crankcase as claimed in claim **11**, further comprising the step of opening the at least one outlet valve during a downstroke of the at least one piston cylinder,

wherein air is pushed out of the compressor crankcase through the open outlet valve.

14. The method of cooling a compressor crankcase as claimed in claim **11**, further comprising the step of establishing a cooling cross-flow of air that is directed from a first side of the compressor crankcase, over the crankshaft assembly, and out of an opposing second side of the compressor crankcase,

wherein the at least one inlet valve is supported on the first side of the compressor crankcase, and

wherein the at least one outlet valve is supported on the opposing, second side of the compressor crankcase.

15. The method of cooling a compressor crankcase as claimed in claim **11**, the oil-free compressor further comprising a first nozzle positioned on the at least one inlet valve and a second nozzle positioned on the at least one outlet valve.

16. The method of cooling a compressor crankcase as claimed in claim **11**, further comprising the steps of:

providing an inlet air filter operatively connected to the at least one inlet valve; and

filtering the air that is pulled into the compressor crankcase via the at least one inlet valve using the inlet air filter.

17. The method of cooling a compressor crankcase as claimed in claim **15**, further comprising the steps of:

providing an inlet air filter on the first nozzle of the at least one inlet valve; and

filtering the air that is pulled into the compressor crankcase via the at least one inlet valve using the inlet air filter.

18. The method of cooling a compressor crankcase as claimed in claim **11**, wherein the at least one inlet valve and the at least one outlet valve comprise check valves.

19. The method of cooling a compressor crankcase as claimed in claim **11**, wherein the at least one inlet valve is supported on the compressor crankcase on a first side of the at least one piston cylinder, and

wherein the at least one outlet valve is supported on the compressor crankcase on an opposing second side of the at least one piston cylinder.

20. The method of cooling a compressor crankcase as claimed in claim **11**, further comprising the steps of:

providing an unloader valve assembly on the at least one piston cylinder, and

exhausting fluid from the at least one piston cylinder via the unloader valve assembly.

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