CONTRA-ROTATING AXIAL FAN SYSTEM AND TRANSMISSION FOR DRY AND EVAPORATIVE COOLING EQUIPMENT

A contra-rotating fan system for evaporative cooling equipment and air-cooled heat exchangers. The system can include a first axial fan disposed in an air conduit of an evaporative equipment unit, a second axial fan disposed in the air conduit and arranged coaxially with the first fan, a transmission for driving the first axial fan and the second axial fan and a motor for driving the transmission, wherein the direction of rotation of the first axial fan is opposite to the direction of rotation of the second axial fan.
The present invention is directed to systems, methods, and arrangements for providing contra-rotating axial fans, and fan drive systems. More specifically, the present invention is directed to systems, methods, and arrangement for providing contra-rotating fans and fan drive systems for condenser and evaporative cooling equipment. Even more specifically, the present invention is directed to axial fans and fan drive systems for dry and evaporative cooling equipment, as well as for heating, ventilation, air conditioning, refrigeration, and/or industrial processes. More specifically, the present invention is directed to axial fan drive assemblies for evaporative, dry, and hybrid wet/dry cooling equipment.

The present invention is directed to axial fans and fan drive systems for evaporative, dry, and hybrid wet/dry cooling equipment. Common applications for evaporative cooling equipment, such as cooling towers, include providing cooled process medium for heating, ventilation, air conditioning, and refrigeration ("HVACR"), manufacturing, refrigeration, electric power generation, and industrial processes (oil refineries, chemical manufacturers, etc.). In operation, the cooling towers serve to transfer heat from the process medium into the surrounding environment. Similarly, common applications for air- and water-cooled equipment, such as condensers, include providing cooled process medium for HVACR, manufacturing, refrigeration, and electric power generation. Finally, common applications for hybrid cooling equipment, such as wet/dry evaporative coolers, include providing cooled process medium for HVACR, manufacturing, refrigeration, and electric power generation. Generally speaking, as is generally known in the art, condensers and coolers serve to transfer heat from the process medium into the surrounding environment. Such condensers may be a standalone piece of equipment or a part of a larger "packaged" piece of HVACR equipment and/or industrial process equipment.
In an open circuit cooling tower, the process fluid to be cooled is delivered to the cooling tower and is typically distributed by a series of nozzles that atomize the process fluid over a heat-transfer medium located inside the heat-exchanger section, commonly referred to as a "fill." The fill facilitates heat transfer by promoting evaporation through commingling the process fluid with dry, outside air. The fill provides a large surface area and facilitates contact between the process fluid and the dry, unsaturated airstream supplied by a fan within the cooling tower. As the process fluid droplets pass through the fill, heat is transferred to the atmosphere through the discharge airstream of the cooling tower. A portion of the process fluid is lost through the endothermic process of evaporation, leaving the remaining process fluid at a lower temperature than it was before it entered the cooling tower. The cooled process fluid is collected in a collection basin at the bottom of the cooling tower and then withdrawn therefrom.

Closed-circuit cooling towers, also known as fluid coolers, have similar functionality, with a difference being that the process fluid is contained within one or more heat-transfer coils and not directly exposed to the surrounding environment. Water stored in the collection basin of the unit is typically sprayed over the coil(s) to promote heat transfer from the liquid to the make-up water, while at the same time promoting the endothermic process of evaporation. The end result is the process fluid within the coil is cooled through evaporation of spray water on the outside surface of the coil, and to a lesser degree, heat is transferred through the temperature gradient between the spray water/intake air temperature and the coil when atmospheric conditions allow.

Evaporative condensers are nearly identical to a closed-circuit cooling tower, or fluid cooler, except for the process medium. In the case of an evaporative condenser, the process medium is a refrigerant delivered directly from the evaporator of an HVACR machine. The evaporative condensers are typically used in the refrigeration industry, cold storage, ice skating rinks, cryogenics, and so forth. Hybrid versions of closed-circuit cooling towers employ the addition of fins to the coil circuits, similar in design to those employed on air-cooled condensers. Where atmospheric conditions and/or system load conditions allow, the fluid cooler is switched from the conventional evaporative, a.k.a "wet operation," cooling mode to an air-cooled, a.k.a. "dry operation," by switching off the spray water pump. This effectively changes the machine from a closed-circuit cooling tower into an air-cooled condenser. The purpose of these hybrid
cooling units is to save water and energy by arresting the evaporation of water and the elimination of the energy required to operate the spray water pump when atmospheric conditions and system load conditions allow.

[0006] Dry coolers and condensers have similar functionality to closed-circuit cooling towers with the difference being that they rely solely on heat transfer through direct and/or indirect contact of the process medium and the heat exchanger surface with outside air. Dry coolers and condensers have similar construction and component arrangements to closed-circuit cooling towers with a difference being that they omit components associated with the evaporative cooling process, such as, but not limited to, spray water pump and distribution systems, drift eliminators, and collection basins. Air-cooled condensers use heat exchangers of the "Liquid to Air" or "Gas to Air" variety, while and water-cooled condensers use heat exchangers of the "Liquid to Liquid" or "Gas to Liquid" variety, which are similar in design and construction to those employed in closed-circuit cooling towers.

[0007] In operation, airflow through dry and evaporative cooling equipment is typically facilitated by a fan in combination with an intake air conduit and an exhaust air conduit, which are provided for each heat transfer section, unit, or cell, of the equipment. In induced-draft equipment, the fan is typically mounted near the exhaust of the unit and used to draw air from the intake through the interior of the unit and across the heat-exchange surface located inside the heat-exchanger section. In forced-draft equipment, the fan is typically mounted near the intake and pushes the air through the interior of the cooling unit, across the heat exchange surface located inside the heat exchanger section, and out via the exhaust.

[0008] Several considerations are present during the installation and design of dry and evaporative cooling systems, including airflow, sound output, space requirements, energy requirements, and vibration transmission. It is desirable to minimize noise emitted by operation of the fan, the energy consumed by the fan drive system, and the vibrations emitted by the fan drive system. However, minimizing these negative attributes requires reducing the rotational speed of the fans, which limits the heat exchange capacity of a given unit design by falling below the required minimum airflow and static pressure. Independent of minimizing negative attributes of the conventional axial fan systems currently in use, it is also desirable to employ a fan arrangement with a higher overall efficiency that can generate an increased amount of airflow.
and static pressure at a given energy input value. Such a fan arrangement would increase the thermal capacity ratings of existing dry and evaporative equipment designs, while at the same time increasing the energy efficiency of the units themselves, as well as that of the entire HVACR and/or industrial process system in which they are installed.

[0009] As disclosed herein, one solution to minimize the negative attributes and/or increase thermal capacity ratings and energy efficiencies of dry and evaporative cooling equipment is the use of a contra-rotating, multi-stage fan arrangement. A contra-rotating, multi-stage fan arrangement is capable of meeting minimum airflow and static pressure requirements at rotational speeds that are lower than that of currently employed, axial fan systems. A contra-rotating, multi-stage fan arrangement is also capable of increased airflow and static pressure at a given energy input than that of currently employed, axial fan systems.

[0010] A solution to minimize the negative attributes of condenser and cooling tower operation, while meeting minimum airflow and static pressure requirements of a given piece of dry or evaporative cooling equipment unit is therefore desired.

**BRIEF SUMMARY OF THE INVENTION**

[0011] According to a first aspect, a contra-rotating fan system for dry and/or evaporative cooling equipment is disclosed. The system can include a first axial fan disposed in an air conduit of an evaporative equipment unit, a second axial fan disposed in the air conduit and arranged coaxially with the first fan, a transmission for driving the first axial fan and the second axial fan and a motor for driving the transmission, wherein the direction of rotation of the first axial fan is opposite to the direction of rotation of the second axial fan.

[0012] According to a second aspect, a contra-rotating fan system for an air-cooled heat exchanger comprises: a first axial fan disposed in an air conduit of an evaporative equipment unit; a second axial fan disposed in the air conduit and arranged coaxially with the first fan; a transmission means; a first power output means for transferring power from the transmission means to the first axial fan; a second power output means for transferring power from the transmission means to the second axial fan; a power input means for transferring power to the transmission means; wherein the direction of rotation of the first axial fan is opposite to the direction of rotation of the second axial fan.
According to a third aspect, a contra-rotating fan system for evaporative cooling equipment comprises: an evaporative cooling equipment unit enclosure having evaporation fill therein; an air conduit coupled to the unit enclosure and having a narrower width than the unit enclosure; a first axial fan disposed in the air conduit; a second axial fan disposed in the air conduit and arranged coaxially with the first fan, walls of the air conduit closely enclosing the tips of the first axial fan and the second axial fan; a power transmission structure configured to drive the first axial fan and the second axial fan, wherein the power transmission structure comprises (a) a lower drive unit having a first drive assembly with a first predetermined drive ratio and (b) an upper drive unit having a second drive assembly with a second predetermined drive ratio, wherein the first drive assembly comprises a center pinwheel driver, an outer pinwheel receiver, and a plurality of intermediate pinwheels, wherein the lower drive unit is operatively coupled to a motor, the lower drive unit being configured to (1) drive the upper drive unit, and (2) rotate the first axial fan at a first speed of rotation in a first direction; and a motor for driving the power transmission structure, the motor, and the power transmission structure driving the first axial fan and the second axial fan with at least one speed configured to (i) maintain airflow through the air conduit at a minimum value necessary to maintain an endothermic process of evaporative cooling, and (ii) maintain static pressure within the unit enclosure at a minimum value necessary to move air through the unit enclosure at the minimum value of airflow; wherein the direction of rotation of the first axial fan is opposite to the direction of rotation of the second axial fan.

According to a fourth aspect, an evaporative cooling equipment unit comprises: an evaporative cooling equipment unit enclosure; at least one air conduit coupled to the enclosure, the at least one air conduit being narrower than the unit enclosure; a first axial fan disposed in the at least one air conduit; a second axial fan disposed in the at least one air conduit and arranged coaxially with the first fan, walls of the at least one air conduit closely enclosing the tips of the first axial fan and the second axial fan; a motor; a transmission structure operatively coupled to the motor, to the first axial fan, and to the second axial fan; and wherein the transmission structure drives the first axial fan in an opposite direction of rotation to the second axial fan, and wherein the motor and the transmission structure drive the first axial fan and the second axial fan with at least one speed configured to (i) maintain airflow through the at least one air conduit at a minimum value necessary to maintain an endothermic process of evaporative cooling, and
(ii) maintain static pressure within the unit enclosure at a minimum value necessary to move air through the unit enclosure at the minimum value of airflow.

[0015] According to a fifth aspect, an evaporative cooling equipment contra-rotating fan system comprises: an evaporative cooling equipment unit enclosure; an air conduit coupled to the enclosure and being narrower than the unit enclosure; a first axial fan and a second axial fan disposed inside the air-restricted conduit and arranged coaxially with respect to each other, walls of the conduit closely enclosing the tips of the first axial fan and the second axial fan; a transmission structure for driving the first axial fan and the second axial fan in opposite rotational directions, the transmission structure having first and second shafts respectively coupled to the first and second axial fans and extending from the enclosure into the air conduit; and a means for driving the transmission to (i) maintain airflow through the air conduit at the minimum value necessary to maintain an endothermic process of evaporative cooling, and (ii) maintain static pressure within the unit enclosure at a minimum value necessary to move air through the unit enclosure at the minimum value of airflow.

[0016] In certain aspects, the transmission structure comprises (a) a lower drive unit having a first drive assembly with a first predetermined drive ratio, and (b) an upper drive unit having a second drive assembly with a second predetermined drive ratio, wherein the first drive assembly comprises a center pinwheel driver, an outer pinwheel receiver, and a plurality of intermediate pinwheels, wherein the lower drive unit is operatively coupled to a motor, the lower drive unit being configured to (1) drive the upper drive unit, and (2) rotate the first axial fan at a first speed of rotation in a first direction.

[0017] According to a sixth aspect, a contra-rotating axial fan system comprises: a first axial fan disposed in an air conduit; a second axial fan disposed in the air conduit and arranged coaxially with first axial fan; a transmission, the transmission comprising of two main assemblies; lower drive assembly and an upper drive assembly; wherein the lower drive assembly is configured to receive power from a motor and is configured to (i) transfer power to the upper drive assembly and (ii) rotate the first axial fan in a first direction; wherein the upper drive assembly is configured to rotate the second axial fan in a second direction; wherein the direction of rotation of the first direction is opposite to the direction of rotation of the second direction. The lower and upper drive assemblies may be housed in separate enclosures and
coupled externally, housed in a common enclosure internally coupled, fully integrated into a single assembly housed in a single enclosure, or one or both assemblies integrated within an axial fan hub and/or fan motor.

[0018] According to a seventh aspect, a contra-rotating transmission comprising: a lower drive assembly; and an upper drive assembly, wherein the lower drive assembly is configured to receive power from a motor and is further configured to (i) transfer power to the upper drive assembly and (ii) rotate a first axial fan in a first direction; wherein the upper drive assembly is configured to rotate the second axial fan in a second direction; wherein the direction of rotation of the first direction is opposite to the direction of rotation of the second direction.

**BRIEF DESCRIPTION OF THE FIGURES**

[0019] These and other advantages of the present invention will be readily understood with reference to the following specifications and attached drawings, wherein:

[0020] Figure 1a shows a first exemplary embodiment of a contra-rotating fan system for dry or evaporative cooling equipment.

[0021] Figure 1b shows an exemplary embodiment of a transmission for a contra-rotating fan system.

[0022] Figure 1c shows a variant of the first exemplary embodiment of the contra-rotating fan system for dry or evaporative cooling equipment using two motors.

[0023] Figure 2a shows a second exemplary embodiment of a contra-rotating fan system for dry or evaporative cooling equipment.

[0024] Figure 2b shows an exemplary embodiment of a transmission and fan hub for a contra-rotating fan system.

[0025] Figure 2c shows a variant of the second exemplary embodiment of the contra-rotating fan system for dry or evaporative cooling equipment using two motors.

[0026] Figure 3a shows a third exemplary embodiment of a contra-rotating fan system for dry or evaporative cooling equipment.
Figure 3b shows a variant of the third exemplary embodiment of the contra-rotating fan system for dry or evaporative cooling equipment using two motors.

Figure 4a shows a fourth exemplary embodiment of a contra-rotating fan system for dry or evaporative cooling equipment.

Figure 4b shows a variant of the fourth exemplary embodiment of the contra-rotating fan system for dry or evaporative cooling equipment using two motors.

Figure 5a shows a fifth exemplary embodiment of a contra-rotating fan system for dry or evaporative cooling equipment.

Figure 5b shows a variant of the fifth exemplary embodiment of the contra-rotating fan system for dry or evaporative cooling equipment using two motors.

Figure 6a shows a sixth exemplary embodiment of a contra-rotating fan system for dry or evaporative cooling equipment.

Figure 6b shows an exemplary embodiment of a transmission for a contra-rotating fan system.

Figure 7a shows an exemplary embodiment of a contra-rotating fan system for an induced-draft, air-cooled heat exchanger.

Figure 7b shows an exemplary embodiment of a contra-rotating fan system for a forced draft air cooled heat exchanger.

Figure 8a is an exemplary embodiment of a first contra-rotating axial fan system for evaporative cooling equipment.

Figure 8b is an exemplary embodiment of a second contra-rotating axial fan system for evaporative cooling equipment.

Figure 8c is an exemplary contra-rotating transmission and motor for use with the system of Figure 8b.
Figure 8d is a first view of an exemplary contra-rotating axial fan assembly for use with the system of Figure 8b.

Figure 8e is a second view of the exemplary contra-rotating axial fan assembly for use with the system of Figure 8b.

Figure 9a is a front, isometric view of an exemplary embodiment of a contra-rotating transmission for use in a contra-rotating axial fan system.

Figure 9b is a side, cross-sectional view of the exemplary embodiment of a contra-rotating transmission.

Figure 10a is a front, isometric view of a lower drive unit of the exemplary embodiment of a contra-rotating transmission.

Figure 10b is a top, plan view of the lower drive unit of the exemplary embodiment of a contra-rotating transmission.

Figure 11a is a front, isometric view of an upper drive unit of the exemplary embodiment of a contra-rotating transmission.

Figure 11b is a top, plan view of the upper drive unit of the exemplary embodiment of a contra-rotating transmission.

**DETAILED DESCRIPTION OF THE INVENTION**

Embodiments of the present invention will be described hereinbelow with references to the accompanying drawings. Alternate embodiments may be devised without departing from the spirit or the scope of the invention. In the following description, well-known functions or constructions are not described in detail because they would obscure the invention in unnecessary detail. Further, to facilitate an understanding of the description, discussion of several terms used herein follows. According to at least one exemplary embodiment, contra-rotating fan systems for dry coolers (e.g., an air-cooled heat exchanger, HVACR condenser, etc.) and evaporative cooling equipment are disclosed. The fan systems may include a pair of axial, contra-rotating fans (or other rotating components) and associated drive and transmission components.
As used herein, the word "exemplary" means "serving as an example, instance, or illustration." The embodiments described herein are not limiting, but rather are exemplary only. It should be understood that the described embodiments are not necessarily to be construed as preferred or advantageous over other embodiments. Moreover, the terms "embodiments of the invention," "embodiments," or "invention" do not require that all embodiments of the invention include the discussed feature, advantage, or mode of operation.

As used herein, the term "input shaft" shall be understood to refer to any device that applies torque to the transmission (e.g., a contra-rotating transmission so as to initiate and/or maintain rotation of the transmission gearing arrangement(s)).

As disclosed herein, a multi-stage axial fan system may be configured to enable contra-rotation, as well as co-rotation, of two or more axial fans or other rotating components (e.g., impellers, fans, gears, mechanical linkages to another device or system, etc.). Indeed, multi-stage axial fan systems may deliver and reap the benefits of co- and contra-rotating, multi-stage axial fan systems, including, but not limited to, altering static pressure, flow rate, horsepower ("HP") consumption, fan system efficiency, sound, harmonics, thermal efficiency of cooling unit (e.g., an evaporative cooling unit or HVACR system), thermal performance of cooling unit, layout, and sound quality of cooling unit, etc.

Employing a pair of coaxial, axial fans (e.g., coaxial, contra-rotating axial fans), in lieu of a single fan, provides a number of advantages. For instance, a pair of contra-rotating axial fans can produce a higher cubic foot per minute ("CFM") output while maintaining minimum static pressure required for air to travel from intake to discharge in evaporative cooling equipment and air- or water-cooled equipment, thus increasing the amount of heat exchanged from the process fluid to the waste airstream. Accordingly, a pair of contra-rotating axial fans provides greater thermal efficiency in terms of total heat rejection typically measured in British Thermal Units per Hour ("BTU/h"). Thus, the axial fan system provides increased thermal and/or energy efficiency. Table 2 provides exemplary target design parameters for an exemplary air-cooled heat exchanger.
<table>
<thead>
<tr>
<th>Description</th>
<th>English</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Heat: Duty</td>
<td>15.0 Million Btu/Hr</td>
<td>4.4 MW</td>
</tr>
<tr>
<td>Hot Fluid Inlet Temperature</td>
<td>250 °F</td>
<td>121 °C</td>
</tr>
<tr>
<td>Hot Fluid Outlet Temperature</td>
<td>150 °F</td>
<td>95.6 °C</td>
</tr>
<tr>
<td>Air Flow Rate</td>
<td>869,000 lb/Hr</td>
<td>109 Kg/s</td>
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<tr>
<td>Air Inlet Temperature</td>
<td>100 °F</td>
<td>37.8 °C</td>
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<tr>
<td>Outlet Temperature</td>
<td>172 °F</td>
<td>77.8 °C</td>
</tr>
<tr>
<td>Transfer Rate</td>
<td>90.0 Btu/(Hr-Sq.Ft.- °F)</td>
<td>511 W/(Sq.M- °C)</td>
</tr>
</tbody>
</table>

Table 1

[0052] Indeed, employing a pair of contra-rotating axial fans enables dry and evaporative cooling equipment manufacturers to substantially increase and maximize thermal capacity in existing or new coil products by utilizing a denser coil design, thereby allowing for more surface area in a given coil-space volume. The surplus static pressure generated by contra-rotating axial fans also allows for the use of larger coils with, or without, increased fins per inch (“FPI”) and coil rows that can carry larger pressure drops than existing equipment, thus increasing the thermal capacity of air-cooled equipment in every coil, cross-sectional area size currently in use. Additional opportunities for thermal capacity increases can be realized due to the present axial fan system's allowance for the use of denser and higher performance heat transfer mediums with higher associated pressure drops. In addition, this arrangement allows the use of increased heat-exchanger air travel (e.g., taller fill drifts, additional coil rows, etc.) than those that are currently being used.

[0053] In other words, contra-rotating axial fans enable the system to generate large amounts of static pressure at a given power input, while maintaining minimum airflow requirement, thereby creating the opportunity to utilize the surplus static pressure advantageously in dry and evaporative cooling equipment design. In a contra-rotating configuration, one fan is generally responsible for the increase in static pressure while the other fan is generally
responsible for the gross air flow. A leading fan may be primarily responsible for air flow (moving air), while the leaving fan is mainly responsible for generating static pressure (compressing air). The surplus static pressure generated by the contra-rotating fan system allows for the use of higher performance components with higher pressure drops, including, but not limited to, the components discussed previously in detail. This may be accomplished using the same amount of (or less) power to the motor (e.g., a 10 HP motor) depending on the goals for a given piece of equipment (low sound, efficiency, layout footprint, layout height, layout restrictions, etc.).

[0054] An example use of the resulting surplus static pressure includes the ability to increase the heat transfer surface area by utilizing larger heat-exchanger sections with increased air travel, which is not possible with single stage and co-rotating multi-stage axial fan systems. The surplus static pressure is used to overcome the higher pressure drop across the heat exchanger section as the overall air travel of the heat exchanger section is increased.

[0055] When it is not advantageous to use heat-exchanger sections with increased air travel (for reasons such as dimensional constraints, manufacturing costs, etc.), the surplus static pressure can alternatively be utilized by increasing the amount of heat-transfer surface area in a given heat-exchanger section at the expense of pressure drop across the heat-exchanger section. For example, in dry cooling equipment, the density of coil fins can be increased and/or the coil surface area may be increased by more densely packing the existing coil frame. Coil finning is rated in the industry as FPI. This concept is also true for cooling units that utilize finned coils such as hybrid wet/dry coolers and more increasingly standard, closed-circuit cooling towers.

[0056] Evaporative cooling equipment that does not use a coil can take advantage of the surplus static pressure by increasing the air travel (drift) of the heat-transfer medium's surface (e.g., the fill). Alternatively or conjunctively, the heat-transfer medium's surface can be more densely packed to provide more heat-transfer surface area at the expense of pressure drop across the heat-exchange medium.

[0057] Yet another possible way to take advantage of the surplus static may be to use drift eliminators of a denser design with larger pressure drop that would allow the maximum amount of airflow in a given heat exchanger size to be increased without forcing the process medium to
be ejected out of the air discharge. Current industry maximum-flow-rate velocities are approximately 800 feet per minute (FPM).

[0058] The ability to utilize heat-exchanger sections with increased air travel leads to the opportunity to increase thermal capacity in any given cross-sectional area or "footprint" of the condenser or cooler. In the evaporative cooling industry, this is also referred to as "box size." Thus, the increase in efficiency stemming from using a pair of contra-rotating axial fans provides the user a thermal "box advantage." That is, a user can deliver the same output using evaporative cooling equipment having a smaller footprint, or, in the alternative, provide increased output without requiring larger footprint, cooling equipment. This is particularly pertinent when the footprint of the evaporative cooling equipment is a consideration or limitation (e.g., in urban areas). For example, HVAC systems installed in tall buildings require a great amount of cooling capacity, but provide limited rooftop space for mechanical equipment (e.g., building ventilation equipment, exhaust flues, elevator equipment, window-washing equipment, etc.). Similarly, such configurations allow for evaporative cooling equipment to be placed closer to solid objects, making it more suitable for tight layouts and reducing the minimum requirement for overall air intake sizes allowing for reduction in height opportunities on contra-flow-induced-draft units. Contra-flow-induced-draft units are typically taller than other configurations due to the air intake at bottom of the equipment. However, the air intakes can be shortened at the expense of pressure drop by use of surplus static pressure, thus shortening the overall height of the equipment.

[0059] Finally, a contra-rotating axial fan system can also be configured with standard axial fans that operate at a lower rotation per minute ("RPM"), as opposed to specialized axial fans, which are often utilized by evaporative cooling equipment manufacturers. That is, specialized axial fans may be specifically engineered to produce minimum design CFM and static pressure at the lowest possible RPM. However, enabling the contra-rotating axial fan system to operate with standard axial fans allows evaporative cooling equipment manufacturers to utilize inventory standard fans in lieu of having to stock two or more types of fans to accommodate low-sound projects. In addition, specialize axial fans (e.g., engineered, low-RPM fans) are typically more than double the cost of standard fans. Generally, the lower the RPM of a fan system, the lower the sound power level generated. The sound power level difference
between two identical fan systems running at different RPMs is described by the following equation:

$$\text{Sound Power Level Difference} = 20 \log_{10} \frac{\text{RPM System } #1}{\text{RPM System } #2}^{2.5}$$

[0060] The surplus static pressure, as described previously, can also be applied to the use of more substantial sound attenuators with higher pressure drops that are unable to be used with current fan systems, further enhancing the low-sound capabilities of the equipment utilizing this fan arrangement.

[0061] Fans may be selected (e.g., by cooling equipment manufacturers) utilizing fan manufacturer-provided fan curves or fan manufacturer selection software that generates fan curves. Indeed, the cooling equipment manufacturer determines the minimum pressure drop for a particular piece of equipment, minimum/maximum fan diameter for use with the equipment, and the power input maximum for use with the equipment. Using that information, the equipment manufacturer may generate a fan curve with software, or look up existing fan curves, and select a specific fan that meets the criteria with the maximum amount of flow (i.e., CFM). Fan curves typically have an X-axis of airflow (CFM) and a Y-axis of static pressure. Multiple curves may be shown per plot, with each curve representing a specific fan blade angle. Each plot represents a specific fan RPM, input HP, number of blades, diameter, and tip clearance, thus the number of plots possible for a single fan size is seemingly infinite; which is why selection software is typically employed when selecting fans for new equipment designs.

[0062] For example, a single-stage fan system may have an airflow output of 36,000 CFM, while maintaining the design minimum of 0.9 inches of static pressure. Increasing the rotational speed of the single fan system will result in an increase in CFM output and required HP input power, however, because the static pressure drops below the 0.9 inch minimum at air flows higher than 36,000 CFM, the fan system would cause a thermal capacity de-rate in the cooling equipment rather than achieving the goal of a thermal capacity increase. If the airflow of that fan is increased, the fan would be running "off the curve," meaning that the fan system is no longer operating at the maximum airflow at the minimum 0.9 inches of static pressure required by the design of the cooling equipment.
There are at least two methods of increasing the airflow of an existing fan system. A first method to increase the RPM at the expense of input power (HP). If input power (HP) is unable to be increased, a second method is to re-pitch (e.g., changing the blade angle) the fan blades to increase airflow, at the expense of static pressure, regardless of whether the RPM is increased or left constant. However, by using a pair of contra-rotating axial fans, a user can achieve, as an example, 39,000 CFM with 1.25 inches of static pressure at the same RPM as the previous single-stage fan system example of 36,000 CFM at 0.9 inches of static pressure, thus providing an additional 3,000 CFM and a static pressure surplus of 0.35 (i.e., air horsepower). The 39,000 CFM at 1.25 inches of static pressure would be performance-based on a fan manufacturer fan curve generated by software or through actual wind tunnel data.

However, the data used in the above examples represents only one solution. For example, the contra-rotating system may produce 45,000 CFM at the same 0.9 inches of static pressure or conversely the same 36,000 CFM at 1.5 inches of static pressure. Indeed, an objective of these examples is to illustrate that the contra-rotating axial fan system extends the design palette of a given axial fan design on both the X-axis (air flow) and Y-axis (static pressure). Co-rotating fans expand the design palette single dimensionally on the X-axis of airflow only. Increasing the HP input of a fan system with an extended fan curve design palette (e.g., using a contra-rotating system) enables a user to achieve performance beyond that of a single, or even a multi-stage, co-rotating axial fan system. Thus, the contra-rotating system yields unmatched performance that generates unprecedented cooling equipment thermal efficiencies.

Surplus static pressure is particularly beneficial with multi-cell, counter-flow, induced-draft units as the intermediate cells experience large thermal de-rates associated with an air HP deficiency with a higher minimum static pressure requirement than the end cells. This may be attributed to the intermediate cells competing for outside air with the cells they are sandwiched between, while the end cells have the luxury of not having to compete for air on one full face of the four-sided air intake.

This contra-rotating fan system mitigates, or removes, the thermal de-rate in the affected cells by properly utilizing and applying its ability to create a large surplus of static
pressure (i.e., air HP) across the cells in a manner that allows each cell to draw the same amount of intake air.

[0067] Turning now to the figures, Figure 1a shows a first exemplary embodiment of a contra-rotating fan drive system 100 for dry and evaporative cooling equipment. The contra-rotating fan drive system 100 can include a first fan 102 and a second fan 104, which may be disposed in an air conduit 106. Air conduit 106 may be in fluid communication with the interior of evaporative cooling equipment unit 10 and the exterior environment. The first and second fans 102, 104 and air conduit 106 may be provided in any location on an evaporative cooling equipment unit 10 that enables system 100 to function as described herein. In some exemplary embodiments, air conduit 106 may be an exhaust air conduit, for example, in an induced-draft cooling unit. In other exemplary embodiments, air conduit 106 may be an intake air conduit, for example, in a forced-draft cooling unit. Air conduit 106 may also function as a fan cowl for fans 102, 104.

[0068] The first fan 102 and second fan 104 may be axial fans and may be arranged coaxially with respect to each other. In some exemplary embodiments, fans 102, 104 may include removable airfoil-type blades which may be pitched to a desired angle. The blades may be pitched such that the blade pitch of first fan 102 may be different from the blade pitch of second fan 104.

[0069] A motor 108 may be provided to drive system 100. Motor 108 may be an electric motor, or any motor known to one having ordinary skill in the art that enables system 100 to function as described herein, and may have any power rating suitable for the particular application of system 100. Motor 108 may drive an output shaft 110 on which a drive pulley 112 is mounted. Drive pulley 112 may engage a belt 114, which can in turn engage a driven pulley 116 that is coupled to an input shaft 118 of transmission 120.

[0070] Transmission 120 may drive fans 102, 104 via first and second output drive shafts 122, 124. First fan 102 may be rigidly coupled to first output drive shaft 122, while second fan 104 may be rigidly coupled to second output drive shaft 124. First and second output drive shafts 122, 124 may be arranged coaxially with respect to each other such that first output drive shaft 122 drives first fan 102 and second output drive shaft 124 drives second fan 104. To
that end, second output drive shaft 124 and second fan 104 may each have a bore defined therein, the bores being sized such that first output drive shaft 122 may pass through the bore. Transmission 120 may include gearing arrangements for rotating the first and second output drive shafts 122, 124 at speeds different from the speed of the input shaft 118.

[0071] Transmission 120 may also include gearing arrangements, for example a planetary-gear set, that are adapted to drive first fan 102 in a direction counter to that of second fan 104. Furthermore, transmission 120 may be adapted to drive first fan 102 at a different speed than second fan 104.

[0072] An exemplary embodiment of transmission 120 is shown in Figure 1b. In some exemplary embodiments of transmission 120, input shaft 118 may engage first output drive shaft 122 via a gear or belt drive that may be adapted for gearing reduction. Alternatively, input shaft 118 may be rigidly coupled to, or may function as, first output drive shaft 122, with gearing reduction provided by pulleys 112, 116. The first output drive shaft 122 can carry a sun gear 126a that engages a plurality of planet gears 126b, which, in turn, engage a ring gear 126c. The planet gears 126b are coupled to a carrier 128 that can maintain the positions of the planet gears 126b. Carrier 128 may be held stationary so as to allow the planet gears to act as idlers. The ring gear 126c may be coupled to second output drive shaft 124. Thus, in operation, first output drive shaft can rotate sun gear 126a, causing ring gear 126c to rotate in a direction opposite to the sun gear 126a, and thereby rotating second output drive shaft 124 in a direction opposite to that of first output drive shaft 122. The ratios of the gears may further be adapted to rotate second output drive shaft 124 at a speed different than that of first output drive shaft 122.

[0073] In yet other exemplary embodiments, transmission 120 may be substantially similar to that disclosed in U.S. Patent 6,540,570, entitled Counter Rotating Transmission, the disclosure of which is hereby incorporated by reference in its entirety. Therefore, while Figure 1b generally illustrates a planetary speed reducer with a spur gear output, other arrangements known in the art are entirely possible and contemplated. For example, Figure 2b illustrates another arrangement suitable for the transmission of Figures 1a and lc.

[0074] An exemplary layout for contra-rotating fan drive system 100 is shown in Figure 1a. A support member 130 may be coupled to an evaporative cooling equipment unit 10.
Motor 108 and transmission 120 may be mounted on support member 130. Motor 108 may be mounted in a substantially laterally offset position from transmission 120 and oriented such that belt 114 can engage drive pulley 112 and driven pulley 116. Transmission 120 may be mounted proximate air conduit 106 such that first and second output drive shafts 122, 124 can extend towards fans 102, 104, which may be disposed within air conduit 106. In the exemplary embodiment, support member 130, as well as motor 108 and transmission 120, may be mounted within the interior space of the dry or evaporative cooling equipment unit 10. The specific layout and positioning of the components of system 100 may depend on the configuration of the particular dry or evaporative cooling equipment unit 10 with which system 100 may be used and may be adapted or modified as desired by one having ordinary skill in the art.

[0075] Another exemplary layout for contra-rotating fan drive system 100b employing two motors is shown in Figure 1c. In certain situations, it may be advantageous to employ two motors when controlling the two fans. For example, the first fan 102 and second fan 104 may be separately powered. Indeed, a user may wish to power or throttle a single fan without disengaging or adjusting the transmission. Another reason to employ two motors would be "power matching" and lack of a transmission solution for a particular need. Moreover, two motors will precisely control the amount of torque applied to each fan without any interference or power loss through a transmission, which can be advantageous because contra-rotating transmissions are often expensive and generally require frequent maintenance. For convenience of illustration, substantially similar functional elements to those in the first exemplary embodiment are represented by similar numerals, wherein the duplicated components are designated with the trailing "a" or "b." Thus, a detailed description of the substantially similar elements may be omitted.

[0076] As illustrated, a first support member 130a may be coupled to an evaporative cooling equipment unit 10. A first motor 108a and transmission 120a may be mounted on the lower support member 130a. Motor 108a may be mounted in a substantially laterally offset position from transmission 120a and oriented such that a first belt 114a can engage a first drive pulley 112a and driven pulley 116a. Transmission 120a may be mounted proximate air conduit 106a such that output drive shafts 122, 124 can extend towards fans 102, 104, which may be disposed within air conduit 106. Similarly, a second motor 108b and transmission 120b may be
mounted on the upper support member 130b. Motor 108b may be similarly mounted in a substantially laterally offset position from transmission 120b and oriented such that a second belt 114b can engage a second drive pulley 112b and driven pulley 116b. Transmission 120b may be mounted proximate air conduit 106a such that output drive shafts 122, 124 can extend towards fans 102, 104, which may be disposed within the upper end air conduit 106. In this embodiment, support member 130a, as well as motor 108a and transmission 120a, may be mounted within the interior space of the evaporative cooling equipment unit 10, while the upper support member 130b, as well as motor 108b and transmission 120b, may be mounted within the upper end of the interior space of the air conduit 106. The specific layout and positioning of the components of system 100c may depend on the configuration of the particular dry or evaporative cooling equipment unit 10 with which system 100c may be used and may be adapted or modified as desired by one having ordinary skill in the art.

[0077] Figure 2a shows a second exemplary embodiment of a contra-rotating fan drive system 200 for evaporative cooling equipment. For convenience of illustration, substantially similar functional elements to those in the first exemplary embodiment are represented by similar numerals, with the leading digit incremented to 2. Thus, a detailed description of the substantially similar elements may be omitted. The second exemplary embodiment has substantially similar structure and functionality to the first exemplary embodiment, except for the features described below.

[0078] In the second exemplary embodiment, motor 208 may be coupled to a transmission 240 that may function as, or be coupled to, output drive shaft 242. Transmission 240 can include any gear arrangement that enables the contra-rotating fan drive system 200 to function as described herein. The gear arrangement can function to rotate output drive shaft 242 at a speed different from that of output shaft of motor 208. For example, the gear arrangement may include an output gear rigidly coupled to output drive shaft 242.

[0079] Output drive shaft 242 of transmission 240 may extend to first fan 202 and may be rigidly coupled thereto so as to drive first fan 202. Second fan 204 may be arranged coaxially with output drive shaft 242. Second fan 204 is integrated with second transmission 250 through the fan hub. Therefore, as illustrated, the second transmission 250 may be integral with the fan hub. Second transmission 250 can be configured to receive the drive shaft 242 and, using a gear
arrangement, cause the integrated second fan 204 to operate at a different speed and/or direction. So as to support the integrated second transmission 250 and second fan 204 in place, a support structure 256 can extend between, and be coupled to, transmission 240 and the hub of second fan 204 housing the integrated second transmission 250.

[0080] Second transmission 250 can further include a gear arrangement that can be operatively engaged with both output drive shaft 242 and second fan 204. For example, transmission 250 may be a simple planetary arrangement wherein the shaft 242 passes through as a single shaft and drives fan 202. Fan 204 may be attached to the ring carrier whereby the fan hub becomes the ring carrier by integrating the gear assembly with the fan hub. The shaft 242 that passes through will engage the sun gear inside the fan hub that in turn engages the idlers and counter rotates the ring carrier/fan hub as an integrated assembly. The gear arrangement can be operable to rotate second fan 204 in a direction opposite to that of output drive shaft 242 and consequently in a direction opposite to that of first fan 202. The gear arrangement can further be operable to rotate second fan 204 at a speed different from that of output drive shaft 242 and consequently first fan 202.

[0081] This embodiment is useful in that it enables the fans to counter rotate using a single shaft which is otherwise impossible. Specifically, the fans are able to counter rotate because the shaft 242 passes through the transmission to rotate fan 202 while also imparting power to the sun gear of transmissions. However, a double-shaft arrangement may be employed wherein a first shaft is placed between from transmission 240 and transmission 250 and a second shaft from transmission 250 to fan 202. The double shaft arrangement yields substantially the same outcome as a one piece shaft that passes through transmission 250. Each transmission may employ a planetary gear arrangement as disclosed herein, an equivalent thereof, or other gear arrangements known in the art are entirely possible and contemplated. As is known in the art, a standard planetary arrangement for counter rotation generally comprises one or more outer gears, or planet gears, revolving about a central, or sun gear. Typically, the planet gears are mounted on a movable arm or carrier which itself may rotate relative to the sun gear. Simple planetary-gear systems have one sun, one ring, one carrier, and one planet set. Compound planetary gears typically involve one or more of the following three types of structures: meshed-planet (there are at least two more planets in mesh with each other in each planet train), stepped-planet (there
exists a shaft connection between two planets in each planet train), and multi-stage structures (the system contains two or more planet sets).

[0082] In some exemplary embodiments, a sun gear 254a may be carried by output drive shaft 242. The sun gear 254a can engage a plurality of planet gears 254b that are disposed within second transmission 250. The planet gears 254b can, in turn, engage a ring gear 254c. The planet gears 254b may be coupled to a carrier 258, which can maintain the positions of the planet gears. Carrier 258 may in turn be coupled to stator portion 252 of second transmission 250, thereby allowing carrier 258 to be held stationary so as to allow the planet gears to act as idlers. The ring gear 254c may be coupled to, or may be part of, the rotor of second fan 204. Thus, in operation, first output drive shaft can rotate sun gear 254a, causing ring gear 254c to rotate in a direction opposite to the sun gear, thereby rotating second fan 204 in a direction opposite to that of first output drive shaft 222. The ratios of the gears may further be adapted to rotate second fan 204 at a speed different than that of first output drive shaft 222.

[0083] An exemplary layout for contra-rotating fan drive system 200 is shown in Figure 2a. A support member 230 may be coupled to an evaporative cooling equipment unit 20. Motor 208 and transmission 240 may be provided as an integrated unit and may be mounted on support member 230. Second fan 204 may be integrated with second transmission 250 through the fan hub. Therefore, as illustrated, the second transmission 250 may be integral with the fan hub. Motor 208 and transmission 240 may be mounted proximate air conduit 206 such that output drive shaft 242 can extend towards fans 202, 204, which may be disposed within air conduit 206. In the exemplary embodiment, support member 230, as well as motor 208 and transmission 220, may be mounted within the interior cavity of the dry or evaporative cooling equipment unit 20. The specific layout and positioning of the components of system 200 may depend on the configuration of the particular dry or evaporative cooling equipment unit 20 with which system 200 may be used and may be adapted or modified as desired by one having ordinary skill in the art.

[0084] As discussed above, in certain situations, it may be advantageous to employ two motors when controlling the two fans. Again, for convenience of illustration, substantially similar functional elements are represented by similar numerals, wherein the duplicated
components are designated with the trailing "a" or "b." Thus, a detailed description of the substantially similar elements may be omitted.

[0085] An exemplary layout for contra-rotating fan drive system 200b employing two motors is shown in Figure 2c. As illustrated, a lower support member 230a may be coupled to a dry or evaporative cooling equipment unit 20. Motor 208a and transmission 240a may be provided as an integrated unit and may be mounted on lower support member 230a. Motor 208a and transmission 240a may be mounted proximate air conduit 206 such that a first output drive shaft 242a can extend towards second fan 204, which may be disposed within air conduit 206. Similarly, an upper support member 230b may be coupled within the upper end of the air conduit 206. Motor 208b and transmission 240b may be provided as an integrated unit and may be mounted on upper support member 230b. Alternatively, as illustrated and described with regard to Figure 2a, either, or both, of transmissions 240a, 240b may be integral with a fan hub (see second transmission 250, Figure 1a). Motor 208b and transmission 240b may be mounted proximate air conduit 206 such that a second output drive shaft 242b can extend towards second fan 202, which may be disposed within air conduit 206.

[0086] In this embodiment, support member 230a, as well as motor 208a and transmission 220a, may be mounted within the interior cavity of the dry or evaporative cooling equipment unit 20, while the upper support member 230b, as well as motor 208b and transmission 220b, may be mounted within the upper end of the interior space of the air conduit 206. The specific layout and positioning of the components of system 200b may depend on the configuration of the particular dry or evaporative cooling equipment unit 20 with which system 200b may be used and may be adapted or modified as desired by one having ordinary skill in the art.

[0087] Figure 3a shows a third exemplary embodiment of a contra-rotating fan drive system 300 for dry or evaporative cooling equipment. For convenience of illustration, substantially similar functional elements to those in the first exemplary embodiment are represented by similar numerals, with the leading digit incremented to 3. Thus, a detailed description of the substantially similar elements may be omitted. The third exemplary embodiment has substantially similar structure and functionality to the first exemplary embodiment, except for the features described below.
In the third exemplary embodiment, motor 308 may drive a drive shaft 310 that can function as, or be coupled to, an input shaft of transmission 320. Transmission 320 may drive fans 302, 304 via first and second output drive shafts 322, 324 and may have substantially similar structure and functionality to any of the embodiments of transmission 120.

An exemplary layout for contra-rotating fan drive system 300 is shown in Figure 3. A first support member 330 and a second support member 332 may be coupled to a dry or evaporative cooling equipment unit 30. Motor 308 may be mounted on first support member 330 while transmission 320 may be mounted on second support member 332. Motor 308 may be mounted substantially proximate transmission 320. Transmission 320 may be mounted proximate air conduit 306 such that output drive shafts 322, 324 can extend towards fans 302, 304, which may be disposed within air conduit 306. In the exemplary embodiment, support members 330, 332, as well as motor 308 and transmission 320, may be mounted within the interior space of the dry or evaporative cooling equipment unit 30. Alternatively, as illustrated and described with regard to Figure 2a, transmission 340 may be integral with a fan hub (see second transmission 250, Figure 1a). The specific layout and positioning of the components of system 300 may depend on the configuration of the particular dry or evaporative cooling equipment unit 30 with which system 300 may be used and may be adapted or modified as desired by one having ordinary skill in the art.

In certain situations, it may be advantageous to employ two motors when controlling the two fans. Again, for convenience of illustration, substantially similar functional elements are represented by similar numerals, wherein the duplicated components are designated with the trailing "a" or "b." Thus, a detailed description of the substantially similar elements may be omitted.

An exemplary layout for contra-rotating fan drive system 300b employing two motors is shown in Figure 3b. As illustrated, a first set of support members comprising a first support member 330a and a second support member 332a may be coupled to a dry or evaporative cooling equipment unit 30. A first motor 308a may be mounted on support member 330a while transmission 320a may be mounted on support member 332a. Motor 308a may be mounted substantially proximate transmission 320a. Transmission 320a may be mounted
proximate air conduit 306a such that output drive shaft 324 can extend towards second fan 304, which may be disposed within air conduit 306.

Similarly, a second set of support members comprising a first support member 330b and a second support member 332b may be coupled to a dry or evaporative cooling equipment unit 30. A first motor 308a may be mounted on support member 330a while transmission 320a may be mounted on support member 332a. Motor 308a may be mounted substantially proximate transmission 320a. Transmission 320a may be mounted proximate air conduit 306a such that output drive shaft 322 can extend towards first fan 302, which may be disposed within air conduit 306. Alternatively, as illustrated and described with regard to Figure 2a, either, or both, of transmissions 320a, 320b may be integral with a fan hub (see second transmission 250, Figure 1a).

In this embodiment, support members 330a, 332a, as well as motor 308a and transmission 320a, may be mounted within the interior space of the dry or evaporative cooling equipment unit 30, while support members 330b, 332b, as well as motor 308b and transmission 320b, may be mounted within the upper end of the interior space of the air conduit 306. The specific layout and positioning of the components of system 300b may depend on the configuration of the particular dry or evaporative cooling equipment unit 30 with which system 300b may be used and may be adapted or modified as desired by one having ordinary skill in the art.

Figure 4a shows a fourth exemplary embodiment of a contra-rotating fan drive system 400 for dry or evaporative cooling equipment. For convenience of illustration, substantially similar functional elements to those in the first exemplary embodiment are represented by similar numerals, with the leading digit incremented to 4. Thus, a detailed description of the substantially similar elements may be omitted. The fourth exemplary embodiment has substantially similar structure and functionality to the first exemplary embodiment, except for the features described below.

In the fourth exemplary embodiment, motor 408 may drive an output shaft 410, which may be coupled to a connecting drive shaft 415 via a first coupling 411. Connecting drive shaft 415 may in turn be coupled to an input shaft 418 of a transmission 420 via a second
coupling 411. Couplings 411 may be rigid couplings or may be flexible couplings. In certain embodiments, a connecting shaft may be unnecessary. Rather, the same end goal may be accomplished using only the couplings 411, which can function as a very short connecting shaft. The couplings 411 may further comprise an elastomer-housed inside for vibration dampening and act as a designed failure point, should the fan drive lockup suddenly, to prevent the motor from being damaged or destroyed. A suitable type of coupling may be chosen for a particular application by one having ordinary skill in the art.

[0096] Transmission 420 may drive fans 402, 404 via first and second output drive shafts 422, 424 and may have substantially similar structure and functionality to any of the embodiments of transmission 120. Alternatively, as illustrated and described with regard to Figure 2a, transmission 420 may be integral with a fan hub (see second transmission 250, Figure 1a).

[0097] The drive shaft 410 and connecting shaft 415 may be oriented at an angle to the first and second output drive shafts 422, 424 of transmission 420. Therefore, an angle gearing arrangement may be combined with gearing arrangements described in previous in-line embodiments to achieve a right angle input/output shaft arrangement (or other desired arrangement) while achieving the desired function of the system 400. The angle gearing arrangement may be any known gearing arrangement that enables system 400 to function as described herein and may include gear reduction capabilities. In some exemplary embodiments, the angle gearing arrangement may be disposed external to transmission 420. In other exemplary embodiments, transmission 420 may be adapted by one having ordinary skill in the art to include an angle gearing arrangement therein.

[0098] An exemplary layout for contra-rotating fan drive system 400 is shown in Figure 4a. A support member 430 may be coupled to a dry or evaporative cooling equipment unit 40. Motor 408 may be mounted in a substantially laterally offset position from transmission 420 and disposed externally to dry or evaporative cooling equipment unit 40, while transmission 420 may be mounted on support member 430 and disposed within the interior space of unit 40. For example, motor 408 may be mounted on an exterior surface of the enclosure 42 of unit 40. Connecting shaft 415 may extend from motor 408 to transmission 420 via an aperture in the air conduit 406. Transmission 420 may be mounted proximate air conduit 406 such that
output drive shafts 422, 424 can extend towards fans 402, 404, which may be disposed within air conduit 406. The specific layout and positioning of the components of system 400 may depend on the configuration of the particular dry or evaporative cooling equipment unit 40 with which system 400 may be used and may be adapted or modified as desired by one having ordinary skill in the art.

[0099] In certain situations, it may be advantageous to employ two motors when controlling the two fans. Again, for convenience of illustration, substantially similar functional elements are represented by similar numerals, wherein the duplicated components are designated with the trailing "a" or "b." Thus, a detailed description of the substantially similar elements may be omitted.

[00100] An exemplary layout for contra-rotating fan drive system 400b employing two motors is shown in Figure 4b. A first support member 430a may be coupled to a dry or evaporative cooling equipment unit 40. Motor 408a may be mounted in a substantially laterally offset position from transmission 420a and disposed externally to dry or evaporative cooling equipment unit 40, while transmission 420a may be mounted on support member 430a and disposed within the interior space of unit 40. For example, motor 408a may be mounted on an exterior surface of the enclosure 42 of unit 40. Connecting shaft 415 may extend from motor 408a to transmission 420a via an aperture in the air conduit 406. Transmission 420a may be mounted proximate air conduit 406a such that output drive shaft 424 can extend towards fan 404, which may be disposed within air conduit 406. Alternatively, as illustrated and described with regard to Figure 2a, either, or both, of transmissions 420a, 420b may be integral with a fan hub (see second transmission 250, Figure 1a).

[00101] Similarly, a second support member 430b may be coupled to a dry or evaporative cooling equipment unit 40. Motor 408b may be mounted in a substantially laterally offset position from transmission 420b and disposed externally to dry or evaporative cooling equipment unit 40, while transmission 420b may be mounted on support member 430b and disposed within the interior space of unit 40. For example, motor 408b may be mounted on an exterior surface or bracket. Due to the close proximity of the motor 408b to transmission 420b, a connecting shaft may be unnecessary. Rather, the same end goal may be accomplished using only the couplings 411, which can function as a very short connecting shaft. The couplings 411 may
further comprise an elastomer-housed inside for vibration dampening and act as a designed failure point, should the fan drive lockup suddenly, to prevent the motor from being damaged or destroyed. Transmission 420b may be mounted proximate air conduit 406b such that output drive shaft 422 can extend towards fan 402, which may be disposed within air conduit 406.

[00102] The specific layout and positioning of the components of system 400b may depend on the configuration of the particular dry or evaporative cooling equipment unit 40 with which system 400b may be used and may be adapted or modified as desired by one having ordinary skill in the art.

[00103] Figure 5a shows a fifth exemplary embodiment of a contra-rotating fan drive system 500 for dry or evaporative cooling equipment. For convenience of illustration, substantially similar functional elements to those in the fourth exemplary embodiment are represented by similar numerals, with the leading digit incremented to 5. Thus, a detailed description of the substantially similar elements may be omitted. The fifth exemplary embodiment has substantially similar structure and functionality to the fourth exemplary embodiment, except for the features described below.

[00104] In the fifth exemplary embodiment, motor 508 may drive a drive shaft 510, which may be coupled to an input shaft 518 of a transmission 520 via a coupling 511. Couplings 511 may be rigid couplings or may be flexible couplings. A suitable type of coupling may be chosen for a particular application by one having ordinary skill in the art. The drive shaft 510 may be oriented at an angle to the output drive shafts 522, 524 of transmission 520. Therefore, an angle gearing arrangement may be provided, substantially as described in the exemplary embodiment of system 400. In certain embodiments, a connecting shaft may be unnecessary. Rather, the same end goal may be accomplished using only the couplings 511, which can function as a very short connecting shaft. The couplings 511 may further comprise an elastomer-housed inside for vibration dampening and act as a designed failure point, should the fan drive lockup suddenly, to prevent the motor from being damaged or destroyed.

[00105] An exemplary layout for contra-rotating fan drive system 500 is shown in Figure 5a. A support member 530 may be coupled to a dry or evaporative cooling equipment unit 50. Motor 508 may be mounted in a substantially laterally offset position from transmission 520.
Transmission 520 may be mounted proximate air conduit 506 such that output drive shafts 522, 524 can extend towards fans 502, 504, which may be disposed within air conduit 506. Alternatively, as illustrated and described with regard to Figure 2a, transmission 520 may be integral with a fan hub (see second transmission 250, Figure 1a). In the exemplary embodiment, support member 530, as well as motor 508 and transmission 520, may be mounted within the interior space of the dry or evaporative cooling equipment unit 50. The specific layout and positioning of the components of system 500 may depend on the configuration of the particular dry or evaporative cooling equipment unit 50 with which system 500 may be used and may be adapted or modified as desired by one having ordinary skill in the art.

[00106] In certain situations, it may be advantageous to employ two motors when controlling the two fans. Again, for convenience of illustration, substantially similar functional elements are represented by similar numerals, wherein the duplicated components are designated with the trailing "a" or "b." Thus, a detailed description of the substantially similar elements may be omitted.

[00107] An exemplary layout for contra-rotating fan drive system 500b employing two motors is shown in Figure 5b. A first support member 530a may be coupled to a dry or evaporative cooling equipment unit 50. Motor 508a may be mounted in a substantially laterally offset position from transmission 520a and disposed within dry or evaporative cooling equipment unit 50, each of which may be mounted on support member 530a and disposed within the interior space of unit 50. Alternatively, as illustrated and described with regard to Figure 2a, either, or both, of transmissions 520a, 520b may be integral with a fan hub (see second transmission 250, Figure 1a).

[00108] Connecting shaft 515 may extend from motor 508a to transmission 520a via an aperture in the air conduit 506. Transmission 520a may be mounted proximate air conduit 506a such that output drive shaft 524 can extend towards fan 504, which may be disposed within air conduit 506. Similarly, a second support member 530b may be coupled to a dry or evaporative cooling equipment unit 50. Motor 508b may be mounted in a substantially laterally offset position from transmission 520b and disposed within air conduit 506 on support member 530b. Due to the close proximity of the motor 508b to transmission 520b, a connecting shaft may be unnecessary. Rather, the same end goal may be accomplished using only the couplings 511.
which can function as a very short connecting shaft. The couplings 511 may further comprise an elastomer-housed inside for vibration dampening and act as a designed failure point, should the fan drive lockup suddenly, to prevent the motor from being damaged or destroyed.

[00109] In this embodiment, first support member 530a, as well as motor 508a and transmission 520a, may be mounted within the interior space of the dry or evaporative cooling equipment unit 50, while second support member 530b, as well as motor 508b and/or transmission 520a, may be mounted within the interior space of the air conduit 506. For example, the motor 508b may be external to the air conduit 506. The specific layout and positioning of the components of system 500 may depend on the configuration of the particular dry or evaporative cooling equipment unit 50 with which system 500b may be used and may be adapted or modified as desired by one having ordinary skill in the art.

[00110] Figure 6a shows a sixth exemplary embodiment of a contra-rotating fan drive system 600 for dry or evaporative cooling equipment. For convenience of illustration, substantially similar functional elements to those in the fifth exemplary embodiment are represented by similar numerals, with the leading digit incremented to 6. Thus, a detailed description of the substantially similar elements may be omitted. The sixth exemplary embodiment has substantially similar structure and functionality to the fifth exemplary embodiment, except for the features described below.

[00111] In the sixth exemplary embodiment, motor 608 may drive a drive shaft 610, which may be coupled to a connecting shaft 615 via a first coupling 611. Connecting shaft 615 may in turn be coupled to an input shaft 618 of a dual output transmission 660 via a second coupling 611. Couplings 611 may be rigid couplings or may be flexible couplings. A suitable type of coupling may be chosen for a particular application by one having ordinary skill in the art. In other exemplary embodiments, connecting shaft 615 may be omitted and drive shaft 610 may be coupled to input shaft 618 via a rigid or flexible coupling 611. In certain embodiments, a dual output motor may be used in place of the dual output transmission 660 of Figure 6a.

[00112] Dual output transmission 660 may be disposed in between first fan 602 and second fan 604. A first output drive shaft 662 may extend to, and be rigidly coupled to, first fan 602;
while a second output drive shaft 664 may extend to, and be rigidly coupled to, second fan 604. Furthermore, input shaft 618 may be oriented at an angle to the output drive shafts 662, 664 of dual output transmission 660. Dual output transmission 660 can therefore include a gearing arrangement for transferring power from input shaft 618 to output drive shafts 662, 664. An exemplary gearing arrangement is shown in Figure 6b. For example, the gearing arrangement may include an input gear 666 carried by input shaft 618, a first output gear 668a carried by first output drive shaft 662 and engaged with the input gear and a second output gear 668b carried by second output drive shaft 664 and engaged with the input gear. The input and output gears may be bevel gears and may have differing ratios. Dual output transmission 660 can thus drive output drive shaft 662 at a different speed than, and in a direction counter to, output drive shaft 664. However, any other configuration for dual output transmission 660 that enables system 600 to function as described herein may be contemplated and provided by one having ordinary skill in the art.

[00113] An exemplary layout for contra-rotating fan drive system 600 is shown in Figure 6a. A support member 630 may be coupled to a dry or evaporative cooling equipment unit 60 and disposed within the interior space thereof. Fans 602, 604 may be disposed within air conduit 606 and dual output transmission 660 may be mounted within air conduit 606 between fans 602, 604. The fan and transmission assembly may be supported on support member 630 by second shaft 664, which may be coupled to a turntable 634. Turntable 634 may include a fixed portion coupled to support member 630 and a rotating portion to which second shaft 664 may be coupled. The rotating portion may be rotatably coupled to the fixed portion of turntable 634. Bearings, rollers or any other friction reducing members may be provided to facilitate the rotatable coupling between the rotating portion and the fixed portion of turntable 634.

[00114] Motor 608 may be mounted in a substantially laterally offset position from dual output transmission 660 and disposed externally to dry or evaporative cooling equipment unit 60. For example, motor 608 may be mounted on an exterior surface of the enclosure 62 of unit 60. A motor mount 636 may be provided so as to position motor 608 relative to dual output transmission 660 so as to facilitate the coupling between motor 608 and dual output transmission 660. Connecting shaft 615 may extend from motor 608 to dual output transmission 660 via an aperture in the enclosure 62. The specific layout and positioning of the
components of system 600 may depend on the configuration of the particular dry or evaporative cooling equipment unit 60 with which system 600 may be used and may be adapted or modified as desired by one having ordinary skill in the art.

[00115] In certain situations, it may be advantageous to employ two motors when controlling the two fans. Again, for convenience of illustration, substantially similar functional elements are represented by similar numerals, wherein the duplicated components are designated with the trailing "a" or "b." Thus, a detailed description of the substantially similar elements may be omitted.

[00116] An exemplary layout for contra-rotating fan drive system 600b is shown in Figure 6b. A first support member 630a may be coupled to a dry or evaporative cooling equipment unit 60 and disposed within the interior space thereof. Fans 602, 604 may be disposed within air conduit 606, a first dual output transmission 660a may be mounted within air conduit 606 between fans 602, 604 and second dual output transmission 660b may be mounted atop of fan 602.

[00117] The fan and transmission assembly may be supported on support member 630 by second shaft 664, which may be coupled to a first turntable 634a. First turntable 634a may include a fixed portion coupled to support member 630 and a rotating portion to which second shaft 664a may be coupled. Similarly, second turntable 634b may include a fixed portion coupled to first dual output transmission 660a and a rotating portion to which second shaft 664 may be coupled. The rotating portion may be rotatably coupled to the fixed portion of turntables 634a, 634b. Bearings, rollers, or any other friction reducing members may be provided to facilitate the rotatable coupling between the rotating portion and the fixed portion of turntable 634.

[00118] Motor 608a may be mounted in a substantially laterally offset position from dual output transmission 660a and disposed externally to dry or evaporative cooling equipment unit 60. Motor 608b may be similarly mounted in a substantially laterally offset position from dual output transmission 660b and disposed externally atop motor 608a. For example, motor 608a may be mounted on an exterior surface of the enclosure 62 of unit 60. A first motor mount 636a may be provided so as to position motor 608a relative to dual output
transmission 660a so as to facilitate the coupling between motor 608a and dual output transmission 660a. A second motor mount 636b may be provided so as to position motor 608b relative to dual output transmission 660ab so as to facilitate the coupling between motor 608b and dual output transmission 660b.

[00119] Connecting shaft 615a may extend from motor 608a to dual output transmission 660a via a first aperture in air conduit 606. Similarly, connecting shaft 615b may extend from motor 608b to dual output transmission 660b via a second aperture in air conduit 606. The specific layout and positioning of the components of system 600a may depend on the configuration of the particular dry or evaporative cooling equipment unit 60 with which system 600a may be used and may be adapted or modified as desired by one having ordinary skill in the art.

[00120] As described with regard to Figures 1 through 6, the contra-rotating fan drive systems may be employed with dry or evaporative cooling equipment. Examples of such dry cooling equipment include air-cooled heat exchangers. Indeed, an air-cooled heat exchange refers to a pressure vessel that cools a circulating fluid within finned tubes by forcing ambient air over the exterior of the tubes. Air-cooled heat exchange is a "green" solution as compared to cooling towers and shell and tube heat exchangers because they do not require an auxiliary water supply (water lost due to drift and evaporation, plus no water treatment chemicals are required).

[00121] Figures 7a and 7b illustrate exemplary air-cooled heat exchangers. An air-cooled heat exchanger generally comprises, one or more tube bundles 714 (e.g., bundles of heat transfer surface), an air-moving device (e.g., a fan, blower, or stack), a plenum 708 between the one or more tube bundles 714 and the first and second fans 702, 704 and a support structure high enough to support the various components while allowing air to enter beneath the air-cooled heat exchanger at a reasonable rate. The plenum 708 may be an enclosure that provides for the smooth flow of air between the first and second fans 702, 704 and one or more tube bundles 714.

[00122] The support structure may comprise a support member 724, fan ring 706, column support 718, and inlet bell 720. Here, the air-moving device may be a contra-rotating fan drive system as discussed with regard to Figure 2a. That is, the contra-rotating fan drive system may comprising a first fan 702, a second fan 704, and a drive assembly comprising a motor 716.
coupled to a transmission 722, which mechanically rotates the first and second fans 702, 704. Indeed, motor 716 and transmission 722 may be provided as an integrated unit and may be mounted on support member 724. The contra-rotating fan drive system may comprise a variable-pitch fan hub for further increased temperature control and power savings.

[00123] The air-cooled heat exchanger may further comprise one or more headers and/or fan maintenance walkways with ladders to grade and louvers for process outlet temperature control. The air-cooled heat exchanger may further comprise recirculation ducts and chambers for protection against freezing or solidification of high-pour point fluids in cold weather.

[00124] A tube bundle 714 generally refers to an assembly of tubes, headers, side frames, and tube supports. Usually the tube surface exposed to the passage of air has extended surface area in the form of fins to compensate for the low heat transfer rate of air at atmospheric pressure and at a low enough velocity for reasonable fan power consumption. The tube bundle 714 may further comprise, operatively coupled thereto, a nozzle 710 and header 712. A plenum 708 may be configured between the one or more tube bundles 714 and the first and second fans 702, 704.

[00125] Figure 7a illustrates an air-cooled heat exchanger arrangement 700a that or pulls it across the bundles, which is generally referred to as an induced-draft arrangement, while Figure 7b illustrates an air-cooled heat exchanger arrangement 700b that forces the air across the bundles, which is generally refer to as a forced-draft arrangement. As illustrated, the plenum 708 may be either box type (Figure 7a) or slope-sided type (Figure 7b). The slope-sided type typically gives an increased distribution of air over the bundles and is commonly used with induced-draft arrangements because hanging a machinery mount from a slope-sided, forced-draft plenum can present structural difficulties.

[00126] Generally speaking, advantages of an induced-draft arrangement typically include: (1) better distribution of air across the bundle; (2) less possibility of hot, effluent air recirculating into the intake — that is, the hot air is discharged upward at approximately 2.5 times the intake velocity, or about 1,500 feet per minute; (3) better process control and stability because the plenum covers 60% of the bundle face area, reducing the effects of sun, rain, and hail; and (4) increased capacity in the fan-off or fan-failure condition, since the natural draft stack effect is much greater. Advantages of a forced-draft arrangement, on the other hand, typically include:
possibly lower horsepower requirements if the effluent air is very hot (horsepower varies inversely with the absolute temperature); (2) better accessibility of fans and upper bearings for maintenance; (3) better accessibility of bundles for replacement; and (4) accommodates higher process inlet temperatures. Table 2 provides exemplary target design parameters for an exemplary air-cooled heat exchanger ("ACHE").

<table>
<thead>
<tr>
<th>Description</th>
<th>English</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube Material (Includes Headers)</td>
<td>Steel</td>
<td></td>
</tr>
<tr>
<td>Tube Length</td>
<td>32.0 Feet</td>
<td>9.75 Meters</td>
</tr>
<tr>
<td>Tube Outside Diameter</td>
<td>1.00 Inch</td>
<td>25.4mm</td>
</tr>
<tr>
<td>Tube Thickness (12 BWG)</td>
<td>0.110 Inches</td>
<td>2.79 mm</td>
</tr>
<tr>
<td>Fin Material</td>
<td>Aluminum</td>
<td></td>
</tr>
<tr>
<td>Fin Height</td>
<td>5/8 Inch</td>
<td>15.9 mm</td>
</tr>
<tr>
<td>Fin Spacing</td>
<td>10 Fins/Inch</td>
<td>0.40 Fins/mm</td>
</tr>
<tr>
<td>Fin Type</td>
<td>Extruded</td>
<td></td>
</tr>
<tr>
<td>Number of Tube Rows</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Number of Tubes/Row</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>Total Number of Tubes</td>
<td>316</td>
<td></td>
</tr>
<tr>
<td>Equilateral Tube Pitch</td>
<td>2.5 Inches</td>
<td>63.5mm</td>
</tr>
<tr>
<td>Bare Tube Surface Area</td>
<td>2,660 Sq. Ft.</td>
<td>247 Sq. M.</td>
</tr>
<tr>
<td>Fin Tube Surface Area</td>
<td>56,500 Sq. Ft.</td>
<td>5,250 Sq. M.</td>
</tr>
<tr>
<td>ACHE Length</td>
<td>32.0 Feet</td>
<td>9.75 Meters</td>
</tr>
<tr>
<td>ACHE Width</td>
<td>11.0 Feet</td>
<td>3.35 Meters</td>
</tr>
<tr>
<td>Component</td>
<td>Value</td>
<td>Value</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>ACHE weight</td>
<td>30,900 lbs</td>
<td>14,000 Kg</td>
</tr>
<tr>
<td>Motor Shaft Power</td>
<td>33.4 HP</td>
<td>24.9 KW</td>
</tr>
</tbody>
</table>

**Table 2**

While the air-cooled heat exchanger is illustrated with a contra-rotating fan drive system as shown and described with regard to Figure 2a, the contra-rotating fan drive systems of the other figures may be similarly employed. For example, a belt-driven assembly, such as the arrangement shown and described in Figures 1a and 1b, may be employed. Alternatively, the transmission 722 and motor 716 may be separate components, as shown and described in Figures 3a and 3b. Similarly, the contra-rotating fan drive system may employ a drive shaft between the motor 716 and transmission 722, as shown and described in Figures 4a, 4b, 5a, and 5b. Finally, the contra-rotating fan drive system may employ a dual output transmission, as shown and described in Figures 6a and 6b. Accordingly, a contra-rotating fan drive system for use in an air-cooled heat exchanger should not be limited to the specific arrangements illustrated in Figures 7a and 7b.

Turning now to the figures, Figure 8a illustrates another exemplary embodiment of a contra-rotating fan drive system 800a for WET/DRY cooling equipment using a contra-rotating transmission. As discussed with respect to the earlier configurations, the contra-rotating fan drive system 800a can include a first fan 802 and a second fan 804, which may be disposed in an air conduit 806. Air conduit 806 may be in fluid communication with the interior of the WET/DRY cooling equipment unit 820 and the exterior environment. As discussed with respect to the earlier configurations, the first and second fans 802, 804 and air conduit 806 may be provided in any location on a WET/DRY cooling equipment unit 820 that enables system 800a to function as described herein. In some exemplary embodiments, air conduit 806 may be an exhaust air conduit, for example, an induced-draft cooling unit. In other exemplary embodiments, air conduit 806 may be an intake air conduit, for example, a forced-draft cooling unit. Air conduit 806 may also function as a fan cowl for first and second fans 802, 804.

A motor 808 may be provided to drive the contra-rotating fan drive system 800a. Motor 808 may be an electric motor, or any motor known to one having ordinary skill in the art.
that enables system 800a to function as described herein, and may have any power rating suitable
for the particular application of system 800a. Motor 808 may drive an output shaft 810 on which
a drive pulley 812 is mounted. Drive pulley 812 may engage a belt 814, which can in turn engage
a driven pulley 816 that is coupled to an input shaft 1012 of transmission 900.

[00130] An operator may change the ratios of the fan drive system 800a by adjusting the
size (e.g., diameter) of drive pulley 812 and driven pulley 816. If the belt drive ratio is greater
than 1:1, then the fan drive system may be classified as a double reduction fan drive system and
the ratio for the belt drive would be multiplied by the transmission drive ratio to determine the
"final fan drive ratio"; conversely an overdriven reduction fan drive system is achieved when the
belt drive ratio is less than 1:1 (i.e., "overdrive").

[00131] Employing a contra-rotating transmission design enables the user to employ
alternative gear ratios that are simply not possible with co-rotating fan arrangements, that is,
without having to replace the transmission. Thus, the contra-rotating transmission design
provides a fully adjustable, final fan drive ratio in lieu of the existing fixed-transmission ratios
that are not field adjustable. Finally, while a belt 814 is illustrated, alternative means for driving
driven pulley 816 would include, for example, chain and sprockets, banded belts, cogged or
synchronous belts, power band, cable, and rope.

[00132] A support member 830 may be coupled to a WET/DRY cooling equipment
unit 820. Motor 808 and transmission 900 may be mounted on support member 830. Motor 808
may be mounted in a substantially, laterally offset position from transmission 900 and oriented
such that belt 814 can engage drive pulley 812 and driven pulley 816. Transmission 900 may be
mounted proximate air conduit 806 such that the drive shaft 1112 can extend upward such that
first and second fans 802, 804 are disposed within air conduit 806. A preferred embodiment may
use the transmission output shaft in lieu of a drive shaft 1112, while alternative embodiments
may have a female output sleeve on the transmission to accommodate a drive shaft.

[00133] Alternatively, as illustrated in the drive system 800b of Figures 8b through 8e, the
motor 808 may be coupled directly to the transmission 900, thereby obviating the need for belts
and pulleys. Figures 8c through 8e provide a detailed view of an exemplary contra-rotating fan
assembly arrangement for use with the system 800b. In yet another embodiment, the motor 808
may be integrated with the transmission 900 to form a singular assembly or component, which is
generally known as a "gearhead" motor in the industry.

[00134] Referring generally to the drive systems 800a, 800b of Figures 8a and 8b, transmission 900 may drive first fan 802 via drive shaft 1112. First fan 802 may be rigidly coupled to the drive shaft 1112, which may be a flanged drive shaft, while second fan 804 may be coupled to a fan-hub mounting plate within the transmission 900, which effectively functions as a fan hub when not employing a separate fan hub. The transmission 900 may further comprise a hollow fan driveshaft 902 that encloses the drive internals and serves as a protective, sealed drive case in conjunction with the fan-hub mounting plate.

[00135] Drive shaft 1112 and the hollow fan driveshaft 902 may be arranged coaxially with respect to each other such that drive shaft 1112 drives first fan 802 and the hollow fan driveshaft 902 drives second fan 804 by way of the fan-hub mounting plate. Transmission 900 may include gearing arrangements for rotating the drive shaft 1112 and the hollow fan driveshaft 902 at speeds different from the speed of the input shaft 1012. As discussed above, transmission 900 may also include internal drive component arrangements that are adapted to drive first fan 802 in a direction counter to that of second fan 804. Furthermore, transmission 900 may be adapted to drive first fan 802 at a different speed than second fan 804.

[00136] As is known in the art, power transmission systems, such as presently disclosed contra-rotating transmission 900, typically require lubrication. Normally, oil is introduced to the transmission 900 or transmission system to reduce wear on the various moving parts, while also serving the function of heat dispersion. A problem with oil is that, when two drive assemblies (e.g., upper assembly 1100 and lower assembly 1000) rotate in opposite directions, the oil is churned to form a foam emulsion. To combat this foam emulsion, a defoamer or an anti-foaming agent may be added; however, due to the high rotational speeds, such defoamers and anti-foaming agents are insufficient in contra-rotating transmissions. For example, contra-rotating transmissions currently used for propulsion in marine and aeronautical applications employ expensive and complicated oiling systems that require frequent maintenance. An oil-free, contra-rotating transmission, as disclosed herein, does not require such maintenance, nor does it require frequent overhauls.
Accordingly, the presently disclosed contra-rotating transmission 900 may be lubricated with grease in lieu of oil. Unlike oil, grease does not suffer the drawback of foaming. Indeed, a sealed case and grease lubrication allows for the possibility of a substantially, permanently lubricated transmission that requires no maintenance for the lifetime of the unit, while conventional gearboxes require regular oil changes. Therefore, according to at least one exemplary embodiment, an oil-free, contra-rotating transmission for evaporative cooling equipment is also disclosed. The oil-free, contra-rotating transmission disclosed herein can provide a compact, integrated arrangement for varying the rotational speed and rotational direction of first and second axial fans 802, 804.

There are a number of suitable types of grease that may be used in conjunction with the oil-free, contra-rotating transmission 900. For example, biodegradable, food-grade grease and solid lubricants may be used. This reduces the necessity for frequent maintenance of contra-rotating transmission 900, while also reducing the environmental impact of the contra-rotating transmission 900. Furthermore, the oil-free transmission is an environmentally friendly alternative to conventional gearboxes that require oil changes. Indeed, grease technology has advanced to the point that the development of this transmission as a permanent, lubricated sealed-case unit is feasible. Synthetic grease with an additive package suited for this transmission may be employed to repel water infiltration, dissipate heat, withstand wide temperature ranges, absorb shock loads, anti-seizing agent, etc. While a synthetic grease solution may not be as environmentally friendly as biodegradable grease, since it is permanently sealed in the case it would be environmentally friendly in that it never needs to be exposed to the outside environment, while eliminating the need for oil changes and the generation of waste oil over its lifetime. Permanent, lubricated, sealed ball bearings may be employed to work in conjunction with the specially formulated grease.

Figures 9a and 9b illustrate an exemplary embodiment of a contra-rotating transmission 900. Indeed, a contra-rotating transmission 900 may include an upper drive assembly 1100 and a lower drive assembly 1000. The lower drive assembly 1000 may be coupled with an input power source via a transmission input shaft 1012. The lower portion of the input shaft 1012 may be hollow and designed to receive the output shaft of a power source (e.g., an electric motor) and configured to transfer torque from the input power source to a pinwheel.
driver 1002 (e.g., a center-pinwheel driver), which may be operatively coupled to the solid upper portion of the input shaft 1012. The torque may then be transferred, via one or more pinwheels, to the upper drive assembly 1100. Torque from the input shaft 1012 may ultimately be used to rotate two contra-rotating fans 802, 804, which may be operatively coupled with the upper drive assembly 1100 and/or lower drive assembly 1000. For example the upper drive assembly 1100 may be configured to rotate a first fan 802 in a first direction (e.g., clockwise), while the lower drive assembly 1000 may be configured to rotate a second fan 804 in a second direction, which may be opposite the first direction (e.g., counter-clockwise). While not illustrated, as is known in the art, one or more thrust washers may be positioned throughout the transmission 900 at the various connection points to reduce any friction and/or to function as spacers. The thrust washers may be fabricated from less corrosive materials, such as brass or bronze.

[00140] While Figure 9a illustrates the contra-rotating transmission 900 with the hollow fan driveshaft 902 removed, as illustrated in Figure 9b, the hollow fan driveshaft 902 may serve as a protective casing and may be used to enclose the upper drive assembly 1100 and a lower drive assembly 1000 of the contra-rotating transmission 900 in embodiments that employ integrated drive assemblies such as illustrated in Figure 9a. For example, the hollow fan driveshaft 902 may be constructed by integrating one or more parts to form a hollow fan driveshaft that ultimately drives second fan 804. For example, the hollow fan driveshaft 902, or portion thereof, may be operatively coupled with the fan-hub mounting plate, or, as illustrated herein, the fan-hub mounting plate may also be integral with outer pinwheel receiver 1004. Thus, as illustrated, the components used to construct the hollow fan driveshaft 902 may include one or more pinwheel receivers 1004a. The hollow fan driveshaft 902 may be coupled at one end to a hollow driveshaft base 924 to form a sealed casing for housing upper drive assembly 1100 and lower drive assembly 1000. Moreover, as illustrated in Figure 9b, one or more plates 904, 906, 910 may be provided between the various components or assemblies to increase structural integrity of the transmission 900. The one or more plates 904, 906, 910 may be further configured to receive an end of one or more shafts (e.g., shaft 908) and/or sleeves (e.g., sleeve 1010) while permitting the shafts or sleeves to rotate as needed. Indeed, a stop plate 912 may be positioned at the end of each shaft to rotatably secure the distal ends of the one or more shafts and/or sleeves, thereby prohibiting unwanted movement in, or against, direction A.
The hollow fan driveshaft 902 also serves as a protective casing and may be further sealed to protect the components of upper drive assembly 1100 and the lower drive assembly 1000 from the elements (e.g., weather, dirt, oxidation, moisture infiltration or loss, etc.), thus preserving the lubricant (e.g., grease) inside for a greatly extended, useful lifespan. The hollow fan driveshaft 902, or components thereof, may be fabricated from, for example, steel (A36, 8018, 8045, etc.), alloy steel (4130, 4140, 8620, etc.), stainless steel (300 series, 400 series, 600 series, etc.), tool steel (01, A2, M4, etc.), titanium (grade 2, grade 5, alloy, etc.), aluminum (alloy 6061, alloy 2024, alloy 7075, etc.), cast iron, known metal alloys, powdered metals for sintering (e.g., 3D Printers) or a combination thereof. For example, the hollow fan driveshaft 902, or components thereof, may be fabricated from aluminum alloy 6061 and may be further subjected to additional metal treatments to alter the properties of the metal to meet a specific design parameter or need. For example, the metal may be heat treated with one or more of the following treatments: annealing, case hardening, precipitation, strengthening, tempering, quenching, etc. The metal may also be subjected to surface finishing treatments intended to alter the metal surface properties and appearance to meet specific design parameter or need such as, but not limited to, grinding, polishing, buffing, shot peening, media blasting, plating, anodizing, oxidizing, pickling, acid treating, etc. In certain embodiments, the components of the transmission 900 may be formed from recycled or recyclable materials such as aluminum, steel, iron, other or recycled metals alloys. However, one of skill in the art would understand that other materials may be employed to meet a particular need (e.g., corrosion resistance, weight limitations, strength requirements, etc.). Furthermore, the outer surface of the various components may have a weatherproof coating, chemical application, powder coating, bonded polymer, or similar treatment, and/or be made of or enclosed in a ceramic, plastic, any available non-corrosive material, or corrosion-resistant metal alloy such as aluminum, stainless steel, bronze, or titanium. Moreover, one of skill in the art would understand that two or more different materials may be used to fabricate the various case components.

Turning now to Figures 10a and 10b, a perspective view and top plan view of the lower drive assembly 1000 are illustrated, respectively, with the upper drive assembly 1100 removed. As illustrated, the lower drive assembly 1000 may comprise a center pinwheel driver 1002, a plurality of intermediate pinwheels 1006 and an outer pinwheel receiver 1004, which may be integrated with, or otherwise coupled to, the hollow fan driveshaft 902. Indeed,
the hollow fan driveshaft 902 and the outer pinwheel receiver 1004 may be formed as a single component. That is, the inner circumferential surface of the hollow fan driveshaft 902, or portion thereof, may comprise thereon a plurality of pinwheel receiver spacers 1004b, which define a plurality of gullets 1004a. For illustrative purposes, the upper pin support plate 1006a of each intermediate pinwheel 1006 has been removed to better depict the plurality of perpendicularly disposed rollers 1008.

[00143] The various power transmission components (e.g., the pinwheel driver 1002, intermediate pinwheels 1006, and outer pinwheel receiver 1004) may be fabricated from a metal alloy of suitable strength to meet the design loads. The metal alloy may be further subjected to one or more heat treatments and surface treatments to alter the metal physical properties, surface, and appearance to meet desired strength, hardness, abrasion resistance, appearance, corrosion resistance, shock resistance, surface smoothness, etc. However, one of skill in the art would understand that other materials may be employed to meet a particular need (e.g., corrosion resistance, weight limitations, strength requirements, etc.). For example, the outer surface of the various components may have a weatherproof coating, chemical application, powder coating, bonded polymer, or similar treatment, and/or be made of or enclosed in a ceramic, plastic, any available non-corrosive material, or corrosion-resistant metal alloy such as aluminum, stainless steel, bronze, or titanium. Moreover, one of skill in the art would understand that different materials may be used to fabricate the various power transmission components.

[00144] As illustrated, the outer pinwheel receiver 1004 and pinwheel driver 1002 may each comprise a plurality of gullets 1002a, 1004a (e.g., female components). Center pinwheel driver 1002 may further comprise a sleeve 1010 for receiving an end of the input shaft 1012. The sleeve 1010, to prevent slippage and/or rotation, may be sized and shaped to receive a correspondingly sized and shaped input shaft 1012. For example, as illustrated the end of the input shaft 1012 and/or sleeve 1010 may be a polygon (e.g., star-shaped, triangular, square, pentagonal, hexagon, etc.), oval, semicircle, asymmetrically-shaped, etc. In certain embodiments, sleeve 1010 may include a notch (keyway) that can be aligned with a corresponding notch (keyway) on the input shaft 1012, so as to create a space of the same shape and dimension as a piece of metal stock (key) to be inserted into the aligned notches (keyways) in order to fix the rotation of center pinwheel driver 1002 to the input shaft 1012. In fact, the various shafts, axles, and the like, or at
minimal, the ends thereof, may employ similar techniques to prevent slippage and/or rotation of the various pinwheels, pinwheel drivers, and pinwheel receivers. For example, the various shafts are illustrated as being hexagonal where coupled to the pinwheels, pinwheel drivers, and pinwheel receivers.

[00145] In other exemplary embodiments, center pinwheel driver 1002 may be coupled to the input shaft 1012 in any suitable manner. For example, the motor 808 may be integrated with the transmission 900 to form a combination motor/contra-rotating transmission apparatus. A combination apparatus could reduce on-site assembly time and reduce materials by omitting the need for coupling between the motor/transition.

[00146] As noted above, and as illustrated herein, one or more outer pinwheel receivers 1004 may be integrated with one or more components (e.g., pinwheel receiver spacers 1004b and hollow fan driveshaft base 924) as a component used to construct the hollow fan driveshaft 902. For example, outer pinwheel receiver 1004 can be coupled to hollow fan driveshaft 902, or portion thereof, that is coupled to a fan-hub mounting plate. To that end, outer pinwheel receiver 1004 transfers torque from pinwheels 1006 through the hollow fan driveshaft 902 of which it is integrated with, which in turn transfers torque to the fan-hub mounting plate that enables contra-rotating transmission 900 to function as described herein. To that end, outer pinwheel receiver 1004 as part of the hollow fan driveshaft 902 that ultimately drives the fan-hub mounting plate may include support coupling structures, which may be any coupling structure that enables the contra-rotating transmission 1000 to function as described herein. For example, coupling structures can be threaded bores that can receive a bolt or other threaded fastener. In certain embodiments, fan blades may be coupled (e.g., bolted) directly to fan-hub mounting plate, or hollow fan driveshaft 902, which effectively functions as a fan hub.

[00147] In the illustrated example, the pinwheel driver 1002 engages a first set of four intermediate pinwheels 1006, which are fixed in place via pinwheel drive shafts 908, but rotates their respective drive shafts about their axes in the opposite direction of rotation as that of the pinwheel driver 1002, while simultaneously engaging the hollow fan driveshaft 902 via the integrated outer pinwheel receiver 1004 rotating it in the same direction as the pinwheels 1006. That is, the four intermediate pinwheels 1006 simultaneously transfer and divide the torque from the pinwheel driver 1002 to the hollow fan driveshaft 902 via the outer pinwheel receiver 1004

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and the upper drive assembly via the pinwheel drive shafts 908. Indeed, pinwheel drive shaft 908 may be rotatably secured in place at its distal ends. Examples include, but are not limited to, the use of ball bearings, bushings, sleeves, blind holes with proper clearance, etc., each of which may be located and secured in the upper housing plate 904 and lower housing plate 906. While four intermediate pinwheels 1006, 1106, are illustrated throughout, one of skill in the art would understand that greater or fewer intermediate pinwheels 1006, 1106 may be used. For example, additional intermediate pinwheels may be used to increase robustness by providing additional engagement points. Alternatively, fewer intermediate pinwheels may be used to reduce weight and/or size, or to accommodate a particular casing shape.

[00148] Each intermediate pinwheel gear 1006 may comprise two or more circular pin support plates 1006a separated by a plurality of perpendicularly disposed pins 1008. The pins 1008 may be arranged along the outer circumferences of said two or more pin support plates 1006a and configured to receive and drive, therebetween, one or more pinwheel receiver spacers 1004b. Each pin 1008 may comprise inner pin 1008a and a hollow cylinder 1008b. Indeed, the hollow cylinder 1008b may be hollow as to provide a space for an inner pin 1008a such that it is rotationally arranged around said inner pin 1008a. Thus, in operation, the hollow cylinder 1008b can rotate around said pin 1008a, thereby greatly reducing friction between the pinwheels, pinwheel drivers, and pinwheel receivers.

[00149] While the pins 1008 are illustrated as the hollow cylinder 1008b that can rotate around a pin 1008a, other embodiments are possible. For example, solid pins without inner pins 1008a may be recessed into pin support plates 1006a with blind holes in pin support plates to provide proper clearance to allow pin to rotate in the blind hole. In another alternatively, both inner 1008a and hollow cylinder 1008b may be recessed into the pin support plates 1006a with the inner pin 1008a recessed further so as to allow the hollow cylinder 1008b to rotate around the inner 1008a. Finally, solid pins 1008 with no inner pins 1008a may be recessed into pin support plates with the pin fixed into a tight, blind hole with no clearance and unable to rotate.

[00150] While outer pinwheel receiver 1004 and pinwheel driver 1002 are illustrated and described as being female, with the intermediate pinwheels 1006a being male, the opposite arrangement may be employed. That is, the outer pinwheel receiver 1004 and/or pinwheel driver 1002 may be replaced with pinwheels of the same diameter and corresponding number of
pins as there are gullets and the intermediate pinwheels 1006 may be replaced with a pinwheel idler of the same diameter and corresponding number of gullets as there are pins.

[00151] Notably, the gearing may be multi-phased, or more specifically, as illustrated, dual-phased. That is, each drive component may comprise two or more offset layers of gullets 1002a, 1004a, and/or pins 1008, wherein the two or more layers are offset by rotating each layer by a predetermined number of degrees with respect to the preceding layer. For example, in the illustrated dual-phased arrangement, the outer pinwheel receiver 1004 and pinwheel driver 1002 may be fabricated with two offset, but otherwise identical, gullet profiles 1002a, 1004a separated by a gap or spacers 1004b. Similarly, each intermediate pinwheel 1006 may be fabricated from three pin support plates 1006a, having a layer of pins 1008 sandwiched between each pin support plate 1006a. As illustrated, a dual-phased offset pinwheel driver/receiver may be phased in a manner such that a gullet of the first layer aligns at the exact midpoint between the gullets of the second layer.

[00152] By offsetting two layers, the number of rollers 1008 and/or gullets 1002a, 1004a in a given wheel diameter can be effectively doubled. This increases the points of contact between the power transmission components within the transmission, allowing for a denser power distribution within the transmission. Correspondingly, in a tri-phased arrangement (i.e., three layers), the number of rollers 1008 and/or gullets 1002a, 1004a in a given wheel diameter can be effectively tripled, while it is quadrupled in a quad-phased arrangement (i.e., four layers). Thus, the greater the number of phases, the denser power distribution within the transmission.

[00153] A denser power distribution significantly lowers the power being transferred at each point of contact thus significantly increasing the capacity rating of the transmission. The increased power density also allows for the overall size of the transmission to decrease as compared to single-phased transmissions of same capacity. The denser power distribution within the transmission also allows for an increased ability in withstanding shock loads, which is one of the most common failure points of conventional transmissions and gearboxes. The presently disclosed pinwheel design provides the ability to withstand shock loads; however, by multi-phasing the pinwheel design, the shock load resistance is substantially increased further. For example, in a dual-phase arrangement, at no time during the 360-degree rotation of the input shaft 1012 is there a loss of engagement between the pinwheels and the pinwheel
drivers/receivers; in fact, the level of engagement is greater than that of a single-phase design across the entire 360-degree span of rotation.

[00154] An advantage of increasing pin engagement is its effect on backlash. That is, in this case, the amount of travel in degrees that the input shaft 1012 may be rotated in reverse direction before the output shaft 1112 (or hollow fan driveshaft 902) begins to rotate. This is commonly described as "slop" or "play" and it is the result of gaps present between the moving parts that engage inside the transmission. These gaps are present for an infinite multitude of reasons and, in most cases, are required for reasons such as lubrication allowance, thermal expansion allowance, jam prevention, etc. In fact, the utilization of multi-phased pinwheels in the contra-rotating transmission 900 virtually eliminates backlash due to the high number of pins engaged during all 360 degrees of input shaft 1012 rotation. This can facilitate greatly reducing or completely eliminating the likelihood of generating shock loads, in the event that the input shaft rotation were to be suddenly reversed while in motion. For example, "wind milling," a common problem for gear-driven WET/DRY cooling equipment with no anti-reversing measures, where the fans are being driven in one direction by an outside force such as wind and then the power input to the transmission is turned on, suddenly reversing the rotation of the fans. In some exemplary embodiments, contra-rotating transmission 900 may further include a locking mechanism, so as to allow a particular fan to spin in one direction while impeding the fan from spinning in the reverse direction to prevent condition such as "wind milling."

[00155] Multi-phasing also serves to transfer power from the motor in a more diffuse way by not concentrating the loads on the pins that are engaged. Continuing with the prior example, when four intermediate pinwheels 1006 are employed in a dual-phase arrangement, the power is evenly distributed across the four pinwheel engagement points, times two layers, because substantial pin engagement is achieved through the entire 360 degrees of rotation (i.e., irrespective of the rotational position of the gear system). Thus, when, for example, 1 horsepower (HP) is applied at the input shaft, each pinwheel is required to transfer 1/4 HP through the pins that are in various stages of engagement times two layers. Conversely, each pinwheel in a single-layer system would be required to transfer 1/4 HP utilizing half as many pins in various stages of engagement, thereby increasing the force applied to each individual pin, increasing abrasion force (wear and tear), increasing heat generation, and lowering the overall
capacity of the pinwheel itself. Finally, a dual-phase arrangement further enables operators to construct a more compact unit while yielding the same efficiency because the input power can be more densely distributed through the gearing system.

[00156] The number of gullets 1002a, 1004a and pins 1008 may be adjusted to achieve a particular gearing ratio as desired by one having ordinary skill in the art. The spacing from center to center of the pins and gullets is known to those skilled in the arts as "pitch." As is generally known in the art, the pitch is a value that has direct implications to pinwheel engagement, transmission longevity, overall transmission backlash, etc. Final drive ratio (i.e., the number of revolutions of transmission input shaft: one revolution of pinwheel output shaft) is determined by dividing the number of gullets of the pinwheel receiver by the number of pins in a pinwheel for the upper drive assembly 1100. For the lower drive assembly 1000, the final drive ratio is determined by dividing the number of gullets of the pinwheel receiver by the number of pins in a pinwheel and then subtracting one revolution.

[00157] Moreover, while a dual-phase arrangement is illustrated throughout, one of skill in the art would understand that greater or fewer phases, or layers, may be used. Alternatively, a single layer may be used to reduce cost, weight, and/or size. For example, additional layers may be added to increase robustness by providing additional engagement points. However, the phase will be shifted to accommodate the additional layer. Indeed, the following equation may be used to yield the degree of rotation each subsequent layer is to be rotated from previous layer:

\[
\text{Degree Of Rotation Each Subsequent Layer} = \left( \frac{360 \text{ degree}}{\text{No. Layers}} \right) \left( \frac{\text{No. Pins / Gullets}}{} \right)
\]

[00158] For example, referring to the system illustrated in Figure 10a, the second layer of the intermediate pinwheel 1006 and the pinwheel driver 1002 is rotated by 11.25 degrees because each dual phased with 16 pins or gullets.

\[
11.25 \text{ Degrees} = \left( \frac{360 \text{ degree}}{2 \text{ Layers}} \right) \left( \frac{1}{16} \right)
\]

[00159] Conversely, the second layer of the outer pinwheel receiver 1004 is rotated by 3.75 degrees because it is dual phased with 48 gullets.
Turning now to Figures 11a and 11b, a perspective view and top plan view of the upper drive assembly 1100 is illustrated atop, and operatively couple with, the lower drive assembly 1000. For convenience of illustration, substantially similar functional elements to those in the lower drive assembly 1000 are represented by similar numerals, with the leading digit incremented to 4. As illustrated, the upper drive assembly 1100 may comprise a center pinwheel receiver 1102, and a plurality of intermediate pinwheels 1106. For illustrative purposes, the upper pin support plate 1106a of each intermediate pinwheel 1106 has been removed to better show the plurality of perpendicularly disposed pins 1008.

As illustrated in, for example, Figures 9a and 9b, the center pinwheel receiver 1102 may be integrated with output shaft 1112, which may be configured to rotate opposite hollow fan driveshaft 902. The output shaft 1112 may be configured to receive a fan hub. For example, the output shaft 1112 may be flanged, male, keyed male, female, female keyed, etc. Alternatively, the fan hub may be integrated with to the output shaft 1112 such that fan blades can be fixed directly to output shaft 1112 in manner that the output shaft 1112 functions as a fan hub.

As discussed with respect to the lower drive assembly 1000, the drive assembly may be multi-phased, or more specifically, as illustrated, dual-phased. Similarly, as discussed above, the number of gullets 1102b, 1104b and pins 1008 may be adjusted to achieve a particular gearing ratio as desired by one having ordinary skill in the art.

The operation of the contra-rotating transmission 900 will now be described. All rotational directions (e.g., clockwise and counter-clockwise) will be described as viewed in direction A. That is, as viewed from the top (e.g., as illustrated in Figures 10b and 11b). In operation, torque may be applied to the input shaft 1012 in the clockwise direction via a motor 808. Torque is then transferred from the input shaft 1012 to the center pinwheel driver 1002, which similarly rotates in the clockwise direction. In the illustrated example, the center pinwheel driver 1002 engages a first set of four intermediate pinwheels 1006, which are fixed in place via pinwheel drive shafts 908, but rotate their respective drive shafts 908 about their axes in the counter-clockwise direction, while simultaneously engaging the hollow fan driveshaft 902 via the integrated outer pinwheel receiver 1004 rotating it counter-clockwise. As
discussed above, a second fan 904 may be coupled, directly or indirectly, to the outer pinwheel receiver 1004 via hollow output shaft 902 and/or fan-hub mounting plate such that the second fan 804 also rotates in the counter-clockwise direction. For example, fan blades may be coupled to the hollow output shaft 902 or the fan-hub mounting plate.

[00164] In addition to driving the outer pinwheel receiver 1004, the first set of four intermediate pinwheels 1006 drive a second set of four intermediate pinwheels 1106 via their respective drive shafts 908, which extend from the lower assembly 1000 to the upper assembly 1100, as best illustrated in Figures 9a and 9b. For example, the drive shafts 908 to which the first set of four intermediate pinwheels 1006 are attached may be extended to also serve as the drive shafts 908 for the second set of four intermediate pinwheels 1106 attached in the same or similar manner. As a result, first and second set of four intermediate pinwheels 1006, 1106 rotate coaxially in the counter-clockwise direction at the same rotations per minute (RPM).

[00165] While the same RPM is output to both sets of pinwheels 1006, 1106, differing number of pins 1008 and/or pitch diameters may be used to change the speed of subsequent gearing. For example, the first set intermediate pinwheels 1006 may employ pinwheels having 16 pins 1008 while the second set intermediate pinwheels 1106 may employ pinwheels having 8 pins 1008. As a result, each set of pinwheels 1006, 1106 can drive their respective pinwheel receivers 1004, 1102 at different RPMs while rotating at same RPM via the common drive shafts 908.

[00166] The second set of four intermediate pinwheels 1106 engage the center pinwheel receiver 1102, which rotates in the clockwise direction. The center pinwheel receiver 1102 may be operatively coupled and/or fully integrated with a fan output shaft 1112, which may then be configured to drive a first fan 802 in the clockwise direction. As a result, the second fan 804 rotates in the counter-clockwise direction while the first fan 802 rotates in the clockwise direction.

[00167] For a dual-phased arrangement transmission 900 operating fans, which can range from 40 to 156 inches in diameter (3.5 - 14 feet) with 20 HP at the input shaft 1012, the pinwheel receiver may be approximately 7 inches in overall diameter, the intermediate pinwheels 1006 and the center pinwheel driver 1002 may be approximately 2 inches in overall diameter.
Upper pinwheels may be, for example, approximately 1 inch in overall diameter while the upper center pinwheel receiver may be approximately 3 inches in overall diameter. However, as one of skill in the art would recognize, these values may be adjusted to meet a particular need or durability.

[00168] Each layer of the dual-phased arrangement may be, for example, 5/16 inches thick. Though, when a single-phased arrangement is employed, the system may be limited to 10 HP at the input shaft to not exceed capacity ratings based on the strength of the materials being used. That is, the dual-phased arrangement allows for twice the power transmission capacity for the contra-rotating transmission 900.

[00169] The presently disclosed contra-rotating transmission 900 may be employed in cooling towers having horsepower ranges typically from 1 to 250 HP. For example, the presently disclosed contra-rotating transmission may be employed in more traditional, packaged cooling towers which have typical motor ranges from 1 to 100 HP. More recently, 100 HP motors have been employed in a desperate attempt to generate more capacity. However, using the present system and transmission, only a 60 HP motor is required to generate the same airflow at the same static pressure.

[00170] Similarly, they may be employed in field-erected cooling towers that range typically from 50 HP to 250 HP and up. Generally speaking, the presently disclosed contra-rotating transmission may be used to drive fans from, for example, 40 inches up to 40 feet in diameter with cubic foot per minute (CFM) typically in excess of 10,000 CFM. Indeed, in addition to the systems 800a, 800b of Figure 8a and 8b, the presently disclosed contra-rotating transmission 900 may be used in conjunction with fan drive systems such as those described in commonly owned PCT application number PCT/US2013/070430, which was filed on November 15, 2013, and parent U.S. Patent Serial No. 13/678,095, filed on November 15, 2012, both of which are hereby incorporated by reference in their entirety. Furthermore, the contra-rotating transmission 900 should not be limited to use with HVACR systems and devices. On the contrary, such a contra-rotating transmission 900 may drive other systems or devices where contra-rotating of fans, impellers, fans, gears, mechanical linkages (e.g., to another device or system), and/or other rotating components are desired, including, without limitation, construction machinery, manufacturing machinery, wind tunnels, and propulsion systems, such
as those associated with marine vessels (e.g., in connection with bow thrusters), aerial vehicles,
and land vehicles.

[00171] The embodiments described herein can provide several advantages over conventional, single-stage fan systems for dry and evaporative cooling equipment. First, due to the increased efficiency inherent to a contra-rotating fan arrangement, lower rotational speeds are required for the fans of the contra-rotating systems disclosed herein. Consequently, utilizing any of the embodiments disclosed herein in a cooling tower can result in decreased noise levels and decreased energy requirements when compared with single-stage fan systems. Furthermore, the embodiments disclosed herein can result in reduced vibration transmission to the evaporative cooling equipment unit due to the cancelling out of the gyroscopic forces of the fans. The reduced vibration can be beneficial for meeting updated building codes that have strict vibration requirements and can also facilitate increased life of the mechanical components of the fan drive systems.

[00172] Additionally, the dual axial fans of the embodiments disclosed herein can generate higher static pressure within the evaporative cooling equipment unit than can be generated by conventional single-stage fan units, which can present several advantages. The higher static pressure can result in an increased thermal performance of the dry and evaporative cooling equipment unit with which the contra-rotating fan system is used. As a result of this higher static pressure, air may be drawn from portions of the cooling unit that are typically known as low performance areas, such as the corners of the unit or other areas with suboptimal airflow when single-stage fans are used. Additionally, the higher static pressure can shrink the air envelope requirement for a cooling unit; thereby facilitating improved flexibility for the layout of the cooling equipment and air-cooled heat exchangers. Furthermore, as a consequence of the increased static pressure, sound attenuation devices may be used in conjunction with the embodiments disclosed herein, as the pressure drops created by the sound attenuation devices are mitigated by the increased pressure generated by the dual axial fans, allowing the evaporative cooling equipment unit or air-cooled heat exchanger to maintain satisfactory thermal performance. Additional advantages of the embodiments disclosed herein include the reduction of the necessity to de-ice the fan blades, as the contra-rotating action of the two axial fans inhibits ice from forming during operation.
The foregoing description and accompanying figures illustrate the principles, preferred embodiments, and modes of operation of the invention. However, the invention should not be construed as being limited to the particular embodiments discussed above. Additional variations of the embodiments discussed above will be appreciated by those skilled in the art.

Therefore, the above-described embodiments should be regarded as illustrative rather than restrictive. Accordingly, it should be appreciated that variations to those embodiments can be made by those skilled in the art without departing from the scope of the invention as defined by the following claims.
What is claimed is:

Claim 1. A contra-rotating propulsion system comprising:

a first rotating component;
a second rotating component arranged coaxially with the first rotating component;

and

a transmission, the transmission comprising (a) a lower drive unit having a first drive assembly with a first predetermined drive ratio and (b) an upper drive unit having a second drive assembly with a second predetermined drive ratio,

wherein the first drive assembly comprises a center pinwheel driver, an outer pinwheel receiver, and a plurality of intermediate pinwheels,

wherein the lower drive unit is operatively coupled to a motor, the lower drive unit being configured to

(i) drive the upper drive unit, and
(ii) rotate the first rotating component at a first speed of rotation in a first direction,

wherein the upper drive unit is configured to rotate the second rotating component at a second speed of rotation in a second direction,

wherein the direction of rotation of the first direction is opposite to the direction of rotation of the second direction.

Claim 2. The contra-rotating propulsion system of claim 1, wherein the first speed of rotation is different from the second speed of rotation.

Claim 3. The contra-rotating propulsion system of claim 1, wherein the second speed of rotation is substantially equal to the first speed of rotation.

Claim 4. The contra-rotating propulsion system of claim 1, wherein the second drive assembly comprises a center pinwheel receiver, and a second plurality of intermediate pinwheels.
Claim 5. The contra-rotating propulsion system of claim 4, wherein each of said first plurality of intermediate pinwheels is operatively coupled to a corresponding one of said second plurality of intermediate pinwheels.

Claim 6. A contra-rotating transmission, comprising:

a lower drive unit, said lower drive unit comprising a center pinwheel driver, an outer pinwheel receiver, and a first plurality of intermediate pinwheels; and

an upper drive unit, wherein the lower drive unit is operatively coupled to a motor and is configured to

(i) drive the upper drive unit, and
(ii) rotate a first rotating component in a first direction, wherein the upper drive unit is configured to rotate a second rotating component in a second direction, wherein the direction of rotation of the first direction is opposite to the direction of rotation of the second direction.

Claim 7. The contra-rotating transmission of claim 6, wherein the upper drive unit comprises a center pinwheel receiver, and a second plurality of intermediate pinwheels.

Claim 8. The contra-rotating transmission of claim 7, wherein each of said first plurality of intermediate pinwheels is operatively coupled to a corresponding one of said second plurality of intermediate pinwheels.

Claim 9. The contra-rotating transmission of claim 7, wherein said first plurality of intermediate pinwheels and said second plurality of intermediate pinwheels are configured to rotate at the same rotation per minute.

Claim 10. The contra-rotating transmission of claim 6, wherein the center pinwheel driver, the outer pinwheel receiver, and the first plurality of intermediate pinwheels are in a dual-phased arrangement.
Claim 11. The contra-rotating transmission of claim 10, wherein each phase of said dual-phased arrangement is rotated by a predetermined number of degrees.

Claim 12. The contra-rotating transmission of claim 7, wherein the center pinwheel receiver and the second plurality of intermediate pinwheels are in a dual-phased arrangement.

Claim 13. The contra-rotating transmission of claim 12, wherein each phase of said dual-phased arrangement is rotated by a predetermined number of degrees.

Claim 14. The contra-rotating transmission of claim 6, wherein the speed of rotation of the first rotating component is different from the speed of rotation of the second rotating component.

Claim 15. The contra-rotating transmission of claim 6, wherein said first rotating component and said second rotating component are arranged coaxially with respect to one another.

Claim 16. The contra-rotating transmission of claim 7, wherein each of said first and second plurality of intermediate pinwheels comprises two or more disks separated by a plurality of perpendicularly disposed rollers.

Claim 17. The contra-rotating transmission of claim 16, wherein each of said plurality of perpendicularly disposed rollers comprises an inner pin and a hollow cylinder rotationally arranged around said inner pin.

Claim 18. The contra-rotating transmission of claim 6, wherein the contra-rotating transmission is oil-free.

Claim 19. A contra-rotating propulsion system, comprising:

a first rotating component;
a second rotating component arranged coaxially with the first rotating component; and

a transmission, the transmission comprising a lower drive unit and an upper drive unit,
wherein the lower drive unit comprises a center pinwheel driver, an outer pinwheel receiver, and a plurality of intermediate pinwheels,

wherein the lower drive unit is operatively coupled to a motor and is configured to

(i) drive the upper drive unit via said plurality of intermediate pinwheels, and

(ii) rotate the first rotating component in a first direction,

wherein the upper drive unit is configured to rotate the second rotating component in a second direction, which is opposite to the direction of rotation of the first direction.

Claim 20. The contra-rotating propulsion system of claim 19, wherein each of said plurality of intermediate pinwheels comprises two or more disks separated by a plurality of perpendicularly disposed rollers.
Figure 9a
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

F04D 19/00(2006.01)i, F28C 3/08(2006.01)i, F16H 1/28(2006.01)i

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)
F04D 19/00; B63H 5/10; B64C 11/48; F16H 1/28; B64C 11/48; F28C 3/08

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

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic database consulted during the international search (name of database and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: propulsion, transmission, pinwheel, receiver, motor, roller, and disk

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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<tr>
<td>Y</td>
<td>US 5795200 A (LA[N]N, BRYAN JAMES) 18 August 1998 See column 3, line 33 - column 5, line 14 and figures 1-3.</td>
<td>1-20</td>
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<td>Y</td>
<td>US 2008-0089786 AL (SINREICH, MARK G.) 17 April 2008 See paragraphs [0025]-[0034] and figures 1-6.</td>
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<td>16, 17, 20</td>
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<td>US 3054998 A (DAVENPORT, FRANKLYN J.) 08 October 1991 See column 6, line 58 - column 7, line 9 and figures 5-7.</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

* 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)
  "O" document referring to an oral disclosure, use, exhibition or other means
  "P" document published prior to the international filing date but later than the priority date claimed
  "T" later document published after the international filing date or priority date and 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 19 May 2015 (19.05.2015)

Date of mailing of the international search report 19 May 2015 (19.05.2015)

Name and mailing address of the ISA/KR

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