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ENGINEERING

S Y S T E M S O L U T I O N S

Green is good. All manufacturers, consulting engineers and researchers are trying to develop technologies and applications that will improve our quality of life while protecting the planet we live on.

In the case of centrifugal chillers, this starts with refrigerant selection. The movement to HFC refrigerants, including HFC-134a, spawned the development of the second generation of centrifugal compressor technology – the positive pressure compressor. This article explains advantages of positive pressure compressors, the challenges faced and how they have been overcome.

Although consulting engineers do not need to be able to design a chiller from scratch (that's our job!), a strong basic understanding can lead to better application and building designs. If you would like further information on basic chiller fundamentals, please refer to McQuay's AG 31-002, Centrifugal Chiller Fundamentals and AG 31-003, Chiller Plant Design. Both are available at www.mcquay.com.

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Positive Pressure Chillers

The Next Generation Centrifugal Chiller Design

As manufacturers strive to find environmentally responsible refrigerant solutions, many innovative technologies are being incorporated into centrifugal chiller design. In particular, the desire to use HFC-134a as a refrigerant has led to the development of the positive pressure chiller.

The decision to develop centrifugal chillers that can use HFC-134a has arisen because HFC-134a is non-flammable, efficient, has zero ozone depletion potential, has no phase-out schedule as a greenhouse gas, and is classified in the most desirable refrigeration category (A1) by ASHRAE Standard 34, Safety. Its thermodynamic properties make it an excellent choice for centrifugal and screw compressors.

Why positive pressure?

Positive pressure compressors are advantageous because it is extremely difficult to maintain a perfect seal in a negative pressure vessel. Instead, it is generally accepted there will be some leakage, and that special equipment (a purge unit) will be provided to periodically remove contaminants that leak into a chiller.

The contaminants (non-condensables) that leak into a chiller can hurt performance by as much as 5% because the compressor pumps them around the chiller without getting any cooling effect from them. Contaminants (particularly moisture) can also damage a chiller. Moisture reacts with Carbon to form Carbonic Acid, which attacks copper tubing and motor windings. While it is common practice to change the oil annually in a negative (low) pressure chiller, positive pressure chillers do not require an oil change. For example, when was the last time you changed the oil in your refrigerator?

To combat contaminants, negative pressure chillers usually require purge units. In addition to removing contaminants, a purge unit will also remove some refrigerant and release it into the atmosphere. While modern purge units are very efficient, older purge units can result in the loss of up to 25% of the chiller charge annually. For environmental reasons, it is strongly recommended that older purge units be replaced with modern, efficient purge units.

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What factors affect the speed of positive pressure chillers?

To answer this question, it is necessary to step back and understand what a centrifugal compressor is trying to do. The goal of a chiller is to make (typically) 44°F chilled water and reject the heat into 85°F condenser water. To get the heat out of the chilled water, the refrigerant needs to be colder (or about 42°F). To get the heat into the condenser water the refrigerant needs to be hotter (or about 97°F). This is shown in Figure 1. The compressor's job is to raise the temperature of the refrigerant to make this happen.

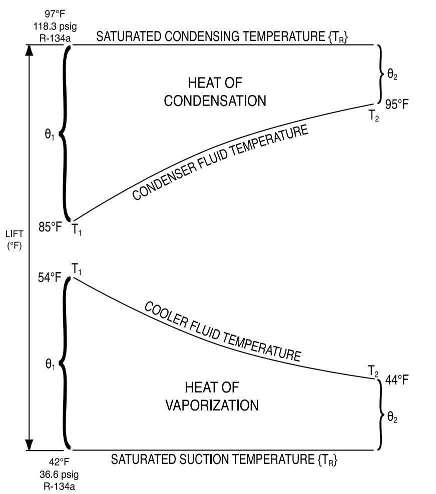


Figure 1 – Typical operating conditions for HFC–134a chiller

All compressors raise the temperature by compressing refrigerant. A centrifugal compressor does this by converting velocity pressure to static pressure. The faster the refrigerant moves (impeller tip speed) the larger the temperature (pressure) change. Table 1 lists the operating parameters for a 1000-ton chiller. An interesting note is that the tip speed is basically the same (around 650 feet per second) for all refrigerants.

Another key property that needs to be considered is the volume flowrate of the refrigerant. HCFC-123 requires about 17 cfm/ton while HFC-134a only requires about 3 cfm/ton. The volume flowrate sets the impeller size. As shown in Table 1, the HCFC-123 compressor must circulate over 17,000 cfm of refrigerant, which explains the larger size of these compressors. In the case of HCFC-123, it is possible to use a direct drive motor operating at 3550 rpm. Once the tip speed and rpm are known it is possible to calculate the wheel diameter (about 40 inches).

With the smaller flow rate offered by HFC-134a, it is possible to use a much smaller impeller (about 12 inches). This is why HFC-134a based chillers are smaller than HCFC-123 chillers. Because the same tip speed is required, the rpm for the HFC-134a chiller must increase.

What about impeller stresses?

Intuitively, higher rpm might appear to mean higher stresses. In reality this is not the case. Dynamic stress on the impeller is proportional to tip speed (not rpm) so a large impeller (HCFC-123) spinning slowly or a small impeller (HFC-134a) spinning quickly both see the same stresses.

While the 12,000 rpm impeller speed in the above example might seem a little daunting, high speed technology is commonplace and surrounds our every day lives. Consider the turbocharger in a car or diesel engine that spins at over 100,000 rpm! Gas turbines used in aircraft spin at over 50,000 rpm. These truly high-speed machines operate at 4 to 5 times critical speed. Positive pressure compressors operate below the first critical speed.

In fact, the small impeller has the advantage of being very light. The impeller used in the above example weighs only 9 pounds, which can be important during starting, stopping and electrical power problems. The lightweight impeller significantly lowers the stress applied to the motor during startup. When the compressor is turned off, the lightweight impeller spins to stop in only a few seconds.

It is not uncommon to have electrical phase shifts in the incoming power to the motor (usually caused by a new power plant coming online in the power grid). When this happens, the motor attempts to realign itself with the phase shift. This can cause such an abrupt jolt to the compressor that large impellers can shear the key off the shaft. However, large impeller compressors usually have devices to protect the compressor from such an occurrence.

Table 1 Operating parameters for a 1000-ton chiller

Refrigerant	HFC 134a	HCFC 22	HCFC 123
Chiller size (tons)	1000	1000	1000
Compressor Gas Flow Rate (cfm/ton)	2.68	1.74	17.08
Compressor Gas Flow Rate (cfm)	2680	1,740	17,080
Tip Speed (fps)	653	678	629
Wheel Speed (rpm)	11,884	19,464	3550@60hz
Wheel diameter (in)	12.6	8	40.6
Acoustic Velocity@ 50°F (fps)	484	535	417
Minimum. Inlet Diameter. (in)	4.6	3.5	13

What about the bearings?

While low-speed compressors can get by with roller (ball) bearings, a more sophisticated solution is required for high-speed compressors. The preferred choice is oil film sleeve bearings. These are also found in car engines, aircraft turbines and many industrial applications where long life is a key requirement.

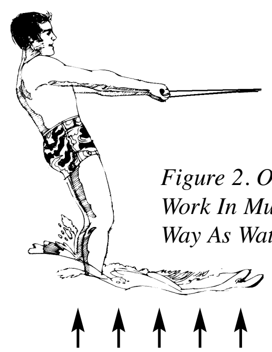


Figure 2. Oil Film Bearings Work In Much The Same Way As Water Skis.

How do oil film bearings work?

With oil film bearings, the shaft literally rides on an oil film the same way a water skier rides on the water. The faster the water skier goes, the "harder" the water appears. For the bearing, the faster the shaft turns, the more protection the oil film offers.

How long will oil film bearings last?

Without metal to metal contact, there is no wear, and the service life for oil film bearings (in theory) is infinite. Roller bearings have metal to metal contact and thus a finite life span. This is usually described in the form of L_{10} 80,000, or approximately 10% of the bearings will fail by 80,000 hours of use.

Damage can be caused to an oil film bearing if a foreign material enters the oil. Positive pressure chillers (by their very nature) do not allow contaminants from the atmosphere into the compressor, so a major source of contamination is removed. Very efficient (25 micron) oil filters are used to purify the oil.

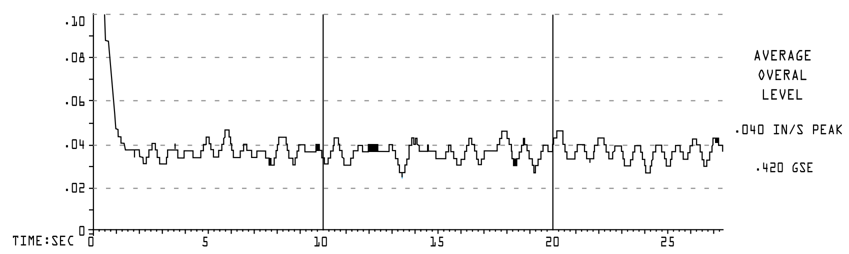
What about vibration and sound?

Vibration can damage the compressor and transfer sound and vibration issues in the building. Figure 3 shows the vibration chart from a chiller tested on a McQuay test stand. McQuay performs vibration analysis on all centrifugal chillers The industry standard is 0.14 inches per second. McQuay centrifugal chillers typically perform around 0.04 inches per second.

With positive pressure compressors, the sound energy is concentrated in the third and forth octave bands. While sound in these higher octave bands seems loader to the human ear, it is easier to attenuate. Low frequency sounds are much more difficult to attenuate (a 60 Hz sound has a wavelength of 18.7 ft.).

The solution for high-frequency sound is a special, inexpensive treatment that is applied to the discharge line (and possibly the condenser) in the factory or the field. Such a treatment can reduce the sound levels by as much as 8 dB. Further sound improvements can be obtained by injecting liquid refrigerant into the discharge of the compressor or using other sound attenuating technologies.

Figure 3 – Vibration Chart



Sound is created by vibration. The higher the compressor speed, the higher the frequency of the sound. In the case of a negative pressure chiller, a large portion of the sound energy is concentrated around 3600 rpm (the motor speed) or 60 Hz. This is the first octave band and the most difficult to attenuate.

Other advantages of positive pressure chillers

Any pressure vessel over 15 psi must be ASME certified. Stringent manufacturing standards, quality control and third party validation are all required to obtain ASME certification. Although a chiller with HFC-134a operates at only 120 psi (your home air conditioner operates at over 250 psi), the chillers are supplied with the quality control required to bear the ASME certification.

Purge unit maintenance is avoided with positive pressure chillers, because there is no purge unit. Also, positive pressure chillers avoid the performance penalty associated with purge units, as well as the potential for damage to the internal workings of the chiller from an improperly operated purge unit.

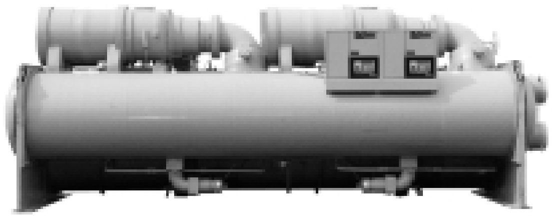
Conclusions

Modern positive pressure high-speed chillers represent the second generation in centrifugal compressor design. Their existence became possible once the technology from aircraft gas turbines was developed. Although a high-speed compressor might (at first glance) seem like it is under more stress, the opposite is true. The bearings used in high-speed compressors can have an indefinite life span.

Positive pressure compressors resolve the issues created by negative pressure chillers. In addition, they allow a compressor to be developed to specifically use HFC-134a, the most environmentally balanced refrigerant in the market place and the only common centrifugal refrigerant that does not have a scheduled phase-out date.

McQuay Centrifugal Water-Cooled Chillers

Setting New Standards With HFC-134a Refrigerant and High Efficiency



McQuay Centrifugal chillers offer you the most efficient means of providing cold water for use in air-conditioning systems or process cooling applications. Our WSC Single Compressor Centrifugal Chiller and WDC Dual Centrifugal Chiller offer unmatched part load efficiency, reliability, environmentally friendly HFC-134a refrigerant, and a small footprint for more usable space. With numerous compressor, motor, evaporator, and condenser combinations, McQuay centrifugal chillers can be built to your specific design conditions for each project. Specific features and benefits include:

Innovative positive pressure compressor design is specifically suited for HFC-134a refrigerant. It prevents contaminants and non-condensables from entering the chiller where they can rob performance and damage critical components. No purge unit is required eliminating additional maintenance.

Patented moveable diffuser expands the compressor operating window allowing for unmatched part load efficiency – a major consideration given that chillers spend 99% of their operating hours under part load conditions.

Continued on back page.

McQuay Centrifugal Water-Cooled Chillers continued from page 3.

Hermetic refrigerant cooled motor doesn't require the leaky, failure prone shaft seals an open motor design needs. With today's tough environmental standards, why run the risk of losing your entire refrigerant charge when the seal fails? No additional mechanical equipment room cooling is required since the motor is cooled internally by circulating refrigerant.

Standard bolt-together construction allows for field disassembly and reassembly to facilitate the difficult rigging work often associated with retrofit installations.

Compact HFC-134a compressor design and unique shell configuration offers the smallest footprint per ton in the industry.

MicroTech™ controller with Open Protocol™ allows for easy integration into your building management system.

Additional features and benefits of the WDC Dual Centrifugal Chiller design include:

Variable Speed Drives (VSD) provide the best part load performance (IPLV) in the industry.

Complete redundancy of all mechanical systems allows a damaged component to be removed and repaired without shutting down the other compressor, providing an automatic backup that allows the chiller to provide 60% of its design capacity in the unlikely event of a failure.

For more information on McQuay Centrifugal Water-Cooled Chillers, contact your local McQuay Representative or visit www.mcquay.com.

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