Copeland Digital Scroll for Refrigeration : A simple mechanical system to achieve the broadest step-less modulation range

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ABSTRACT

A way of reducing compressor output is inevitably needed in almost every application. With the emphasis today on saving energy by reducing head pressures a simple and effective capacity control method can bring enormous benefits. Without the means to run efficiently at low percentage capacity on/off compressor cycling is most commonly used. This method introduces large fluctuations and high power consumption due to heavily loaded heat exchangers.

This paper describes how the Digital Scroll modulation is achieved in a very simple way based on its unique feature called axial compliance. The paper then discusses the potential energy savings, the simple controls to drive the modulation mechanism and finally goes through the applications in racks and condensing units.

INTRODUCTION

A compressor always needs to be selected to have a capacity exceeding the load at the design condition. When the load is reduced, the capacity can be very much more than required. For a single compressor connected to multiple evaporators the over-sizing can be represented in a simple way as shown in Figure 1.

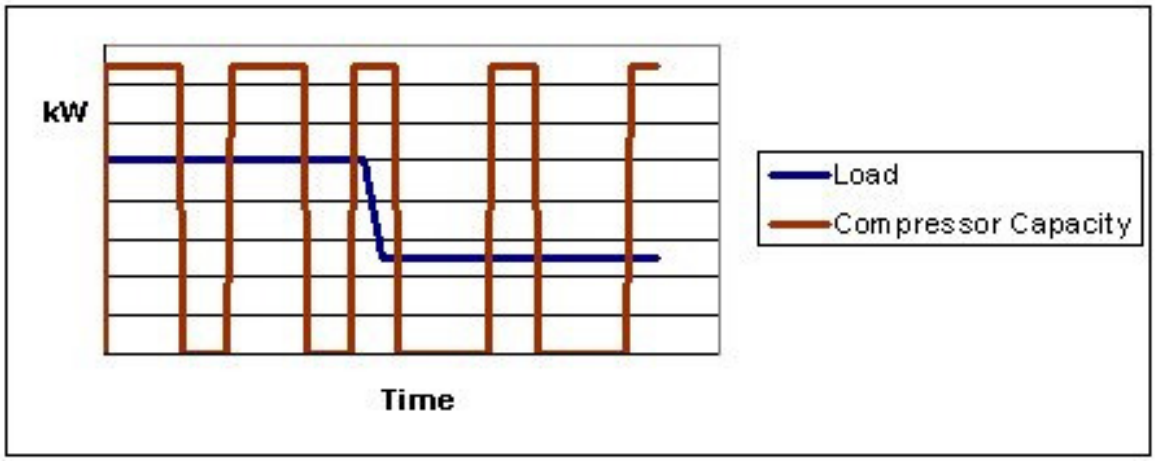

Figure 1 Graph illustrating compressor cycling behaviour with load reduction

This illustrates the situation where the expansion valve on one evaporator closes, and the load is correspondingly reduced. The compressor then cycles and is running only for short periods. A system having several evaporators served by one

compressor may well be required to operate when only one evaporator is cooling. This places very large fluctuating loads on the system which causes erratic behaviour of the expansion valve which leads to lack of proper control and can lead to system failure.

In addition to this, compressor capacity tends to increase as condensing pressure falls. For example a cold room at zero ° C with a load of 10kW at 32°C outside air temperature has a compressor with a capacity of 10kW which exactly matches this load at the design point. The typical load at each average monthly air temperature is shown in Fig 2.

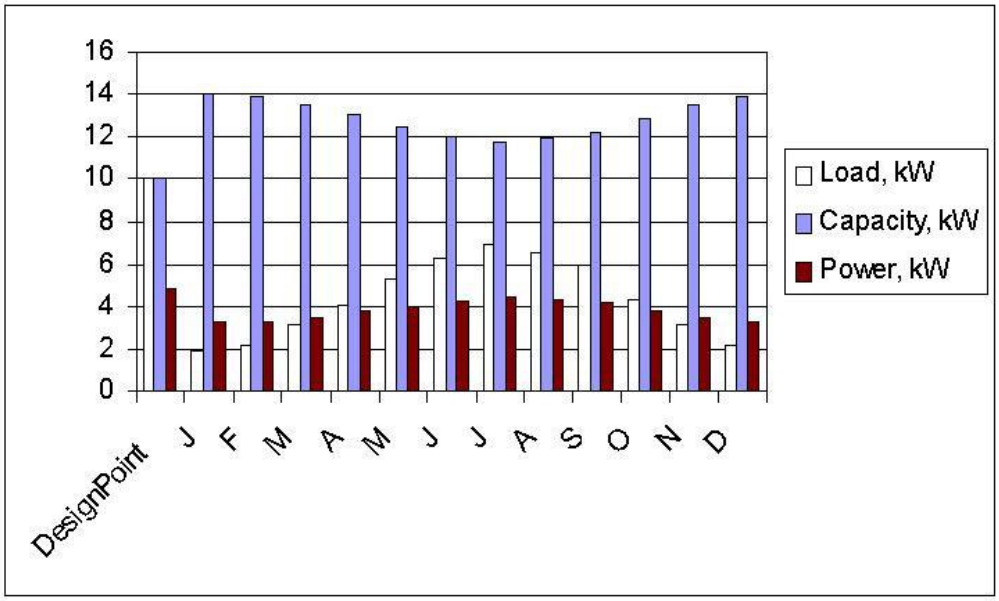

Figure 2 Variation of compressor capacity and load with ambient conditions

A way of reducing compressor output is inevitably needed in almost every application. With the emphasis today on saving energy by reducing head pressures a simple and effective capacity control method can bring enormous benefits. Without the means to run efficiently at low percentage capacity on/off compressor cycling is most commonly used. This method introduces large fluctuations and high power consumption due to heavily loaded heat exchangers.

Multiple compressor solutions overcome this problem to some extent and stepping by means of cylinder unloading is used with piston compressors enabling the use of relatively large machines. With scrolls, packs typically use smaller compressors allowing more flexibility. Up to three scrolls can work with a very simple oil equalisation system which keeps costs down. The benefits of continuous capacity load matching can be realized with the Copeland Digital Scroll without the need for complex and expensive inverter systems. Digital Scroll provides a simple and effective 100% to 10% capacity solution.

PRINCIPLE OF OPERATION OF DIGITAL SCROLL

With Digital Scroll the modulation is achieved in a very simple way. The standard Copeland Scroll has a unique feature called axial compliance. Axial compliance allows the fixed scroll to move by a very small amount so that the scrolls are separated during standstill, and for the first few revolutions on starting. Normally

when the compressor is running, gas forces are used to bring the scrolls together to touch at the tips. But if the scrolls can be made to separate when the compressor is running, and with increased the axial separation as illustrated in Figure 3, the compressor can run at full speed with no compression or gas circulation. The motor runs and orbits the moving scroll, but the capacity is zero. By switching to normal operation with the scrolls loaded together and operating with the normal compliance mechanism, the compressor behaves just like a standard scroll, and provides 100% capacity.

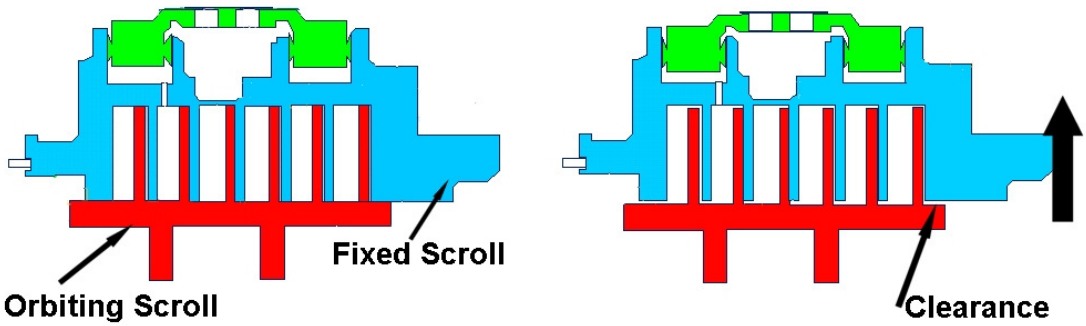

Figure 3 Lifting the fixed scroll introduces a clearance and compression ceases

This separation which introduces the modulating effect is achieved by alternate lifting and engaging the fixed (upper) scroll, and this occurs in response to a pulse width modulated signal. Because the shaft rotates continuously at 100% speed full lubrication is maintained at all times.

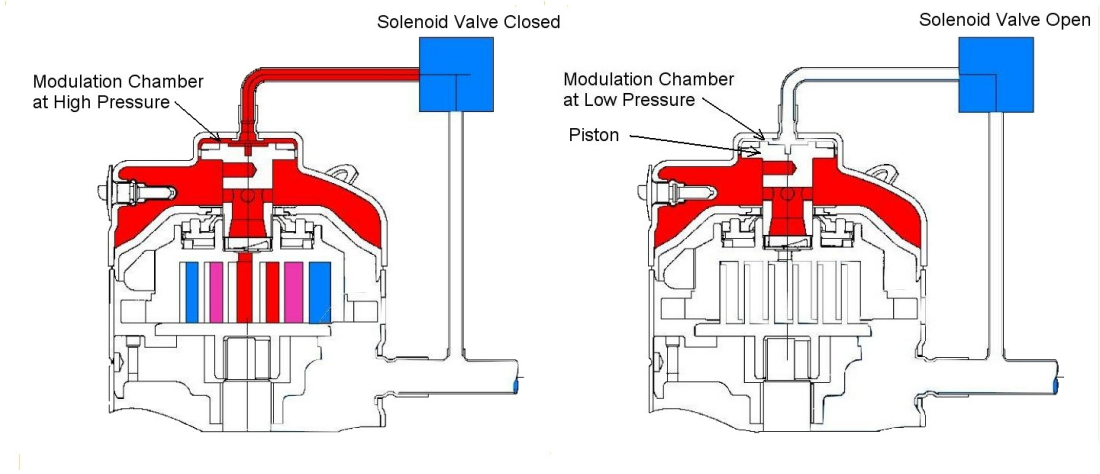

Figure 4 The fixed scroll is positioned by a piston actuated by internal gas pressure

The scroll lifting mechanism is illustrated in Figure 4. In the top cap there is a piston which is fitted rigidly to the upper scroll. The diagram on the left shows the loaded state corresponding to normal scroll operation as in the left diagram in Figure 3. There is no pressure difference across the piston. This piston can be actuated by gas pressure to change to the unloaded state as shown in the picture on the right. The solenoid valve is opened to allow the modulation chamber above the piston to communicate with suction pressure via the external tube. Discharge pressure on the lower side of the piston forces it upwards, bringing with it the

upper scroll. Although there is a small mass transfer from high side to low side on each cycle the external tubing arrangement is not a by-pass in the usual sense of the term.

The compressor is switched between the loaded and unloaded states with a cycle time of typically 20 secs. The duration of the loaded state within this time determines the capacity. At this modulation frequency there is sufficient thermal inertia to allow almost all systems to experience continuous capacity output from the compressor. The power input drops close to zero during the unloaded period.

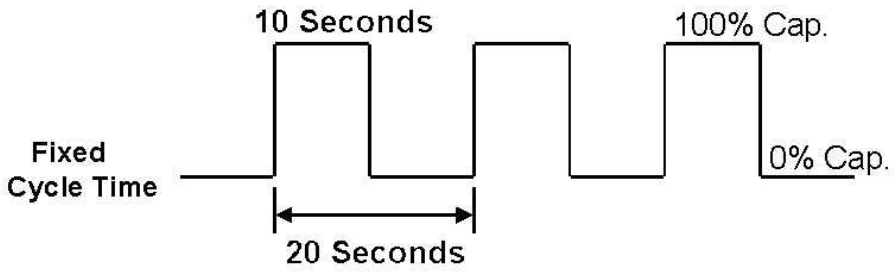

Figure 5 A simple digital waveform from the controller activates the unloading

BENEFITS

With a Digital Scroll multiple compressor systems can use fewer, larger scrolls in a pack or condensing unit, with one modulating scroll available to trim the load. The principal benefit of having fully modulating compressor capacity available on a pack is closer control of suction pressure, and hence a higher average suction pressure with corresponding power savings.

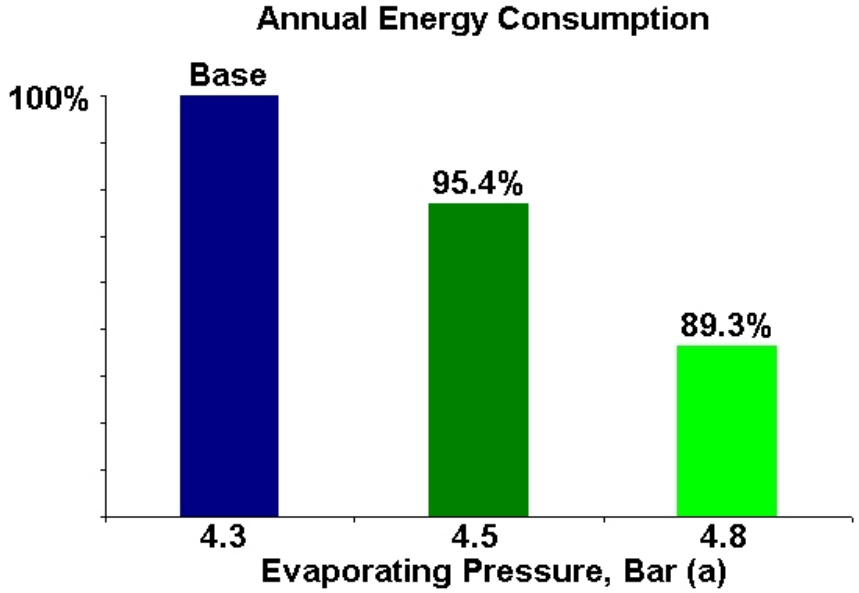

Figure 6 Energy savings resulting from increasing suction pressure

The percentage saving of energy by raising the average evaporating pressure for a medium temperature R404A application is illustrated in Figure 6. Increasing from 4.3 to 4.5 bara (one degree Celsius) could save 4.6% of energy cost. For a chain

of 100 retail stores each with a nominal 30kW capacity pack this could represent a saving of 20k € per annum.

Until the advent of Digital Scroll, the only practical means of achieving continuous modulation has been to apply inverters. However, the inverter introduces additional power losses making the compressor less efficient than the Digital compressor at capacities of more than approximately 50%. An inverter driven compressor has a more limited range of application than the equivalent fixed speed version whereas the Digital Scroll has the same operating envelope as the standard equivalent.
Also a speed modulated compressor can give rise to resonant frequencies at certain speeds. It is much easier, more effective, and cheaper to apply a Digital Scroll than an inverter driven compressor when continuous pack capacity modulation is desired. The Digital Scroll is the same as its fixed speed counterpart, with the sole addition of a solenoid valve.

Control is made simple with the EC2 and EC3 controllers provided by Copeland. The Alco EC2 controller is ideal for two scrolls, one digital and the other fixed speed. The suction pressure based control will operate one on/off compressor and there is a PWM output for the digital compressor. The modulation cycle time is fixed at 20 seconds and the minimum capacity can be adjusted down to 2 seconds (10%) through the parameters of the controller. The EC3 controller is designed to control up to four compressors, one being digital.

Figure 7 Alco EC2 Controller for a two scroll fully modulating system

Figure 8 Alco EC3 can control up to four compressors, one being a digital

The option of an additional proportional 0-10V output for an Alco FSP Series or frequency inverter fan speed controller makes it very suitable for twin compressor condensing units. Both the EC2 and the EC3 have TCP/IP capability.

Twin compressor condensing units are a highly effective way of managing capacity fluctuations. Often only one modulating compressor is needed for a large part of the annual cycle, and this, combined with continued use of the full condenser surface provides very good efficiency. When the outdoor temperature is high and both compressors are needed, and the digital will be used trim the compressor to exactly match the load.

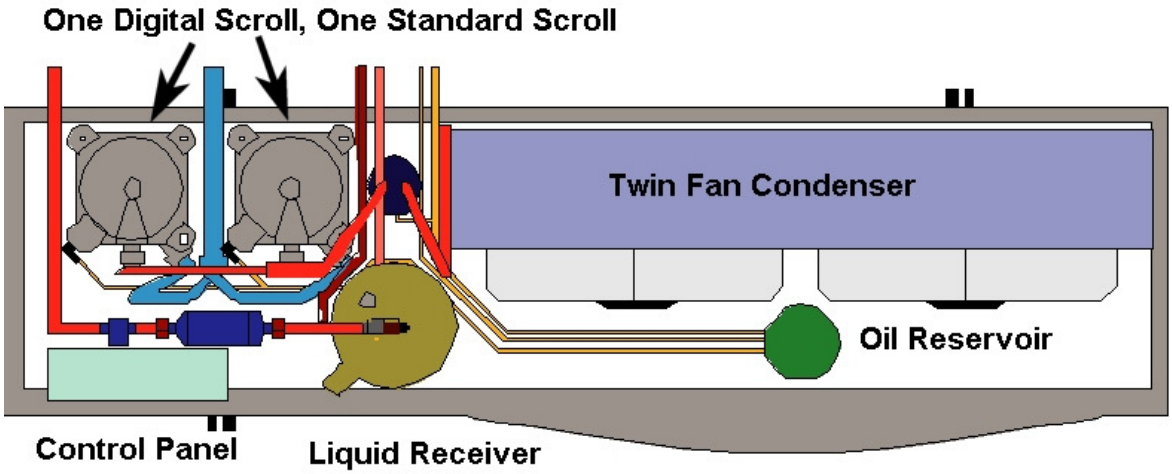

Figure 9 Outdoor condensing unit with the latest Copeland Scroll™ technology

The technology is suitable for use in a network. Network configurations can have up to four condensing units, each unit with one or two compressors.

In summary, efficient capacity modulation down to 10% is now available with Copeland Digital Scroll. It utilises a simple mechanical unloading method which is extremely reliable and does not introduce any unwanted electrical harmonics or vibration resonances into the system.