DIGITAL SCROLL TECHNOLOGY

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ABSTRACT

This paper describes a new technology for capacity modulation – Copeland Digital Scroll™. This new technology is fundamentally different from the traditional inverter technology. It is unique, reliable and very simple to apply. The capacity modulation in the Digital Scroll compressor is achieved by the time averaging of a "loaded state" and "unloaded state". The paper explains how these states are physically obtained in the Digital Scroll compressor. The paper also describes the advantages of using the Digital Scroll and the future advances of this technology by using R410A and vapor injection.

KEY WORDS

Copeland Digital Scroll, capacity modulation, oil return, electromagnetic interference, R410A, vapor injection.

INTRODUCTION

Global warming and ozone depletion are serious issues facing the environment and the HVAC industry has a challenging task to limit this damage. For the air-conditioning industry, the system efficiency is very important because it determines the amount of energy that is being consumed for cooling or heating. Many countries are creating minimum efficiency grades, to ensure that the industry continually strives towards developing more efficient systems and reducing the needs of energy. The increasing buying power of consumers globally is also generating a large demand for the development of air-conditioning systems that provide a higher level of comfort than that provided by the standard fixed capacity systems. These trend, economic and environment related, is placing a growing demand for the development of variable capacity systems. A variable capacity system offers unique benefits – it has higher seasonal energy efficiency and is able to control the room temperature to a much tighter band, thus ensuring higher customer comfort.

Technologies that have been used to achieve modulation so far have been the variable speed compressor driven by the inverter, multiple compressors along with bypass circuits (hot gas and liquid), 2 speed compressors and also 2-step capacity control compressors. In this paper, we are going to talk about a new concept of achieving capacity modulation that has been developed by Copeland Corporation, after doing many

years of research. This new technology, Copeland Digital Scroll™, is unique, simple, and extremely reliable and has the potential to make fundamental changes in the market.

DIGITAL SCROLL TECHNOLOGY

The beauty of this technology is its inherent simplicity. The standard Copeland scroll has a unique feature called axial compliance. This allows the fixed scroll to move in the axial direction, by very small amounts, to ensure that the fixed and orbiting scrolls are always loaded together with the optimal force. This optimal force holding the 2 scrolls together at all operating conditions ensure the high efficiency of Copeland scrolls. The Digital Scroll operation builds on this principle. The physical hardware of the Digital Scroll is explained with the help of Figure 1. A piston is fixed to the top scroll to ensure that when the piston moves up, the top scroll also moves up. There is a modulation chamber at the top of the piston that is connected to the discharge pressure through a bleed hole of diameter 0.6 mm. An external solenoid valve connects the modulation chamber with the suction side pressure. When the solenoid valve is in the normally closed position, the pressure on either side of the piston is discharge pressure and a spring force ensures that the two scrolls are loaded together. When the solenoid valve is energized, the discharge gas in the modulation chamber is relieved to the low pressure. This causes the piston to move up and consequently the top scroll also moves up. This action separates the scrolls and results in no mass flow through the scrolls. De-energizing the external solenoid valve again loads the compressor fully and the compression is resumed. It should be noted that the movement of the top scroll is very small – 1.0 mm and consequently the amount of high-pressure gas that is bled from the high side to the low side is very little.

The Digital Scroll operates in two stages – the "loaded state", when the solenoid valve is normally closed and "unloaded state", when the solenoid valve is open. During the loaded state the compressor operates like a standard scroll and delivers full capacity and mass flow. However, during the unloaded state, there is no capacity and no mass flow through the compressor. The 2 states of the Digital Scroll are shown in Figure 2.

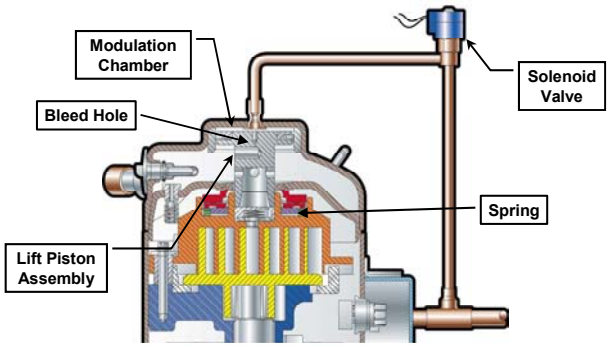

Figure1: Digital Scroll Compressor

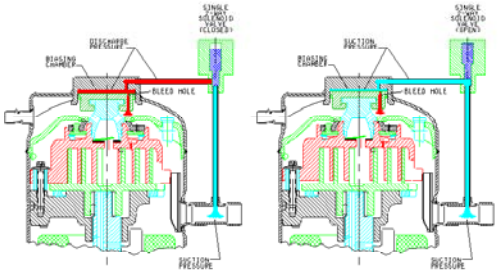

Figure2: Modulation Mechanism

At this stage, let us introduce the concept of a cycle time. A cycle time consists of a "Loaded State" time and "Unloaded State" time. The duration of these 2-time segments determine the capacity modulation of the compressor. Example: In a 20 seconds cycle time, if the loaded state time is 10 seconds and the unloaded state time is 10 seconds, the compressor modulation is (10 seconds x 100% + 10 seconds x 0%)/ 20 = 50% (Figure 3). If for the same cycle time, the loaded state time is 15 seconds and the unloaded state time is 5 seconds, the compressor modulation is 75%. The capacity is a time averaged summation of the loaded state and unloaded state. By varying the loaded state time and unloaded

state time, any capacity (10%-100%) can be delivered by the compressor.

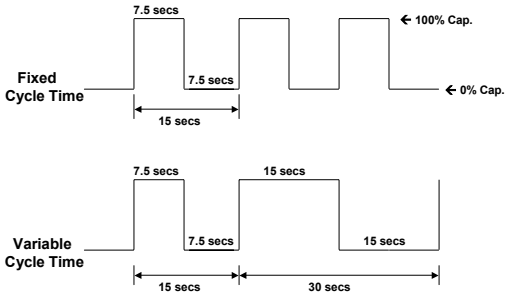

Figure3: Concept Of Cycle Time

Pressure Traces

Due to the loading and unloading of the scrolls, the suction and discharge pressure fluctuates during any cycle. During the loaded state, the suction pressure starts dropping and the discharge pressure starts increasing. During the unloaded cycle, the suction pressure starts increasing and the discharge pressure starts decreasing (Figure 4). Figure 4 shows the suction and discharge pressure with a 12 seconds cycle time and 50% modulation, ie. 6 seconds loaded and 6 seconds unloaded. In order to conserve the thermal mass and to keep the flow of liquid to the evaporator, it is experimentally determined that a receiver helps. Ex.: A 5 liters receiver for a 6 HP system is a good choice. This fluctuation in pressures has no effect on the reliability of various system components like copper tubes, valves etc.

Power Consumption

During the loaded state the compressor consumes full load power. But during the unloaded state, the motor runs freely without any load. The power consumption is very little, about 10% of the full load power. Fluctuation in power consumption is challenging to measure. A power meter that is able to integrate the power consumption over a period of time is the ideal instrument to record the total power drawn. This low power consumption during the unloaded state ensures a high efficiency for the Digital Scroll.

Cycle Time

Cycle time is an important parameter in the Digital Scroll operation. The same capacity can be obtained by using different cycle times. For example, 50% capacity can be obtained by having a 7.5 seconds loaded time and 7.5 seconds unloaded time. Alternately, 50% capacity can be achieved by 15 seconds loaded time and 15 seconds unloaded time (Figure 3). Copeland has experimentally determined the ideal cycle time for each capacity modulation. The "cycle time" and "capacity modulation" is inversely related. Lower the capacity modulation, longer should be the cycle time (Figure 5) At those ideal cycle times; the system energy efficiency is the maximum.

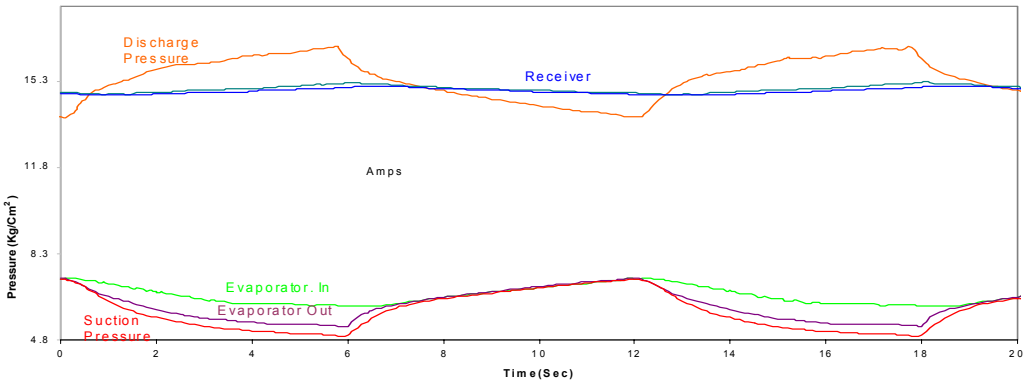

Figure 4: Discharge And Suction Pressure Traces

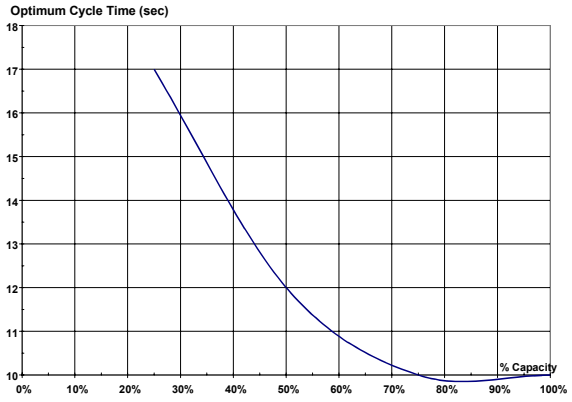

Figure 5: Cycle Time

PERFORMANCE OF DIGITAL SCROLL

Wide Capacity Range

Capacity from 10%-100% is an unmatched output from the Digital Scroll. This wide capacity output is continuous and seamless. This is an enhancement over the inverter technology, where capacity outputs can only be achieved in steps. The seamless delivery of capacity also ensures that there is a very tight control on room air temperature. A wide capacity output also contributes to a high seasonal energy efficiency of the system. Start – stops of the compressor consumes more energy. The wider capacity output of the Digital Scroll reduces the number of start- stops.

High Seasonal Energy Efficiency

For modulated systems, single point efficiency is not the right measure of the efficiency of the system. The seasonal energy efficiency ratio (SEER) has to be calculated to get a good idea of the savings from operating the system year- round. The Digital Scroll performance has been evaluated as per the JIS & ARI standard and it shows excellent SEER. The SEER advantage becomes even greater for a tandem configuration – a Digital Scroll compressor in tandem with a fixed speed compressor. At full load capacity, when both compressors are operating, the system has a high EER and at 50% capacity, when only one compressor is operating at full load, the system operates at high EER also.

Oil Return

Oil return is a major issue in variable capacity multiple evaporator systems. Current technologies use an oil separator and/or complicated oil return cycle to ensure oil return after some period of operation. The Digital Scroll is an unique compressor – it does not require an oil separator or an oil return cycle. There are 2 factors that make the oil return easy. Firstly, the oil leaves the compressor only during the loaded cycle. So at low capacities, very little oil leaves the compressor. Secondly, as explained before, the compressor operates at full capacity during the loaded cycle. The gas velocity in the loaded cycle is sufficient to return oil back to the compressor. Our testing has shown that oil is able to return back to the compressor in the worst operating condition – low modulation, 100 meter pipe length and 30 meter elevation (with standard oil traps), both straight and reverse elevation.

Dehumidification

Dehumidification is necessary to ensure customer comfort and this becomes more important during low modulation operation. In the inverter system, at low modulation, the compressor operates at a lower frequency. This reduces the mass flow of refrigerant and results in a higher suction pressure. This results in a higher Sensible Heat Factor (SHF). The Digital Scroll compressor provides very good dehumidification because it operates at a lower suction pressure than the inverter. As mentioned before, during any modulation output, the compressor operates at full capacity during the loaded part of the cycle. This full capacity operation results in a lower average suction pressure that leads to a lower SHF.

Electromagnetic Interference

Electromagnetic interference is a major issue in inverter driven systems. In many countries, particularly Europe, there are strict regulations on the amount of electromagnetic interference that any device can emit. The Digital Scroll system generates negligible electromagnetic interference because the loading and unloading of the scrolls is a mechanical

operation. This unique feature not only eliminates the need for expensive electromagnetic suppression electronics, it also adds to the reliability and simplicity of a Digital system.

Rapid pull down

Quick pull down of room temperature and quick adjustment to demands are essential for customer comfort. Digital Scroll, because it can transition from 100% capacity to 10% capacity or vice versa instantaneously by changing the loaded and unloaded cycle time, can react to the changes in system demand much faster without having to pass through intermediate speed changes as is necessary in the inverter systems.

Reliability

Reliability of system and electronics is an issue in developing markets in Asia. In an inverter system, the electronics is typically complicated and exposing this complicated electronics to the uncertainties in installation and the extremes of weather, results in reliability issue. The situation is made further complex by the usage of various bypasses – hot gas bypass and liquid bypass. We will discuss about these bypass circuits shortly, but the bottomline is that complex systems have a higher probability of failure. The Digital Scroll system is fundamentally simple. Figure 6 shows the typical electronics for the outdoor unit controller.

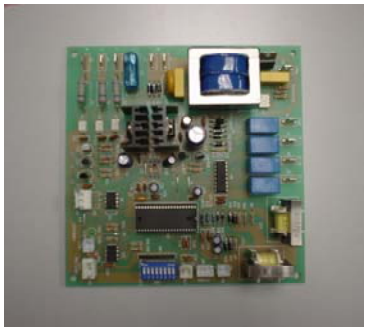

Figure 6: Typical Electronic Controller

Refrigerant Bypass Circuits

Hot gas bypass and liquid bypass is used in most of the present technology options. These protection devices are required because the compressor is not able to go down to very low capacities. The Digital scroll is able to go down to as low as 10% capacity and so these bypasses are not required, resulting in cost savings and system simplicity.

Compactness

A smaller footprint leads to lower material cost, packaging, storage and shipping cost. A Digital Scroll system because of its simplicity, can be designed to be more compact and the savings in space can be as much as 30% over present technology options.

APPLICATION FLEXIBILITY

The Digital scroll compressor can be used in various applications – single evaporator or multiple evaporators. A 6Hp Digital scroll compressor can be used as the building block to go to higher capacities – tandem configuration. A fixed speed scroll compressor of 6 Hp can be used in tandem with a 6 Hp Digital scroll to get a tandem capacity of 12 Hp. This concept can be extended to expand to much higher capacities in the commercial market. Designing of modular systems of higher capacities has been a challenging task with inverter technology, especially due to the oil return sensitivity. The Digital Scroll can be used easily to build the modular systems.

ALTERNATE REFRIGERANTS

Currently the Digital Scroll is available in R22 and R407C. Copeland Corporation is developing this technology with R410A, as we believe that R410A will be the future refrigerant of choice for the residential and light commercial market. R410A offers multiple advantages – higher system energy efficiency, better Total Equivalent Warming Index, better dehumidification due to higher heat transfer coefficient, enhanced heat pump heating performance, no fractionation or glide issues and cost optimization through smaller copper tubes and lesser refrigerant.

FUTURE ADVANCES WITH DIGITAL SCROLL TECHNOLOGY

An enhancement to the Digital Scroll technology is the Digital Scroll EVI (Enhanced Vapor Injection). The basic vapor injection cycle concept is the increase in evaporator capacity through enhanced subcooling (higher delta H) instead of large displacement (higher mass flow). The concept is similar to a two stage cycle with a subcooler, but with the inter stage vapor injected back to the same compressor. For the scrolls, it is easy to inject the vapor during the "staged" compression process. There are several advantages of vapor injection – higher efficiency than larger displacement at the same capacity (since addition of the vapor injection power is done from the intermediate pressure and not the suction pressure), better gain than using a passive liquid suction heat exchanger (Figure 6 and 7). With HFCs like R410A, there is more favorable performance gain (Table 1).

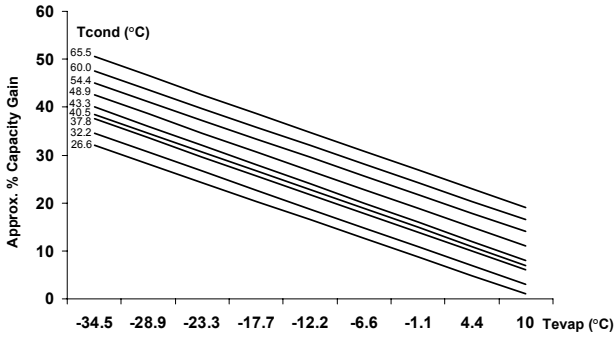

Figure 6: Typical % Compressor Capacity Gain With Vapor Injection

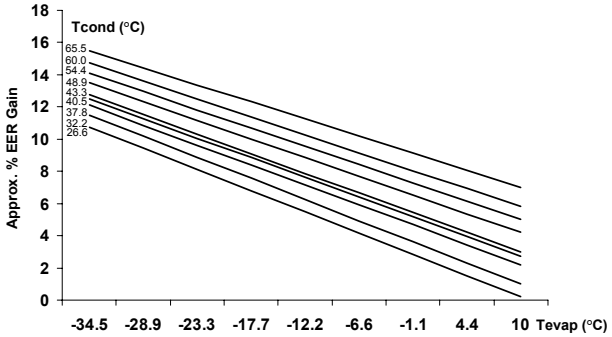

Figure 7: Typical % Compressor EER Gain With Vapor Injection

	%Btuh Gain	Base Delta h	Vapor Injection Delta h	%Btuh / °F SubCooling
R22	27%	77.9	98.9	0.3755
R134a	32%	73.8	97.3	0.444
R410A	33%	83.4	110.8	0.458
R404A	45%	58.4	85.0	0.625

Table 1: Refrigerant Effect On Vapor Injection

SUMMARY

Capacity modulated systems are a fast emerging need of the market and the Digital scroll is a very good option for such applications. The Digital scroll system offers unique advantages – an output capacity that exactly meets the demand, better humidity control at low capacity, a wide capacity range, easy oil return even with long pipe length and ease of application. There are fewer system components, no issue of electromagnetic interference and thus a simplified system architecture.