to boil liquid refrigerant (not the oil) so that only refrigerant gas is present during startup. On Performer scroll compressors, the heater mounts externally on the shell bottom.

Other Means of Compressor Protection

Compressor protection is not always achieved internally to the compressor. Carrier applies additional, external safeguards to assure safe, reliable compressor operation. For instance, in AquaSnap air-cooled chillers, the Scroll Protection Module (SPM) houses a "communicating" circuit board that continually exchanges operating information with the chiller's main control panel. Software elements provide the following compressor protection features:

• *Single-Phase Protection.* The chiller main control panel continuously examines the three-phase power source entering the unit. Upon the loss of any one phase, the chiller control system interrupts the power source to the unit. Loss of a phase in a three-phase system causes reverse rotation in the compressors.

• *Startup Protection.* Using information from the SPM(s), the chiller control system monitors compressor suction and discharge pressure in the first few seconds of startup. If the compressor fails to achieve a differential pressure (e.g., discharge pressure increases less than 10 psig), or if the discharge pressure decreases, the compressor stops.

• *Excessive Starts.* The chiller cycles compressors on and off to achieve a defined leaving chilled water temperature set point. The AquaSnap chiller control software uses an *adaptive deadband* to automatically increase or decrease the deadband around the set point. This ensures that a compressor never starts more than 12 times in any given hour. Excessive starts can cause overheating in the motor.

• *Compressor Operating Parameters.* Every scroll compressor has defined operating parameters, that is, acceptable combinations of

suction and discharge pressure (suction and discharge temperature) in which it was designed to perform continuously and reliably. Operation outside the acceptable parameters can damage the compressor. The AquaSnap chiller control system has the parameters, referred to as the *operating map*, programmed into the unit software. The chiller control system uses the operating map to stage compressors on and off within acceptable parameters, and to continuously monitor overall refrigerant circuit performance.

EFFICIENCY AND PERFORMANCE

There are two ways to think of compressor efficiency: a) the individual, thermodynamic efficiency of a compressor alone, or b) the efficiency of the compressor as it performs in a system. The first method is a useful measure for compressor designers; the second has more meaning for building owners and HVAC designers.

Compressor designers customize scroll compressors for each different refrigerant, isolating on the compressor's individual performance. Variations in scroll geometry, shell design, oil selection and other features optimize the compressor-refrigerant combination.

Chiller designers focus on the efficiency of the overall system. Carrier's Model 30RB AquaSnap air-cooled chiller operates with R-410A and has full-load EER values of 9.6 to 9.9 Btu/hr-W (1.25 to 1.21 kW/ton), and IPLV (Integrated Part Load Value—ARI 1998) of about 13.5 to 14.0 Btu/hr-W (0.89 to 0.86 kW/ton).

By comparison, similar chillers with screw compressors have somewhat better full load efficiency, but do not achieve part-load efficiency available with scroll compressors. Table A (on page 12) compares typical efficiencies for similarly sized chillers with different compressor types operating at the same conditions.

Table A
Comparison of Typical Chiller Efficiencies

Chiller Compressor Type	Full Load EER, Btu/hr-W	Part Load IPLV, Btu/hr-W
Scroll	9.6 – 9.9	13.5 – 14.0
Standard Rotary Twin-Screw	9.6 – 9.8	12.5 – 13.3
High-Efficiency Rotary Twin-Screw	10.0 – 10.5	12.7 – 13.8

Note: Efficiencies shown are typical of chillers that are available as of October 2004.

A share of the indicated efficiency difference is due to the nature of part-load control with multiple, smaller scroll compressors versus single, large screw compressors with a slide valve or lift valves.

The capacity of a screw compressor depends on the compressor displacement and the relative locations of the discharge and suction ports. If the ports are at the extreme opposite ends of the screws (with no intermediate openings), the compressor operates at its full displacement capacity. Adjusting compressor displacement is the most commonly employed method of capacity control.

Lift valves adjust displacement in a finite number of incremental steps. Lift valves are plugged openings at defined locations along one or both rotor bores. When all the valves are closed, refrigerant gas follows the normal line of compression from the fixed suction port to the fixed discharge port, and the compressor operates at full capacity. Opening the first lift valve (closest to the suction port) shortens the effective lobe length and delays the start of compression until a point downstream of the open valve. Compression cannot start until refrigerant gas is trapped between the meshed lobes and the compressor housing. Compressor capacity depends on which lift valves (at what locations) and how many lift valves are open.

There are two types of *slide valves* used for screw compressor capacity control. The first, used in smaller compressors, opens and closes fixed ports with essentially the same effect as lift valves. The second, which is frequently used in large machines, adjusts both the displacement and the discharge port size and location through a theoretically infinite modulating range. In both cases, when the slide valve adjusts, it creates a radial opening that reduces compressor displacement.

Slide valves are slightly more efficient than lift valves; however, both types of capacity control involve inefficiencies. In contrast, multiple, staged scroll compressors operating in a system have no capacity control-related inefficiencies. When a scroll compressor is operating, the system capacity increases by an incremental step. When the compressor stops, the system capacity drops by an incremental step and the energy flow associated with that compressor stops. Table B compares the percent load and percent energy consumption of similar systems with three different compressor types. The first uses three scroll compressors with staged capacity control.

The second and third systems use single, twin-screw compressors, one equipped with lift valves and the other with a slide valve for capacity control. The scroll compressor advantage is apparent. At two-thirds load, the screw compressors use 9% to 27% more energy than the scroll machine, and at one-third load, the screw machines consume 61% to 97% more than the scroll system.

Table B
Comparison of Typical Compressor Performance

Nominal Control Step	Three Scroll Compressors		Single, Twin-Screw Compressor with Lift Valves		Single, Twin-Screw Compressor with Slide Valve	
	% Load	% Energy	% Load	% Energy	% Load	% Energy
Full	100	100	100	100	100	100
2/3	67	67	70	85	67	73
1/3	33	33	45	65	33	53

Note: Performance information is at the same operating conditions and is typical for compressor that are available as of October 2004.

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