Capacity modulation for air conditioning and refrigeration systems

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Second in a series

Capacity modulation for air conditioning and refrigeration systems has aroused new interest as a method to achieve higher levels of efficiency. Numerous methods of modulation are available with different costs and efficiencies.

This series will examine the advantages, disadvantages, and characteristics of each approach, with the specific case of air conditioning systems rated by seasonal energy efficiency ratio (SEER) examined in detail. Also discussed is the need for new compressor rating points in the modulated and high efficiency areas.

The trend toward modulation nd new system rating points rings up several questions which eed to be answered. These inlude:

- What methods of modulation re available?
- What factors need to be conidered in comparing different pproaches to modulation?
- What is the most costffective method of modulation?
- What effects do modulation nd the operating load profile ave on compressor and system esign?
- What compressor rating oints are suitable in the SEER nd dual capacity environment?
- What is the benefit of increasng the number of modulation teps?
- What effect will modulation ave on non-air conditioning aplications?

Methods of modulation

Numerous approaches to the roblem of capacity control are vailable. The ones believed to be ost applicable are listed in able 3 with comments regarding exibility, reliability, noise, and evelopment time.

Flexibility refers to the ability change such variables as low/ igh capacity ratio for dual apacity systems, the number of odulation steps possible, and e efficiency at selected conditions to allow design flexibility d adaptability in response to anges in operating conditions, plications, and regulations.

For example, if one motor is ed to operate the compressor at l capacity levels, the motor degn must be a compromise at two more operating conditions, and is relative inflexibility is noted several of the modulation aproaches. Also, some of the ratgs are divided by large and mall compressors since some of e techniques are presently used large compressors, but not in mall sizes.

With regard to reliability of mpressors: A detailed study erformed by an independent rearch organization found that odulated compressor systems ill experience a slightly higher ilure rate than nonmodulated ystems, due primarily to their dditional complexity and umber of parts.

However, the reliabilities of the ystems which are rated in Table were almost identical. Therere, none of the systems could be xcluded on the basis of reliability lone.

Among the rated approaches, wo-speed motors were found to be e least reliable, primarily because of the number of contactors d other electrical components quired to change winding connections for speed changes.

This is the approach primarily being utilized today in small systems, and is therefore used as the standard of comparison. Seasonal efficiency in this approach is not improved by reducing on/off cycling, but by improving the steady-state efficiency of the system.

This approach is probably the only one feasible when the savings from more costly modulation approaches cannot be justified — for example, in very small systems or systems used in regions with short cooling seasons.

Two-speed motors

This approach uses two-pole/four-pole motor technology to operate a compressor at two different speeds — typically 3,500 rev/min and 1,750 rev/min. Motor designs could be made with other speed ratios; however, efficiency, costs, and power factor would likely suffer somewhat.

Its use will reduce on/off cycling at part load, but its steady-state efficiency at different operating conditions and speeds must be a compromise. The ratio of low capacity to high capacity for two-pole/four-pole motors is fixed at slightly more than 1:2 due to the fixed speed ratio. This capacity ratio may not be optimum for the maximum SEER.

Blocked suction

This approach is relatively inexpensive and is the most efficient form of cylinder unloading. It uses a conventional multicylinder compressor and achieves reduced capacity by physically blocking off suction gas to one or more of the cylinders.

This reduces on/off cycling at part load, but its steady-state efficiency at different capacities must be a compromise due to the use of one motor. In addition, some loss of efficiency is encountered in the unloaded state due to piston friction and irreversible compression and expansion processes in the unloaded cylinder.

The low/high capacity ratio is fixed at slightly more than 1:2 (for twin cylinder machines) which may not be optimum for the maximum SEER.

Dual compressors

This approach uses two separate motor-compressors in a common refrigerant circuit to achieve two (or even three) steps in capacity to reduce on/off cycling at part load.

An important attribute of dual compressors is that the low/high capacity ratio is not fixed at 1:2 as it is with several other modulation methods. This can result in higher SEER's, as well as being more efficient with different load profiles for non-air conditioning applications.

Also, each compressor can be optimized to operate most efficiently at the conditions which it will normally see, resulting in higher overall efficiency. The compressors used (for residential systems) typically can be high-volume, low-cost conventional compressors which leads to low cost and proven components.

Gas bypass compressors

This approach achieves modulation by bypassing compressor discharge gas directly to the low pressure side of the system. The resulting low efficiency eliminates it from consideration as a means of improving system efficiency.

Another form of modulation which could be included in this category is high-to-low-side equalization, in which the discharge plenum of one or more cylinders is valved off from the discharge line and exposed to suction pressure.

In this case, suction gas is not pumped to high pressure and then bypassed to suction. Rather, refrigerant at suction pressure is pumped through the cylinder, thereby only suffering the flow losses through the valves. Due to this source of inefficiency, this approach to modulation also was not considered further.

Variable speed motors

This approach uses solid state electronics technology to vary the frequency and voltage supplied to the motor in order to vary the speed and thus achieve variable capacity.

In the ultimate design, the capacity range would go from zero to the maximum limit of the compressor. There are, however, practical limits to the minimum speed that can be achieved with proper lubrication.

Cost of controls and the development time required have eliminated it from further consideration in this study, although the costs are dropping rapidly with new technology which may make this approach more viable in the near future.

Geared compressors

This approach uses a simple transmission to vary the compressor speed with constant motor speed. Long development time eliminates it from further consideration in this study.

This approach holds a suction valve open in one or more cylinders of a multicylinder compressor to obtain reduced capacity.

It is presently used in large compressors and probably compares favorably in terms of efficiency with high-to-low side equalization. However, in small sized compressors, it is felt that the losses associated with pumping refrigerant in and out of the suction valve reduce the compressor efficiency enough to eliminate this approach from further consideration in this study.

Variable displacement compressors

This approach uses mechanical means to vary the displacement of the compressor in order to reduce capacity mechanically. Complexity and long development time eliminate this approach from further consideration in this study.

Modulation approach	Capacity ratio flexibility	Efficiency flexibility	Reliability Large systems	Reliability Small systems	Noise	Development time Large systems	Development time Small systems
On/off cooling	0	0	5	5	A	0	0
Two speed motors	1	3	2	2	A	S	S
Blocked suction	0	2	4	4	A	0	0
Dual compressors	4	5	3	3	A	0	S
Hot gas bypass	5	1	4	U	A	0	S
Variable speed motor	5	4	U	U	U	L	L
Geared compressor	4	2	U	U	U	L	L
Suction valve lifting	0	2	A	U	A	0	L
Variable displacement	4	2	U	U	U	L	L

Flexibility scale: 0-inflexible; 5-maximum flexibility
Reliability scale: 0-least reliable; 5-most reliable; U-unknown
Noise scale: A-acceptable; U-unknown
Development time: 0-none; S-short term; L-long term (5 years)

Table 3