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TWIN SCREWS OF THE FUTURE FOR AIR CONDITIONING AND REFRIGERATION

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ABSTRACT

Many developments and demands are now apparent on a worldwide basis that taken together in proper perspective tend to predict a significant change in the importance of twin screw compressors to our industry's future.

Our industry is now and has been very cost competitive and that fact alone has caused many a second thought about where twin screw type compressors really fit, especially in the large and growing world of air conditioning. Reciprocating machines currently dominate in compressor size ranges from 3 tons up, but it is also obvious that scroll compressors are making rapid penetration in increasing sizes.

Where does the twin screw of the future fit and why. This paper explores many different developments and demands and attempts to assess what they all could mean to the future of twin screw type compressors within our industry. Typical items to be explored are as follows:

<u>Pertinent Developments and Demands of the 1990's</u>

- CFC Crisis with Attendant HFC Introduction
- Efficiency Demands
- Development of Fast and Accurate Machining Methods
- Oil Separation Developments
- Noise Reduction Demands
- Vibration Reduction Demands
- Rolling Element Bearing Developments
- High Reliability Demands
- Demands for Reduction in Equipment Size and Weight
- Developments in Variable Speed
- Demands for Non-Stepped Capacity Modulation
- Demand for minimum cost

The last item in the above list could have been the first. The order of listing has little significance. These and other items will be examined and an attempt will be made to draw definitive conclusions.

NOMENCLATURE

Vi as it is used in this paper refers to the closed chamber (trapped) volume existing at the beginning of the rotor compression process divided by the volume remaining in this closed chamber at the point of starting exposure to the discharge ports.

Radial discharge porting is located within the surface of intersecting cylinders that closely surround the outside diameter of the rotors.

Axial discharge porting is located in the discharge end plane which is perpendicular to the axes of the rotors and in very close proximity thereto.

Tons as referred to in this paper refers to Air Conditioning tons only. The paper considers that approximately 2 CFM is required per R-22 screw compressor ton.

CFM refers to cubic feet of swept intake volume per minute of operation.

INTRODUCTION

Centrifugal compressors have proven best at handling large volumes of vapor. This fact has allowed them to dominate the larger tonnage Air Conditioning market with the low pressure CFC R-11 as the refrigerant of choice (attendant high CFM requirement per ton). However, a move must be made away from R-11 in the near term future. The HCFC R-123 is a potential (almost direct) replacement for R-11 but concerns exist here which may take many years to completely resolve. R-22 is currently regarded as the only short term acceptable refrigerant for all around air conditioning purposes but it is a relatively high pressure refrigerant (attendant low CFM per ton) and therefore is not well compatible with centrifugal products in the lower tonnage chiller market. Reciprocating compressors are used in multiple for a portion of this range yet there is an upper limit as to how many reciprocating compressors are reasonable on a given unit. High tonnage individual reciprocating compressors are neither practical nor cost effective in today's market and thus there is a rapidly growing belief that screw type compressors have a place.

Twin Screw type compressors (See Figure I) have evolved over the past 25 years to the point where their utilization now dominates air compression requirements for the entire construction industry. The fundamental reason for this dominance is the innate reliability potential of two rugged rotors as opposed to all the moving parts required in the reciprocating and rotary vane type compressors that did dominate prior to the introduction of the twin screws.

Twin Screws are also moving into dominance in the Industrial Refrigeration Industry where similar reliability concerns abound.

In any event, the continuing development of twin screw technology coupled with the CFC problem leads to a demand for R-22 twin screw technology in the 100 to 500 Ton Air Conditioning range.

Development of Fast and Accurate Machining Methods

A study of Figure I which shows the compression/discharge sides of twin screw rotors will lead one to the conclusion that these rotors must be very accurately machined and located if vapor is to be prevented from leaking from high pressure areas within the compressor to low pressure areas. The worst area for such leakage is right down through the mesh line between the male and female rotors. While compression and discharge is taking place on the shown side of Figure I rotors, intake is taking place on the underside of these rotors.

The end result of leakage here is that energy is expended to compress vapor which then leaks down to the intake side of the compressor. Obviously, leakage to the intake side reduces the amount of fresh vapor the compressor can induct yet the compressor is absorbing input energy as if it were pumping 100% fresh vapor. Obviously, it is very important to have well fitting rotors which in turn are very accurately positioned.

It is also obvious to all that efficiency demands are increasing rapidly. There are many reasons for this such as power costs, power availability, environmental concerns, population increases in developing countries, etc. The end result is that efficiency will count more and more as the future unfolds.

A twin screw compressor has no restrictive inlet valves or outlet valves. All it has is properly positioned ports which in some cases are also adjustable in location/size. The end result here is essentially an ideal form of positive displacement compression if only the parts can be made and positioned accurately enough to avoid efficiency robbing internal leakage.

This is where the development of fast and accurate machining methods is proving so important to the twin screws of the future for Air Conditioning and Refrigeration. It used to be that rotors could be crudely machined and crudely sealed by dumping in huge quantities of oil but that did not result in the efficiency levels that are necessary today in Air Conditioning and Refrigeration. New rotor machining methods have very recently been developed that can very rapidly finish rotor flanks to profile accuracies of 15 microns or less. (One micron is .00003937 inches, thus 15 microns is .0006 inches). It is now reasonable to expect rotor interlobe clearances in the .002 inch range considering all stack up tolerances in the compressor whereas only a few short years ago, interlobe clearances in the .007 inch range were commonplace.

The high side to low side leakage rates when considering an R-22 compressor are dramatically lower when we drop from an interlobe average of .007 to .002 inches. A reasonable viscosity lubricant can dynamically seal a .002 inch gap but not adequately a .007 inch gap when considering R-22 and high efficiency.

For housing machining, very accurate and fast numerically controlled machining centers have also evolved to the practical level. The end result is that the goal of accurate and well positioned rotors is now within reasonable reach and thus removes another barrier that has been impeding <u>highly efficient</u> twin screw compression for Air Conditioning and Refrigeration.

<u>CFC Crisis with Attendant HFC Introduction</u>

This subject has already been discussed to some extent in prior portions of this paper but there exists an additional fundamental point of importance. We have discussed the use of R-22 as an alternative to R-11. R-11 is a CFC and is in trouble. R-22 is a HCFC and may very well be in future trouble as more and more emphasis is put on both ozone depletion potential and global warming potential. This concern brings us to HFC compounds such as R-134A which may prove to be required in the future.

R-22 is a relatively high pressure refrigerant of relatively moderate density and as such has allowed the development of reasonably efficient and low cost reciprocating compressors up to about 40 tons in nominal capacity at efficiency levels reasonable for the time.

Now, if an HFC such as R-134A is required in the future (many people are already convinced they will be required), this will have quite an impact on where screw compressors will balance off cost-wise relative to other types of compression. R-134A is a moderate pressure level refrigerant and as such will require more displacement per ton than does R-22. As an average, let us assume about 50% more displacement is required per ton. This means that a 30 ton R-22 recip. compressor now becomes a 20 ton compressor with R134A.

Further to this, the current recip. compressors are moderately efficient with R-22 as considerable tonnage is achieved per CFM. However, if we reduce the tonnage obtained with a given CFM, we have not caused much impact on the pumping losses of the compressor because we have not changed the CFM (i.e., the volume of gas pumped). In the case of a reciprocating compressor, this means the intake and discharge cylinder valve pumping losses are now spread over less tons and thus up goes the KW/Ton. Now with the increasing pressure on efficiency, there is nowhere to go without dramatically increasing costs, thus, the twin screw now becomes more attractive. This is because of several factors as follows:

1. Lower internal screw leakage due to lower pressure differential than with R-22.

2. Intake and Discharge losses are much lower than a recip. because of no valves thus less impact here.

3. Very easy to increase displacement by lengthening rotors that were designed for R-22. (Lower pressure allows more length without load increase.)

4. Reciprocating options do not exist without decreasing efficiency or dramatically increasing cost. This is because reciprocating design has evolved with R-22 to where they are now at an effective cost/efficiency limit.

5. It is not unreasonable to assume at least a 50% average increase in dollars per ton when considering HFC recips compared to R-22 recips.

These factors will tip the scales to screws in the future.

Oil Separation Development

Oil separation has been considered a major problem with screws. High cost, bulky, difficult to understand, etc.

Looking at screws of the future, we see less oil required for sealing per unit of compressor displacement. This coupled with major advances in the simplicity/understanding of separation techniques leads to separation costs so low as to be almost negligible in total system cost.

Some are expending much effort in development of techniques that allow for sealing of the screw compression process by ingestion/injection of liquid refrigerant only. If there is a significant advantage in product cost that can be realized via this route with no net reduction in cycle efficiency, then one must support the direction. However, if the overall picture favors moderate oil injection with its inherent improvement in overall reliability, then the very moderate cost of simple and small separators is of little concern.

In any event, the real issue here is that sealing of the twin screw compression process is becoming much easier with dramatically improved machining accuracies of the future. This coupled with new understanding of simple separators can now lead one to the conclusion that oil separation concerns and costs have become almost a non issue and will not impede in any way the progress of twin screws.

Noise and Vibration Reduction

Pure rotation of balanced components does not result in vibration. Thus a twin screw compressor has no intrinsic problems in this regard. However, manufacturing inaccuracies can contribute to vibration and noise. Again, the machining accuracy advances referred to earlier help in this regard when comparing twin screw to twin screw. However, when comparing to recip, the answer is obvious. Recips have inherent unbalance, screws do not.

Regarding noise, machining accuracy has much to do in reduction of rotor interaction noise. Proper Vi matching has a major impact on twin screw noise. Proper matching of radial and axial porting also impacts noise and when all is done intrinsically that can be done, one uses reactive muffling to cancel remaining pulses with attendant possibility of very quiet compressors.

There exists increasing demand for low noise and vibration especially in Europe and Japan. There is no question that modern screw compressors will lead in satisfying those demands.

Rolling Element Bearing Development

In recent years, three major advances have taken place in rolling element bearings. These all impact the future of screw compressors for Air Conditioning and Refrigeration. They are as follows:

1. Reduction in steel defects: Major process improvements have resulted in significant reduction of material inclusions in both bearing rolling elements and races. Increases in basic load ratings have resulted from these process improvements.

2. Improvement in bearing accuracies: Rotors are positioned by bearings. Rolling element bearings are now available at reasonable costs with very precise concentricities and very tight clearance ranges. This has all contributed to the improvement in twin screw compressor efficiency as well as innate improvements in reliability and reduction in noise.

3. Better understanding of lubrication theory: Classic bearing theory states that the fatigue life in hours of a rolling element bearing is inversely proportioned to the RPM (rev. per minute). New theory now better

recognizes the quantitative impact of viscosity, speed, and contamination on rolling element bearing life. New application manuals show that the hydrodynamic support effected by proper viscosity/speed relationships (in the absence of adverse contamination) can even result in infinite rolling element bearing life with moderate loading.

This translates to compressors achieving very long service lives when proper viscosity and filtration requirements are taken into consideration.

High Reliability Demands

Pure rotation, rolling element bearings, proper filtration, absence of valves, excellent positioning of rotors, inherent ability to pass liquid refrigerant. All of these factors when executed properly contribute to the goal of achieving the inherent reliability potential of the twin screw compressor. Compare this to a reciprocating compressor with cylinder valves, sleeve bearings, oil pumps, etc., and the inherent reliability potential of the twin screw is obvious.

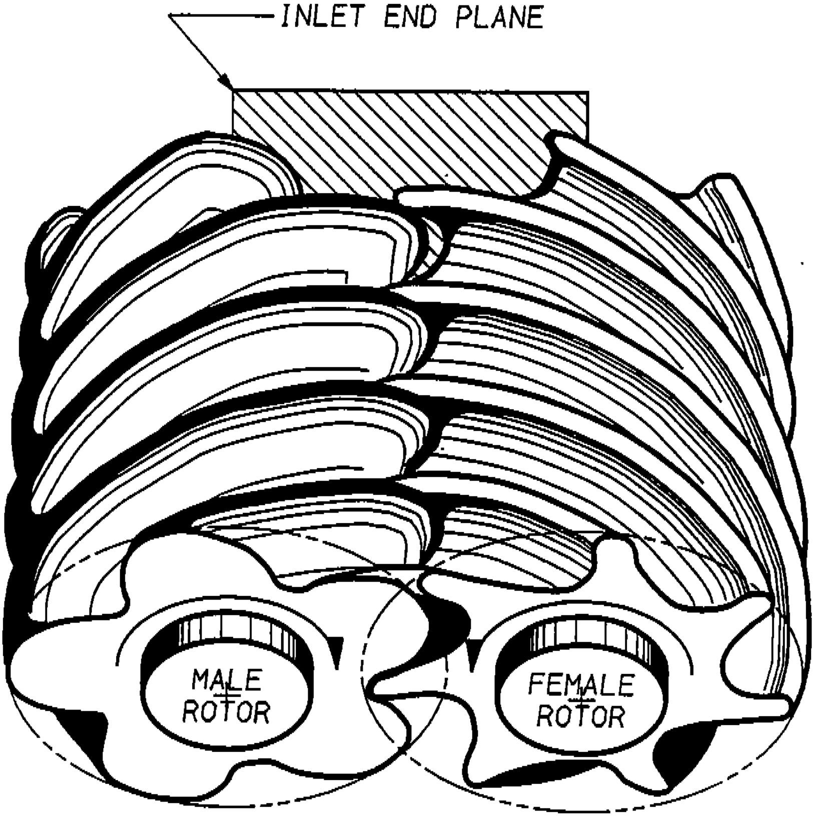
However, the twin screw is not forgiving of design or manufacturing errors. For this reason, the best possible engineering and manufacturing must be utilized and only then will the innate reliability potential be achieved.

As was discussed earlier, the construction industry has totally gone over to twin screws for reliability reasons and the Industrial Refrigeration world is not far behind. Air Conditioning and Commercial Refrigeration applications are next. The demands are certainly there and the twin screw can meet those demands with proper designs and manufacturing systems.

CONCLUSIONS

All of the items discussed lead in the direction of properly executed twin screw compressors for future Air Conditioning and Refrigeration applications. Additional inherent advantages exist in the direction of reduced size and weight. Twin screws are especially adaptable to variable speed whether engine or motor driven. Vi control is quite easy to accomplish in modern twin screws. As inverter drives come down in cost, it is not difficult to predict multiple compressor screw packages with one swing compressor inverter driven and all compressors having variable Vi. This will allow infinite capacity modulation on a very efficient basis.

The demand for minimum cost will always be with us as it should be and, as the future unfolds, the screw compressor will help in achieving that minimum cost. It will become cost competitive with reciprocating compressors of the future. It will help to reduce total life cycle costs through its improved reliability and improved efficiency. It will take time to achieve all these goals but the way is clear for Twin Screws of the Future for Air Conditioning and Refrigeration.



COMPRESSION/DISCHARGE SIDES OF
TWIN SCREW ROTORS

FIGURE 1