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Screw Compressors Control of Vi and Capacity 'The Conflict

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CONTROL OF Vi AND CAPACITY

"THE CONFLICT"

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ABSTRACT

Significant confusion exists within the Air Conditioning and Refrigeration Industry with regard to the real impact of Vi or Volume Ratio on screw compressor performance. Add to this the effect on Vi as a screw compressor unloads and the confusion gets worse. Several newer designs of screw compressors have variable Vi as well. What does this mean and what impact does varying the capacity of a particular compressor have on our ability to vary its Vi? What does this mean in terms of overall compressor efficiency in actual applications?

The theoretical limitations of screw compressors with regard to the above areas are discussed in detail only after the necessary fundamentals have been extensively covered. The interest herein is to help clarify this important subject to responsible members of the Air Conditioning and Refrigeration Industry in order that screw compressors will be better understood and applied.

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 rotor housing discharge port. It is variously referred to as volume ratio, volume reduction ratio, closed volume reduction ratio, effective volume reduction ratio, etc. In all cases, it means the trapped volume existing at the beginning of the compression process divided by the reduced volume existing at the point of initial exposure to the discharge port.

Capacity control as the term is used herein refers to the bypassing of vapor (gas) back to the inlet side of the compressor <u>before</u> it has exited the rotor housing discharge port.

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.

INTRODUCTION

This paper deals with the fundamentals of twin screw compressors in such a manner that both the screw compression process along with the inherent geometrical limitations of the process within the actual compressor can be better understood.

The common methods of capacity control and compression ratio control that are in use today are also discussed along with their inherent limitations as well.

At full capacity output, twin screw refrigerant compressors are realistically limited to maximum closed volume reduction ratio (Vi's) in the vicinity of 5.5 to 1 because of the rapid decrease in geometrically available axial discharge port area when higher volume reduction ratios are attempted. At part load, the maximum possible closed volume reduction ratios are proportionally less as well; i.e., 5.5 at full capacity becomes 2.75 at 50% capacity.

If a typical refrigeration application calls for a volume ratio (Vi) of 5.5 to 1 or greater, then there is certainly no reason or possibility left to vary this ratio since 5.5 is the maximum we can realistically design into the compressor in the first place.

The only common method of varying Vi today is through use of a rotor housing slide valve which varies only the <u>radial</u> discharge porting while the axial porting remains fixed <u>at the</u> highest possible value. At full load Vi's of greater than <u>4.5</u> to 1 or so, there is essentially no <u>radial</u> discharge port are<u>a left</u> so the real possibility of full <u>capacity</u> output Vi variation is now from 4.5 on down.

To restate the point: If the application calls for a Vi of 4.5 or greater at full load, a fixed Vi axial port is the only choice as there is no possibility of achieving a performance improvement with variable Vi even at full load.

Vi variation is only useful when relatively low volume reduction ratios are called for by the actual application in question; and even then, when compressor capacity falls to 50% or so, all theoretical benefit is gone. This paper attempts to explain why this is so along with the penalty associated with utilization of a (moving unloading stop type) variable Vi machine whenever it is not <u>clearly</u> justified by the application in question.

BASIC COMPRESSOR OPERATION

The general operation of a twin screw compressor can be understood by viewing Figure 1 and Figure 2. Figure 1 looks at the compression/discharge sides of a typical twin screw compressor. In Figure 1, the male rotor (left side) rotates clockwise and the female rotor rotates counterclockwise. By studying the diagram, it can be recognized that multiple volume chambers exist and these chambers reduce in volume towards the right side of the diagram as the rotors revolve. For clarity, no rotor housing has been shown but the discharge end plate is shown diagrammatically in a shaded fashion. Also shown is the axial discharge porting which would exist for a full load Vi of 5.5 along with an outline of the radial porting possibilities that exist for a full load Vi of 2.75. One can note that the Vi in question is the maximum closed volume associated with a given volume chamber starting compression divided by the volume remaining in that chamber volume upon initial exposure to the discharge port in question.

Figure 2 shows the operation of the compressor in a more diagrammatic fashion and, as noted, starts the process of unwrapping the volume chambers in order that the general compressor operation can be better understood. Note that the first closed chamber on the diagram has been unwrapped in order that its true volume may be visualized. Also note the reduction in volume as the axial discharge port is approached by these moving chambers as they reduce in volume.

Figures 3, 4, 5 and 6 track one unwrapped and meshed volume chamber from the start of compression to the essential completion of discharge/intake. Note that the complete unwrapped compressor has been depicted on the diagram for clarity; although to improve understanding, we are tracking only one meshed volume chamber as the compressor rotates. Obviously all other volume chambers are undergoing similar and simultaneous processes. Also note that as the rotors revolve and the seal line moves towards the discharge end of the compressor, compression is taking place between the seal line and the discharge end while intake is taking place in the dashed volume chambers appearing in back of the seal line. (Intake is taking place underneath the rotors when looking at the compression side and therefore is shown by dashed lines in this diagram.)

Figures 7, 8, and 9 add (to the basic unwrapped diagram) an outline of a conventional unloading type slide valve set up for a full load Vi of 2.0. As this slide valve is moved towards discharge in order to unload the compressor, one can see that the discharge port advances in position until all that remains is axial discharge porting. Unloading is usually initiated after approximately a 20% reduction in maximum chamber volume has been accomplished through bypass back to suction. Therefore, initial unloading tends to reduce the effective volume reduction ratio somewhat because the radial port does not advance significantly in position although the effective closed volume chamber has now reduced to 80% of its initial value. This means that the Vi is also only essentially 80% of its initial value. Also note that at about 50% capacity, there is no radial discharge porting left and therefore, the volume ratio is now determined by the fixed axial port and the degree of unloading. If we had a full load axial Vi of 5.0 and are now on axial porting only and the compressor capacity is only 50%, then the effective Vi is now .5 times 5.0 or 2.5. Study of this diagram will clearly demonstrate what happens as a conventional slide valve type compressor is unloaded. A reduction to 25% capacity now reduces the effective Vi to .25 x 5.0 or 1.25 actual. Therefore, the effective Vi of the compressor went down as unloading was initiated and then rose somewhat and then fell again.

Figures 10, 11, and 12 add an outline of a typical movable unloading stop type of variable Vi to the basic unwrapped diagram and demonstrates what happens whenever the full load Vi is increased to the maximum value of 5.0 and then the compressor unloads. Because the full load Vi variation was accomplished by allowing the unloading stop position to move deeper into the compression zone, it is obvious that more compression work has to be done on the gas that is to be bypassed back to suction. Note that this is a penalty associated with this method of varying the full load Vi.

CONCLUSIONS

With the movable stop type of slide valve, the point in the compression process where unloading bypass is initiated moves towards discharge as the full load Vi is increased thus causing higher compression losses in the bypassed gas when unloaded as compared to the conventional unloading type slide valve.

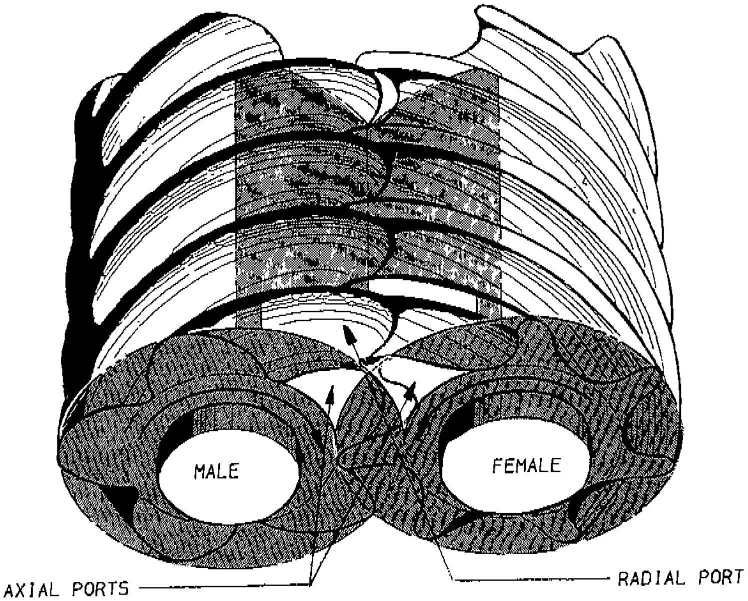
The "conflict" arises here because of the application sensitivity of the (movable unloading stop) variable Vi approach to the variable Vi question. If the compressor involved is to spend signfiicant time in the unloaded state, then the "variable Vi" becomes a liability in that more work is done on the gas prior to unloading bypass. Further to that, if a typical refrigeration application calls for a relatively high Vi in the first place (greater than 4.5), a compressor without variable Vi should be selected because the greater unloading loss will always be present in the "variable Vi" machine because of the operating position of the movable stop.

It becomes necessary to totally understand the tradeoffs involved if one is to make truly effective use of the movable unloading stop type of variable Vi. If the application calls for a Vi of less than 4.5 and a high percentage of the operating time will be in the highly loaded state, then the variable Vi could have an advantage. However, the conflict exists and all application factors must be very clearly analyzed before making a decision to utilize a "variable Vi" machine over a "fixed Vi" machine because as one can see, fundamental geometric limitations within the compressor design itself severely limit the true Vi "variability" of the machine.

Serious consideration of these inherent limitations leads to the conclusion that the screw compressor in general cannot have very good part load performance when used in applications that call for volume reduction ratios from about four on up. This indeed is the case yet they are being used more and more because of other characteristics that make them very attractive to the end user of refrigeration equipment.

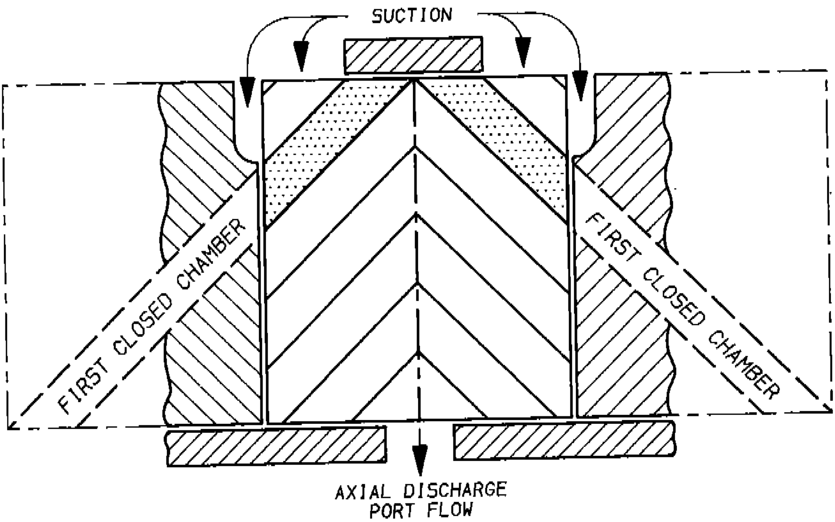
From an overall efficiency standpoint, it would be desirable to use variable speed screws combined with variable Vi. In this way, the inherent adaptability of the compressor to variable speed could mate very well with some degree of variable Vi for more efficient variable capacity operation at various compression ratios. An additional alternative (which is already used somewhat) would be to use multiple screw compressors for a given application in order to insure that a high percentage of the total capacity required is always being efficiently delivered by fully loaded compressors.

In conclusion, the basic purpose of this paper has been to enhance the understanding of state-of-the-art screw compression in general, with the goal in mind of better utilization of manufacturer's existing product offerings as well as adding some food for thought as to what might happen in the future if manufacturing costs of both variable speed drives and screw compressors become low enough to allow it.



TYPICAL VIEW LOOKING AT COMPRESSION / DISCHARGE SIDES OF PAIRED ROTORS

FIG. 1



TYPICAL VIEW LOOKING AT COMPRESSION SIDE OF PAIRED ROTORS WITH FIRST CLOSED CHAMBERS UNWRAPPED

FIG. 2

FIRST CLOSED VOLUME

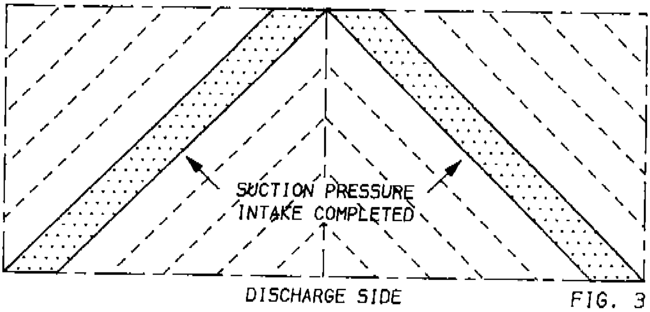


FIG. 3

EARLY STAGE OF COMPRESSION / INTAKE START

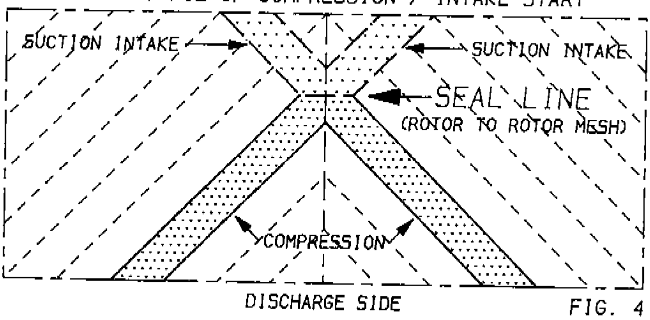


FIG. 4

LATER STAGE OF COMPRESSION / INTAKE

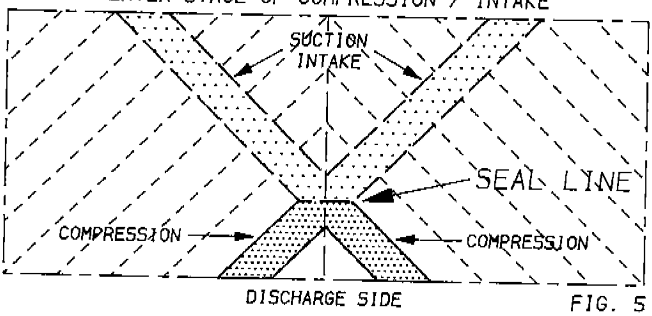


FIG. 5

DISCHARGE / INTAKE BEING COMPLETED

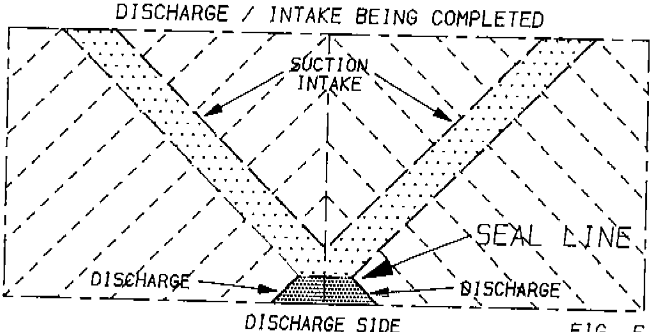


FIG. 6

PROGRESSION OF ONE UNWRAPPED AND MESHED VOLUME CHAMBER DURING ROTATION

DEPICTION OF CONVENTIONAL SLIDE VALVE SET UP FOR A FULL CAPACITY Vi ≈ 2.0

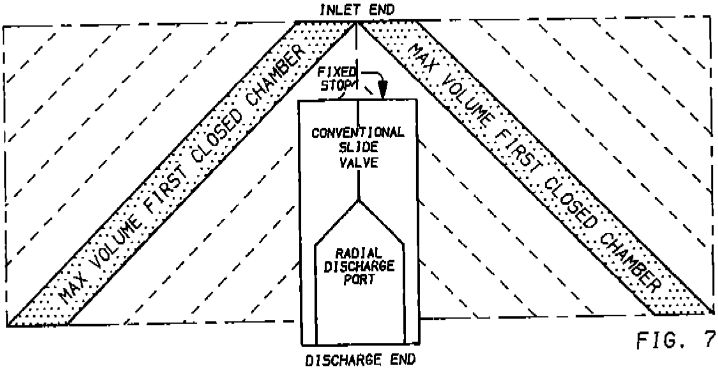


FIG. 7

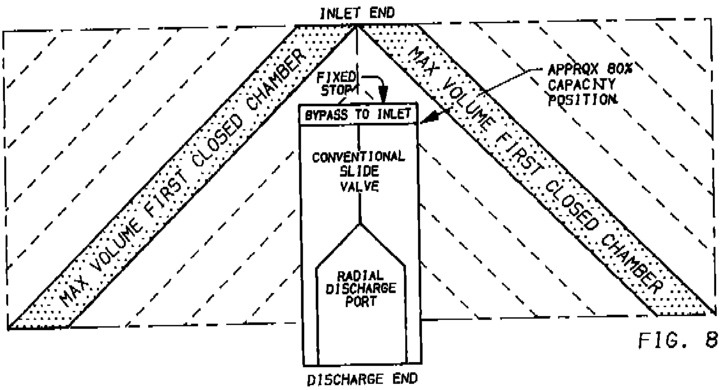


FIG. 8

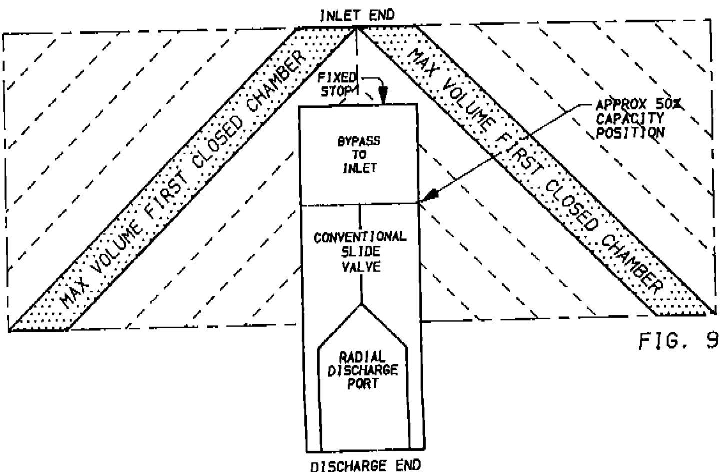


FIG. 9

MOVABLE UNLOADING STOP FULL CAPACITY
VARIABLE VI FROM 2 MINIMUM TO 5 MAXIMUM

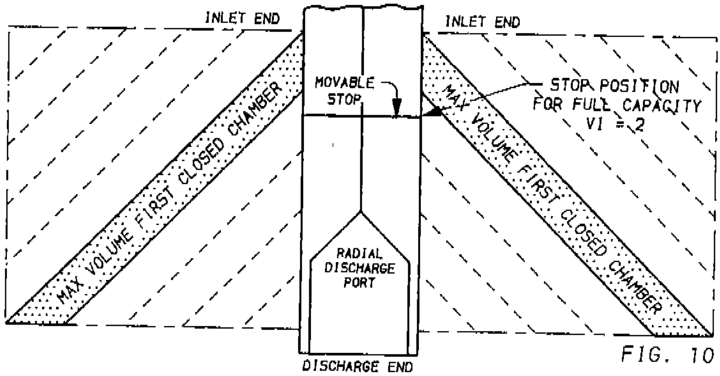


FIG. 10

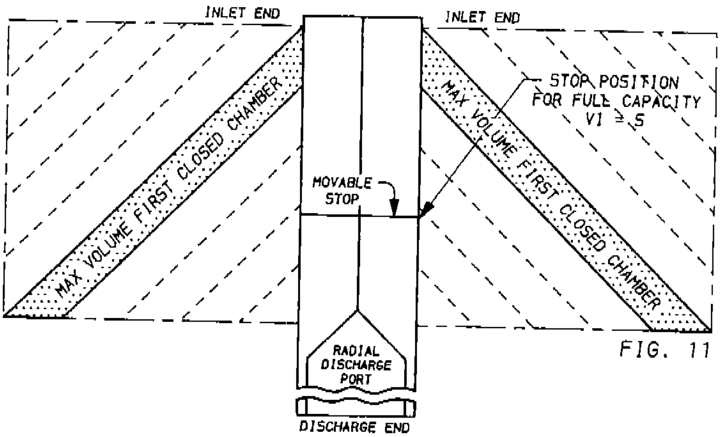


FIG. 11

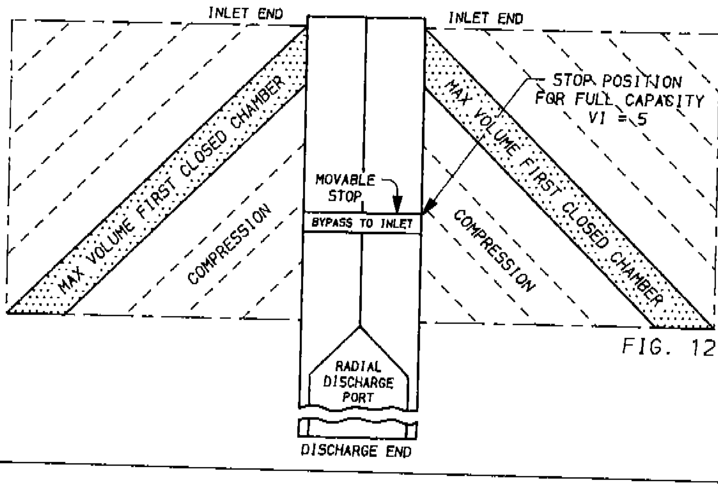


FIG. 12