Torad Rotary Spool Compressor

Communication White Paper By:

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Introduction:

The rotary spool compressor shares various attributes with the legacy rotary compressors, sliding vane and rolling piston. However, the rotary spool compressor has several key improvements allowing the mechanism to overcome the historical limitations of the legacy rotary compressors which allow the rotary spool compressor to achieve higher efficiencies and yet maintain the simple design and low manufacturing cost of a rotary machine.

A hermetic rotary spool compressor assembly is shown in Figure 1. The rotary spool compressor has only one major moving assembly, which is a rotor mounted eccentrically to a housing. An exploded view of the mechanism assembly is shown in Figure 2. There are three key improvements from legacy rotary compressors.

1) The vane is constrained by means of an eccentric cam allowing the end to be held in close proximity to the cylinder housing bore while never contacting the bore, which eliminates friction and wear.
2) The vane is sealed to the bore via a tip seal which is configurable to be well balanced exerting adequate force on the bore to seal the gas, while at the same time generating minimum friction.
3) The rotor has affixed endplates that rotate with the central hub and vane forming the rotating spool and uses dynamic sealing elements, between the endplates and cylinder housing, to minimize leakage between the compressor containment and the process pockets.

These improvements allow the rotary spool compressor to overcome the challenges faced by legacy rotary compressors. This gives the rotary spool compressor the following advantages:

1) High efficiency – due to the constrained vane and the rotating end walls, the frictional drag is greatly reduced from that of a sliding vane or rolling piston compressor.
2) Extremely scalable – greatly reduced sliding friction on the vane and end walls allow the rotary spool compressor to scale to much larger sizes than ever possible with sliding vane or rolling piston compressors.
3) High displacement density – the spool compressor processes two pockets of gas with each revolution of the shaft, whereas the rolling piston processes one pocket of gas. This allows the spool compressor to have approximately 80% more sweep volume with each revolution.
4) High speed operation – as the friction elements are greatly reduced, the spool compressor is able to operate at high speed relative to the conventional sliding vane machine.
5) Wide speed range – due to the deployment of active sealing elements, the spool compressor is able to run over a wide speed range to facilitate operation with Variable Frequency Drive (VFD). This can also be done without over-speeding the compressor, while maintaining efficiency at very low rotating speeds.
6) Lowest overall cost of production
    a. No complex geometries – simple machine tools, simple process controls and low capital cost
    b. High displacement density allows small package size and low raw material usage.
7) High Reliability
    a. Due to the active sealing elements, the spool compressor is impervious to liquid flood-back as any over-pressurization of the compression cavity will cause the tip seals to move out of the way and relieve the pressure. Naturally, continued liquid flood-back will result in tip seal wear.
    b. The spool compressor operates with the oil system in the discharge side and as such the risk of oil dilution due to liquid flood-back is small.

c. The use of engineered plastics for the side seal and the tip seal combined with the high side oil system allow the spool compressor to absorb some contaminants without damaging the machine.

Comparison to a Sliding Vane

A schematic of a sliding vane is shown in Figure 3a. The advantages of a sliding vane device are well-known as the machine origins date back to the 1700s and have been manufactured in various forms from late 19th century[1,2] to current. They can be best described as the following:

1) High displacement density – high volumetric capacity in a compact physical package.
2) Low production cost due to the simple geometry
3) Low capital equipment cost also due to the simple geometry

The major disadvantages are also well-known and these are described as:

1) Low efficiency – due to the high friction, of the vane running in direct contact on both the inside diameter of the bore as well as the fixed end walls, power losses are high.
2) Speed and scalability limits – as a result of high friction the speed and size are limited due to ever decreasing efficiency, wear problems, and excessive heat management issues, as speed and size increase.
3) The limited tolerance to particulate and liquid refrigerant flood-back. The sliding vane requires tight clearance to the fixed surfaces. As a result, particulate and liquid refrigerant flood-back, have shown to be problematic in service.

[1] Rotary Air Compressor and Pump, US Patent No. 459,527
[2] Improvement in Rotary Pump, US Patent No. 141,000

Comparison to a Rolling Piston

A schematic of a rolling piston is shown in Figure 3b. The advantages of a rolling piston device are well-known and the earliest patent found is from 1909[3]. The closets embodiment that we have today is represented by a GE patent from 1956[4]. They can be best described as the following:

1) Good displacement density
2) Low production cost – simple geometry
3) Adequate efficiency and good variable speed operation

The major disadvantages are also well-known and are described below.

1) Limited scalability due to manufacturing limits and high slide velocities of metal to metal parts.
2) The limited tolerance to particulate and liquid refrigerant flood-back. The sliding vane requires tight clearance to the fixed surfaces. As a result, particulate and liquid refrigerant flood-back, have shown to be problematic in service.

[3] Rotary Compressor, US Patent No. 910,175
[4] Rotary Compressor, US Patent No. 2,833,101

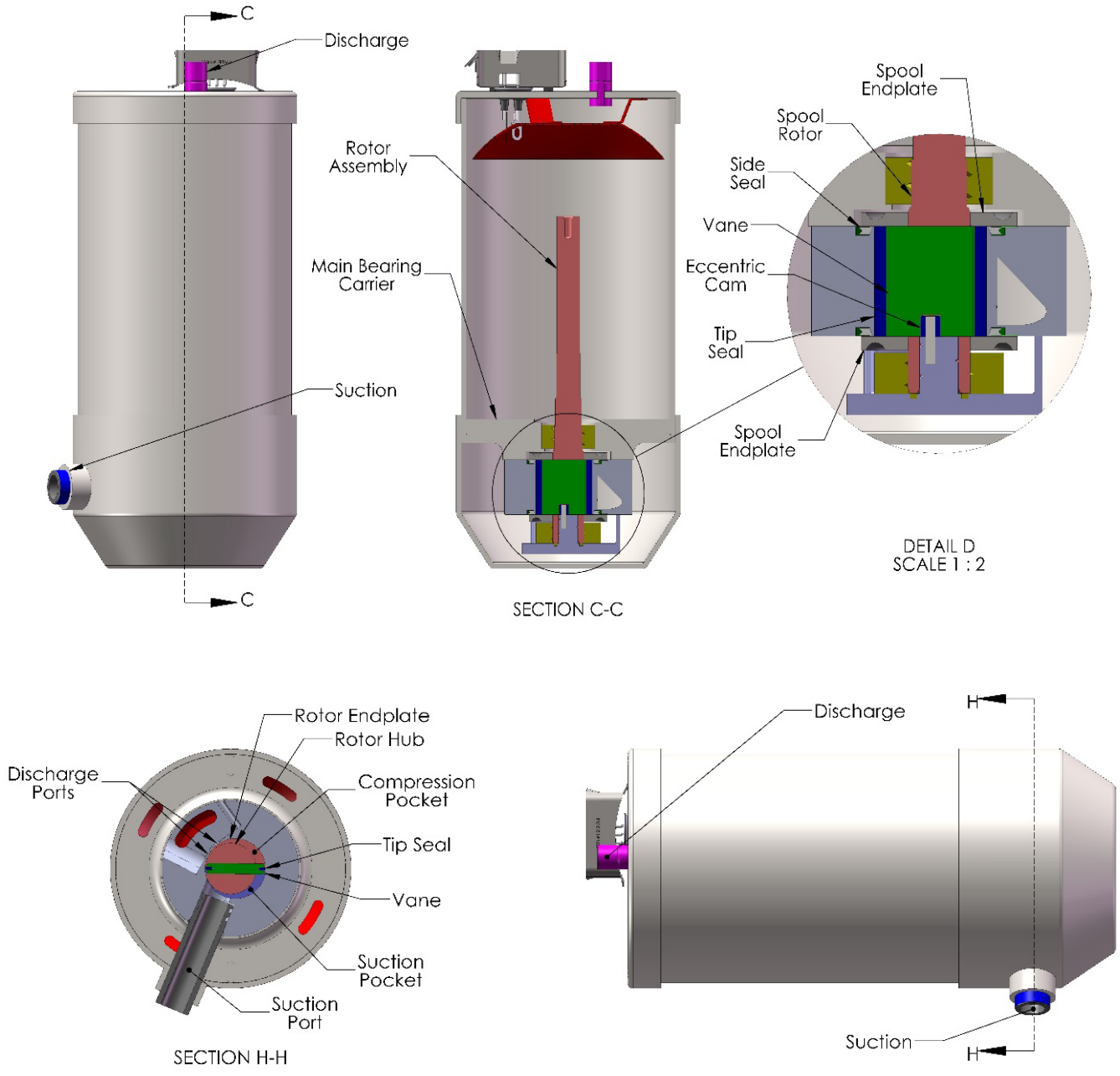

Figure 1: A hermetic rotary spool compressor assembly highlighting the spool compressor mechanism and its key components. The hermetic motor assembly is not shown.

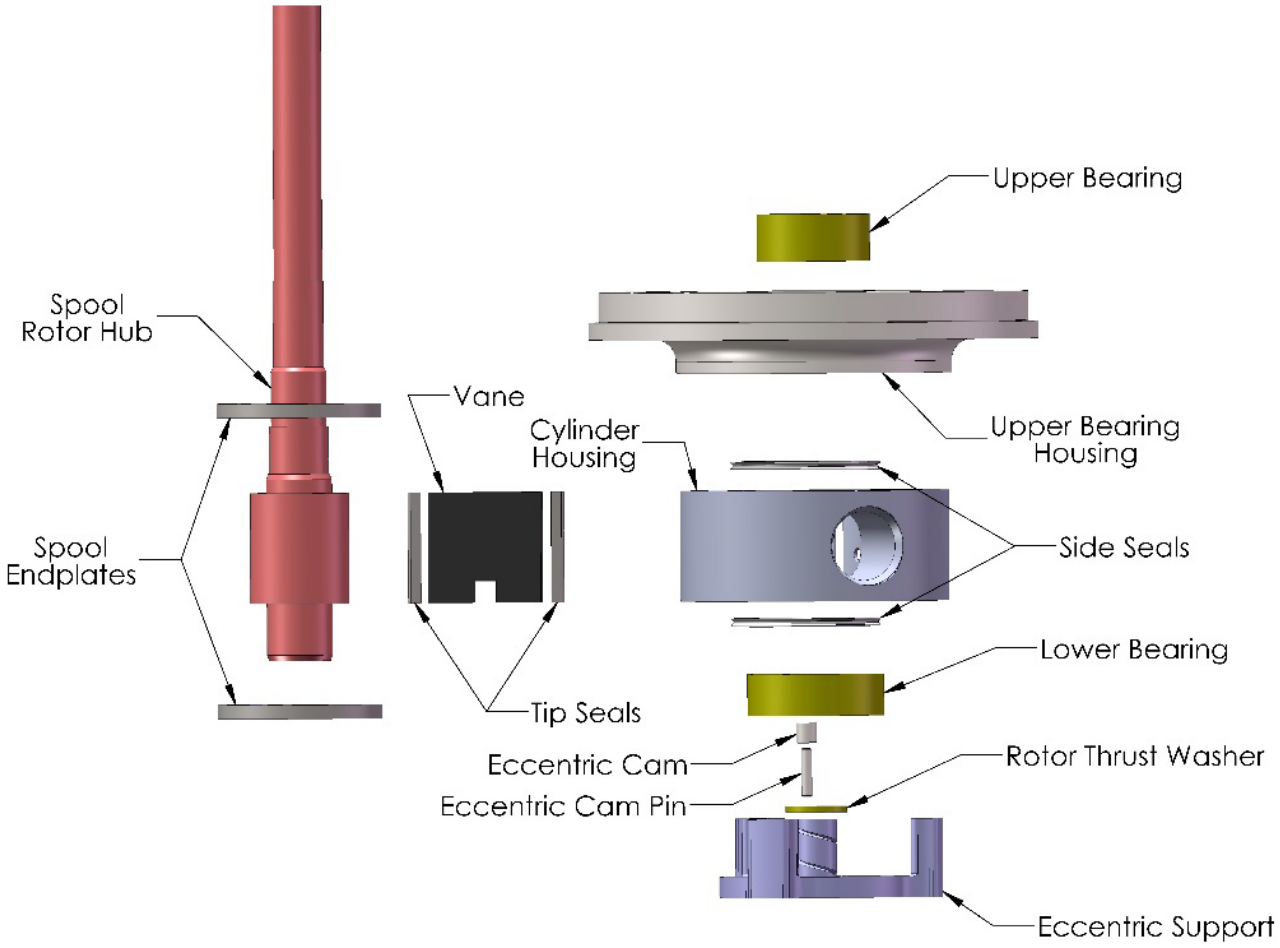

Figure 2: Exploded view of rotating spool compressor mechanism assembly. The rotor assembly is shown on the left and the cylinder housing and bearing assemblies on the right.

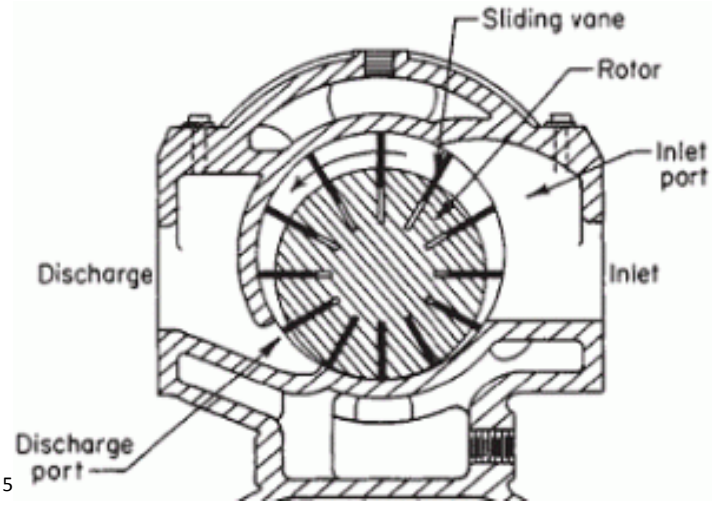

Figure 3a. *Sliding Vane*[5]

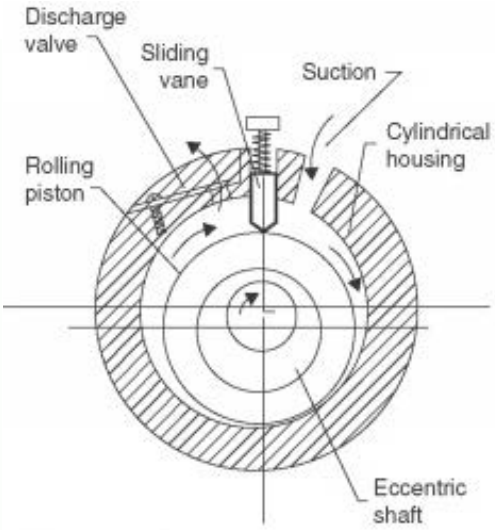

Figure 3b. *Rolling Piston*[6]

[5] http://www.enggcyclopedia.com/2011/05/compressors/
[6] http://www.ref-wiki.com/content/view/31166/28/

Applications:

Commercial Air Conditioning: 12 – 100 Tons

The rotary spool compressor is well suited for application in the commercial air-conditioning market due to the compact nature of the device and the ability to be packaged well in a hermetic or semi-hermetic configuration. The spool compressor can be designed to give good performance over a wide operating speed range for VFD applications. For fixed speed designs at the smaller end of the range, a 2-pole 3,550 rpm design is appropriate but this will transition to a 4-pole design at the larger end of the range. In either case, the motor diameter is the limiting dimension to the overall size of the spool compressor. The upper end boundary can stretch to at least 100hp with effective performance from a cost/efficiency balance. Above that size, screw compressors will outperform the spool but will always be a more expensive option.

Due to the high displacement density of the rotary spool compressor, it can be applied cost effectively with many refrigerants. In the commercial AC market, R410A is most commonly used and for this reason much of the early development work has been performed using this refrigerant. The spool compressor can easily be applied on R407C and can even be applied on R134a cost effectively, where a scroll compressor cannot compete.

The rotary spool compressor can also be designed with an economizer for improved system efficiency and the possibility for a cost effective 2-stage compressor exits for high ambient application where keeping good capacity under high head pressure would be an advantage.

Transport/Mobile AC/Engine Driven AC

The rotary spool compressor has many attributes that could be exploited in the transport sector and these are described as below.

1) Compact low weight design – due to high density displacement, the potential exists to take space and weight out of the design for the compressor/driver for containers and other transportation applications.

2) Engine driven – due to positive sealing elements, the machine is very effective at small diesel engine direct drive speeds from 500 – 3,000 rpm.

3) Operation with different refrigerants – the spool compressor is effective with many refrigerants.

4) Wide operating range – as the spool compressor does not have an internal volume ratio, it is possible to handle many operating conditions with good efficiency matched with a variable speed drive. For example, a container unit that needs to be able to handle many temperatures depending on the specific product being carried.

5) 2-Stage – a two stage direct-drive machine can be envisioned as the compact nature of the mechanism would make this possible. This could provide a host of benefits including maintaining good efficiency and capacity under high head pressure applications, the ability to have multiple evaporator conditions on the same unit using one compressor and reduced space requirements.

Residential A/C

The rotary spool compressor is the perfect solution for residential AC starting from the upper end of the rolling piston technology. The spool compressor could be considered as more cost effective than a twin cylinder rotary depending on production volumes. The spool compressor also has some attributes making it more attractive than a rolling piston, such as a high tolerance to liquid refrigerant flood back as well as a good tolerance for contamination.

Light Commercial A/C

The rotary spool compressor can also serve as a bridge product between the residential market and the commercial market based largely on a residential design. In this way, the spool

compressor is applied on the high end of the residential market above the rolling piston machines and then stretches up into the light commercial optimized a platform for could go from 5 – 12 tons. The compact and cost effective nature of the spool compressor would work well in this space.

