Higher Efficiency, Lower Sound, and Lower Cost Air Conditioning Compressors: Part 1 – Efficiency

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HIGHER EFFICIENCY, LOWER SOUND, AND LOWER COST AIR CONDITIONING COMPRESSORS
PART 1 - EFFICIENCY

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ABSTRACT

This two-part paper describes a compressor redesign program for improving efficiency, lowering sound emission, and cost. Part I indicates how the efficiency goals were met through reduced flow losses, reduced superheat in suction flow path, and improved valve and port design.

INTRODUCTION

Common reciprocating compressors utilize steel flapper valves and a Cylinder Head that encloses a suction and discharge plenum. In these compressors, the suction gas enters the cylinder head into the suction plenum, passes through a steel flapper valve into the cylinder on the suction stroke, is compressed on the discharge stroke and is forced through a steel flapper valve into the discharge plenum. Heat transfer occurs from the high temperature discharge plenum to the low temperature suction plenum across the cylinder head wall, which separates the plenums.

In the Inertia compressor (Fig. 1) the gas flow and valve system is improved, resulting in cooler gas entering the cylinders and reduced flow losses through the valving. The suction gas is routed through the crankcase wall, through the piston, and enters the cylinder past a polymeric suction valve that floats freely on top of the piston. The free-floating valve results in increased valve open time and decreased flow losses. On the discharge stroke the gas is compressed and forced past a polymeric discharge valve that allows a large flow area with significantly reduced re-expansion volume. The cylinder head on this compressor is devoted entirely to the discharge plenum. The result of the cooler suction gas into the cylinder and reduced flow loss through the valve system is a very high-efficiency reciprocating compressor. The trade off for the efficiency improvement is in higher air-borne sound and higher cost than with Bristol Compressors standard product line, although the Inertia compressor remains very competitive in both sound and cost with competitive products.

The challenge presented was to design a compressor with efficiency equal to, or better than, the Inertia compressor but with lower sound and cost. In general, efficiency gains normally come at the expense of sound and cost. In approaching the challenge, the initial steps involved maximizing efficiency within the marketing constraints of compressor size, the objective being to maintain the overall size and mounting characteristics as the standard steel flapper valve product currently in production. Also, the further objectives were to reduce sound and cost. Therefore, a standard production steel flapper valve model (Fig. 2) was chosen as the baseline for improvement. The compressor size range involved with this development is 1-1/2 to 3 Ton capacity.

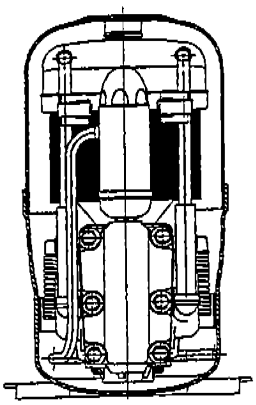

FIGURE 1
H25BQ
Inertia

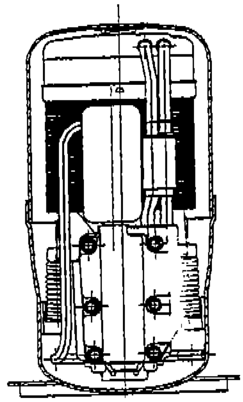

FIGURE 2
H23BS
Steel Flapper Valve Baseline Model

After efficiency targets were achieved, sound characteristics and discharge pulse characteristics were evaluated and programs were implemented to bring air-borne sound levels and discharge pulse in line with objectives while maintaining efficiency improvements. The costs of various alternatives were evaluated throughout the process.

Research and development to achieve this objective has been completed and the resulting design is patent pending. Compressors have undergone extensive reliability qualification testing, including over 100 compressors tested at various extreme conditions. The design was released to production in November 1997. This paper will summarize the design process, which included extensive development testing. The sound and discharge reduction programs are covered in Part 2 of this paper.

EFFICIENCY IMPROVEMENT

Initial design consideration was based on an analysis of the flow path within the compressor. Based on this analysis it was determined that the flow path would need to be less restrictive from the suction side all the way through to the discharge. To help in understanding the contribution of the major components, a Taguchi experiment, Full Factorial L8 Orthogonal Array [1] with 2 repetitions per trial, was performed. The factors chosen for study were suction tube area, suction port area, discharge port area, and shockloop diameter. The results of this study showed that, with very high confidence levels, the suction tube size and shockloop size should be increased. The study did not show a significant contribution from port size increase although later design iterations and testing would prove the need for redesigned ports and valves.

In addition to the changes in flow area throughout the compressor, it was felt that there was excessive superheat in the suction gas due to the close proximity of the suction plenum to the discharge plenum in the cylinder head. In the Inertia compressor the suction gas is separated from the discharge gas, resulting in less superheat at the suction valves than with the standard compressor. In the conceptual phase of the new compressor design, major consideration was given to the reduction of superheat at the suction valve. This was achieved through the use of a cylinder head redesign to allow the use of a separate suction manifold as seen in Figure 3 below. The initial manifold used was a nylon injection molded part but was later changed to steel to reduce air-borne sound levels. The manifold provides a large cool gas suction plenum which is connected to a second small suction plenum in the cylinder head. The separation of the suction plenum from the hot cylinder head results in suction plenum gas temperatures approximately 27 °F cooler than in the standard compressor.

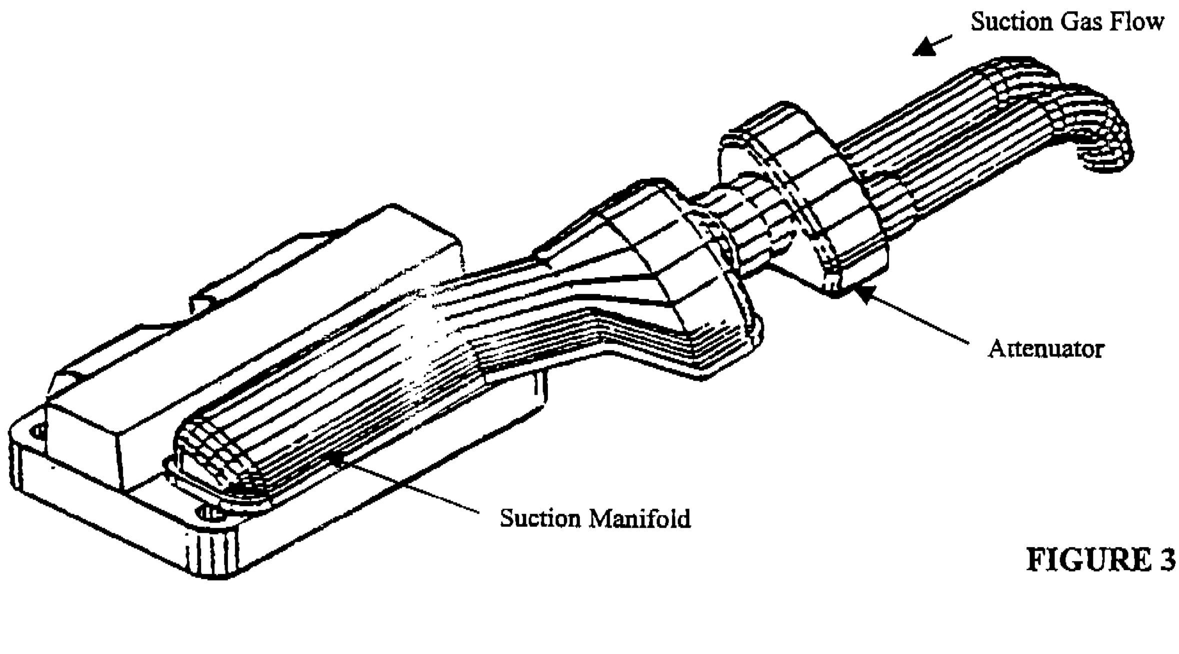

FIGURE 3

Both suction port and discharge port flow areas were increased and increases in valve stress due to the larger flow areas required a valve redesign. Finite Element and modal analysis was performed using ALGOR software to model various valve designs for initial testing. The objective of design iteration was to maintain valve timing characteristics of the baseline models in current production while resisting the higher loading with the increased port size. The valve plate thickness was also decreased to offset re-expansion volume increases associated with the larger discharge ports.

The final compressor design is as shown in Fig. 4 below. Efficiency gains of 5-6% at the ARI test condition (45°F Evaporator / 130°F Condenser) were realized in comparison to the baseline model. Gains at higher mass flow conditions, more typical of actual AC applications, were in the range of 13-14%. Approximate contributions to this gain, attributable to individual design changes, can be seen below in Table 1.

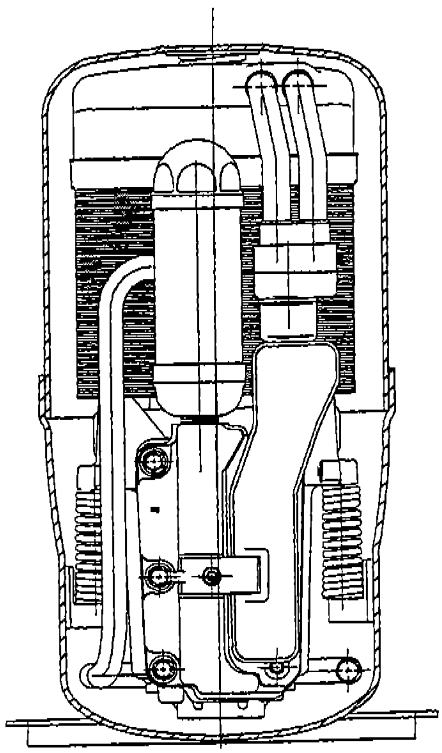

FIGURE 4

H29B Model

TABLE 1
Approximate Contributions of the Various Changes
(Improvement from baseline)

Larger suction tubes	1.1%
Reduced superheat at suction valve	1.5%
Redesigned suction ports/valves	0.6%
Redesigned discharge ports/valves	0.7%
Reduced valve plate thickness	0.7%
Larger shockloop	1.2%

Confirmation testing of the design changes confirmed the efficiency improvements expected. A summary of the efficiency improvements for a 35,000 BTU/Hr model is shown below in Table 2. The efficiency is stated in terms of EER (Energy Efficiency Ratio, BTU/Watt Hr). As can be seen from this data, efficiency goals were met in comparison to the Inertia compressor and there was significant improvement in comparison to the baseline model.

35,000 BTU/Hr Model	Condition (Evaporator Temp./Condenser Temp.)		
	45°/130°F	45°/110°F	45°/100°F
Std. Production Compressor (Steel Flapper Valves)	10.3	13.3	15.4
Inertia Compressor	11.0	14.9	17.4
Improved Compressor	10.9	14.9	17.5
Improvement from standard compressor	5.8%	12.0%	13.6%

TABLE 2

Costs were also reduced as compared to Inertia and sound was reduced by approximately 3 dBA. Design issues relative to sound and discharge pulse reduction to target values are detailed in Part 2 of this paper.

CONCLUSIONS

- Efficiency targets were achieved through improved gas management, reduced flow restrictions, and improved valve design.
- Cost targets were achieved through innovative construction and utilization of current production, steel flapper valve, compressor as a baseline.

REFERENCES

[1] Ross, P.J., 1988, *Taguchi Techniques for Quality Engineering*, McGraw-Hill Book Co., New York.