2000

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# A NOVEL AUTOMOTIVE TWO-STAGE A/C COMPRESSOR

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## ABSTRACT

A novel automotive two-stage a/c compressor is presented. The compressor utilizes a unique two-stage, rolling-piston rotary design to achieve improved performance in thermal efficiency and in NVH. The compressor has improved durability, especially under low lubrication and dry running operation. Manufacturing of compressor components are made easier by using simple (circular and rectangular) shapes for most parts.

Design of the compressor will be presented along with design and performance characteristics.

## INTRODUCTION

A novel two-stage rotary compressor (referred as VF2 hereafter) is designed and developed for automobile application. The objective of this positive-displacement refrigeration compressor is to achieve a well-balanced customer attributes in performance, Noise-Vibration-Harshness (NVH), durability, variable capacity, manufacturability and cost/investment for automobile application.

## DESIGN CHARACTERISTICS

Figure 1-3 show the outer image, the cross section and schematic of compression principle of the VF2 compressor, respectively.

Low pressure refrigerant vapor is introduced into the first-stage compression chamber via ports situated in the sliding vanes . The port's geometry and shape is optimized to time the entrainment of refrigerant kinematically. The first-stage compression is completed by the gradual reduction of volume with a crescent shape cross section formed between inner wall (circular) of housing and outer wall of the rolling piston (Rotor). The rotor is driven eccentrically by the crank shaft.

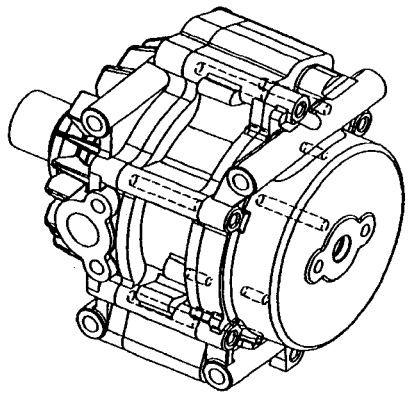

*Figure 1 VF2 Compressor Body*

The compressed vapor after first stage is discharged into intermediate plenum in the rear housing through reed valve. The refrigerant vapor at this intermediate pressure and temperature is introduced into the second-stage chamber formed by inner wall of rotor and the outer wall of the post to complete the full compression.

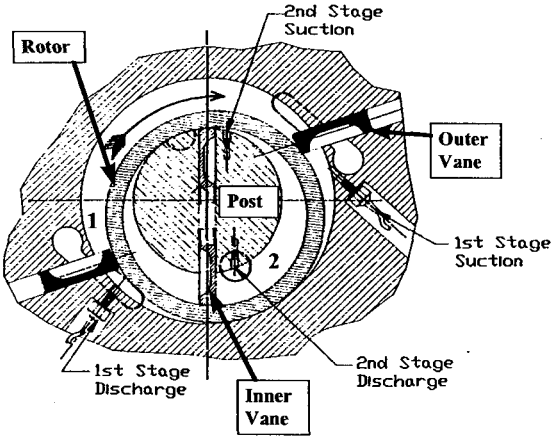


*Figure 3 VF2 Compression Principle*

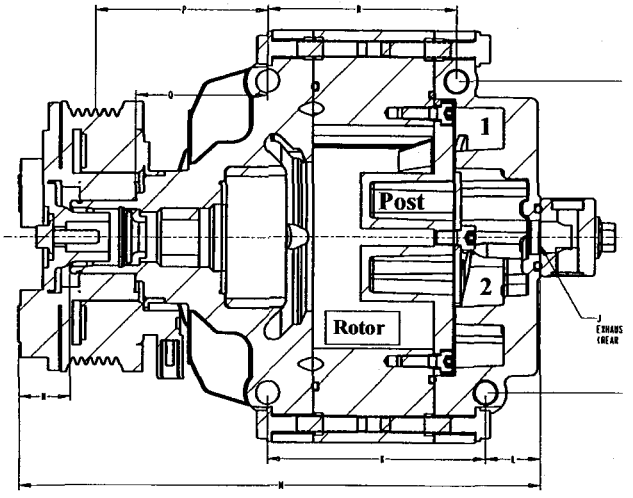


*Figure 2 Cross Section of VF2 Compressor*

Design challenges lie in several areas:

1) The sealing of internal components to meet the performance requirement at lower operating speeds (idle condition of mobile vehicles).
2) The durable operation at higher speed (bearing, reed valves)
3) The durable operation under limited lubrication or even dry condition, which occurs in automobile a/c applications due to loss of charge and/or slugging.
4) Good NVH characteristics.

## SIMULATION

Simulation based on the first-law (mass and energy), heat transfer, kinematics and dynamics (reed valve) is used to detail the loss mechanism of VF2 compressor. Figure 4 depicts the simulation flow chart and Figure 5 is the analysis result. It is recognized that throttling and friction losses at high speeds are significant. The results are used in the optimization of design such as inlet/outlet port geometry (CFD), selection of coatings and machining requirement of sliding surfaces.

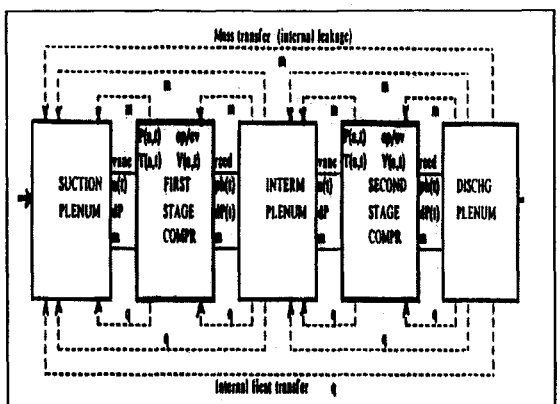


*Figure 4 VF2 Simulation Flow Chart*

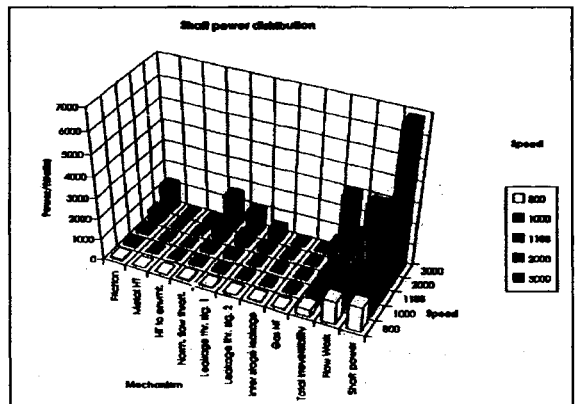

*Figure 5 Power Loss Breakdown*

## DESIGN OF EXPERIMENT (DOE)

The methodology of Taguchi robust DoE is applied to the current 2-stage automobile A/C compressor system. Figure 6 shows the P-diagram of the compressor.

The performance objective of the compressor is to utilize minimum power in order to achieve desired cooling capacity. Thus the output responses (*y*) are the measurable such as mass flow rate (volumetric efficiency), horse power, coefficient of performance (COP), isentropic efficiency, etc. For the purpose of the study, mass flow rate, torque and discharge temperature are selected as ideal function parameters. For the input (*M* value), ideal values under a certain condition (head pressure and suction pressure/temperature) are used.

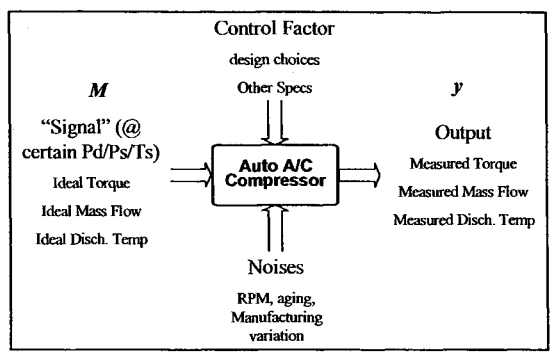


*Figure 6 P-diagram of Auto A/C Compressor System*

Detailed study is presented in Huang, et al [1].

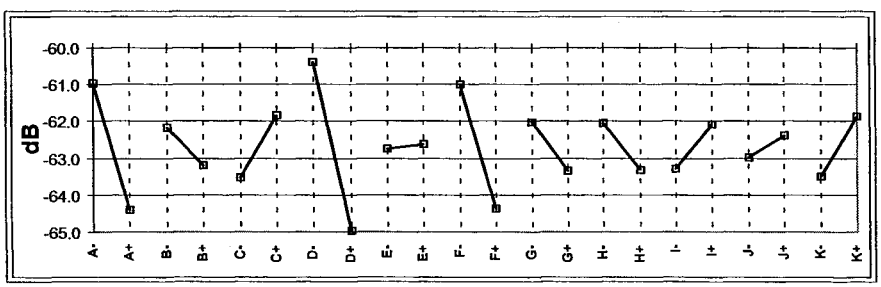


*Figure 7 S/N Effect Plot*

The DoE result shown in Figure 7 suggested that design factors A, C, D and F (it turned out that all these four parameters are clearances) are critical parameters and design target and tolerance should be maintained to ensure robust performance.

## PERFORMANCE

Performance of VF2 compressor is demonstrated in this section. Comparison is made with the other two fixed-displacement compressors: swash plate piston type (Visteon FS10) and a scroll type compressor.

| Test Point: 1000rpm/344psig/45psig/65F | *VF2* | *Scroll* | *FS10* |
|---|---|---|---|
| Capacity (W) | *2907* | *2985* | *3594* |
| COP | *1.56* | *1.58* | *1.57* |
| Vol. Eff (%) | *81* | *94* | *70* |
| Discharge Temp. (C) | *97* | *97* | *95* |
| Sound Power (dBA) | *67* | *71.6* | *73* |

*Table 1 Calorimeter Performance @ 1000RPM*

Table 1 and 2 compare the calorimeter performance output at two test points, respectively. Overall, VF2 compressor is competitive and its characteristics is closer to scroll type due to its rotary motion.

Figure 8 benchmarked the clutch engagement torque of three compressors while Figure 9 illustrates the comparison of discharge pressure pulsation.

| Test Point: 3000rpm/246psig/20psig/32F | *VF2* | *Scroll* | *FS10* |
|---|---|---|---|
| Capacity (W) | *5584* | *5880* | *5750* |
| COP | *1.32* | *1.52* | *1.19* |
| Vol. Eff (%) | *76* | *91* | *55* |
| Discharge Temp. (C) | *96* | *92* | *102* |
| Sound Power (dBA) | *79* | *79* | *84* |

*Table 2 Calorimeter Performance @ 3000RPM*

Experimental PV charts for both 1st and 2nd stages are shown in Fig. 10 and Fig. 11, respectively.

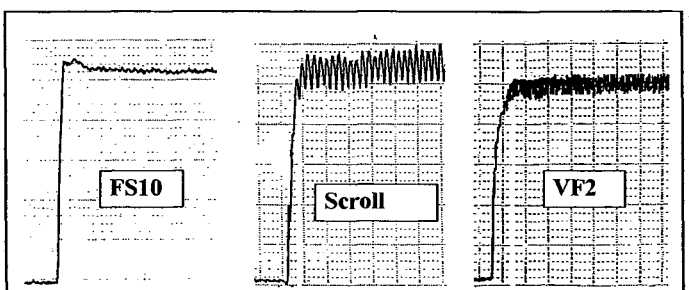


*Figure 8 Clutch Engagement Torque @ 1188RPM/269psig/37psig/64F test point*

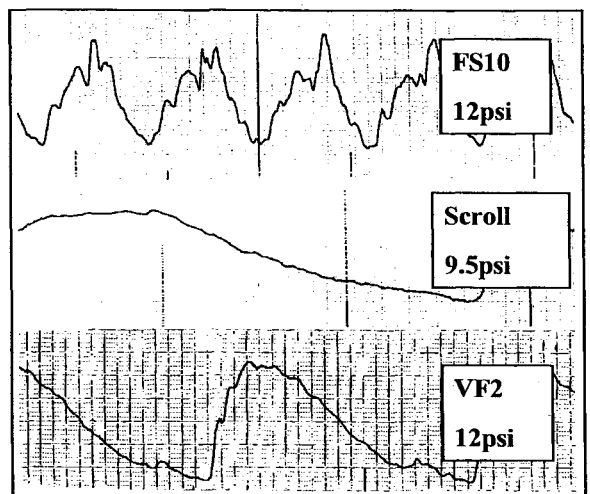


*Figure 9 Discharge Pressure Pulsation*

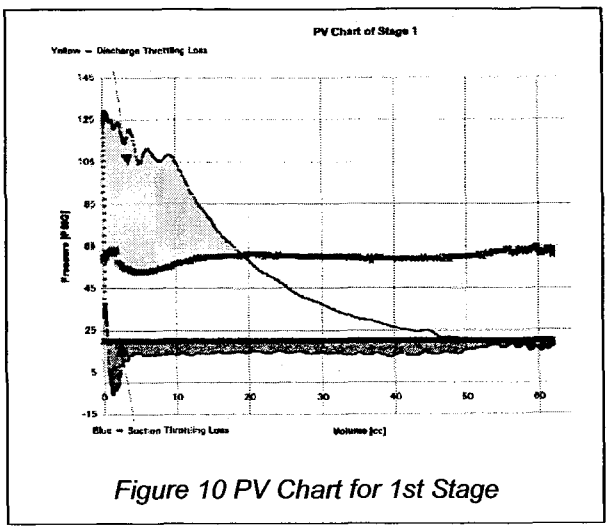


*Figure 10 PV Chart for 1st Stage*

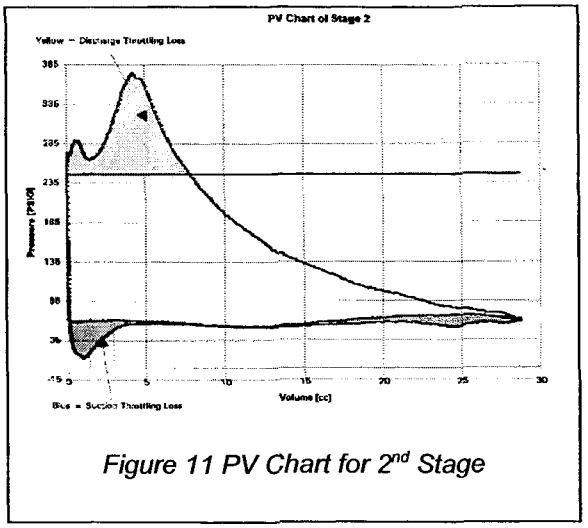


*Figure 11 PV Chart for 2nd Stage*

## DURABILITY AND VARIABLE CAPACITY

VF2 compressors have undergone rigorous durability testing including high pressure (up to 500psig discharge pressure), high speed (up to 8000 RPM continuously and 10,000 RPM intermittently), liquid slugging and low-charge, low-oil tests.

Special design features and consideration for high mileage application is detailed in the paper by Sud, et al [2]. It is demonstrated that VF2 compressor lasts more than 150,000 miles in a semi-trailer application.

Due to its unique two-stage compression, VF2 compressor is readily adaptable to variable-capacity compressor. Harte et al [3] details the development and results.

## SUMMARY

A novel, two-stage compression, rotary compressor (VF2) for mobile vehicle (belt-driven) is developed to meet high-mileage requirement under severe automotive application conditions. VF2 Compressor has demonstrated its high-mileage durability. Its performance is competitive among current production fixed-displacement compressors in R134a system. Durability of VF2 compressor has been demonstrated in lab and on vehicle.

## REFERENCE

[1] Yong Huang, et al "Dynamic Parameter Optimization of an Automobile A/C Compressor Using Taguchi Method", Proc. 1998 Int. Compressor Engineering Conf. at Purdue, 1998, Purdue University, pp261-266.

[2] Lavlesh Sud, et al "Development of Rotary Compressor for Semi/Trailer Truck Application", Proc. 2000 Int. Compressor Engineering Conf. at Purdue, 2000, Purdue University.

[3] Harte, et al "Design and Development of a Variable Rotary Compressor", Proc. 2000 Int. Conf. Compressor, 2000, Purdue University.