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THE HISTORY OF A HIGH EFFICIENCY VALVE FROM CONCEPT
THROUGH FIELD ACCEPTANCE

by
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ABSTRACT

As a result of research done in the early '70's on the loss mechanisms and causes of failure in compressor valves, a new line of valves was designed and developed. The new line of valves has losses less than one-third the losses in earlier valves and is also more reliable. This paper outlines the basis for the improvements in efficiency and reliability, and describes the development process leading to the efficient, reliable valve now in production. This development process took over 10 years including laboratory development and extensive field testing.

INTRODUCTION

In 1974, Dresser-Rand engineers decided to take a new look at losses in compressor valves and discovered that large decreases in the losses were possible with relatively small changes in valve design; specifically using seats with narrower slots to increase the flow area through the guard. About the same time, the use of non-metallic plates in gas field compressors was starting. These have several advantages including the ability to run with higher impact velocities and hence avoid the necessity of using the very low lifts required with steel plates at gas field compressor speeds (about 1000 rpm). A new valve design was started to utilize these two advances.

5-1/4" prototype valves built in 1975, were used to test the efficiency of the new valve under field conditions and a very significant improvement was seen. The prototype valves were then left in service to determine the reliability of glass filled nylon plates at .140" lift.

Preproduction valves in 5-1/4" and 7-1/2" sizes were then manufactured and an extended field test with 162 valves was started. Severe reliability problems were encountered with the plastic plates used at that time. These were eventually solved through changes to the plate thickness, the spring button material, the spring pattern and improvements to the composition and manufacture of the plates.

The HPS valve (U.S. Patent #4,184,508 and 4,307,751) was first used in a low speed gas compressor in 1982 and was released for production in 1985. It is now widely used in gas gathering, gas lifting, enhanced oil recovery and refinery compressors. Improvements to the valve have continued to be made since the initial preproduction valves were made. In particular, the plate material has been changed to a specially formulated, carefully manufactured, Peek based material and to allow operation of high pressure valves at high speeds, the springs have been redesigned to prevent their going solid. Quality control has also been improved to prevent reoccurrence of some of the start up problems encountered.

VALVE DESIGN

The philosophy behind the design of the HPS valve was to incorporate the advances made in valve optimization and materials to design a very high efficiency valve with well proven design features. Simplicity and lack of narrow flow passages were design goals to allow reliable service in harsh environments.

Optimization

The initial concept of the HPS valve resulted from a series of flow tests in which the pressure drop across the valve and the flow rate through the valve were measured (Fig. 1). We quantify the efficiency of a valve by the "Equivalent Area." This is defined as the area of an ideal orifice that would give the same pressure drop as the actual valve at the same flow rate. It is significantly smaller than the seat area, the lift area or any other flow area in the valve and is the true measure of the valve's efficiency. We were looking for a way to predict the equivalent area of a valve from its geometry. We found that this could be done with good accuracy for a range of valve designs by modeling the valve as three orifices (Fig. 2). The first orifice (F_S) represents the restriction through the seat; the second (F_L), the lift area; and the third (F_G), the restriction between the plates and through the guard. The gas obviously flows through these three orifices in series. The tests on different valve geometries allowed us to calculate the flow coefficients associated with each orifice C_S , C_L and C_G . With this information, the equivalent area of any new design can be calculated.

$$\frac{1}{F_{eq}^2} = \frac{1}{(C_S F_S)^2} + \frac{1}{(C_L F_L)^2} + \frac{1}{(C_G F_G)^2} \quad (1)$$

Thus the most efficient valve can be designed

Analysis shows that a valve will have the maximum possible equivalent area, i.e., minimum pressure loss, if

$$\frac{\text{Seat Area}}{\text{Guard Area}} = \frac{F_G}{F_S} = \frac{(C_G)^{2/3}}{(C_S)} \quad (2)$$

For conventional valves, the values of C_S and C_G are such that

$$\frac{(F_G)}{(F_G)_{opt}} = \frac{(C_G)^{2/3}}{(C_S)} = 0.76 \quad (3)$$

That is, the seat area should be less than the guard area. We found that most valves made at that time had the seat area larger than the guard area. This was because compressor performance was calculated using the seat area, so valves with a large seat area gave better calculated efficiency and the poor actual efficiency caused by the large pressure drop across the guard was not considered.

Thus the first design criteria for the HPS valve was that the seat and guard flow areas be proportioned to minimize the total pressure drop (Equn 3).

Plate Material

It was decided that non-metallic plates would be used in all HPS valves when the operating pressures and temperatures allowed this. The reasons for this were:

- 1) Non-metallic plates are more resistant to impact damage and thus allow reliable operation at high lifts,
- 2) Non-metallic plates will not harm a cylinder if they do fail,
- 3) Non-metallic plates are highly resistant to corrosion, and
- 4) Non-metallic plates can tolerate dirtier conditions than metal plates.

Lift

Based on the decision to use non-metallic plates, it was known that higher lifts could be used and .140" was selected for reliability testing. Our old style valves which at that time ran with .090" lift, were remachined for .140" lift and installed at two typical gas gathering sites. No failures occurred over an extended operating period and the lift of .140" was selected for the HPS valve.

Number and Width of Plates

Once the lift and overlap (sealing surface) are selected, the optimum number of plates and hence the width of the plates can be chosen. When the HPS was designed, we did this by trial and error, designing valves with different numbers of plates and calculating their equivalent area using equation (1). We now know that the optimum sealing surface length, which determines the number of plates is given by

$$l = \frac{F_{\text{seal}}}{\delta}$$
$$\text{and } \frac{F_{\text{seal}}}{\frac{\pi}{4}D^2} = \frac{1}{1 + \left\{ \frac{(C_L)^{2/3}}{(C_S)} + \frac{(C_L)^{2/3}}{(C_G)} \right\} \left(\frac{h}{\delta} \right)^{2/3}}$$

where l = Seal surface length for maximum F_{eq}
 F_{seal} = Seal surface area for maximum F_{eq}
 δ = Seal surface width
 D = Valve diameter
 h = Lift
 C_S, C_L, C_G = Flow coefficients as above

As expected, this shows that, if the lift is low, then the lift area controls the flow and the optimum valve will have a large number of plates to increase the lift area. If the overlap is large, then the area "wasted" by the sealing surface reduces the seat and guard areas significantly and the optimum valve will have few plates.

In designing the HPS valve, we found that the old valves of all sizes through 6-1/2" already had the optimum number of plates. We increased the number of plates in the 7-1/2" valve from 4 to 5.

PROTOTYPE TESTING

Steady Flow Tests

To test our optimizing methods, accurate wooden models of the 5-1/4" and 7-1/2" HPS valves were made and tested in the steady flow rig (Fig. 1). The results of these tests for the popular 5-1/4" size confirmed the optimization methods used as a 35% decrease in the pressure drop compared to our previous valves at .140" lift and the same flow rate was measured. The decrease in pressure drop comparing the HPS at .140" lift to the previous valve at .090" lift was 65%, i.e., the HPS had only one-third the pressure drop of the most efficient valve we were then supplying. This improvement was partially due to the increased lift and partially due to the optimization.

Later in the development cycle when the full line of valves had been designed and built, all sizes were tested. The results of tests on the production valves confirmed the results of the wooden model tests (Fig. 3). Note that the pressure drop is inversely proportional to the square of the equivalent area.

Performance Test

The first prototype 5-1/4" HPS valves were tested at a typical gas gathering site in Texas. Performance with three valve types was measured by an orifice for capacity and an electronic cylinder indicator for horsepower. The performance of the compressor was tested over a range of pressure ratios by pinching the suction. The results (Fig. 4) compare the HPS valve to our previous valve at 0.090" and 0.140" lift and a poppet valve in wide use in gas gathering at that time. The horsepower required to compress the same amount of gas through the same ratio is 11% less with the HPS than with any of the other three valves. It must be pointed out that this was a relatively low efficiency application to begin with and that efficiency gains of this magnitude will not always be obtained.

Reliability Tests

Prototype valves were made in 5-1/4" and 7-1/2" sizes and 162 of these valves were installed in the field at 5 sites and close contact with the operations and maintenance personnel at these sites was maintained. A significant number of reliability problems were found and work continued for several years to resolve these. The following changes had to be made before reliable operation at these test sites was obtained:

i) The original HPS nylon plates were .125" thick. This was thicker than many plates used at that time, .100" being common, but was proved inadequate. The plate thickness was increased to 0.250" with major benefit to plate life.

ii) We learned a lot about the problems of manufacturing non-metallic plates of good quality and the extra expense involved in doing this. In particular, we had problems of plate dimensional instability due to poor molding and stress relieving practices and due to excess water absorption caused by composition and manufacturing methods. As described below, we have been working continuously since that time to improve our plate materials. To allow for the instability of the best plates available at that time, the valves were redesigned to provide more clearance for the plate and to maintain adequate sealing area after plate distortion.

iii) The initial spring buttons were made of glass filled Teflon and, in some applications, excessive wear rates were encountered. A change to a PPS (POLYPHENYLENESULFIDE) based material reduced wear to acceptable levels, but additional development has been done in this area and Peek (POLYETHERETHERKETONE) based materials are now used.

iv) Plate failures were concentrated at the spring positions in some cases. This was thought to be due to bending of the plate (.125" thick) over the spring and was solved by adding springs wherever the span between springs was greater than 2-1/4".

With these modifications, good valve reliability was obtained.

Plate Materials

All the original HPS development was done with glass filled nylon plates. After completion of the prototype testing, we became more aware of the importance of plate material composition and manufacturing technique. Working with our vendors using available technology and an extensive series of tests in a compressor in our lab., we developed a specification for a nylon based material (ESP) specifically formulated and manufactured as a premium valve plate material. These plates outperformed those made of materials used by other vendors to the extent that thousands of hours of operation could be obtained in the lab. under conditions that caused ordinary glass nylon plates to fail in a few hours. Among the changes made were the size and type of the glass filler, the sizing used to allow the glass to adhere to the nylon, the manufacturer of the nylon resin, the type of anti-oxidant and heat stabilizers used, the elimination of any harmful ingredients such as coloring agents, low cost fillers, and compounds to ease molding, and development of correct machining and stress relieving procedures to maintain the required dimensional stability and flatness.

Prior to the introduction of the HPS valve, we had developed a superior plate material (Hitemp) based on Peek. The main advantages of good Peek based materials over good Nylon based materials are the increased temperature capability (400°F), which can be important during an upset even if the usual operating temperature is less than the 300°F allowable with Nylon; the drastically reduced water absorption and the better physical properties. We have no doubt that Hitemp, while expensive, is the best plate material available today.

In an attempt to reduce the amount of expensive material wasted machining a set of rings, we worked to develop a way of molding the rings to give equal performance to machined rings. Results from laboratory tests of prototypes were encouraging, but results from production plates were unacceptable and this method of manufacture has been abandoned. Another way of reducing cost is to regrind the waste produced during machining and mix it with the material being molded. In many cases, plates with a certain amount of regrind will run successfully, but our tests have shown that they are always weaker than plates made with virgin material and we do not use any regrind. Plates being so important to the reliability of a valve, we have chosen to develop and supply the best plate available regardless of cost.

RECENT IMPROVEMENTS

Since the introduction of the HPS valve, two applications have been found that required adjustment of the design. The first was a high pressure (2000 psi) low speed, CO₂ injection compressor. The special high pressure 7-1/2" HPS valves in the discharge of the final stage of this compressor frequently failed at start up. This was traced to the start up differential pressure when the full discharge pressure was applied to the third stage with atmospheric pressure in the cylinder. This differential pressure, which is much higher than the allowable working differential pressure for Peek based plates, was causing failure at the sealing surface. The problem was cured by increasing the overlap and the valves have run very well since that change was made.

The second problem occurred with some high pressure gas gathering compressors where the impacts on the guard were very high (50 ft/sec). With the outstanding resistance to impact damage of Hitemp valve plates, this did not cause plate failure directly, rather plate failure typical of extremely late closing was seen. Close examination revealed that the springs were going solid, in some cases causing the end coils to overlap and jam the spring in the hole. The spring goes solid because the kinetic energy in the button at 50 ft/sec is more

than the energy absorbed by the spring between the minimum working length and solid. This was cured, with a dramatic resulting improvement in valve life, by designing a longer spring with increased energy absorption.

VALVE APPLICATION

The ideal way to select the valve specification for an application is to run a valve dynamic analysis (Fig. 5). This allows the spring to be chosen to be strong enough to close the valve before the dead center, but not too strong so it causes flutter. It also allows the impact velocities to be calculated to ensure they do not exceed the allowable limits for the material and design used. Valve selection for gas field compressors is easy in that the gas compressed, is always about the same and a given size cylinder is normally used at about the same pressure (because allowable frame loads vary over a narrow range for a compressor line), but difficult because the conditions under which a given cylinder operates may change daily and may not be accurately known when the compressor is sold. This contrasts with a process compressor cylinder which may be sold for a range of gases from hydrogen to carbon dioxide and may have pressures corresponding to a frame load from 30,000 to 210,000 lbs., but which will run for years at about the same conditions and at constant speed. For process compressors, we run a valve dynamic analysis and choose the valves best for the application. For gas field compressors, we can select a valve specification best for the average application of that valve and standardize on this with great benefit to parts inventory requirements, elimination of errors caused by mixing valves intended for different cylinders and removing the necessity of changing valve specifications when conditions change. Valves with plastic plates, especially a premium material such as Hitemp, will run reliably over quite a range of conditions, whereas valves with metal plates require more accurate customizing. We chose to run a large series of valve dynamic analyses and select the best spring for the average conditions seen by each valve size and supply this as the standard selection. In the vast majority of cases, this provides a reliable valve with good efficiency. However, four springs are available and can be used in each valve in the line. In a few cases, e.g., vacuum suction conditions, a non-standard selection spring will be required for optimum efficiency and in a few cases, a non-standard selection spring will improve reliability.

CONCLUSIONS

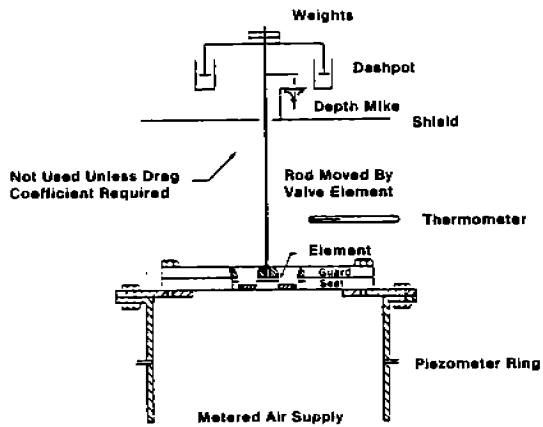
The HPS valve is simple, open and conventional in design, but provides highly efficient performance and good reliability with premium valve plate materials. It may seem surprising that the extensive development described here was necessary for such a seemingly conventional valve, but not at all surprising when the large improvement in efficiency and reliability obtained are considered.

ACKNOWLEDGEMENTS

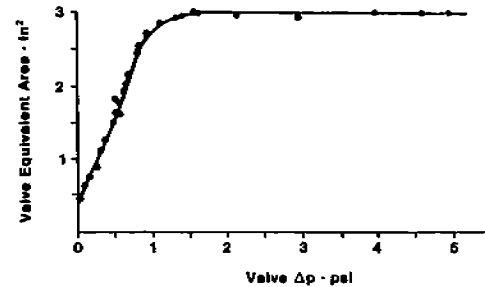
This paper is the history of a valve development lasting over 10 years. Many people at Dresser-Rand's plants at Painted Post and Buffalo as well as in the field contributed to this effort. This paper describes their work.

The author also wants to thank the management of Dresser-Rand for their encouragement and for permission to publish this paper.

Steady Flow Rig



Valve Equivalent Area



Drag Coefficient Test Data

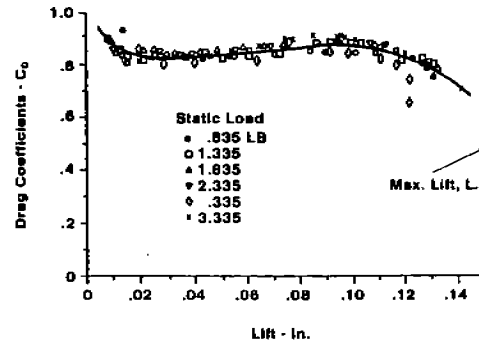
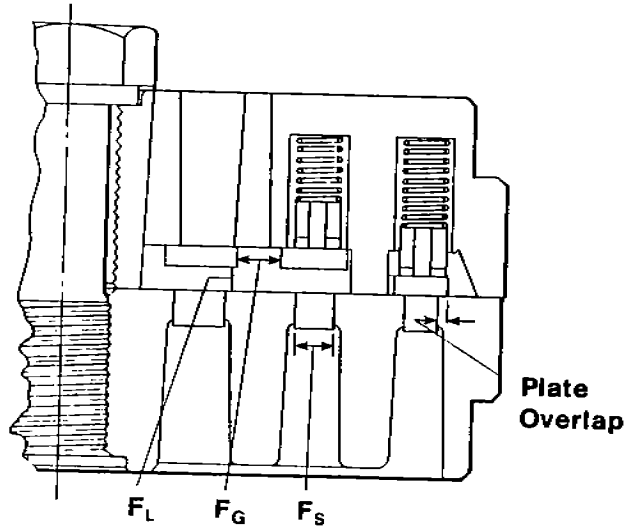


Figure 1

Cross Section Of Valve



Representation Of Valve As Three Orifices

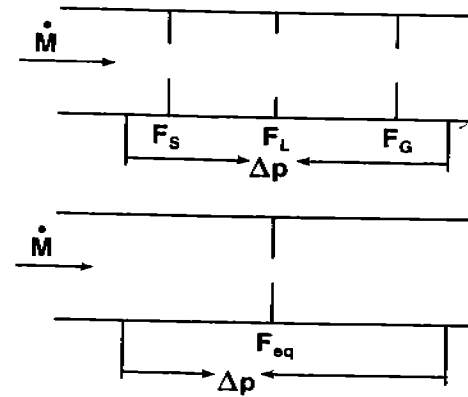


Figure 2

Steady Flow Test Results: HPS And Conventional Valves

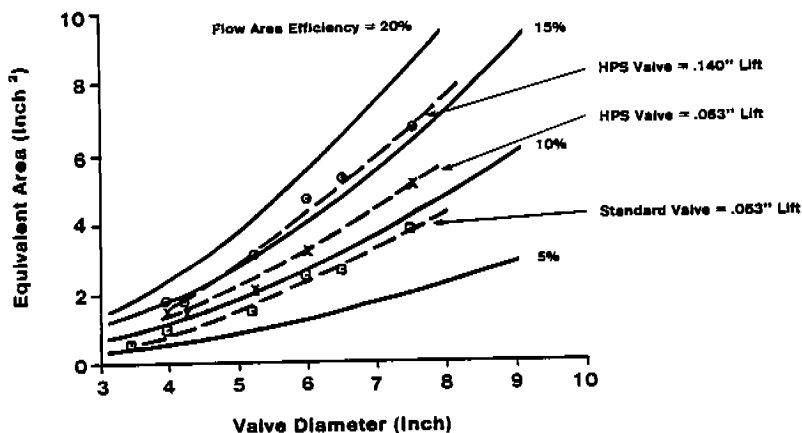


Figure 3

Field Efficiency Test Results

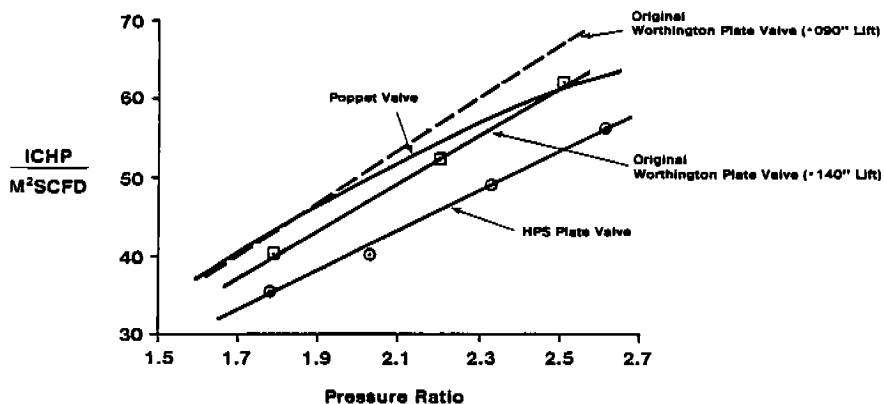
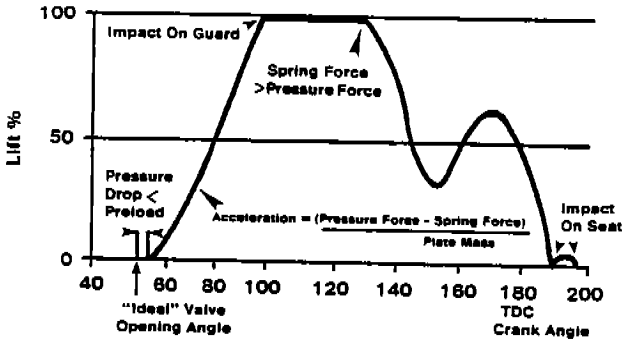
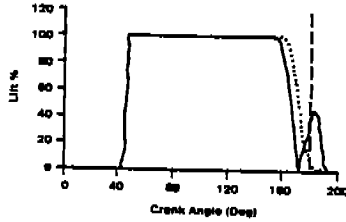
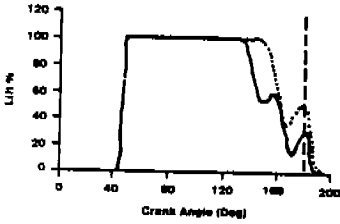


Figure 4

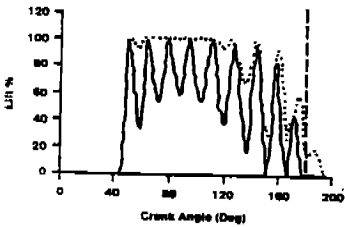
Valve Dynamics



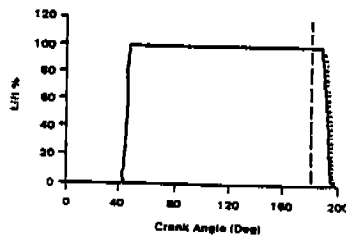
Basis Of Valve Dynamics Calculation



Good Valve Motion



Flutter



Late Closing

Figure 5