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The Influence of Liquids on Compressor Valves

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ABSTRACT

The presence of liquids in a compressor valve environment is a major factor in the life of a valve or sealing element. The nature of the fluid, the quantity in the system and the distribution of the fluid are of major consequence.

Through the use of modelling techniques these influences are analyzed, specifically the affect of geometry on the sticking effect. Several solutions to reduce the effect of sticking are investigated.

INTRODUCTION

Although compressor valves are generally configured for optimum performance under given gas data and operating conditions, the real life environment frequently brings an added element of liquids in the gas stream.

Sophisticated and precise computer programs are employed for valve layout calculations utilizing compression data and thermodynamic gas behaviour at inlet and discharge conditions to minimize the energy needed to perform the compression work and, at the same time, to keep impact energy of the valve plate at minimum to achieve acceptable life standards.

It has been known for some time that valve life is adversely affected from liquids in the gas stream even if the presence is only temporary and intermittent. Accumulations of condensates (water or hydrocarbons) as well as oil or lubricants can be very detrimental to valve life.

Practical experiences therefore are acquired from installations where premature valve failures can be attributed to several factors:

- Separators that either don't work or are not maintained

- Irregular, unpredictable overflow of fluids from separation systems that occur in unpredictable patterns and irregularly.

  This condition is particularly troublesome since the occasional liquid slug is not easily diagnosed and registered. The surest way to detect such liquid carry-over is to monitor and log the pressures and temperatures of a compressor cylinder with a chart recorder. Such transcribers will register deviations from normally sensed operating pressures and temperatures. A temporary drop in temperature at constant pressure is a reliable indication of the occurrence of a liquid carry-over. This is especially true when liquids evaporate during the compression cycle.

- Field experience from a large number of valve operations shows considerably longer valve life in non-lubricated service than in lubricated service. This, despite the fact that the presence of lubricants often reduces the negative influence of corrosive elements frequently found in the gas stream. In this sense, compression equipment employed in air-separation plants can undoubtedly be considered as an example of being truly free of any liquids.

PROCEDURE

Liquids can cause different damaging effects on a compressor valve. In principle the following damaging effects on compressor valve performance can be caused by liquids:

- True liquid slugs: These are rare since they occur only when the volume of liquid in the cylinder exceeds the major portion of the clearance volume. When this occurs the cylinder experiences a high, locally different pressure buildup. Since the discharge valve can normally vent the high pressure buildup and allow the liquid to escape, the effects of such slugs are generally more severe on the suction valves. Under static pressure frequently the weakest element of a valve is the valve plate. At times, damage to rods and crossheads or cylinder heads has been witnessed. In refrigeration compressors it is customary to springload cylinder heads or valves with heavy springs to prevent major damage to equipment.
- Occasionally, one finds valve pockets designed such that a portion of the valve is flooded with liquid. This inhibits the valve motion drastically in this sector. Such valve plates generally break on the opposite side. A simple remedy is to design valve pockets in a way that liquid cannot accumulate but drains constantly.
- Damage to sealing elements such as valve plates or rings by impacting on small liquid accumulations is generally not a problem except if extremely thin sealing elements are in use [Lit. 1].
- Sticking of the sealing elements to seat or guard surfaces is the most frequent effect on valves caused by liquid contamination. This invariably means a delay in the dynamic motion event and results in excessive impact velocities which are very detrimental to valve life.

The presence of liquid carry-over can generally be remedied through scrubbers and separators, yet the majority of compressor valves are exposed to lubricants in their operation. The objective, therefore, is to analyze the influence of lubricants on the valve dynamics and to develop measures to reduce the impact on the valves.

The following mathematical model is based on plate or ring valves, but would also apply to the geometry of strip valves. It is further assumed that the initial gap thickness is equal e_o and filled with liquid over its full width B and that no fluid enters into the gap during the separation of the two surfaces.

The volume of liquid $e \cdot b$ at time t equals that at time $t = 0$, or $e_o \cdot B = e \cdot b$; at this point the linear dimension of the viewed element is equal to 1 and later in the computation a variable for the exposed area is introduced as $A = 1 \cdot B$.

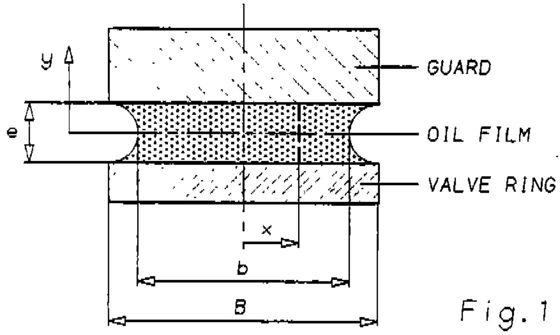


Fig. 1

As the two rigid surfaces separate at velocity $c = de/dt$ the volume of fluid $Q_x = c \cdot x$ has to penetrate at the sectional area indicated by the dashed line.

From NEWTON'S law $\tau = \mu \cdot dv/dy$ for laminar flow which prevails in the narrow gap that we are considering here, we derive that under the dynamic viscosity μ, the flow velocity v and the differential pressure dp at x

$$y \cdot dp = - dx \cdot \tau = - dx \cdot \mu \frac{dv}{dy}$$

and the same integrated in the direction of y

$$dp \int y dy = - dx \mu \int dv.$$

With the boundary conditions that the flow velocity equals $v = 0$ at $y = e/2$ and $y = - e/2$ results the following equation:

$$v = \frac{1}{\mu} \left(\frac{e^2}{8} - \frac{y^2}{2} \right) \frac{dp}{dx} .$$

At x enters the volume

$$Q_x = \int_{-e/2}^{e/2} v \, dy = \frac{e^3}{12 \mu} \frac{dp}{dx} = c \cdot x .$$

The integration with respect to x leads to:

$$\int e^3 \, dp = 12 \mu c \int x \, dx$$

and with $p = 0$ at $x = \frac{b}{2}$ follows:

$$p = \frac{6 \cdot c}{e^3} \mu \left(x^2 - \frac{b^2}{4} \right) .$$

From the pressure we can now equate the force needed to open the gap against the resistance of the fluid. Since the fluid volume is constant, integration is only permitted over the width b.

$$F = -\int_{-b/2}^{+b/2} p\,dx = \mu \frac{b^3}{e^3} \cdot c = \mu \frac{B^3\, eo^3}{e^6} \cdot c$$

Consequently, with $c = de/dt$ integrated over time t :

$$\int F\,dt = \mu\, B^3\, e_o^{\,3} \int \frac{de}{e^6}$$

With the boundary condition $e = e_o$ for $t = 0$ results:

$$\int_0^t F\,dt = \mu \cdot B^3\, e_o^{\,3} \left(\frac{1}{5e_o^{\,5}} - \frac{1}{5e^5} \right) = 0{,}2\,\mu\, A\, \frac{B^2}{e_o^{\,2}} \left[1 - (e_o/e)^5 \right]$$

whereby A defines the surface where the force F acts as $A = 1 \cdot B$.

As Fig. 2 indicates $[1 - (e_o/e)^5]$ rapidly approaches 1 as the gap increases.

The formula

$$\boxed{\int_0^T F\,dt = 0{,}2\,\mu\, A\, \frac{B^2}{e_o^{\,2}}}$$

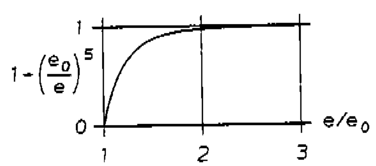


Fig.2

can therefore be used as criteria for the fully released plate (theoretically $e = \infty$) whereby T constitutes the time necessary to achieve complete separation.

What conclusions can one draw from these formula developed in 1964 and published in 1970 [Lit. 2]?

1. To separate the plate requires not only a force F but also time. The shorter the allowed time, the greater is the needed force. Fleming also found this relationship through tests [Lit. 3]. The sticking effect is, therefore, more severe and critical in compressors operating at higher rotating speed. Separation of the plate and guard must occur more rapidly to avoid the slamming effect caused by the back flow of gas.

   The simplest remedy would be to employ a higher spring load. This results not only in rapid separation of plate and guard but also in increased acceleration of the plate throughout the lift. At times, this can lead to an early closure with higher impact velocities, a fact shown on a diagram in a paper by Dr. Woollatt [Lit. 4].

2. The equation shows the influence of the oil viscosity and explains why sticking is generally less damaging on the warmer discharge valves and more severe on the cooler operating suction valves. Often discharge valves have heavier springs and this also minimizes the sticking. Fig. 6, for instance, shows the effect of "oilsticking" in a suction valve and the resultant delay in closing.

3. The width of the plate or ring directly influences the sticking effect. B is part of the formular and impacts also on the area A. One can readily see that sticking of the relatively narrow seatlands rerely causes problems while sticking of the wider guard surface is often a detriment. In a more precise comparison between the sticking effect on the seatland versus the sticking on the guard not only the different surface widths, but also the differences between the forces of separation and between the initial thickness e_o, must be taken into account as is shown by the above equation.
In critical applications where lubricants are abundant the guard surfaces can be especially shaped or profiled to reduce the contact area on the guard. A slight waviness as shown in Fig. 3 is advantageous.

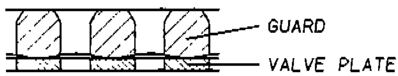


Fig. 3

4. The initial thickness of the oil film e_o depends substantially on the preceding dynamics of the valve plate, specifically the force and time in which the valve plate is pressed against the guard. This variable appears in the equation with its 2nd power and constitutes the value that is most complex to quantify.

This explains why it is extremely difficult to integrate the sticking effect into otherwise precise computer calculations. Although it would be no problem to program the formula outlined above, it becomes irrelevant if all variables cannot be defined with a sufficient degree of accuracy. Without that, no greater accuracy is achieved than by estimating directly an overall value for $\int F dt$.

The phenomena of the dynamic event when the valve plate approaches the guard and the resultant squeezing out of the oil was investigated by Böswirth [Lit. 5].

CONCLUSIONS

In general, every form of liquid present in the valve environment can be considered detrimental. Several valve designs have been developed to operate in non-lubricated cylinders, and those designs that do require lubrication generally operate safely with a minimum amount of lubrication. It can be categorically stated that valves should be sparsely lubricated for best results.

What design concepts can be employed to reduce the sticking effect and its detrimental influence on valve life?

One solution is to adapt the idea outlined in paragraph 3 to valves where the plates are made from plastic polymers. Such plates could be molded with protrusions either in the form of ridges or knob-shaped high points (Fig. 4).

This would definitely reduce the surface contact between the plate and guard [Lit. 6].

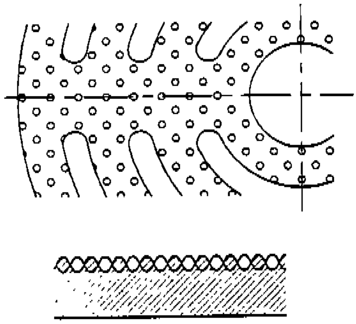


Fig.4

Another approach is to arrange the springs used in valves in such a manner that a progressive separation of the contact surfaces takes place (Fig. 5).

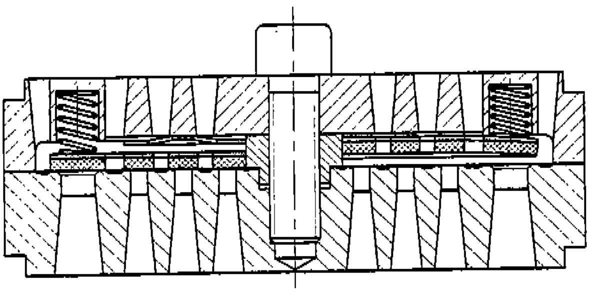


Fig.5

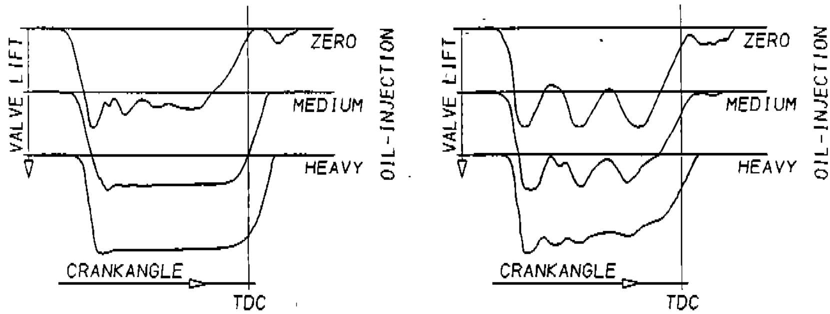
A third effective method is to insert a plate with a slight waviness between the valve plate and the guard, which will produce the following results:

- The separation force is very high but diminishes rapidly since the plate has only a very light curvature. In the subsequent valve dynamic it has no further influence.

- The waviness produces a progressive separation and breaks the oil film.

- To reduce the contact surface, the separation plate can be designed so the width of its rings is narrower than that of the rings of the valve plate.

Fig. 6, portraying a suction valve, shows valve motion monitored with an oscilloscope demonstrating the effects of the variations in oil film on the valve dynamics. The diagram on the left corresponds to a conventional valve without separation plate. The one on the right shows the behaviour of the same valve after a separation plate was installed. As one can see, with normal lubrication the valve dynamics are similar but as the amount of oil was increased, the valve without separation plate responds with a further and further delay in its closure. The impact velocity against the seat which is so critical for valve life clearly is higher in the valve without separation plate while the one with separation plate pretty much retains its dynamic pattern irrespective of oil injection.



WITHOUT SEPARATION PLATE   WITH SEPARATION PLATE

Fig.6

The valve design as shown in Fig. 5 [Lit. 7] has operated very successfully in cylinders where more lubrication was present. Since today's high speed cylinder designs often require excessive lubrication, these valve concepts provide excellent performance even under adverse conditions.

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