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Friedrich Bauer
Hoerbiger Ventilwerke AG

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VALVE LOSSES IN RECIPROCATING COMPRESSORS

Friedrich Bauer
Hoerbiger Ventilwerke AG
Vienna, Austria

ABSTRACT

Overall flow losses of compressor valves are influenced not only by the valve geometry but also are amplified by valve pocket losses.

The magnitude of the pocket losses was measured for four typical pocket shapes. Key variable parameters that influence the losses were established.

The result is shown in "Pocket-Factor" diagrams which shall permit optimization of the pocket shape at the conceptual stage of cylinder design.

INTRODUCTION

The effort to reduce energy losses as much as possible in all technical processes requires a fundamental and detailed knowledge of the reasons for these losses as well as of the respective share of loss contributors. The basic losses in reciprocating compressors are, by now, common and well defined knowledge. The pressure and subsequent energy losses caused by gas flow in and out of the cylinder have generally been referred to as "valve losses".

Because of these existing valve losses, it has been a continuous effort throughout the industry to design more efficient automatic plate valves for compressors. Hoerbiger has been working in this area for a long time and is striving to minimize the flow resistance and losses of the valve.

Aside from the valve itself, the immediate surroundings of the valve also contribute a significant amount of the pressure losses as the gas enters and exits the cylinder.

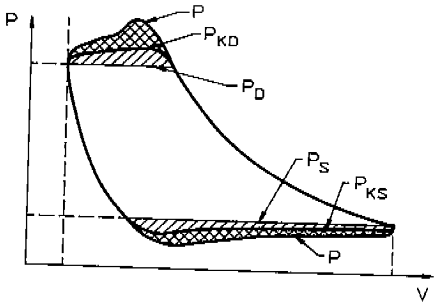


Fig.1: PV Diagram of a compression cylinder

Figure 1 shows a typical pressure volume diagram with the cylinder pressure (P), the suction and discharge line pressures (from pressure gauges P_S and P_D) as well as the pressures measured in the valve chambers (P_{KS} and P_{KD}) during a full compression cycle.

In the diagram the areas comprised by the various pressure curves represent the work performed in a compression cycle. This work, in conjunction with the valve losses, requires closer scrutiny:

-- The lightly-shaded loss areas ($P_S - P_{KS}$ and $P_{KD} - P_D$) cannot be attributed to the valves.
They are caused by restrictions between the valve chamber and the suction line or discharge line / receiver, respectively, where the pressures P_S and P_D have been measured and by dynamic pressure variations outside the cylinder.

-- The heavily-shaded areas in Figure 1 represent the losses caused by the valves mounted in their valve pockets. Besides the valve itself, the valve pocket and caging are other substantial loss contributors.

The pressure loss of the compressor valve itself is determined experimentally in a wind tunnel with the valve mounted on a level surface located perpendicular to the direction of flow. These measurements produce well-defined coefficients of flow with which the pressure loss through the valve can be calculated. This calculation excludes the effects of the rest of the flow system in a cylinder.

As further tests have shown, the pressure losses in the valves mounted in valve pockets can, at times, be greater by a magnitude of two or more than the losses determined through the aforementioned tests.

PROCEDURE

If the ratio of the pressure drop ΔP at a given mass flow through a pocket-mounted valve to the pressure drop at the same mass flow through the valve alone is defined as the "Pocket Factor" (PF), then the pressure loss of the valve installed in the cylinder pocket (the heavily-shaded area) can be calculated at normal conditions by simply multiplying the pressure loss of the valve alone by the pocket factor PF.

$$PF = \frac{\Delta P \text{ valve + pocket}}{\Delta P \text{ valve alone}} = \left(\frac{\Phi \text{ valve alone}}{\Phi \text{ valve + pocket}}\right)^2$$

where $\Phi = A/\sqrt{\zeta}$ and represents the equivalent valve area, A is the free lift area and ζ is the flow coefficient.

By integration it follows that

$$PF \approx \frac{\text{LOST WORK valve + pocket}}{\text{LOST WORK valve alone}}$$

As the losses at the valve and pocket can be reduced by "tuning" the shape of the pocket to the valve, measurements of four different commonly used valve pocket configurations (see Figure 2) have been made to determine "pocket factors" as a function of the most important geometry parameters.

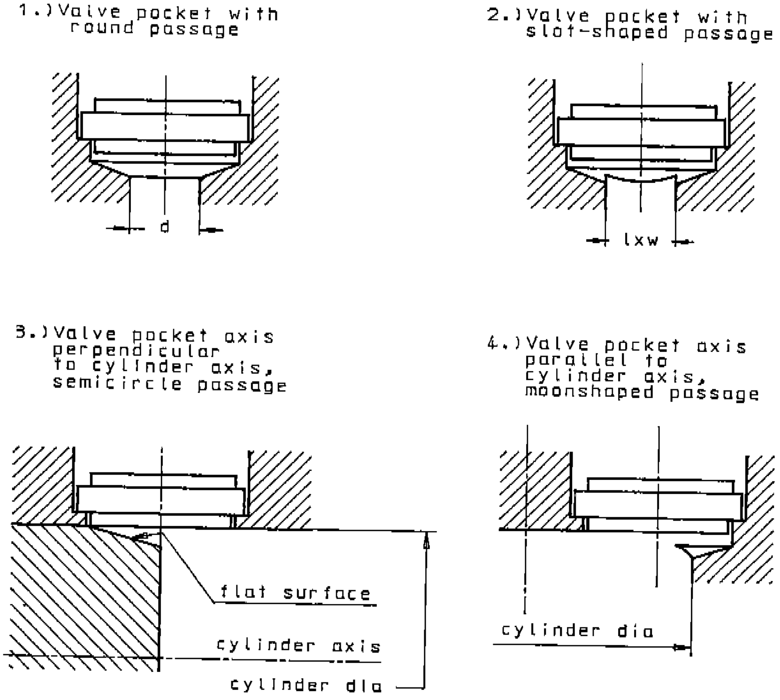
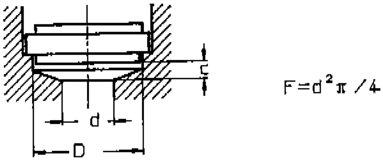


Fig.2-Alternative configurations of cylinder pockets

This research shows that the pocket factors for suction and discharge valves with the same pocket configuration differ due to the opposite directions or flow.

Extensive data were accumulated for each of the pocket configurations and the results were compiled into various diagrams shown in Figures 3 through 6. All plotted values are based on actual tests.

Pocket Configuration 1



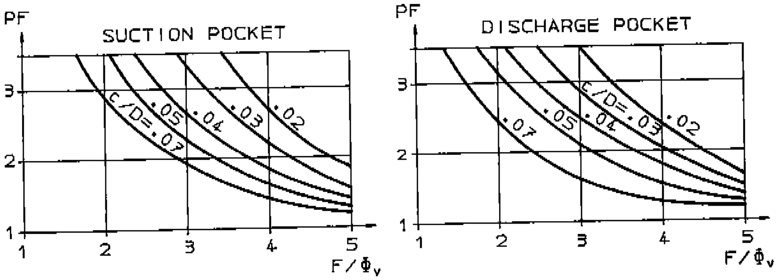


Fig.3-Pocket factor for configuration 1

Figure 3 shows graphs of the pocket factors (PF) vs. the flow passage geometry (F/Φ_v) for the first configuration at a suction and a discharge pocket. The following variables were considered essential in the overall evaluation:

$F = \frac{d^2\pi}{4}$ = the area of pocket passage

F/Φ_v = the ratio of this area to the equivalent valve area

c/D = the ratio defining the valve distance

It is evident from these graphs that the coefficients of flow for the various geometric conditions of the first configuration are different for suction valve pockets and for discharge valve pockets even if the valves and pockets have the same dimensions. The PF for the suction pocket in this case is somewhat higher than the PF for the discharge pocket.

Pocket Configuration 2

$$\frac{c}{D} = \frac{a}{D} + \left(\frac{1}{2} - \lambda\,\frac{l}{D}\right)\tan\alpha$$

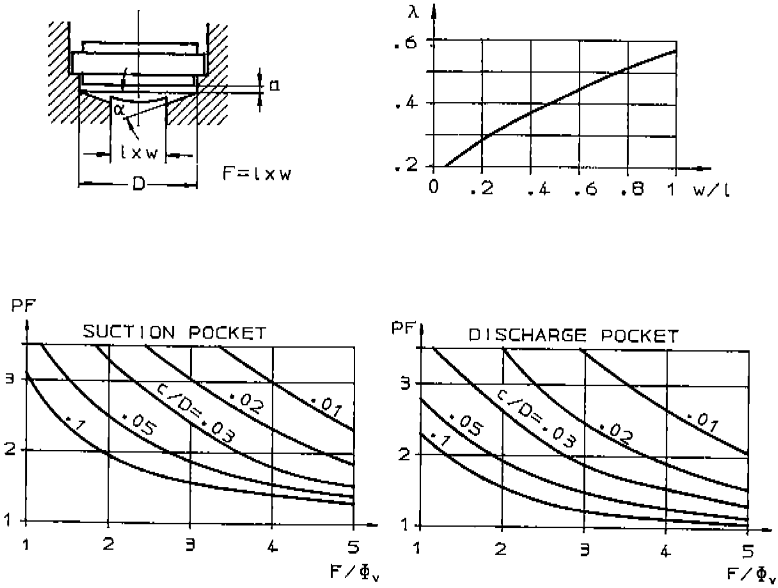


Fig.4-Pocket factor for configuration 2

A comparison of configurations 1 and 2 shows that at an equal ratio of F/Φ_V and equal c/D a slot-shaped passage is better than a round-shaped passage.

The same observation holds for the discharge pocket. The PF is smaller for the discharge pocket than for the suction pocket.

Pocket Configuration 3

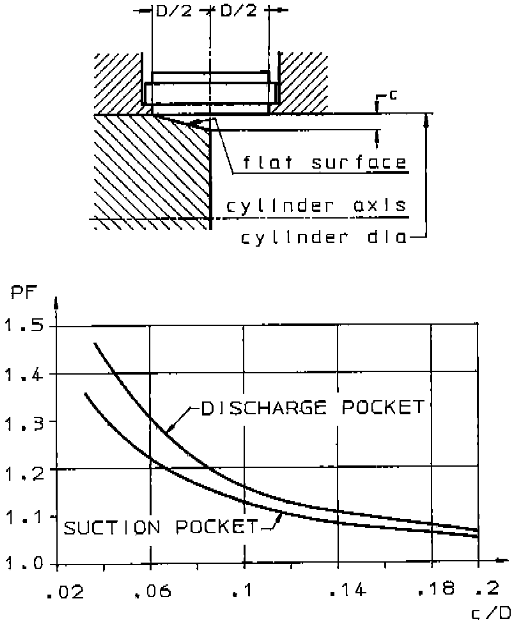


Fig.5-Pocket factor for configuration 3

In configuration 3 the centerline of the valve pocket coincides with the bottom wall of the cylinder end. Half of the valve is in the cylinder head which provides a sloped relief towards the cylinder. The only variable in this case is the angle of the valve pocket recess. Subsequently, there is only one curve shown for the suction pocket and one curve for the discharge pocket. The pocket factors are smaller in this configuration than in the previous two configurations. In this case, the PF for the suction pocket is smaller than the PF for the discharge pocket.

Pocket Configuration 4

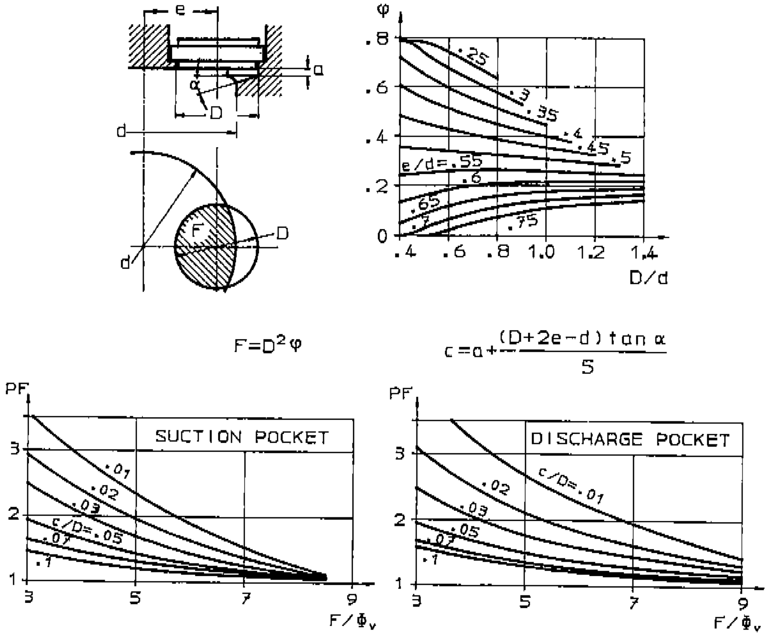


Fig.6-Pocket factor for configuration 4

Configuration 4 gives a variety of results also. A drawing of the overlapping of the cylinder and the valve is provided to help determine the valve exposure $F = D^2 \cdot \varphi$. The value φ is determined by the relationship of the valve diameter to the cylinder diameter and by the eccentricity of the valve to the cylinder.

Figure 6 shows the previously taken approach plotting PF dependent of F/Φ_v and c/D for the sickle-shaped portion of the pocket.

Pocket factors for practical valve exposures in Figure 6 are comparable to results found in pocket configurations 1 and 2.

PF for discharge valves exceed those for suction valves.

CONCLUSIONS

In designing the passages and valve pocket shapes the following observations should be noted:

- During the short periods when the valve is open, the gas flows through a number of passages (i.e., pipes, flanges on cylinders, cylinder passages, valve cages, valves, valve pockets) until it reaches the cylinder itself. All these different areas impose changes in velocity and direction which result in pressure losses.

- Therefore, when speaking of "valve losses", it has to be kept in mind that the lightly-shaded areas in Figure 1 are caused by elements outside of the valve chamber and that the heavily-shaded areas correspond to the real valve losses multiplied by the pocket factor (PF) which depends on the shape of the valve pockets.

- The valve contains the only cross-section in the whole system which can be defined as a "dynamic" cross-section. Its cycle goes from being totally closed to totally open to totally closed during every revolution. The valve motion must be of a nature that no adverse, premature failure occurs. If this function must be performed exactly for a prolonged period of time, it requires considerable design and technological efforts.

  The valve area, therefore, can be regarded as the most expensive area in relationship to the valve surrounding non-variable areas. For instance, one square inch of increased valve area can be obtained only by developing rather complicated designs, by opting for a low valve life, or by utilizing expensive materials.

  Optimizing the flow area around the valve is often attainable with little added cost and, once properly designed, these flow passages are not affected by dynamic conditions.

- Economically and technically, it would be wrong to size the " inexpensive areas" the same or only slightly larger than the valve area, conditions which, unfortunately, are too common. The effort must be focused on increasing the "inexpensive areas" as much as possible in order to achieve minimum overall losses.

When designing new cylinders, three points have to be considered concerning the valve pockets:

1) Clearance volume
2) Total flow resistance
3) Economical manufacturing

The influence of the clearance volume on the cylinder capacity can easily be calculated. The diagrams of this study permit us to determine approximately the total flow resistance of a cylinder at the early design stage. This is certainly of advantage as energy losses are of increasing importance when analyzing compression work.