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The quality of reciprocating compressors is to a large degree determined by the valves used. To fulfill their function as sealing elements, the valves consist of at least three essential parts: a valve seat, a valve plate, and a valve stop. The periodically varying pressure in the cylinder causes the valve plate to move between the two fixed parts - valve seat and valve guard. The velocity of the valve plate at the time of impact is a measure of the stresses of the parts involved.

It is not the purpose of this paper to contribute to the solution for the general impact problem and related stresses on circular plates or rings caused by impact velocity. To qualify the above statement, reference is made to the solution for the impacting rod by S. Timoshenko which concludes: $\sigma = E \cdot v/c$

σ...mechanical stress
E...modulus of elasticity
c...speed of sound within the material of the rod
v...impact velocity of the rod

The relation of impact velocity and life of valve plates cannot be brought into a simple diagram, but will have to be presented by a statistically defined range. This range will be determined by a series of parameters, whereby material, machining, and temperature are only a few of them.

We preclude that the total functions, which are similar to stress-cycle diagrams, are known for our valve plates. This enables us to define the maximum impact velocity which statistically guarantees the required lifetime of the plates. The main criteria therefore for the valve design becomes the maximum impact velocity. The valve calculation in respect to dynamic strength is then a function of the valve motion calculation.

The second important requirement on compressor valves is minimum throttling losses. The solution for this requirement asks for the largest possible valve areas, which in turn ask for high valve lifts. These valve lifts are limited, however, in relation to lifetime, since the impact velocities increase progressively with increasing valve lifts.

On a valve which consists only of valve seat, valve plate, and valve stop; the only variable is the valve lift. We therefore have to assign less importance to the request for low throttling losses and accept relatively high losses in order to fulfill the life requirements. One of the basic developments in valve design was the introduction of a spring element as the fourth main part of a valve. This spring element results in a significant reduction of impact velocities of valve plates and consequently allows an increase of the valve lift compared to a valve without springs. Proportional to the increase of the valve lift, the valve area increases, which results in a reduction of throttling losses. Valve lift and spring load now have to be coordinated to assure that the impact velocity remains within previously determined limits and also to obtain the lowest possible throttling losses.

For a given valve, designed for a specific compressor, the impact velocity is defined by the following unrelated parameters:

Compressor: piston area, piston stroke, clearance volume
Operation: gas, speed, compression ratio
Valve: valve area, spring load, mass of the plate

Such a valve can fulfill the optimum requirements only for a very closely defined operating condition. Any deviation from this condition will result in a deviation of the required criterias (maximum impact velocity or minimum throttling loss or both). A reduction of the impact velocity is practically not unwelcome, theoretically however an indication for possible improvement of the valve. An increase is not acceptable since the required life span of the valve plate cannot be obtained. If the impact velocity remains the same, the optimum criterias are usually not fulfilled, which means a valve improvement for the new operating conditions is also possible.

The maximum of the theoretical area given by our optimization criterias is not exactly defined. A practical application usually does not ask for the ideal valve dimensioning since a compressor normally covers a range of operating conditions which can vary greatly. The problem normally is to design a valve so it "works well" within a certain range of operating conditions.

"Working well" means that the impact velocities within the operating range stay below the allowable maximum, and the existing throttling losses are close to the obtainable minimum losses. As the operating span becomes larger, higher throttling losses have to be accepted. It becomes more and more difficult to dimension the required spring load to keep the impact velocity within allowable limits over the whole range.

The critical impact velocity on a given valve is caused in two ways. First, if the spring load of the valve is too low and the closing motion of the valve plate starts too close to dead center, the plate is accelerated by the gas flowing back through the valve. The closing motion of this valve is then very similar to a valve without springs. Secondly, if the spring load is too heavy, it results in valve flutter. If the operating conditions of a compressor vary considerably, the situation that one spring load is too heavy for one extreme and too light for the other can exist. This effect is well known, especially on compressors with a wide range on speed. There is a great deal of literature published of test results showing valve motions of valve plates with extreme flutter at low speeds, where the flutter decreases as speeds increase.

The most demanding customers of a valve manufacturer are probably manufacturers of refrigeration compressors. They need valves for compressors with operating conditions that vary to a tremendous degree.

There are at least four different refrigerants used (NH_3, R22, R12, and R502), and various temperature levels must be maintained (storage houses, air-conditioning, ice production, and lately also in heat pumps), resulting in different compression ratios. In addition, the compressors are operated at different speeds. The maximum on demands is reached if a compressor is driven by a two-speed motor for capacity regulation. These compressors run at speeds of 1800 RPM (at 60 cycles and full capacity) and also at 750 RPM (at 50 cycles and half capacity). It can safely be stated that with all of the variations mentioned above, one valve cannot give satisfactory results under all conditions.

The basic requirements however to use one valve for both speeds (full and half) have to be fulfilled. Certain pressure limitations can be applied, however, compressor manufacturers are hesitant to accept them.

A present research project which resulted in only one valve design per refrigerant for all speeds and pressure ratios will be discussed at this conference.

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References

1. S. Timoshenko, "Vibration Problems in Engineering", D. VanNostrand Company, 1955