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Evaluation of Oil Stiction in Ring Valves

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INVESTIGATION ON OIL STICTION IN RING VALVES

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INTRODUCTION

For some time there has been the tendency towards establishing the characteristics of the valves of reciprocating compressors by simulation of their behavior by means of mathematical models using computers [1] [2]*.

The execution of these calculations involves the knowoledge of some parameters, among which the discharge - drag - damping and restitution coefficients [3]*.
As a general rule, these parameters are established esperimentally or making theoretical considerations.
The aim of this method is to establish the lift of valves and the stiffness of springs required to have the valve operate without fluttering or violent impacts on the seat or on the valve stop.
Obviously, this system is the more effective the more the real movement of valve during operation and that plotted by the computer correspond.
For this reason, in addition to the correctness of the mathematical model, the knowledge of the afore mentioned parameters is essential.

In spite of an accurate selection of these parameters, sometimes troubles occurred when a good valve behaviour was predicted by the computer.
In those cases the mathematical model showed not to be sufficiently adhering to reality.
This situation was mainly experienced with lubricated machines particularly when the compressor speed was high.

It was found that this deviation was due mainly to the fact that the model did not take into account the stiction force that compels the rings to leave the valve stop with some delay with respect to the beginning of application of the load which tends to close the valve.
As a result, if a higher reliability of the mathematical model is required for the afore mentioned cases too, sticking effect is to be inserted into the calculation.
The quantitative determination of this effect is the main aim of this report.

Before describing the investigation made we feel it desirable to emphasize the fundamental aspects of this phenomenon.

ASPECTS OF STICTION

If we take into account the valves of a reciprocating compressor, whose cylinders are lubricated, the dynamics of rings, when they contact the seat or the valve stop, is established by the contemporaneous actions of the following fluid drag forces; inertia, spring and stiction.
Therefore, the ring leaves the seat or the valve stop with some delay with respect to the theoretical case where the stiction is not considered.
Practically, this phenomenon is causing a delay at the opening and closing stage of the valve.

By experience one can say that the delay at the opening stage does not change the valve behaviour considerably; this is due to the fact that the mating surface of ring towards the valve seat is much smaller than the mating surface towards the valve stop. Furthermore, the delay at opening is always very small because it causes an overpressure (discharge valve) or an underpressure (suction valve) which increases with the delay and the consequent force exceeds the sticking effect soon, while no counteracting extraforce develops for a delay at closing.

For this reason, all of the following considerations apply to the sticking effect at the closing stage, i.e. when the rings leave the valve stop.
As a matter of fact, considering an ordinary valve displacement diagram (fig. 1) one can note that a delay at the closing stage, deforms the theoretical curve (continuous line) to that indicated by dotted line. Consequently, the piston back-stroke occurs when the valve is completely open; this increases the impact velocity of the rings against the seat considerably besides causing back-flow of gas through the valve.
This fact is very harmful to the compressor efficiency and causes a hammering of the rings on the sealing areas, this being shown by a more or less accentuated permanent deformation of the material and, some-times, by breakage of rings themselves.
It is easily understandable that the problem

*Numbers in brackets refer to listings in the bibliography.

worsens when the compressor r.p.m. increase since - the delay time and the duty being the same the stroke part (crank angle) subjected to delay time increases according to the increase of r.p.m. (see fig. 2).

AIM OF THE INVESTIGATION

Stiction phenomena can be noted even in not-lubricated machines that however compress easily condensable gases or those containing dissolved liquid particles. However, as these cases are very few and could be referred to those of the lubricated machines, the investigation made to evaluate the sticking effect does not take them into account.

The aim of the present investigation is that of establishing, in terms of quantity, the sticking effect due to presence of oil, and of finding out a correlation between the forces acting on the rings and the delay time with which rings leave the valve stop with respect to the moment the forces are applied.

The tests were carried out according to the following hypotheses in order to achieve valid results in a quite wide field:

a) An oil having a viscosity of 7° Engler at 50°C has been employed, this oil is the one normally used in compressors for the petrochemical industry.
b) Valve stops used had a geometry to give a damping effect in the final part of the ring lift.
c) Each valve stop of the afore mentioned point has been tested with and without small through-holes in the middle of spring housings.
d) Tests have been carried out without and with variable oil quantities.
e) Tests have been carried out with variable forces acting on the ring.

EXECUTION OF TESTS

The equipment used for test is shown in fig. 3. A ring (1), to which various annular weights (2) can be attached, is pushed against a dummy valve stop (3) by a pneumatically operated plate (4).
The ring (at two diametrically opposed points) and the support plate are provided with transducers connected with an oscilloscope on whose screen the movements of the support plate and of the ring are recorded in the course of time (fig. 4).
When the support plate is suddenly removed by the pneumatic device, the ring is subjected to the two counteracting forces of the weight and of the oil stiction; the ring leaves the valve stop when the weight force has overcome the sticking force and thus with some delay with respect to the beginning of application of the load.
This delay is measured by comparing the support plate motion diagram and that of the ring recorded on the oscilloscope screen (fig. 4).

ANALYSIS OF RESULTS

The diagrams obtained by the values read on the oscilloscope are summarized in fig. 5a. and 5b, these diagrams represent the delay in thousandths of seconds in function of the oil quantity, for different specific forces (load on the ring surface) applied to the ring. The figure 5a. is relating to holed valve stop while the figure 5b. is relating to not-holed valve stop.

The first important consideration to be made is that related to the delay values. These values reach 30 thousandths of seconds when lubrication is abundant and even 80 thousandths of seconds in valve stops without through-holes. These values decrease considerably when lubrication is normal; however they are in the range of 10 thousandths of seconds for valve stops with holes and 20 thousandths of seconds in valve stops without holes.

To have a better idea of the meaning of these values it is useful to refer to the diagram of fig. 2 which shows the crank angle corresponding to the delay time, for various r.p.m. From the examination of this diagram one can note how a certain delay remains within allowable limits for low-speed compressors, while stiction becomes harmful in the high-speed compressors since in this case the delay time tends to become as great as the whole operative cycle of the valve.

As a matter of fact, if we consider a compressor running at 750 r.p.m. with a compression ratio of 2, with 25% clearance volume and with 1,4 compression polytropic curve coefficient, the discharge stage begins at approx. half stroke; therefore the discharge valve cycle is made in approx. 90° corresponding to 20 thousandths of seconds (fig. 2). It is evident in this case that even a delay of only 5 thousandths of seconds corresponding to a crank angle of 22° approx. becomes unacceptable for the correct operation of the valve; as a result it is essential to take this into account at the design stage and to provide for special actions as we will see further.

From the diagrams in fig. 5a. and 5b. it can also be noted that, being the specific force acting on the ring the same, the delay increases according to a more than linear law with the increase of the oil quantity and that, being the oil quantity the same, the increase of the specific force on the ring reduces the delay time definitely.

This consideration can be more clearly noted in fig. 6 showing the delay time diagrams in function of the specific force applied to the ring.
Said diagrams were made considering a lubrication between normal and excessive and were made for the two different types of valve stop.

It is important to take note that some small-diameter holes in the spring seats of the valve stop reduce the delay time remarkably being the oil quantity and specific force at the rings the same.
This is confirmed by what has been experienced in practice: in fact some valve problems have been solved by machining holes in the valve stop.

The sticking effect can be inserted into the mathematical calculation model by means of the diagrams in fig. 6 already described.
That is obtained storing the complete series of these diagrams in the computer memory and modifying the calculation program in such a way to check, for each integration step, when the ring is stationary against the valve stop, the relation between the total force applied to the ring and the delay time.
Since the force applied to the ring changes in the course of time, the detachment time will be a weighted average of the delay times corresponding to the various forces acting at each integration step.

ACTIONS TO BE TAKEN TO REDUCE THE STICKING EFFECT

In general, and particularly on the valves with pneumatic damping in the final part of the ring lift, the troubles caused by stiction can be eliminated by taking one or some of the following action:

- reduction of oil quantity; practice confirmes, that a reduction of oil supply within such limits as to allow a correct operation of sealing elements (piston rings and packing) improves the valve behaviour reducing the delay time.
- valve stop design improvement; some small-diameter through-holes on the bottom of spring seass on valve stop have proved to be useful since, as already said, they reduce the vacuum effect which arises in the gas trapped with oil between ring and valve stop.
- changement of the valve characteristics; by increasing the force of springs that is counteracting in respect of the adhesion force, one succeeds in having the valve closed prior to back-motion of piston which is essential for a good valve behaviour. However, sometimes, this action is to be accompanied with a reduction of lift in order to balance the increase in the force of springs with a higher velocity of the gas and therefore a greater pressure loss on the valve. In fact, fluttering of valve could occur if only the spring load is increased.
- consideration of the sticking effect into the calculation model; doing so, in the design stage, the computer taking account of the delay time which occurs at the closure, gives the correct value for spring load and valve lift.

CONCLUSIONS

The investigation made on sticking effect caused by the presence of luboil consequently leads to:

- the necessity of limiting to that which is strictly necessary the quantity of oil supplied to the compressor cylinders.
- to the use of valve stops with through-holes in the spring housings.
- the necessity of taking into account this phenomenon in the process of determination of the operating characteristics of the ring valves by a mathematical model.

The aforegoing is particularly necessary for high-speed machines.

ACKNOWLEDGEMENTS

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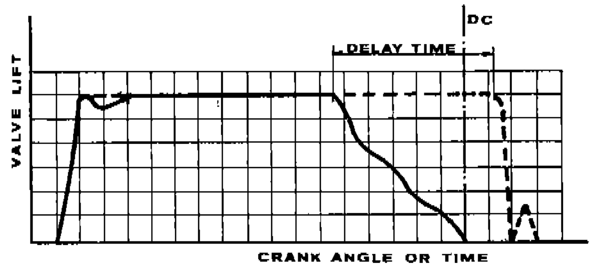

FIG.1 – COMPARISON OF ANALYTICAL DISPLACEMENTS WITH (– – – –) AND WITHOUT (———) OIL STICKING EFFECT

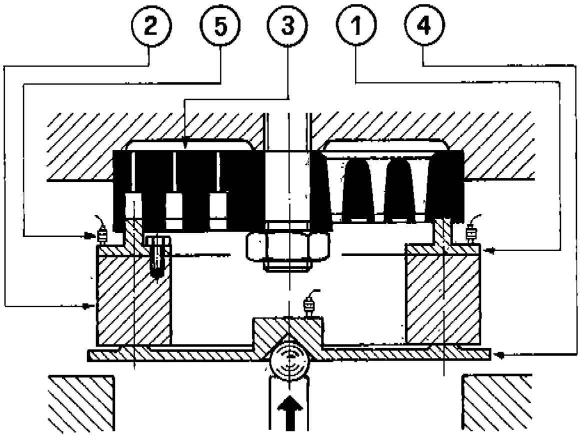

FIG.3 – SCHEMATIC TESTS DEVICE

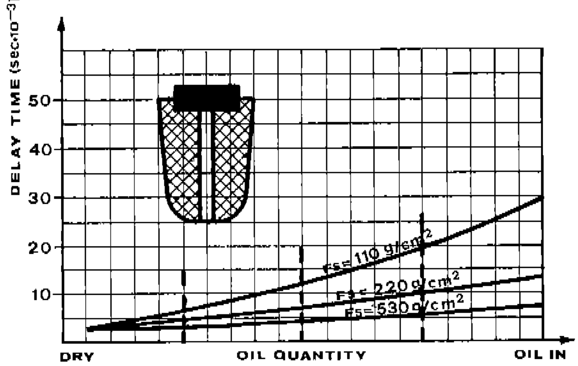

FIG.5a – DELAY TIME CORRELATION WITH SPECIFIC FORCES AND OIL QUANTITY FOR VALVE STOP WITH HOLES

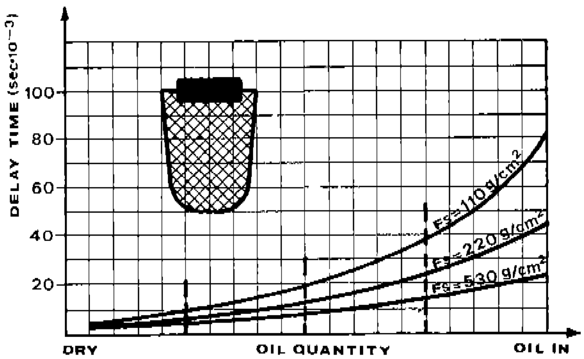

FIG.5b – DELAY TIME CORRELATION WITH SPECIFIC FORCES AND OIL QUANTITY FOR VALVE STOP WITHOUT HOLES

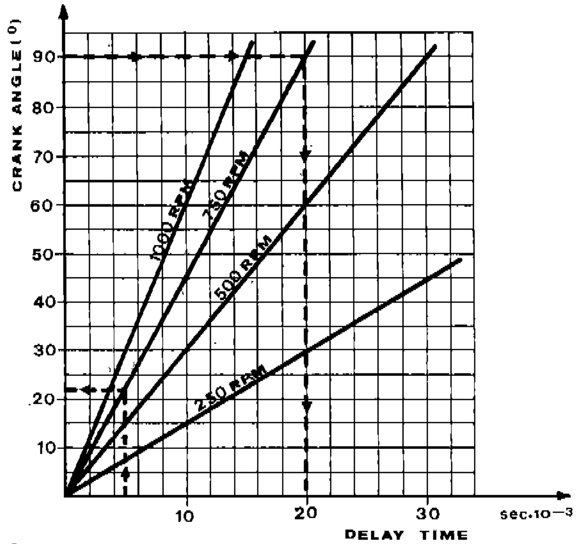

FIG.2 – CORRESPONDENCE BETWEEN CRANK ANGLE, TIME AT VARIOUS RPM

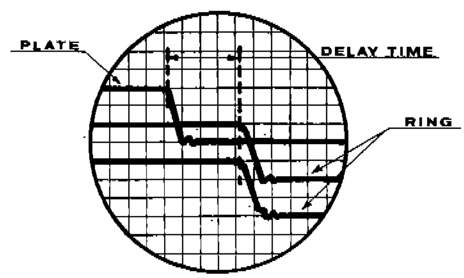

FIG.4 – DISPLACEMENTS RECORDED ON THE OSCILLOSCOPE SCREEW

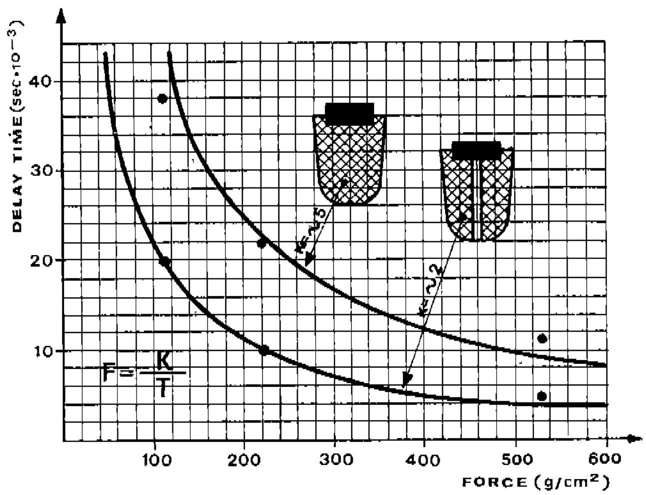

FIG.6 – DELAY TIME – SPECIFIC FORCE CORRELATION OF DIFFERENT VALVE' STOPS FOR ABONDANT LUBRICATION