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# Optimum Utilization of Capacity Control Devices in Reciprocating Compressors

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## ABSTRACT

Capacity control consists of adjusting the quantity of gas supplied by the compressor to suit the fluctuating demands of the plant. In the modern processing plants, energy costs amount to about 65 per cent of the overall costs. Therefore, it is of paramount importance that the control system should be such that the compressor power is almost proportional to the quantity of gas delivered. For the optimal solution of the capacity control problem, certain issues must be taken into consideration at the planning stage of compressor plant so that maximum saving in power consumption is achieved with minimum initial cost and without impairing the safe running of the compressor plant. It is concluded that choice of capacity control device depends on many factors. Each compressor case has to be examined critically to arrive at optimum solution.

## INTRODUCTION

Compressors, as part of process or refrigeration plants, long distance gas supply facilities, metallurgical plants etc. are required to have regulated output for diverse reasons such as:

- pressure variations must be compensated on the suction line;
- uniform pressure must be guaranteed for the irregular requirements of compressed mediums;
- constant cooling temperature must be provided for variable ambient temperatures;
- a certain processing procedure must be maintained.

Capacity control consists of adjusting the quantity of gas supplied by the compressor to suit the fluctuating demands of the plant.

In modern processing plants, energy cost amount to about 65% of the overall costs. Therefore, it is of paramount importance that the control system should be such that the compressor power is almost proportional to the quantity of gas delivered. The reciprocating compressor offers excellent options for energy saving regulation. For the optimal solution of the capacity control problem, certain issues must be taken into consideration at the planning stage of a compressor plant so that maximum saving in power consumptions are achieved without impairing the safe running of the compressor. However, same is also true for already existing, non-regulated or inadequately regulated plants, which can be remodelled for maximum energy savings. It must always be remembered that the basic principle for multi stage compressors is to regulate simultaneously the output of all stages as otherwise the compression ratio in the individual stages would change considerably giving rise to an objectionable increase of the compression temperature and piston rod loading in some of the stages. Capacity regulation can be divided in three basic modes: -

- Stepped control
- Stepless control
- Composite control

These will be examined from the point of view of plant requirements, efficiency, construction and control systems so as to enable their optimum utilization for a particular application.

## STEPPED CAPACITY CONTROL

In this mode, the capacity is regulated in several steps. Three step control, for example, means that the compressor can deliver 100%, 50% and 0% of its capacity, while with five-step control the delivery can be 100%, 75%, 50%, 25% and 0% of the total capacity. Because of its simplicity and hence its reliability in use, stepped control is the most common choice.

### Stop-start Control

This is advantageous in cases where electric motor is used and the demand for compressed gas fluctuates widely, particularly where there are sudden large demands followed by periods of very small consumption or no consumption at all. The method provides entirely 'no loss' regulation and thus almost 100% energy is saved. Stop-start system is used very widely in plants of modest capacity and is usually automatic.

As the demand will only seldom be solely at the two extremes of 'full' and 'zero', a receiver is interposed between the compressor and consumer unit.

The pressure in this receiver can fluctuate within certain limits, and a pressure switch switches the compressor on when the lower limit is reached, and off when the pressure has risen to the upper limit. Examples of this system are found in small compressed-air installations and the like. This system is also occasionally used even in large installations, particularly where there are several units working in parallel. When an increase in output is required, one or more units are brought into operation, and vice versa. Since large compressors can seldom be started other than off-load, bringing in an extra compressor does present difficulty, and this also places limitations on the frequency with which control can be exercised. In pipeline booster stations this system is used in combination with other methods and is usually automatic or remote operated. A further possibility is that of coupling the compress-or with the driver through a clutch, so that it can be driven or disengaged at will without the need for a series of starting operations.

## Suction Valve Unloader Control

With this control system the compressor continues to run, but is prevented from making a positive discharge by preventing suction valves from closing. This is the method used in practically all process compressors.

The valve lifting device in the form of 'fingered yokes' when pushed against valve disc or rings (in case of ring type valves), keeps the valve open even during the compression stage. Obviously, by keeping the valves always open by means of valve lifter, the cylinder capacity is nil. When, instead, the valve lifter withdraws, the suction valve again comes into normal operation and the capacity rises to maximum. These valve lifting mechanisms are produced in a variety of designs, operated manually, pneumatically, or hydraulically.

One most popular version shown in Fig.1 uses a manual and pneumatic actuator suitable for remote control and thus for use with automatic control systems. Fig.2 shows a typical actuator for manual and pneumatic control.

Since the passage of the open suction valve is relatively small, there will be a slight pressure loss resulting in a slight loss of power. In most of the cases, however, it is negligible. Thus, from the point of view of efficiency, the absorbed power reduction is almost proportional to the capacity reduction. If one double-acting cylinder is available, this method of control will allow a choice of 100%, 50% and 0% capacity, i.e., three-step control. Similarly, with two double-acting cylinders capacity regulation of 100%, 75%, 50%, 25% and 0% can be achieved. For reasons of lubrication, an alternating loading of the gudgeon pin is preferred. If, in a double acting cylinder, the load on the gudgeon pin is alternating under normal conditions, it will remain so when the cylinder head side of the cylinder is unloaded. However, the load will be directed to one side of the pin if only the crosshead side of the cylinder is unloaded. If both sides of the cylinder are unloaded, then the inertia forces will usually be enough to produce an alternating load on the gudgeon pin. It is therefore suggested, to unload double-acting cylinders in the sequence 'cylinder-head side first, then cross-head side'.

### Fixed Clearance Pocket Control

By using a clearance pocket, that is an additional clearance volume, which can be cut off from the cylinder by a stop valve, the volumetric efficiency of the compressor is reduced because the expanding gas fills most of the cylinder, and suction valve opens later (Fig. 3 ). From the point of view of efficiency, the absorbed power reduction is proportional to the capacity reduction if allowance is made for losses due to throttling through the valve.

The capacity of the clearance pocket is either constant, or it is divided into several parts, each of which is equipped with its own stop valve allowing stepped control of capacity.

## STEPLESS CAPACITY CONTROL

This method allows continuous regulation of the capacity within the predetermined range. The following methods of stepless capacity control are most widely used.

### Speed Control

As far as the compressor itself is concerned, the simplest method of controlling its capacity is by verying the speed. Thus, if the speed of the driver can be varied, this will give an excellent means of loss free control of the compressor output. The diesel engines, gas engines, st-eam engines, steam turbines and gas turbines are ideally suitted to speed control. However, it must be remember that while in a reciprocating compressor, the torque is independent of the speed (process conditions being constant), this is generally not true of those prime movers whose speed can be regulated. This entails that these prime movers do not usually allow an speed reduction higher than 70%, thereby imposing the range of stepless capacity variation between 100% to 70% only.

### Reverse Flow Control

In this method, capacity reduction is achieved by an unloading device, fitted to each suction valve, which at partial load does not allow the suction valve to close (Fig. 4 ), when the compression stroke starts, but delays this closing in a controlled way. Thus, the gas already in the cylinder will flow back into the suction piping, the amount being proportional to the length of the following compression stroke during which the suction valve remains open.

By varying this delay in the valve closing, it becomes possible to vary the compressor capacity continuously. The major problem is that of actuating the inlet valves, since this must match the speed of the compressor. An ingenious solution has been developed by Hoerbiger of Austria. This utilizes the principle that a dynamic pressure builds up in front of a body placed in the flow of gas, directly proportional to the square of the gas velocity. The disc of the suction valve forms such a body.

Normally, the suction valve is closed by the slight pressure of the valve springs just before the compression stroke starts. In reverse flow regulation, however, spring loaded fingers keep the valve open against the reverse flow of the gas during the compression stroke in the cylinder. The velocity of the gas flowing back rises steadily with increasing piston speeds, building up an ever-increasing dynamic pressure on the cylinder side of the disc valve. This press-ure will try to press the valve disc down on to its seat against the spring loaded fingers. As soon as the force exerted on the valve by the dynamic pressure becomes greater than that of spring loaded fingers, the valve closes. The reverse flow of the gas is thus terminated. The remaining gas in the cylinder is compressed to the desired pressure in the usual manner. This permits regulation to any desired capacity between 100% and 40% of full load, and in special cases stepless capacity reductions down to 15%.

Fig. 5 shows a valve with Hoerbiger reverse flow regulation, in which the load on the spring loaded fingers can be continuously adjusted by shifting the point of support of the springs. This can be done manually or by a pneumatic or hydraulic pressure on a spring loaded diaphragm or piston, so as to provide remote automatic control. From the point of view of efficiency, this method offers absorbed power reduction proportional to the capacity reduction apart from the losses due to flow of gas in both directions through the suction valves.

## Clearance Volume Control

This control works on the similar principle to that of the reverse flow control. A fixed clearance pocket with an unloader controlled suction valve allows incremental opening of the pocket during the compression stroke. The adjustment of the unloader force that keeps the valve open is counteracted by the gas dynamic pressure on the valve plate as it flows into the clearance pocket. The net output of the cylinder is thus reduced and the trapped gas flows back to the cylinder during the expansion stroke and delays the intake of fresh gas into the cylinder. The energy loss involved with a valve controlled clearance pocket is negligible. The method is suitable for manual and automatic operation similar to reverse flow control.

## Adjustable Clearance Pocket Control

In this method the capacity of the clearance pocket is continuously varied by means of a piston on a spindle, providing continuous control of capacity.

The system is completely loss free since there are no restriction between the compressor cylinder and the clearance pocket; the energy spent in compressing the gas within the clearance pocket is completely recovered in the re-expansion. The method is suitable for manual as well as for remote controlled automatic operation (with pneumatic or hydraulic actuators).

<u>By-pass Control</u>

This control is based on the principle of connecting the discharge side of the compressor with the suction side via a by-pass line incorporating a throttle valve. Operation of throttle valve, which is most commonly known as by-pass control valve, can be manual or automatic. By-pass control is a 100% loss system. However, because of its simplicity and reliability, it is often used in conjunction with clearance pocket control, suction valve unloader control etc. In a multi-stage compressor, the by-pass may be total, i.e. between final discharge and the first stage suction, and if necessary, between some or each of the stages.

In most of the cases, the temperature of gas decreases during throttling; one has, however, to examine carefully with the help of Mollier charts, the effect of throttling, and accordingly has to provide arrangement for cooling or heating the gas after by-pass control valve.

## COMPOSITE CONTROL

It is clear from the preceding that each type of control method has got its limitations. Therefore, best results are achieved by combining two or more methods so that each type of control can be used most effectively to get maximum advantage from the point of view of reliability, absorbed power reduction, simplicity in operation and initial installation costs. Of course, now-a-days, with ever increasing energy costs, initial extra investments are not of much relevance as they are paid back by energy savings in the very first year of compressor operation. Some of the combinations in practice are:

- Valve unloaders with fixed or continuous clearance pocket control.
- Valve unloaders with fixed or continuous clearance pocket control alongwith by-pass.
- Valve unloaders with speed control.
- Valve unloaders with reverse flow control alongwith fixed or continuous clearance pocket control.
- Valve unloaders with start-stop control alongwith reverse flow control.

## CONCLUSION

It is concluded that choice of capacity control system depends on so many factors. Each compressor case has to be examined critically to arrive at optimum solution. It is once again emphasized that in modern processing plants involving energy costs amounting to about 65% of the overall costs, considerable energy savings can be achieved by proper utilization of capacity control devices.

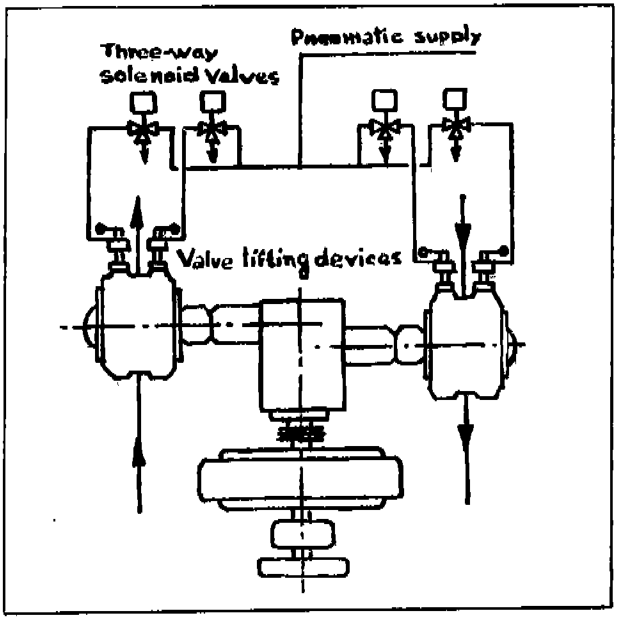



FIG. 1

MANUAL AND PNEUMATIC VALVE ACTUATORS SUITABLE FOR USE WITH AUTOMATIC CONTROL SYSTEM

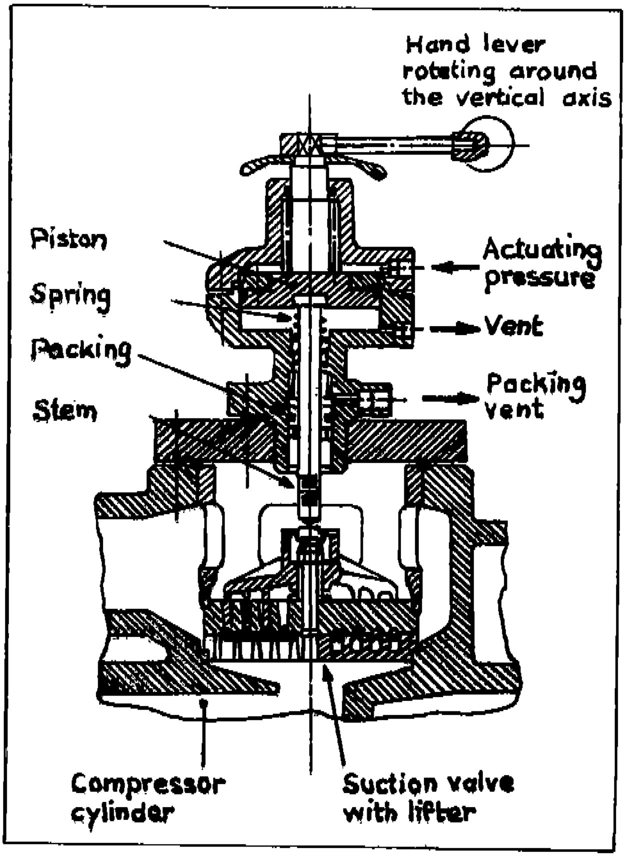
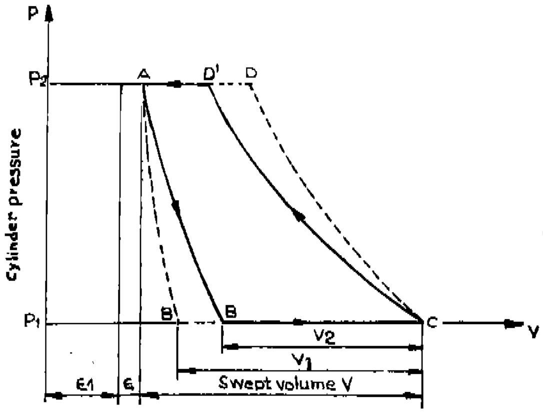



FIG. 2

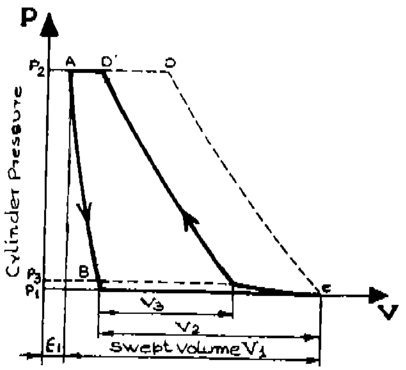
SUCTION VALVE LIFTING MANUAL
AND PNEUMATIC ACTUATOR




$P_1$ suction pressure;
$P_2$ delivery pressure;
$\epsilon$ cylinder clearance;
$\epsilon_1$ clearance pocket volume for capacity reduction;
$V_1$ maximum sucked volume without clearance pocket
$V_2$ reduced sucked volume ($V_1 - V_2$) is the suction capacity decrease due to the clearance pocket volume $\epsilon_1$.

FIG. 3

PRINCIPLE OF CLEARANCE POCKET CAPACITY REDUCTION




$P_1$ suction pressure

$P_2$ delivery pressure

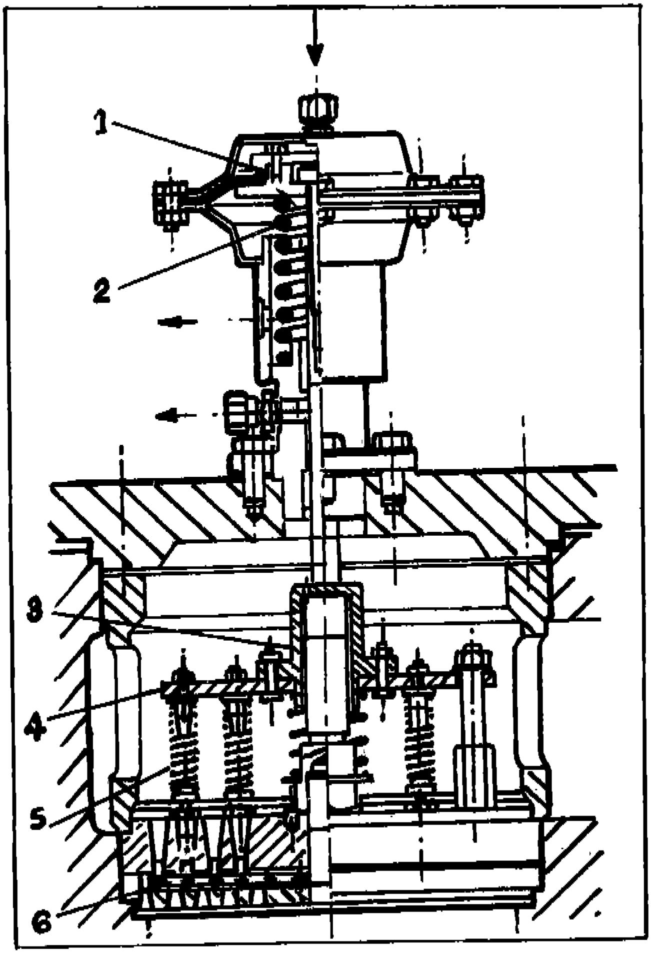
$P_3$ pressure at closing of suction valve

$V_2$ sucked volume

$V_3$ reduced sucked volume ($V_2$-$V_3$ is the suction volume decrease due to reverse flow of gas through the suction valves)

FIG. 4

PRINCIPLE OF CONTINUOUS REVERSE FLOW CAPACITY CONTROL




1 DIAPHRAGM PISTON
2 DAMPING ARRANGEMENT
3 PIN UNLOADER
4 PRESSURE PLATE
5 UNLOADER PIN SPRINGS
6 VALVE PLATE

FIG 5
REVERS FLOW RAGULATION

(COURTESY M/S HOERBIGER, AUSTRIA)