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Comparative Study of Slide Valve and Variable Frequency Drive for Screw Compressor Control System

KEYWORDS: Full load, Part load, Screw compressor, slide valve, VFD

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ABSTRACT Screw compressor is widely used in all refrigeration industry due to its simplicity of operation, reliable & consistent performance over its life span. It replaces nearly all the application in which reciprocating compressor in industrial refrigeration are being used. To control the discharge capacity of the screw compressor various mechanism are used. For screw compressor slide valve control mechanism and variable frequency drive (VFD) are used on a wider scale. The selection of the mechanism highly depends on the operating capacity and operation time of the plant. Any plant either can be operated at full load or part load capacity. The paper aims at the comparative study of two different mechanisms used for controlling the screw compressor. For that various aspects and issues involved in implementation of both the mechanisms are covered. Suitability of each mechanism is justified for specific application area.

I. SCREW COMPRESSOR

An oil flooded screw compressor consists of male and female a rotor which is mounted on the bearing to fix its position on rotor housing. Basic shape of the rotor is screw threaded.

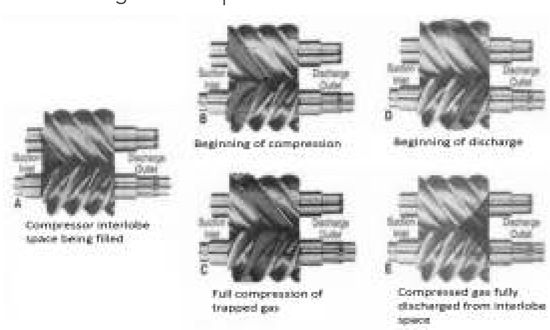

Fig.1 fundamental operation of screw compressor

The driving device is normally connected to the male rotor and it will drive the female rotor using an oil film. In some designs driving device is connect to the female rotor, to produce higher rotor speed thus increasing displacement. But this design increase loading effect on the rotor which overall reduce the rotor life. Fundamental operation of screw compressor is just like a volume reducing device. In this process gas is compressed by pure rotary motion of intermeshing male-female rotors. Gas is travelled from top to bottom. Fig.1 shows the fundamental operation of screw compressor [1]. The process of compression of gas inside the screw compressor can be divided into five different stages that are, (a) Suction of gas, (b) Beginning of compression, (c) Full compression of trapped gas, (d) Beginning of discharge, (e) Discharge of fully compressed gas.

The capacity control of the screw compressor is carried out by means of different techniques in which Slide valve control and variable frequency control are the most widely used techniques.

II. SLIDE VALVE

Screw compressors typically employ slide valve arrangements by which the capacity of the compressor is controlled over a continuous operating range. Slide valve is mechanical device. The position of a slide valve belong to a screw compressor for a refrigeration system is controlled using a gaseous medium. In that priority is given to the gas whichever is at the higher pressure. Preferred source is refrigerant gas. The multiple sources of such gas are connected to a solenoid valve and it will allow the gas to act on the piston. Piston is connected with the actuator and this joint mechanism will control the position of the slide. Opening and closing of the solenoid valve is controlled through the controller. Hydraulic actuation of the piston can also be used to control the position of the slide valve. The valve portion of a slide valve assembly is disposed within and constitutes a part of the rotor housing. Working chamber of the compressor is defined by the certain portion of the slide valve assembly and rotor housing. Fig.2 depicts mechanical construction of slide valve.

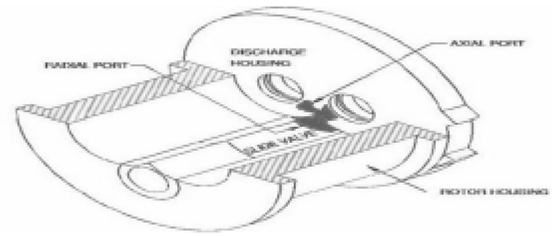

Fig.2 Construction of slide valve

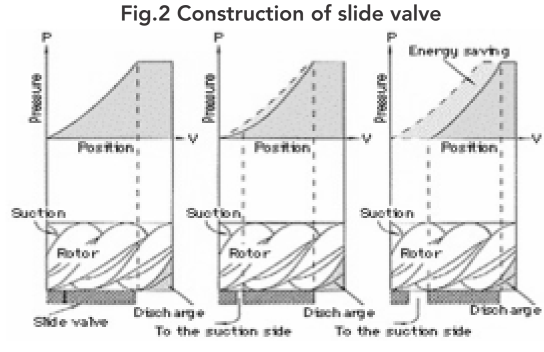

Fig.3 Functional characteristics of slide valve

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Slide Valve (Slide Vane) is the capacity control device for the screw compressor. This slide valve is able to control the capacity range of the screw compressor from 100% down to 10% without surge. The operational functions of the slide valve with corresponding P-V diagram explanations are shown in fig 3. Case-(1) of fig 3 is when the slide vane fully closed for full load operation; When the load reduces say to 80% as shown in Case-(2), the slide vane moves to the right by the controller to allow 20% of the gas bypass back to the suction; The slide valve is moving further to the right in Case-(3) to allow more gas to be bypassed to the suction if the load reduces further. The slide valve moves to the left to closed the bypass opening when the load is increased.

The capacity is controlled using the rotor speed, until the manufacturer's recommended minimum speed is reached. If further capacity reduction is required at the minimum speed, the slide valve is preferred for further capacity modulation.

Advantages of the slide valve mechanism over VFDs in the screw compressor

- Slide valve is cost effective solution.
- For full load operation it has higher efficiency and thus less power consumption.
- It doesn't entertain any electrical noise issue.
- Alleviation of system cost is about 20-30%.
- Very compact in size as all control systems can be mounted on the compressor & motor body itself.
- Technology involved is not as complicated as VFD technology.
- It gives best result for full load compare to VFD.

Disadvantages

From the explanation of the slide valve it is clear that the piston of the slide valve is actuated by the pressurized gas or hydraulic fluid. There is the inconsistency in the characteristics and composition of the fluid supplied or removed by hydraulically actuated slide valve. Its movement during any particular time period may not be precisely consistent, repeatable or predictable. This lack of consistency and repeatability, from the control standpoint, is disadvantageous and reduces the efficiency of the compressor [2].

III. VARIABLE FREQUENCY DRIVE

Screw compressor normally employs an induction motor and to get the control on the speed of the compressor various A.C. drives are used with motor.VFD is one of the most prevalent drives used with induction motor. The basic structure of a VFD consists of a rectifier, a dc link, and an inverter. A rectifier may be of the uncontrolled type if it includes diodes, whereas a controlled-type rectifier includes active semiconductors devices such as thyristors, Insulated Gate Bipolar Transistors (IGBT's), IGCT's, etc. On the other hand, inverters always include active semiconductor devices in order to be able to turn them on and off during the synthesis of ac output voltages. A dc-link capacitor is kept for voltage stabilization. Filters and protection circuitry should always be included to mitigate harmonics and protect the semiconductor devices. Below Fig.4 describe the basic construction and operation of the VFD. VFD is also known as Variable Speed Drive (VSD). In ideal condition a compression system should operate in such a way that the compressor flow delivery is always in line with the demand without causing any additional energy & efficiency losses. The primary function of a VFD is to vary the speed of a three-phase A.C. induction motor. VFDs also provide nonemergency start and stop control, acceleration and deceleration, and overload protection. In addition, VFDs can reduce the amount of motor start-up inrush current by accelerating the motor gradually.

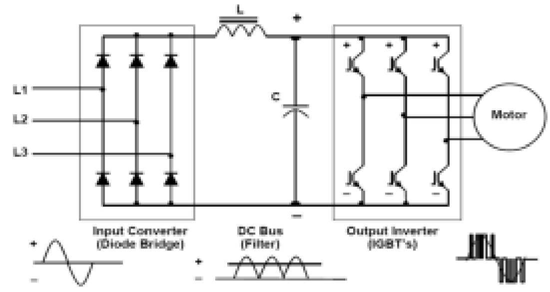

Fig.4 Generalized schematics of VFD

Affinity laws for screw compressor

- Flow is proportional to speed.
  (Flow1 / Flow2) = (RPM1)/ (RPM2)
- Pressure is proportional to the square of the speed.
  (Pressure1 / Pressure2) = (RPM1)2 / (RPM2)2
- HP is proportional to the cube of the speed.
  (HP1 / HP2) = (RPM1)3/ (RPM2)3

There are certain advantages of the VFD drive which are listed below.

- Drive control will reduce the power penalty associated with slide valve
- On compressors with no capacity control, speed control will eliminate other poor control strategies
- Drive control will reduce wear and tear associated with slide valve action
- Drive control allows a precise suction pressure to be maintained. With slide valve, a broad dead band is often maintained to avoid excessive wear
- Drive speed control provides compressor size reduction with the same system capacity demand
- Advanced control & diagnostic interface possibilities (e.g.: SCADA)
- Less maintenance thus reduce the downtime of the system / lower whole of life cycle costs
- Low in rush current / low torque surge and thus less mechanical stress

1) Heat Loss from a Variable-Frequency Drive at full load

Converting ac power to a dc bus and then back to a simulated ac sine wave can use up to 4% of the power that would be directly supplied to a motor if a VFD were not used. For this reason, VFDs may not be cost-effective for motors run at full speed in normal operation. If a motor must output variable speed part of the time, and full speed only sometimes, a bypass contactor used with a VFD can maximize efficiency.

A certain amount of the power transferred through the variable-frequency drive to the motor is lost as heat to the surroundings. The heat loss inside VFD can be expressed by equation shown below.

$H_{loss} = P_t (1 - \eta d)$

Where,

H_{loss} = heat loss to the variable-frequency drive surroundings (kW)

P_t = electrical power through the variable-frequency drive (kW)

ηd = variable frequency drive efficiency

For calculating the maximum heat loss - maximum power transmission through the variable-frequency drive must be used.

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A study of drive catalogue from Rockwell Automation shows watts loss data for particular drive running at full load, full speed and default carrier frequency. In this it shows that for 315kW motor there are external watt losses are nearly 5652 W and internal watt losses are 1298. The total watt losses are nearly 6950W which is about 2% of full load and the electrical losses in motor at full load operating condition is 2.5%. So the total losses of variable speed method can be approximated to 4.5-5% of full load ratting of the VFD [3].

This phenomenon reduces the overall efficiency of the drive at full load operating conditions.

IV. GRAPHICAL COMPARISON

By analyzing slide valve control and VFD control simultaneously, the performance characteristics of percentage capacity (load demand) versus power delivered is explained in the Fig.5 and Fig.6. In those figures one can observe that for a specific compression ratio of ammonia, slide valve control is efficient for full load control that is from 95% to 100% capacity control.

Fig. 5 and 6 depict that at full load the power consumption of VFD is higher than slide valve. This is caused by the electrical losses in the VFD and motor. This results in a net efficiency penalty of 4.5% at full load. Once the compressor unloads below 95%, VFD has an increasing power advantage compared to the fixed speed drive operation (slide valve).

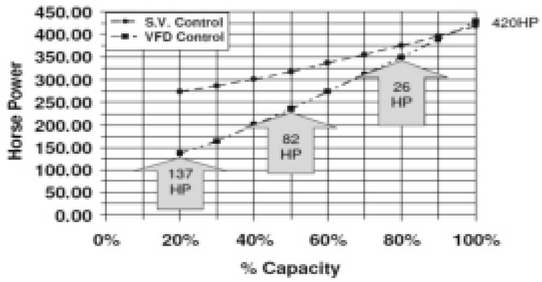

Fig.5 Comparison of Slide valve and VFD at 18.75:1 Compression ratio on Ammonia [4]

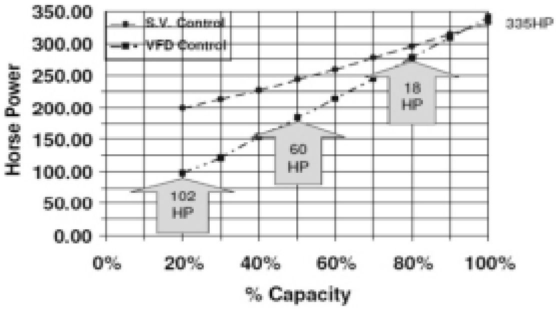

Fig.6 Comparison of Slide Valve and VFD at 13.45:1 Compression ratio on Ammonia [4]

In the case of 60 per cent capacity, the slide valve control consumes approximately 80 percent of the power. Whereas, with VFD control, at 60 percent capacity the power consumption is approximately 60 percent. Thus, capacity control is independent of power consumption in slide valve.

V. CONCLUSION

To control the discharge capacity of the screw compressor various control parameters like suction pressure, inlet mass flow rate, speed of the rotor etc are necessary. In this paper two prevalent control methods in which one is hard (mechanical) control and other one is soft (electronic) control are thoroughly studied and following point can be concluded.

- The soft control can be justified as a part load control; one must consider the load profile and operating conditions that are expected in a particular application.
- The hard control can be justified as full load control because of optimum performance characteristics at full load condition.

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