Compressors Surge Suppression in Asmari Kupal Gas Station Based on Smart Control Technique

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Abstract

Surge and rotating stall phenomena are two dynamic instabilities that occur in both axial and centrifugal compressors. Surge is the stream instability phenomenon in compressor that imposes severe damages to the compressors. Nowadays, suppressing surge phenomenon is one of the most important issues in oil and gas industries, especially when flow reduction or gas reflux is considered. This research seeks to extract the required technical information about control lines, surge lines, and to present a new combined method to determine the performance curve of 6 rows of gas compressors in Asmari Kupal gas pressure boost station (National Iranian South Oil Company) made in Germany by MAN BORSIG Company, and to design a smart controller in order to increase the reliability of the control system and improve the machine performance. Finally, the system performance validity is shown by simulating a surge characteristic curve and implementing two points of the compressor operation condition.

Keywords: surge, compressor curve, rotating stall, stonewall, anti-surge valve

1. Introduction

Pumps and compressors, as the last loop of the exploitation chain of oil and gas industries, have always played a vital role in production. Because of the technical and structural complexities of rotation machinery and the exclusiveness of its production for a few companies, this equipment plays a key role in oil and gas industries. Because of the extended application of centrifuge compressors in energy industries, especially oil and gas industries, the stable performance and at the same time optimum performance of these turbo-machines is considered as an important issue.

The main limiting factor of the compressor performance is aerodynamic instability in the form of surge and rotating stall phenomena, suppression of which leads to limitation in achieving the optimum performance region and thereby decreases the plant yield [1]. The occurrence of these instabilities have some adverse results including sharp reduction in yield, physical damages to plant and forced shut down, that are not desirable at all. Here an engineering compromise is discussed where the maximum operating yield is sacrificed for stable performance. Ensuring a stable function for the system in optimum operating zone is a desirable goal for exploiters of these systems. It should be noted that the maximum yield range is near the instability range.
Surge and rotating stall are the main instabilities in turbo-machines with contrary pressure gradients, among which surge plays a more profound role in destabilizing the centrifuge compressors. The surge control system in gaseous compressors is a basic and very important issue in dynamic stability and in determining the operating zone for the machine. The anti-surge control system designers, who often have a close collaboration with the compressor manufacturers, use this information to find surge lines in special coordination. In fact, the most complex part for the control engineers in designing a surge control system is this very part.

[2-17] has obtained different methods to remove the surge limitation in compressor systems using mathematical models and aerodynamic instability models. Surge avoidance method, based on select the surge control line and design a controller to prevent the system from entering the instable zone. This method has a wide application in industry. The active surge control method, presented by Epstein [2] and addresses the surge stability issue, doesn't have a significant application in industry, and there are only a few works with different control methods and different operators [3, 4]. In [5], using a piston and LQR a controller is presented for surge control. Paper [6] provides a model of the compressor with a surge avoidance system including flow return valves, and designs a PI controller for it.

A high variety of operators has been presented by designers in order to control surge, including Inlet

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Guide Vanes (IGV) [7], Throttle Control Valve (TCV) [8, 9], and Close Couple Valve (CCV) or Anti-Surge Valve [10]. Also in [11] a combination of inlet valves and TCV is presented for surge control. In addition to the operators, there are different control methods for surge suppression, summarized as follows. Several adaptive and passive controllers using CCV operators have been suggested in [10]. Also continue to investigate the compressor control by increasing the complexities of non-disturbance surge control, constant disturbance surge control, time-variable disturbance surge control, non-disturbance stall and surge control. In [12], using CCV operator and a second order sliding mode method, and has presented some controller based on active control just by measuring air flow. Paper [13] has provided two methods from robust feedback control for stabilizing surge phenomenon in compressor. In [14] a predictive model controller has been designed for surge control in centrifugal compressors. The applied MPC uses the least squares method to increase the compressor efficiency.

A high gain, adaptive controller for surge suppression in centrifugal compressors with a inlet duct and a TCV operator has been suggested by [15]. In [16], by control valves around the operating zone, the authors has designed a new, positive feedback controller using pole-place method in order to control surge. A centrifugal compressor with fixed speed and CCV and TCV operators has been studied in [17], where some controllers has been designed for it using Fuzzy, Anti-Windup PID, Gain Scheduling PID, Sliding Mode and Back-stepping methods.

In surge avoidance method, selecting the technique and the controlling tools, as well as determining an appropriate margin between the control line and surge line, is of utmost importance because the stable operation of compressor in optimum operation zone is the most desirable target of these systems. Most of the previous works have focused on compressor stability and preventing the compressor from entering the instability area, thus, in order to have a stable performance, they should be at a distance from the surge line which decreases efficiency.

In this paper, we are seeking a method that, while ensuring stability, uses an appropriate control technique and employs optimally some operators such as CCV and TCV, in order to be able to get the control line closer to the surge line and increase the system efficiency. This method suppresses the surge control valve from unnecessary functioning and energy wastage, and this improves the machine return and can be beneficial for production process in oil and gas industries. It should be mentioned that, if the smart technique is used and its results are implemented, then it can be a landmark in localization of this knowledge and a foreword in self-sufficiency and even exporting this technical knowledge.

The paper is structured as follows. In section 2 is recalled the surge and its suppression methods. In section 3 is presented surge control system. The technical characteristics of a case study system are introduced in section 4. The results of technical researches are discussed in section 5. In section 6 is obtained surge zone and controlling it, and some concluding remarks are presented in the final section 7.

2. Surge and its suppression methods

The surge phenomenon is in fact an axial swing of stream in a compressor. Usually, swing in the stream through a compressor causes swing in pressure. Generally, surge can be considered as a multi-dimensional phenomenon. Surge swing is an undesirable phenomenon in most applications. The fluid behavior in surge depends on the compressor performance and the performance curve of any equipment that is located downstream the compressor and is coupled with it, like turbine and electromotor [7]. There exist three general ways to suppress surge phenomenon in a machine:

- Decreasing outlet pressure
- Increasing inlet fluid stream
- Variable speed drives

If the gas is dangerous or valuable, then the flow return pipes (the second method) are used. In this was the discharged gas can no longer enter the open space and returns to the compressor. Because when the gas is compressed its temperature increases, if the returned gas from the outlet pipe is connected to the inlet pipe, it increases the inlet gas temperature that decreases the compressor efficiency. So the flow return pipe should be installed after the cooler in order to return the cold gas into the compressor. The flow return valve, like discharge valve, can work automatically.

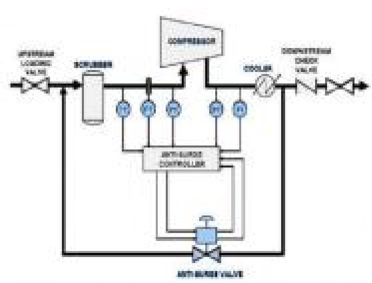

Figure 1. The arrangement of instrument and the return flow pipe

The arrangement in figure 1 is one of the most prevalent arrangements in centrifugal compressors. The effects of inlet and outlet line volume, row outlet cooler, etc. should be considered in this arrangement.

3. Surge control system

Surge control system is among the most sensitive and crucial controllers in a machine control system package. The important characteristics of this control system, which are always considered by credible manufacturers in their designs, are:

- High speed response
- High reliability and accessibility
- Accurate and efficient control algorithm
- High precision, control system, measurement equipment (First Element) and control valve (Final Element)

Generally, there are different arrangements for measuring the compressor parameters in order to find the operating zone, but one of the most prevalent of them is shown in figure 1. In this method, the control system measures some parameters like inlet pressure, inlet temperature, fluid volume, outlet pressure and outlet temperature to calculate head and flow. According to dynamic equations of the machine, the manufacturer of each compressor provides some diagrams called Performance Map. According to these diagrams, the lowest fluid volume that the compressor needs to start operating is extractable in different speeds. (figure 2)

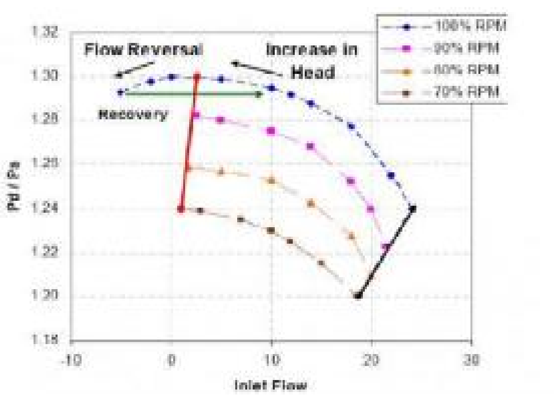

Figure 2. Performance map

Put it simply, the main task of an anti-surge control system is to maintain the compressor operating zone in locus, from 2-dimensional space of the compressor's performance map. This range is determined by different parameters including: surge limit, maximum speed, and power limit, compressor choke limit (Stonewall), minimum speed (figure 3).

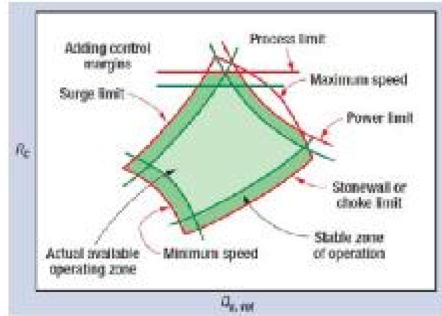

Figure 3. The locus and operating zone of a compressor

Because of an increase in processing and responding speed, which is also required for surge control systems, we often try to consider the coordination axis where the surge line is drawn (for control department) on the basis of simple and exact parameters. For example, the horizontal axis based on the pressure difference of orifice ends and the vertical axis based on quantities like outlet pressure or a function of inlet and outlet pressure.

After specifying the surge line in the determined coordination, the control line equation is determined. The control line is defined with a certain distance on the right side of the surge line (figure 4). The distance between surge line and control line is of utmost importance, because if this distance is greater than the appropriate distance, then we would have energy wastage and, on the other hand, if it smaller than the appropriate distance, then it would increase the possibility of surge phenomenon in the compressor. When selecting this distance, a lot of parameters would be considered, the most important of which are:

- Precision, reliability and response speed of the sensors
- Response speed of surge control valve
- Calculating the system delays (inlet and outlet lines, coolers, etc.)
- The control system speed and precision
- Process variation speed
- Machine revolution speed

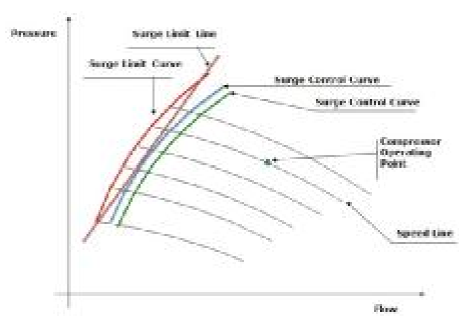

Figure 4. Schematic of surge lines and compressor control

After determining the surge control line, we should implement the control algorithm and finally load it in the control system and conduct some field experiments. It should be noted that complex algorithms are not necessarily efficient. As it was mentioned earlier, algorithms should be as simple, fast and efficient as possible.

4. Technical characteristics of a case study system

Asmari Kupal gas pressure boost station, with 6 rows of electro-compressors and (1+1) arrangement is equipped in three gas parts: the 4th-stage (101 A&B - 2 rows), the 3rd-stage (102 A&B - 2 rows), and the 2nd-stage (103 A&B - 2 rows). The compressors in this station are made in Germany by MAN BORSIG Company. Except the 4th-stage compressors, which are Screw Compressors, other rows are equipped with centrifugal compressors.

Table 1. Technical characteristics of the compressors

Item	102 A/B	103 A/B
Type	RH 035/05	RH035/08
Suction Volume(m^3/h)	1908	1642
Suction Pressure(bar)	0.65	5.64
Suction Temp.(C)	53	52
Discharge Pressure(bar)	6.51	32.6
Discharge Temp.(C)	180	180
Input Power(KW)	240	823
Speed(%100)	14825	13674
1^{st} critical Speed	7300	5810
Anti-Surge Controller Tag	NIC147A/B	NIC167A/B

Surge control system in 2nd and 3rd stage compressors is made in U.S. by CCC Company and is of 3+ type.

This system has some deficiencies including:

- Requiring special expertise for programming
- Drastic dependence upon CCC Company, so that if the system fails, we should demand a similar one from the company.
- Lack of ease (in some impossible cases) in changing the program
- Lack of technical support in Iran
- The existing system is outdated

5. The results of technical researches and reviews

The aim of this section is to find the surge line and control line, that loaded in the existing system. To achieve this goal, all technical evidence and process maps (P&ID) of Kupal gas pressure boost station, and the program of CCC control system were investigated and analyzed carefully in order to reach a general perspective of the performance of its different parts.

Table 2 .process parameters for row 102A&B

Row	Parameter	Summer	Winter
1	Qs(ACMH)	2.5	2.5
2	Ps(BarA)	1.65	1.65
3	Ts©	53	50
4	Ts(K)	326.15	323.15
5	Zs	0.983	0.984
6	$\rho s(Kg/m)^3$	2.4605	2.4395
7	ΔP0(mbar)	160	160
8	MW	39.75	38.39
9	A(flow Measurement Constant)	310	309
10	CV(anti surge valve)	63	63

6. Obtained surge zone and controlling it

Given the fact that the surge control systems of 2nd and 3rd stage compressors in Kupal gas pressure boost station are similar, and the only difference in in their dynamic data for both compressors, and that our goal is to find a solution for extracting surge lines and control lines, from the beginning, the work was based on the 102 A&B compressors (NIC 147 controller).

In the existing system, the following relations are used for signal filtration and normalization.

$$F1(x) = (\Delta Po, c)/(K*Ps*F5(Z) \qquad (1)$$

$$PV1 = Gain1.SV1 + Bias1 \qquad Where$$

$$SV1 = \Delta P0/\Delta P0, span$$

$$PV2 = Gain2.SV2 - Bias2 \qquad Where$$

$$SV2 = (Pd - Pdl)/Pd, span$$

$$PV3 = Gain3.SV3 - Bias3 \qquad Where$$

$$SV3 = (Ps - Psl)/Ps, span$$

$$X = \frac{PV2}{PV3}$$

$$K=0.5(surge\ limit\ line\ slop\ coefficient)$$

$$\Delta Po = \left[\frac{Qs}{A}\right]^2 .\rho s$$

$$\rho = \frac{P.MW}{Z.RO.T}\left(\frac{Kg}{m^3}\right)$$

$$P=gas\ pressure\ (Kpa)$$

T=Gas Temperature (K)
Z=Compressibility Factor
MW=Gas Molecular Weight
R0=8.31441 KJ/(Kg.moleK) universal gas constant

According to these relationships, the conversion function F1(x) on the basis of $X = \frac{PV2}{PV3}$ equals to:

$$F1(x) = -0.0185X^3 + 0.3218X^2 - 0.3662X + 0.1487 \quad (2)$$

$$y = 0.0151x^3 - 0.2577x^2 + 1.997x + 0.333 \quad (3)$$

With an standard deviation of R2 = 0.9976 So, the defined surge control line in CCC controller (NIC 147) can be drawn based on F1(x) function (Figure 5). In fact, the existing control system will work on this basis: whenever there is inlet and outlet pressure on the compressor, the controller calculates F1(x) using Equation (2), this will give the amount of flow control in that point, then by reading the pressure difference between orifice ends the momentum flow is obtained, and by comparing these two values the system can find the deviance.

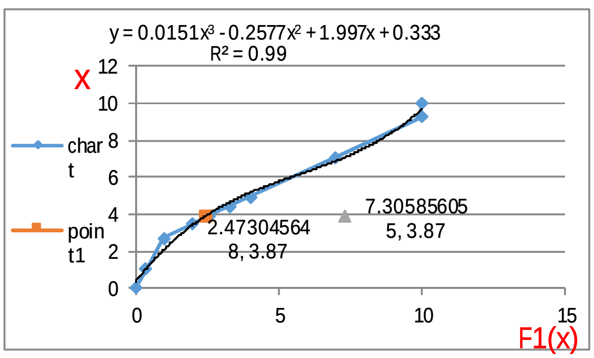

Figure 5. The conversion function F1(x) and surge and operation zones

In normal condition for a compressor, given the parameters in row 102A and by allowing X = 3.87 in equation (2) this will be obtained: F1(x) = 2.4730 (the amount of control for F1(x)). Now we should calculate F1(x) by substituting PV3 and PV1 into equation (1) (K = 0.5 and F5(x) = 1).

F1(x)=PV1/(K*F5(x)*Ps) (4)
F1(X)=(0.6618)/(0.5*1*0.1812) = 7.30585 (Actual)
It can be observed that the actual value for F1(x) has been greater than its control limit and till these two values are not equal, PI controller system cannot be activated. By applying the obtained values into the equations of figure 5, the equations for surge line and control line can be obtained in the new coordination (Pd/Ps-dP) (figure 6).

The equation of surge control line for designing the substitute control system: (in dP coordination of orifice ends in relation to Pd/Ps)

$$\begin{cases} Y = 0.1488 * X - 0.5 \\ Y = 0.1488 * X + 2 \end{cases} \quad (5)$$

The proposed control lines with margin are 63% for the first line and 27% for the second line in relation to the surge line. In well-designed control systems where all the SAT tests has been conducted and monitored by the manufacturer, the proposed margin is 6-10%. As can be seen in the next figures, the distance between operating point and surge zones from both lines is quite suitable, so using the second line equation (Y = 0.1488 * X + 2) as the control line for the new system is the best choice.
To approve the locus of surge and control line, the values of 8 points around surge line in different conditions are extracted and drawn in this coordination in order to ensure its accuracy. Based on the characteristics of the announced 8 points, it is recognized that all the points approve the provided surge line coordination (figure 6).

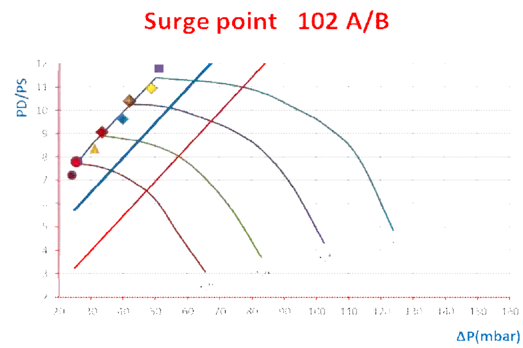

Figure 6. The extracted surge line and the new control line of the compressor.

Based on real-world condition, coordination of the two normal operational points for compressor are also drawn in figure 7 to be compared to the diagram in previous figure, which is another validation for the accuracy of the obtained lines.

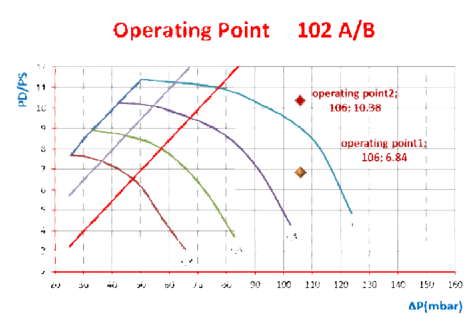

Figure 7. Two points of compressor operating points

7. Conclusion

The proposed controller in this paper shows that there is an engineering compromise between the maximum yield and stable performance. In the proposed controlling plan, considering the arrangements and various equations used for measuring the compressor parameters and applying the real operation points and surge lines in different conditions in the determined equations, the best choice for the control line near the maximum pressure and efficiency area is presented. The competitive advantage of the proposed plan is that this control method can be implemented in practical applications.

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