Anti-surge Control Technologies of Large–sized Chinese Gas Compression Pump

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Abstract

In this paper, we take Jinan Iron & Steel Co. Ltd.'s Gas-steam Combined Cycle Power Generation Gas GCP as the object of study. This is the first application of Chinese large-sized gas compression pump in the field of steam-gas combined cycle power generation and thus initiates the application of technologies of Chinese large-sized gas compression pump. To broaden the pump's relatively narrow working area where the centrifugal compressor functions stably and to minimize the surge incurred therein, we established the anti-surge mathematical model and anti-surge control algorithm applicable to this gas compression pump; according to default settings, we tested anti-surge safety curve and thus figured out the estimated anti-surge safety curve to be incurred in application; then we concluded the anti-surge safety curve of the gas compression pump by fitting the test results of anti-surge safety curve into the estimated anti-surge safety curve. In practice, this gas compression pump not only satisfied the requirement for control function, but also reached the leading level in the same industry of China.

Keywords: *Centrifugal compressor, surge suppression, anti-surge control technologies, performance curve, fitting, correction*

1. Introduction

Gas Compression Pump (hereafter referred to as "GCP" for short) is defined as a gas-supplying device that satisfies the requirement of pressures and temperatures of gas turbine, and is thereby regarded as a key section of technical flow of electricity generation. Jinan Iron & Steel Co. Ltd. 's Gas-steam Combined Cycle Power Generation Gas GCP employs a GCP made by Shenyang Blower Works Group Corporation with motor capacity of 16,500kW, revolving speed of 7,865rpm, and unit capacity of 125,000 m^3 /h, which is the first application of large-sized GCP in Chinese Gas-steam Combined Cycle Power Generation Gas GCP.

If centrifugal compressor works underload and thereby functions within critical low-flow rate area, it is very much likely to cause periodical air flow surges (usually referred to as "surge" for short), which may damage the bearings and seals of the centrifugal compressor or even result in serious accidents [1]. Till now, we are unable to theatrically figure out the correct performance curves or surge points of the centrifugal compressor. On the contrary, we can roughly estimate whether the centrifugal compressor has entered the working condition by testing its performance [2].

The surge of the centrifugal compressor is chiefly caused by decrease of load. To immune GCP from surges, it is necessary to keep the actual surge flow higher than or at least equal to the maximum surge flow at any speed. Usually, two control algorithms, Pd/PS ˜ h/PS% algorithm (variable limit flow method) and DP ˜ h% algorithm (fixed limit flow method), are used in anti-surge control systems. Usually, the anti-surge control systems are established by figuring out the surge points through selected control algorithms at first, and then generating surge curve on the basis of the selected surge points (reserve 3 at least) [3~5].

2. Abbreviations in Control Algorithms

C: Constant

CP: Special Heat at Constant Pressure

CV: Constant-volume Specific Heat

H: Differential Pressure of Restrictive Elements （kPa/MPa） hc h/Ps% Dimensionlessness

HP: Energy Head

CP/CV: Specific Heat Ratio

M: Mass-flow Rate / Mass FLow-pressure-difference relation

MW: Mol.wt.

N: （rpm/min） rotate speed (rpm/min）

T: temperature （k）

Q: （m3/h） Volume Flow (m3/h)

R: Gas Constant

RC: Pressure Ratio

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IJCSI International Journal of Computer Science Issues, Vol. 10, Issue 2, No 2, March 2013
ISSN (Print): 1694-0814 | ISSN (Online): 1694-0784
www.IJCSI.org

Pd/Ps: Dimensionlessness

ρ: Density （kg/m3）

σ : PolytroDiagram exponent

ηP: Polytro Diagram efficiency

Ps: Inlet Pressure （kPa / MPa）

Pd: Outlet Pressure （kPa / MPa）

Note: Corner Mark: S－Entrance of GCP D- Exit of GCP.

3. Anti-surge Control System

3.1 Algorithm Design

As a general rule, a characteristic curve of centrifugal compressor indicates the relation between the ratio (Pd/PS) and the volume flow at entrance. Firstly, according to this curve, coordinate value (Pd/PS、QS(Surge Point) of each surge point under working conditions can be figured out; Secondly, convert the coordinate value of each surge point into a one under coordinate system of Pd/PS% ˜ h/PS%or DP ˜ h% by means of mathematical models; Thirdly, select at least 3 surge points under working conditions and thereby figure out surge curve by making use of polygonal function made up of surge points. When gas flows decrease to the surge points, the surges occurs; meanwhile, the area on the left side of the surge curve is defined as unstable surge area [6].

3.2 Coordinate Plane of Pd/PS～h/PS

$$(\frac{P_d}{P_s})^{\sigma} - 1 = C\,\frac{h}{P_s}$$

3.3 Mathematical Model of Pd/Ps～h/PS Control Algorithm

Mathematical Model at Surge Points:

$$h_s / P_s\% = (\frac{Q_s}{Q_{\max}})^2 \cdot \frac{T_{SR}}{T_s} \cdot \frac{MW}{MW_{SR}} \times 100$$

Mathematical Model at Safety Operating Points:

$$h_s / P_s\% = \frac{P_{SR}}{h_{\max}} \cdot \frac{h_s}{P_s} \times 100$$

Mathematical Model at Surge Points:

$$h_s / P_s\% = (\frac{M}{M_{\max}})^2 \cdot (\frac{P_{SR}}{P_s})^2 \cdot \frac{T_s}{T_{SR}} \cdot \frac{MW_{SR}}{MW} \times 100\%$$

Mathematical Model at Safety Operating Points:

$$h_s / P_s\% = \frac{h_d}{h_{\max}} \cdot \frac{P_d}{P_{df}} \cdot \frac{T_{df}}{T_d} \cdot (\frac{P_{SR}}{P_s})^2 \cdot \frac{T_s}{T_{SR}} \times 100\%$$

3.4. The Constitution of the System of anti-surge Control Algorithm

According to the mathematical model of Pd/PS ˜ h/PS% control algorithm, the constitution of the anti-surge control system can be figured out as below.

The mathematical model of anti-surge control system

$$P_d / P_s = f(\frac{h_s}{P_s}) \text{ or } \frac{h_s}{P_s} = f(P_d / P_s)$$

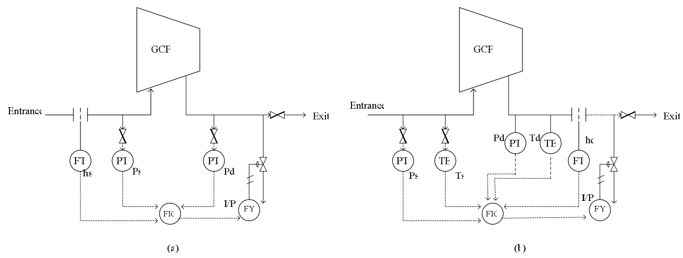

Figure 1. Configuration of anti-surge Control System

According to Diagram 1(a), the anti-surge control system is associated with 3 parameters, Pd, PS and hS

The mathematical model of anti-surge control system:

$$P_d / P_s = f(\frac{P_d}{T_{ds}} \cdot \frac{T_s}{P_s^{\,2}} \cdot h_d)$$

According to Diagram 1(b), the anti-surge control algorithm is associated with 5 parameters, h_d, P_d, Ps, Ts and T_d.

4. Control System Correction of Anti-surge Safety-Operating Points

4.1. Expected Performance Curve of Low-pressure Cylinder

Table1. Default Settings of Low-pressure Cylinder

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Standard Parameters	Ps= Mpa(A)	Ts= ℃	MW=	Z=	Qmax= Nm3/H	Density ρ=	Hsmax
	0.103	35	26.524	1	125000	1.02507526	1.6
(1) Working Condition at Low Flow Rate							
	Ps= MPa	Ts= ℃	MW=	Z=	Qmax= Nm3/H	ρ=	
Parameters in Use	0.09	35	25.7	1	125000	0.86787093	1.6
Parameters	SSPEED	Q(m3/H)	Q(Nm3/H)	Pd (Mpa)	H/Ps%	Pd/Ps	Hs
			68820.98608	0.223	22.42468904	2.47777778	0.485
Safety Operating Points			76386.91601	0.244	42.73784722	2.71111111	0.5975
(2) 2nd Safety Operating Points							
	Ps= MPa	Ts= ℃	MW=	Z=	Qmax= Nm3/H	ρ=	
Parameters in Use	0.093	35	25.755	1	125000	0.89871918	1.6
	SSPEED	Q(m3/H)	Q(Nm3/H)	Pd (Mpa)	H/Ps%	Pd/Ps	Hs
100%			72967.24436	0.234	26.97427912	2.51612903	0.5452
Safety Operating Points			82632.46941	0.258	48.39892473	2.77419355	0.6992
(3) 3rd Working Condition							
	Ps= MPa	Ts= ℃	MW=	Z=	Qmax= Nm3/H	ρ=	
Parameters in Use	0.095	35	25.73	1	125000	0.91715534	1.6
	SSPEED	Q(m3/H)	Q(Nm3/H)	Pd (Mpa)	H/Ps%	Pd/Ps	Hs
100%			81376.10406	0.253	34.97415979	2.66315789	0.6781
Safety Operating Points			89617.24164	0.273	55.72842105	2.87368421	0.8224

In accordance with the foresaid algorithm design and on the basis of default configuration of GCP, a surge boundary curve (as shown in Figure 2) can be figured out by calculating and testing surge points under different flow rates.

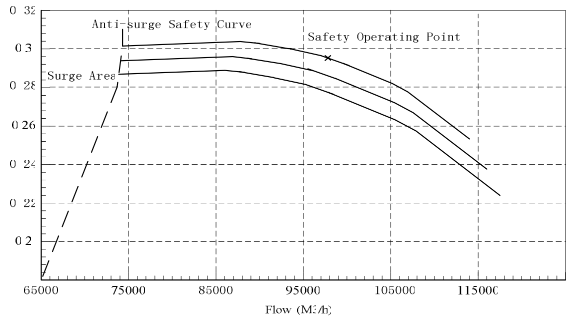

Figure2. Expected Performance Curve of Low-pressure Cylinder

4.2. Expected Performance Curve of High-pressure Cylinder

Table2. Default Settings of High-pressure Cylinder

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IJCSI International Journal of Computer Science Issues, Vol. 10, Issue 2, No 2, March 2013
ISSN (Print): 1694-0814 | ISSN (Online): 1694-0784
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Standard Parameters	Ps= Mpa(A)	Ts= ℃	MW=	Z=	Qmax= Nm3/H	Density ρ=	Hsmax
	0.283	42	26.73	1	1E+05	2.7753	4
(1) Working Condition at Low Flow Rate							
	Ps= MPa	Ts= ℃	MW=	Z=	Qmax= Nm3/H	ρ=	
Parameters in Use	0.265	31	25.73	1	1E+05	2.592	4
	SSPEED	Q(Nm3/H)	Q(Nm3/H)	Pd(Mpa)	H/Ps%	Pd/Ps	Hs
100%			76852	2.4	25.28	9.0566	1.512
Safety Operating Points			83456	2.72	47.6	10.264	1.783
(2) Working Condition at 2nd Safety Operating Point							
	Ps= MPa	Ts= ℃	MW=	Z=	Qmax= Nm3/H	ρ=	
Parameters in Use	0.234	31.2	25.73	1	1E+05	2.2873	4
	SSPEED	Q(m3/H)	Q(Nm3/H)	Pd(Mpa)	H/Ps%	Pd/Ps	Hs
100%			79348	2.55	21.12	10.897	1.6118
Safety Operating Points			86600	2.46	58.05	10.513	1.9199
(3) Working Condition at 3rd Safety Operating Point							
	Ps= MPa	Ts= ℃	MW=	Z=	Qmax= Nm3/H	ρ=	
Parameters in Use	0.25	31.5	25.73	1	1E+05	2.4413	4
	SSPEED	Q(m3/H)	Q(Nm3/H)	Pd(Mpa)	H/Ps%	Pd/Ps	Hs
100%			85511	2.8	28.21	11.2	1.8719
Safety Operating Points			92121	2.455	61.48	9.82	2.1725

Same as calculation of surge boundary curve of low-pressure cylinder, the calculation of surge boundary curve of high-pressure cylinder is shown in Figure 3

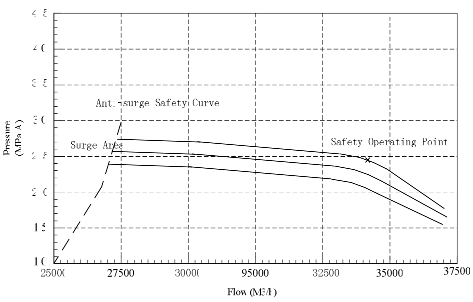

Figure 3. Expected Performance Curve of High-pressure Cylinder

4.3. Test surge curve according to the actual production status

4.3.1. Preparations for test of GCP surges

(1) Fully open three reverse flow valves of CV1205, CV1206 and CV1207.

(2) Close / Open the entrance valves (guide vanes) of CV1201, CV1202 until they reach the degree of 0.

(3) Open the blow-off valve of cv1209 until it reaches certain angle so as to make it meet actual working requirements.

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(4) have other condition met other requirement of start and make other persons take their places

(5) Start GCP

(6) In view of the heavy damage of surge to GCP, it is suggested to avoid surges during the test as possible as you can or to free the GCP from surges as soon as possible.

4.3.2.Surge Test of Low-pressure Cylinder (DMCL706）

(1) Fully open the valve of CV1205

(2) Open the guide vane at the entrance until it reaches 40% or so of the entrance valve, which could be adjusted in consideration of the flows.

(3) Close the return valve of CV1207 until it reaches the proper position and close/ open the return valve of CV1206 until it reaches the proper position so as to immunize the high-pressure cylinder from surges and to establish pipe network.

(4) Slowly close down the return valve from 5% at the beginning to the 1% at the end. After each closedown of the valve, the valve must not be re-opened until the GCP has entered a normal performance. During this period of time, it is required to notice the fluctuations of Pd and flows, the vibrations and the lubricating oil as well [9~10].

(5) Remember to compare the performance curve in practice with the default one; especially, notice the performance of GCP when the curve approaches the surge point. When such indicative surge signs as obvious fluctuations are discovered in the flow of FT1201 at entrance or in Pd of PT 1202 at the exit, it is necessary to immediately open the return valve numbered CV1206 and return valve numbered CV 1205 so as to unload flow pressure. Meanwhile, we record the surge point preceding this one as the critical surge point.

(6) Even though a great deal of air flows into the GCP during the latter section of the performance curve the pressure at exit raises. It is notable that though the fore section and the latter sections are inter-related, what is worth concerning about is both the pressure at the exit and flows at the entrance.

(7)Record and test the data.

(8) Open the guide vane at the entrance by half or so, the exact extent of which hinges on the actual flows. Repeat steps from (2) to (7).

(9) Open the guide vane at the entrance until it reaches 70% or so of the vane. Repeat steps from (2) to (7).

(10) Beware of the overload of the current.

Table3. The Test Result Low-pressure Cylinder's Anti-surge safety curve

Angle of Guide Vane	Pd(Kpa)	Ps(Kp)	Hs(Kpa)	H/Ps%	Pd/Ps	Temperature of Ps
40%	234.35	Ps(Kp) 4.448	Hs(Kpa) 0.33354	H/Ps% 20.30453	Pd/Ps 3.174055	18.6

According to the test result, the critical surge point established when the guide vane reaches 40% of the valve and the break point of default surge curve shall form the new surge curve.

For the comparison between the surge curve after correction and the default surge curve, please refer to Figure 4.

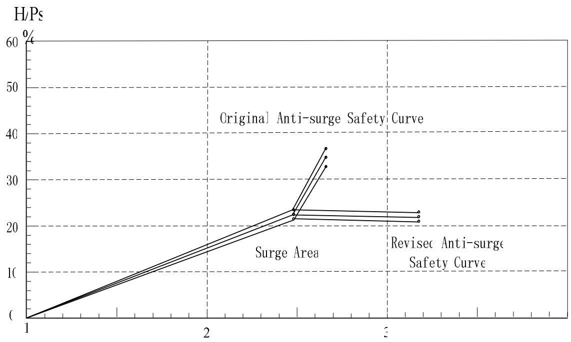

Figure 4. The comparison of surge curves of low-pressure cylinder before and after correction

4.3.3. Surge Test of Compressor（2MCL707）of High-pressure Cylinder

The procedure of surge test of high-pressure cylinder is roughly the same as that of low-pressure cylinder except for the difference in operation of return valve. For the test results, please refer to Table 4.

Table4. Test Results of Surge in High-pressure Cylinder

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Angel of Guide Vane	Pd(Kpa)	Ps(Kpa)	Hs(Kpa)	H/Ps%	Pd/Ps	Temperature at Entrance
40%	2060	70	1.297753	53.59954	12.61705	27
50%	1750	47	1.09635	52.30395	12.48348	29.5
55%	2370	100	1.44199	50.68097	12.2767	31

The theories of both calculation and fitting of the surge curve of high-pressure cylinder are the same as those of low-pressure cylinder. For the comparison between the default surge curve and the surge curve after correction, please refer to Figure 5 shown as below.

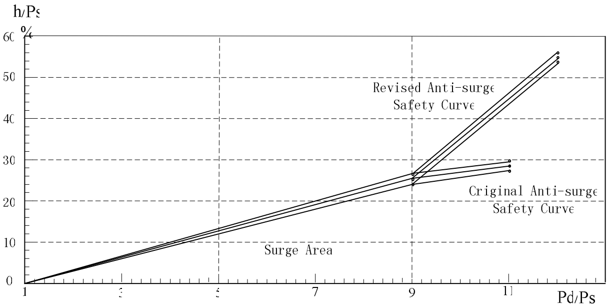

Figure5. Comparison of High-pressure Cylinder's Surge Curves before and after Correction

5. Conclusion

Since 2010 when 1st anti-surge control system of GCP was put into use, 8 such systems have came into service and passed a variety of on-spot tests. It has been found that this system has exceeded its competitors in both control accuracy and stability of performance, which both secures the speedy reaction of the GCP and avoids the malfunctions thereof. By contrast, it is discovered that when the defined low flow decreases under the certain pressure ratio, the after-correction anti-surge safety curve, by contrast to the default one, has more working space and thereby owns more capabilities to secure normal performance of the GCP. Since the time when it was put into operation until now, this system has performed reliably and stably and thus saved manpower and material resources in its maintenance, which have effectively guaranteed the normal operation of the GCP; at the same time, this system generated both considerable economic benefit and social benefit.

This academic thesis (No.: J10LG63) is entitled as one of the research results of Research and Application of Key Control Technologies of Chinese Large-sized Gas Compression Pump, a scientific research program of institutions of higher education of Shandong Province in 2010.

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