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Analysis on the Cause of Bias Flow in Cracked Gas Compressor

Yuying Sun[1,*], Jinsheng Wang[1], Liang Li[2]

[1]*Research Instituted, Shenyang Blower Group Co., Ltd.*
No.16A, Development Road, Economic &Technical Development Zone, Shenyang, China
[2]*SBW installation Maintenance Accessory Co., Ltd.*
No.16A, Development Road, Economic &Technical Development Zone, Shenyang, China
**corresponding author*

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Abstract: Ethylene is one of the largest chemical products in the world, and the ethylene industry is the core of the petrochemical industry. At present, the scale of the largest ethylene plant has reached 1.8 million tons/year. Many petrochemical enterprises have achieved an increase in ethylene production through the transformation and upgrading of the original equipment. The cracked gas compressor is the key moving equipment in the ethylene plant. It is the first procedure of conveying raw gas in the ethylene process and the key unit of the whole process. the weight flow of the compressor limits the maximum production capacity of the plant. This paper takes the cracked gas compressor in an ethylene plant as the research object and analyses the bias flow phenomenon, which refers to the uneven amount of flow in the intake pipelines of the low-pressure cylinder with double-suction structure during the start-up process. From the perspectives of changes in compressor design parameters, differences in actual operating conditions and performance curves, and characteristics of pipe network resistance, we expound the influencing factors that cause drift flow, and put forward reasonable suggestions for the design method of retrofit compressors. It provides a high reference value for the design and smooth start-up of the cracking gas compressor renovation plan.

1. Introduction

Cracked Gas Compressor (CGC) is a key rotating machinery in ethylene plant. Three-cylinders configurations with four or five sections are common configuration of the compressor, usually with one section as a structure of dual inhaling symmetric distribution. Multiple occurrences of the bias flow phenomenon were observed in several worksites such as Fushun Ethylene, Zhongyuan Ethylene, and Daqing Ethylene, etc, on CGCs produced from different manufacturers that adopts this design model. In response to this special flow phenomenon, Guo Zhongsheng studied the phenomenon of drift and the mechanism of drift, Li Mingjiu, Zhao Xin and others studied measures to suppress drift, and Guo Feihu studied the reasons for drift of CGCs during start-up [1-3]. The conclusions drawn from these studies are that the compressor surges during startup and operation, but there is a lack of analysis of the reasons for the compressor surge from the perspective of compressor design. The compressor is a rotating machine that works in conjunction with the pipe network. In different processes, the composition of the pipe network is also different. Tang Yu, Liu Huijie and others discussed the characteristics of the joint work of the compressor and the pipe network, the mechanism of surge occurrence, and the anti-surge adjustment and control methods [4-6]. Chen Xuefei et al. realized the numerical simulation of the compressor from steady state to surge by establishing a correlation model [7].

In this article, we target on one CGC and analyse the basic reason behind the occurrence of bias flow phenomenon. The root cause of the drift phenomenon during the start-up of the new compressor after the retrofit is analysed by comparing the design data and operating data of the compressor before and after the retrofit, the design curve and the operating curve. Reasonable suggestions are put forward for the design of the compressor. The results of this study provide a high reference value for the design and smooth operation of retrofit products.

2. Bias Flow Phenomenon

In the compressor industry, we refer to the significant inconsistency between the aerodynamic parameters of pipelines on both sides of dual inhaling LP cylinder in the start-up stage of CGC with nitrogen or the start-up and acceleration stage of CGC with actual gas as bias flow, namely, the rate of flow is high on one side, and low on the other side. We observe an alleviation of bias flow when the speed of revolution increases in some compressors, while the bias flow phenomenon becomes more severe, with the surge compressors in the intermediate pressure cylinder unable to run normally as the speed of revolution increases. The problem that occurred in the start-up stage in a retrofit compressor in Daqing is the latter one.

3. Analysis of the Cause of Bias Current

Daqing Ethylene has a plant capacity of 350,000 tons/year. The CGC was originally provided by a foreign manufacturer. After a long period of operation and early retrofit, it still could not reach the designed capacity. After a second retrofit, it was replaced with domestic compressors and steam turbines. During the start-up of the modified domestic compressor, the low-pressure cylinder had a serious bias flow problem. After that, a "one-return-one" hot return bypass pipeline and a "two-return-one" cold return bypass pipeline were added to reduce the resistance of the pipe network so that the compressor could be started and put into operation successfully.

The compressor works in conjunction with the pipeline network; therefore, the operating state of the compressor depends on the pipeline network [8,9]. The operating position where the bias flow occurs is in the surge region, From the previous operating experience and improvement methods, we know that bias flow can be effectively solved by opening the "three-return-one" anti-surge valve. In the case of the Daqing retrofitted compressor, when the "three-return-one" valve has been fully opened, bias flow still occurs, indicating that the resistance of the pipeline network is too large. However, in the long-term operation of the imported compressor, bias flow has not occurred, indicating that it matched with the pipeline network appropriately. The main reasons for the poor matching between domestic compressors and the pipeline network are as follows:

3.1. Deviation in the Actual Performance of the Original Compressor

The design parameters and operating parameters of the original compressor before the retrofit are listed in Table 1.

From the comparison of the data in Table 1, we can see that the mass flow rate of every section of the original compressor is less than the design value, especially the mass flow rate of the outlet in the fourth section, which determines the ethylene production, is only 86.8% of the design value. At the same time, the inlet pressure of each section is higher than the design value. With the mass flow rate to be small, the volume flow rate is much lower than the design value. The first section is only 79.4% of the design value, and the fourth section is 82% of the design value, indicating that each section of the compressor is working in the small flow area.

From the comparison of inter-section losses, the inter-section losses in the three locations are much higher than the design value, and the inter-section losses are much larger than the design value. In order to overcome the resistance of the pipe network, the compressor works in the small flow area. In addition, the pressure ratios of the three sections are relatively low; therefore, at the design speed, the operating flow of the entire compressor cannot reach the design value.

Table 1: Comparison of design value and operating value of the compressor before retrofit

	Design value				Operating value			
section	1	2	3	4	1	2	3	4
Speed(rpm)	5170	5170	5170	5170	5175	5175	5175	5175
Weight Flow(t/h)	118.7	111	111.2	114.7	107.8	98.5	98.5	99.5
Molecular Weight	24.17	23.68	23.68	23.73	24.17	23.68	23.68	23.73
Inlet Temperature (℃)	40.6	35	34.5	34.1	30.1	31.2	30	23.7
Discharge Temperature (℃)	109.1	105.8	108.2	106.2	100.4	91.7	90.6	105.5
Inlet Pressure (barA)	1.19	2.75	6.59	15.00	1.31	3.04	7.38	15.27
Discharge Pressure(barA)	2.98	6.90	16.61	37.14	3.34	7.98	17.3	39.09
Pressure Ratio	2.51	2.51	2.52	2.48	2.55	2.63	2.34	2.56
Pressure loss(bar)	0.24	0.32	1.64		0.3	0.6	2.03	
Inlet Volume Flow(m3/h)	53772	43300	17817	7808	42683	30607	13858	6408

3.2. Changes in Design Parameters

The goal of the compressor retrofit is to expand the capacity by more than 10%, so as shown in Table 2, the mass flow of each section is increased by 10-20%, and the pressure ratio of the whole machine is increased by 5% than the original design value. However, the user did not realize the problem with the large intersection loss of the compressor. The intersection loss provided to the retrofit compressor still refers to the design loss value of the original compressor. In order to improve the pressure ratio of the whole machine, the loss value is even slightly smaller than the original design value. As a result, the design parameters of the modified compressor will be very different from the actual situation.

Table 2: Comparison of design values of compressors before and after retrofit

	Original design value				The design value after retrofit			
section	1	2	3	4	1	2	3	4
Speed(rpm)	5170	5170	5170	5170	7020	7020	7020	7020
Weight Flow(t/h)	118.7	110.97	111.201	114.653	130.126	124.2	124.56	137.884
Molecular Weight	24.17	23.68	23.68	23.73	25.133	24.799	24.59	24.939

Inlet Temperature (°C)	40.6	35	34.5	34.1	38	32	32.3	26
Discharge Temperature (°C)	109.1	105.8	108.2	106.2	100.08	96.67	96.04	90.92
Inlet Pressure (barA)	1.19	2.75	6.59	15	1.177	2.734	6.835	15.421
Discharge Pressure(barA)	2.98	6.9	16.61	37.14	2.954	7.065	17.021	38.602
Pressure Ratio	2.51	2.51	2.52	2.48	2.56	2.56	2.56	2.56
Pressure loss(bar)	0.24	0.32	1.64		0.22	0.23	1.6	
Inlet Volum Flow(m3/h)	53772	43300	17817	7808	55943	45444	18068	8199

3.3. Operation of the New Compressor

The new compressor is transforming the compressor and steam turbine and not the pipe network system, Therefore, as shown in Table 3, with the increase of the operating flow of the new compressor, the loss value of the first two sections also increases accordingly. Comparing the flow and pressure-ratio of each section, the volume flow of each section is smaller than the design value. The performance of the third section is similar to that before the retrofit, with its pressure ratio to be much lower than the design value, while the pressure ratio of other sections is higher than the design value. It can be seen that in order to overcome the problems of excessive resistance of the additional pipe network and insufficient pressure ratio of the third stage, the operating speed must be increased. The operating point also moved to the small flow area. But there is no doubt that the capacity of the compressor after the transformation obviously improved compared with the operating value of the original foreign compressor. The inlet flow of the first stage has increased by 25%, and the outlet flow of the fourth stage has increased by 16%.

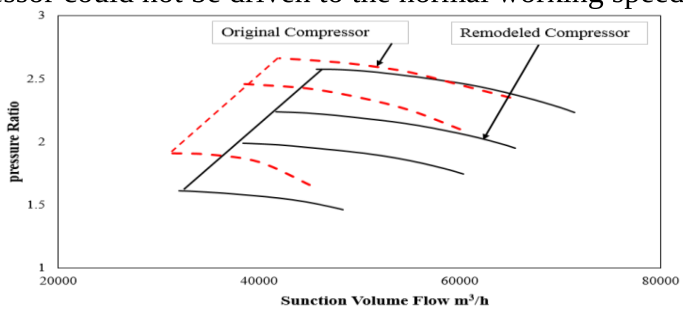
Table 3: Comparison of design values and operating values of new compressors

The design value after renovation					Operating value after renovation			
section	1	2	3	4	1	2	3	4
Speed(rpm)	7020	7020	7020	7020	7120	7120	7120	7120
Weight Flow(t/h)	130.126	124.200	124.560	137.884	134.8	124.6	124.6	115.7
Molecular Weight	25.133	24.799	24.59	24.939	25.133	24.799	24.59	24.939
Inlet Temperature (°C)	38	32	32.3	26	29.8	31	30.5	28.1
DischargeTemperature (°C)	100.08	96.67	96.04	90.92	90.1	92.8	96.5	100.7
Inlet Pressure (barA)	1.177	2.734	6.835	15.421	1.23	2.8	6.8	14.6
Discharge Pressure(barA)	2.954	7.065	17.021	38.602	3.3	7.5	16.1	37.8
Pressure Ratio	2.56	2.56	2.56	2.56	2.683	2.679	2.368	2.589
Pressure loss(bar)	0.22	0.23	1.6		0.5	0.7	1.5	
Inlet Volum Flow(m3/h)	55943	45444	18068	8199	54621	40377	16478	7454

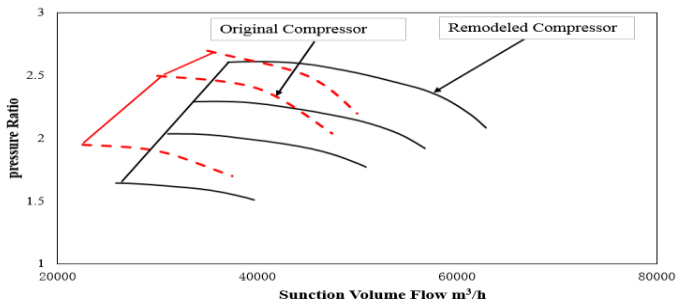
3.4. Comparison of Expected Performance Curve and Surge Line

Since the new compressor needs to meet the requirements of expanding the capacity and increasing the production capacity, the flow rate at the design point of the new compressor becomes larger. The comparison between the performance curves of each section of the new pneumatic scheme of the new compressor and the design value of the original compressor is shown in Figure 1. The solid line in the figure represents the original compressor design curve, and the dashed line represents the new compressor design curve.

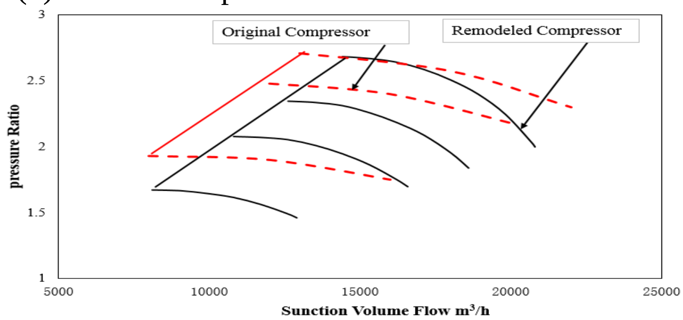
For the design curve of the first and second sections of the new compressor, the design point is shifted to the right by 10% compared with that of the original compressor, and the position of the surge line is shifted to the right by about 20% compared with that of the original compressor, that is, the surge margin is smaller than that of the original compressor. According to this design curve, if the resistance of the pipe network meets the design requirements, the compressor can be started normally. However, because the change in the resistance of the pipe network before the transformation is completely unknown at the time of design, the operation risk brought by the increase of the resistance of the pipe network has not been predicted. Therefore, in the process of increasing the speed at start-up, the bias flow in low-pressure cylinder and surge in the medium-pressure cylinder occurred, and the compressor could not be driven to the normal working speed.



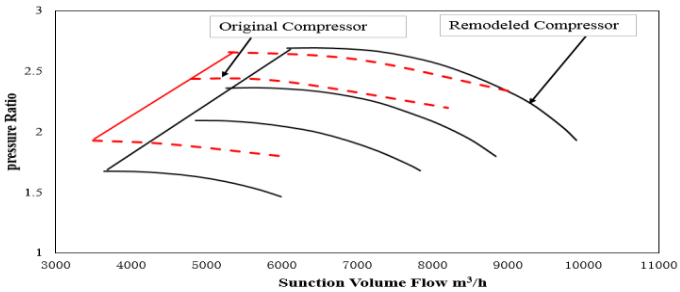
(a) Predicted performance curves of section 1



(b) Predicted performance curves of section 2



(c) Predicted performance curves of section 3



(d) Predicted performance curves of section 4

Figure 1: Comparison of performance curves and surge lines of each section.

The matching relationship between the first section of the compressor and the pipe network is shown in Figure 2. The black solid line group in the figure is the variable speed performance curve of the original compressor, and the red dotted line group is the variable speed performance curve of the transformed compressor. Among the three pipe network curves, Line 1 represents the state of the pipe network before the retrofit, Line 2 represents the state of the pipe network after adding "one return to one" and "two return to one", and Line 3 is the most ideal design pipe network for the new compressor state. The No. 1 pipe network curve intersects with the original compressor design curve, so the compressor and the pipe network have a common operating point and can be run smoothly, but it has no intersection with the modified compressor design curve, and when the compressor speeds up, the generator has been running in the surge area, so it appears as a bias flow of the compressor, the reason why it cannot meet the design flow requirements of the design speed. Line 2 indicates that the resistance of a section of the pipe network is reduced by increasing the loop, so it has an intersection with the compressor curve, thus ensuring that the compressor starts normally.

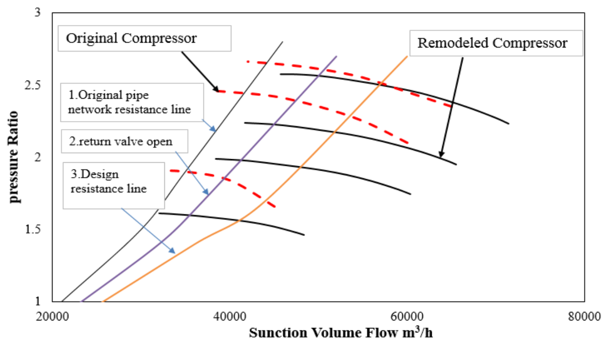


Figure 2: Comparison between compressor design curve and pipe network resistance line.

4. Conclusion and Suggestion

In this paper, by studying the bias flow problem during the start-up process of a low-pressure cylinder after the reconstruction of a Cracking Gas gas compressor, the deviation of the compressor operating data from the design parameters before and after the reconstruction, the difference between the design parameters and the design curve before and after the reconstruction, and the difference between the resistance value of the pipe network and analysing the design values, we summarize the main reasons for the mismatch between the compressor and the pipe network after the transformation and the occurrence of bias flow.

Through the analysis of the above problems, the following suggestions are put forward for the retrofit type compressors:

1) When confirming the design parameters of the modified compressor, it is necessary to understand the actual operation of the original compressor in detail and analyse the differences

between the design value and the operating value, the reasons for the difference. We also need to fully consider whether similar problems will occur when the new compressor is operating.

2) When the resistance of the pipe network system of the compressor before the transformation is too large, it is recommended to transform the pipe network system. If the transformation conditions are not met, the new compressor should be designed according to the actual resistance to improve the compressor's ability to overcome the resistance of the pipe network.

3) For compressors with complex gas components that are prone to coking and scaling, which causes partial blockage, we need to pay close attention to the changing law and trend of the resistance of the pipe network system with operating time, and make rectification plans.

4) In the design of multi-cylinder and multi-section compressors, it is necessary to consider the particularity of the driving conditions as much as possible, and improve the regulation by adding an anti-surge circuit to ensure the stable start of the compressor.

5) Once the compressor is running with bias flow and back flow, it can be judged whether it is back flow or bias flow according to the difference in the inlet temperature of the intake pipes on both sides of the site, as a guiding basis for the improvement of the compressor.

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