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Application and evaluation of variable frequency energy-saving technology for reciprocating compressor in CBM Field

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Abstract. Reciprocating compressor is the most important gas transportation equipment and the most important energy consumption equipment in the CBM gathering and transportation system. The existing variable clearance volume energy saving adjustment method of reciprocating compressor has the characteristics of complex operation and poor timeliness in operation. By carrying out risk identification, developing test scheme and determining control parameters, we successfully completed power frequency high speed reciprocating compressor variable frequency test. The theoretical analysis and practical operation results show that the application of high voltage frequency converter in speed control of reciprocating compressor with high frequency is feasible. The actual controllable frequency modulation range of the reciprocating compressor motor with high frequency and high speed is 34Hz to 55Hz, the resonant frequency of compressor and main motor is 51.5Hz, and the effective energy-saving frequency regulation range is 34Hz to 45Hz. The low frequency operation has better energy saving effect, the unit consumption of gas transportation is reduced by about 3%. It can effectively improve the operation efficiency of the compressor and reduce the unit consumption of gas transportation by reasonably controlling the power frequency motor of the reciprocating compressor by the frequency converter.

1. Foreword

Petrochina Huabei Oilfield CBM Branch Company has 11 gas station and 1 CBM processing center[1]. According to the analysis and statistics of the power collection system, the annual power cost of the gas stations and CBM processing center accounts for 67 percent of the total cost of the branch, while the power cost of the pumping system is only 33 percent last. Therefore, the total energy consumption of the gas station and CBM can be seen as two times the energy consumption of the pumping system, which is the key point of energy saving and consumption reduction. According to the statistics, the pressurization equipment has a total of 53, including 16 for the screw compressor, 37 reciprocating compressor. Reciprocating compressor is the main gas transmission equipment of CBM field ground gathering system and the main energy consumption equipment.

Reciprocating compressor is widely used in petroleum, natural gas, chemical industry and other fields. It belongs to the volumetric compressor, which is the equipment that allows the gas in a certain volume to be drawn in and out of the enclosed space in order to improve the static pressure. The



application of reciprocating compressor in high parameter, low relative molecular mass gas, especially in oil refining enterprises is not replaceable by other types of compressor.

In terms of capacity control and energy saving operation, the reciprocating compressor has the characteristics of complicated operation and poor timeliness[2]. A number of experts have been studying the way that reciprocating compressors are regulated, and by optimizing operational parameters to achieve the goal of reducing energy consumption. The principle of volume flow adjustment of reciprocating compressor was analyzed by Ren Zhi and Wang Cunzhi, and the optimal operation suggestion was put forward in combination with the production situation [4]. Pan Yan, et al. studied the principle, composition and control system of three kinds of capacity control (bypass, variable clearance volume adjustment and HydroCOM step-less capacity control) of reciprocating compressor [2]. Jin Jiangming and other scholars elaborated the development course of the technological development of the step-less capacity control, and considered that the step-less capacity control technology was the basic guarantee to ensure the smooth operation of the compressor. With the continuous improvement of the step-less capacity control technology, the breakthrough could be achieved in the two aspects of equipment stability and energy saving and consumption reduction [6].

In terms of energy saving operation of reciprocating compressor, Wang Wei, et al. analyzed the influence factors of compressor power by analyzing the influence factors of gas components, adiabatic index, gas proportion, thermal conductivity, inlet temperature, exhaust temperature and exhaust pressure, etc. [7].

In the previous research, we can find that in the capacity control of the reciprocating compressors, manual clearance control has low adjustment accuracy and can easily cause the system pressure to fluctuate greatly. By the bypass adjustment, the compressor is repetitive working, low efficiency and high energy consumption, not economical.

The main modes of capacity control of reciprocating compressor include: variable clearance volume adjustment and bypass adjustment[4]. The former has low adjustment accuracy and can easily cause the system pressure to fluctuate greatly. By the bypass adjustment, the compressor is repetitive working, low efficiency and high energy consumption, not economical. Variable volume control and the top open valve control need to increase hydraulic efficiency and control systems to the compressor unit, make more work and invest more.

Therefore, it is necessary to conduct a study of the capacity control and energy-saving measures on reciprocating compressor.

2. Energy conservation technology

High voltage inverter frequency modulation and rotation speed technology is quite mature in the field of screw compressor. Due to the high speed screw compressor adopts variable frequency motor, so the high voltage inverter can adjust the speed of the screw compressor, both have the effect of running smoothly, and achieve energy saving and consumption reduction.

So can a high speed and high frequency reciprocating compressor be integrated with High-voltage conversion technique? How about the operation condition and energy consumption of the compressor after conversion adjustment? In this paper, the application and evaluation of energy saving technology in high speed and power frequency reciprocating compressor are carried out.

2.1. Risk identification

Inverter has a positive significance in motor energy saving and power factor improvement, so with the development of inverter technology, the motor of inverter has been widely used[6]. The newly installed inverter motor is a special motor for inverter, which can be fitted perfectly in the process of use.

So far, all the motor of reciprocating compressors that have been used in this unit is coaxial driven power frequency motor, which can change the speed of reciprocating compressor at the same time when the motor changes speed[7]. Therefore, before the application of variable frequency technology, the influence of both the compressor and the motor should be considered synthetically.

2.1.1. Low - frequency operation risk. Splash lubrication is one of the main lubrication modes of reciprocating compressor. The oil in the crankcase is thrown to the mirror of the cylinder to lubricate the surface friction between the piston and cylinder wall[8]. In low - frequency operation, the crankshaft speed of compressor decreases with the decrease of motor speed, then crankshaft - linkage speed decreases, the lubricating oil is not high enough, the partial lubrication is not in place or in time[9]. This kind of phenomenon is very easy to cause the crankshaft bearing of the compressor to be too hot, until the compressor bearing lock, crankshaft pull off and other major production accidents.

The rated speed of the reciprocating compressor is 1500 r/m, i.e., when the frequency is 50 Hz, the speed is 1500 r/m. To ensure the lubricating effect of the compressor, the rotation speed should not be lower than 900 r/m, and the corresponding frequency is 30 Hz.

2.1.2. Over-frequency operation risk. In over - frequency operation, the speed of the cooling fan of the power frequency motor is increased by the speed of the motor. Therefore, during over - frequency operation, the motor speed is too fast, and the high temperature of the three-phase coil of the motor may cause the motor to burn.

In addition, over the motor rated speed, it increases the probability of fatigue damage, shortening the lifespan of the motor. The rated speed of the power frequency motor is 1500 r/m, and the motor speed can reach the maximum of 1800 r/m and the corresponding frequency is 60Hz.

2.1.3. Other risks. After the frequency converter installed, the output power of the high voltage inverter will have an irremovable harmonic effect on the motor.

The output power of the high voltage inverter will affect the unerasing harmonics of the motor, and the high voltage pulse of the power supply will cause constant impact on the insulation of the motor winding, which will reduce or damage the insulation performance of the motor. The high voltage pulse of the power supply will cause constant impact on the insulation of the motor winding, which will reduce or damage the insulation performance of the motor[10]. The influence of harmonic pulse can be reduced by using high voltage inverter with reliable quality and good performance[11].

In addition, when the compressor is in the same frequency as the motor, it can cause an increase in the vibration value of the compressor and the motor, causing the resonance phenomenon to occur[10-11].

To sum up, although there is a certain risk in the application of variable frequency speed regulation of reciprocating compressor with high frequency and high speed, in theory, a reciprocating compressor motor can realize variable speed control of the range of 30-60 Hz frequency. The application of variable frequency energy saving technology to reciprocating compressor with high frequency and high speed is realized by making a detailed test scheme.

2.2. Test scheme

2.2.1. Parameter control and monitoring. Because the low frequency is going to increase the temperature of the electric motor, which should change the wind road, and increase the forced ventilation device[12].

Meanwhile, in order to monitor the operating status of the compressor and the motor in the process of frequency control and avoid the risk, in addition to the original maintenance project, the following monitoring should be added to the compressor and motor after the conversion control of the power frequency motor:

- Measurement of insulation resistance of motor.
- Measurement of DC current leakage of motor.
- Monitoring of vibration value of compressor and motor.
- Monitoring of coil temperature of compressor and motor.

2.2.2. Test process. There are three reciprocating compressors in the experimental block, Compressor running state: two DTY500 reciprocating compressor (1 #, 2#) running in the least clearance and maximum output capacity, 3# DTY1000 reciprocating compressor for standby, shutdown, Select 3# compressor for test unit.

The steps of the experiment:

- Start the 3# compressor with a frequency of 45Hz. No-loading running half an hour or so, To make sure that the compressor is working properly and the lubricating oil temperature is above 52 degrees, we can do the following procedure.
- 1# compressor load reduction, after running for 10 minutes, shutdown and fill it with oil as a spare.
- Observe the operation parameters of 2# compressor, loading 3# compressor after the inlet pressure gradually increases by 0.01 MPa. Gradually reduce the frequency of frequency converter, 45Hz, 40Hz, 38Hz, 36Hz, 35Hz, each frequency stable operation at least 30 minutes.
- The theoretical minimum frequency can't be less than 30Hz. In the process of frequency modulation, we should keep a close watch on the temperature of the lubricating oil and motor winding, and the vibration value of the compressor. If the abnormal situation occurs suddenly, we need to turn the compressor into to no-loading state to avoid the damage.
- When the inlet pressure has been reduced to 0.030 MPa due to lack of gas inflow, the 2# compressor should be adjusted into no-loading state, and shut it down after 10 minutes. Meanwhile, increase the frequency of the 3# compressor to 55Hz, and control the inlet pressure to 0.032 MPa.
- Adjust the state of 1# compressor as the maximum clearance and minimum output, and then start the compressor and load it. Adjust the frequency of the 3# compressor, control the inlet pressure of the compressor to 0.030 MPa, and observe the transmission flow.

3. Variable frequency control test and effect analysis

3.1. Test data analysis

3.1.1. Resonance frequency. As shown in figure 1 and 2: in over-frequency mode, as the frequency of the compressor increases, its vibration value is slightly higher. Both in the no-loading and loading condition, the main motor of compressor showed a peak vibration in 51.5-52Hz. Therefore, the experiment determines that the 51.5 Hz should be the resonant frequency of the compressor and the main motor. Because the weight of the reciprocating compressor is much greater than motor, the absolute value of vibration of the motor is more pronounced by resonance.

When the compressor is under loading, the vibration value of the motor and compressor has decreased with the decrease of frequency, and the test verifies that the low frequency operation has no resonance. The experiment verifies that there is no resonant phenomenon in low-frequency operation.

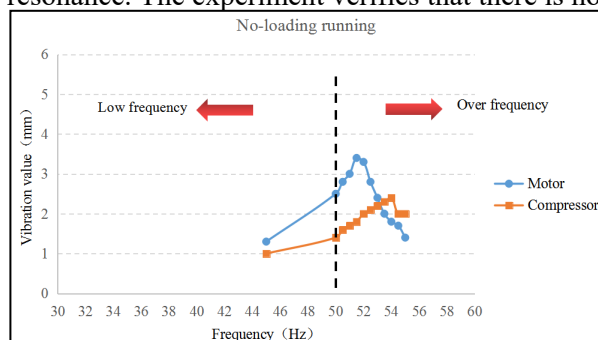


Figure 1. The vibration value change curve in no-loading.

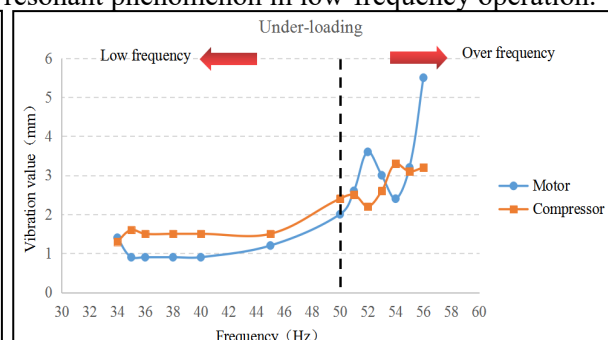


Figure 2. The vibration value change curve in under-loading.

3.1.2. Controllable frequency range. According to the conclusion of chapter 2.1, it can be seen from the conclusion that the motor of power frequency and high speed reciprocating compressor can realize the variable speed control of the range of 30-60Hz. But in reality, due to the effects of the vibration, the motor coil temperature, compressor displacement, the pressure of the inlet and outlet, the actual controllable frequency range is much smaller than the theoretical range.

Table 1 is the key parameters for the operation and energy consumption of the 3# compressor obtained in the test in the no loading (45Hz) and under loading state.

Table1. Key parameters of compressor and motor under loading

Frequency (Hz)	Motor vibration (mm)	Vibration (mm)	Coil temperature (°C)	Output power (kW)	Output current (A)
33	3	1.6	44		
34	1.4	1.3	38	436	47.6
35	0.9	1.6	35	450	47.8
36	0.9	1.5	34	464	48.2
38	0.9	1.5	33	502	48.9
40	0.9	1.5	30	553	50.7
45	1.2	1.5	—	625	
50	2	2.4	—	726	52.5
51	2.6	2.5	34	750	54.3
52	3.6	2.2	36	760	55
53	3	2.6	38	780	55.2
54	2.4	3.3	42	797	56.3
55	3.2	3.1	56	807	56.9

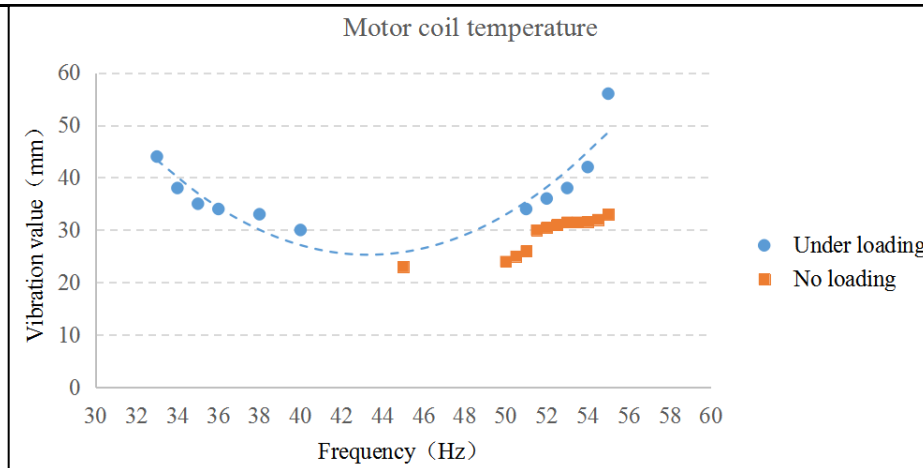


Figure 3. Motor coil temperature variation curve

As shown in Fig.3, the coil temperature has been raised with the frequency change, and it's obvious that the trend line type is parabolic. The main reason is: during the low frequency, the fan speed decreases, the heat dissipation effect is poor, the motor coil temperature gradually increases; during the over frequency, the motor speed rises sharply, and the heat of the motor is far less than that of the coils, causing the coil temperature to rise gradually. The field test data is consistent with the qualitative analysis in chapter 2.1.

The vibration value of the compressor and motor is the most intuitive embodiment of the operation state of the equipment, and it's also an important basis for analyzing the controllable frequency range of the frequency control of reciprocating compressor.

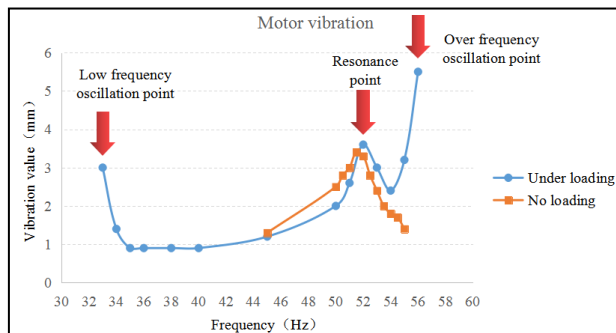


Figure 4. Motor vibration value curve.

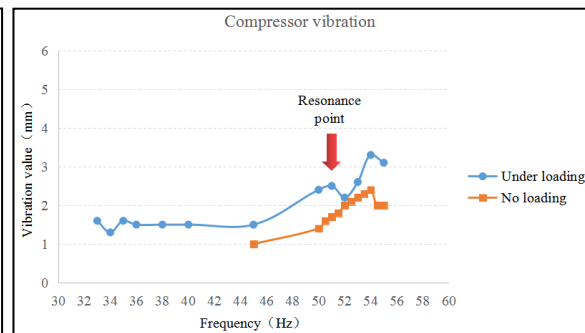


Figure 5. Compressor vibration value curve.

As shown in Fig. 4 and Fig. 5, at low frequency, the vibration values of the compressor and motor is low. When the frequency drops to 34Hz, the motor vibrates obviously rise again, and at 33Hz, the vibration value is doubled. Therefore, it is not recommended to continue to reduce the test frequency, and finally limit 34Hz to the lower limit of the actual controllable frequency range. Therefore, it is not advised to continue to lower the frequency, and ultimately determine the lower limit of the controllable frequency range as 34Hz.

At over frequency, the vibration values of the compressor and motor is increasing with frequency. When the frequency is at 51.5 to 52Hz, there's a vibration spike, and it's a resonance point. When the frequency is 54Hz, the vibration value falls back to 2.4mm. When the frequency is 56Hz, the vibration value changes to 5.5mm, which is approaching the compressor's vibration stop value. At the same time, the motor has a different sound, and the experimenter has activated the contingency plan as plan, turning 3# compressor into no loading and observing the condition of the equipment. Therefore, it is not advised to continue to increase the frequency, and ultimately determine the higher limit of the controllable frequency range as 55Hz.

To sum up, the controllable frequency range of the power frequency motor for reciprocating compressor is 34 Hz to 55 Hz.

3.1.3. Optimal operation mode research. In this paper, after analyzing the controllable frequency range of the reciprocating compressors, the economic operation mode of three reciprocating compressor is analyzed and studied.

According to the CBM block current gas production, maintain the current inlet pressure, outlet pressure and other production parameters, a total of 6 sets of compressor running combinations are designed by changing the operating modes of each compressor. The economic performance indicators of each operation mode are shown in table 2.

Table2. The comparison of production and consumption in various operation modes

Ordinal number	Operation mode	Daily total consumption (kWh)	Daily total production (m ³ /d)	unit consumption (kWh/10 ³ m ³)
1	1# variable clearance 2# variable clearance	17260	211805.3	81.49
2	1# variable clearance 2# over frequency	17720	213845.6	82.88
3	1# variable clearance 3# variable clearance	19760	221167.4	89.3
4	2# Variable clearance 3# low frequency	18370	224528	81.8
5	2# low frequency 3# variable clearance	18840	223091.8	84.4
6	3# over frequency	19840	214938.8	92.3

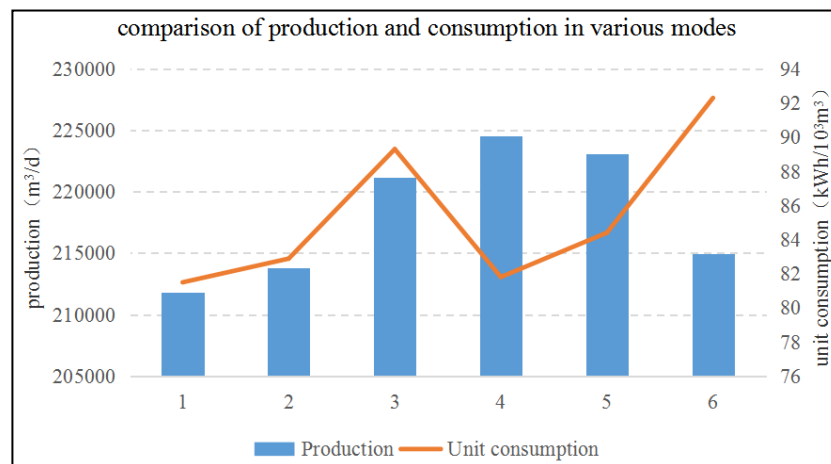


Figure 6. The comparison of production and consumption in six operation modes

The optimal operating mode is based on the high production, and the pursuit of low unit consumption[5].

As shown in Fig.6, the mode 6, which is the single compressor over-frequency (55Hz) running, has the worst energy efficiency. Mode 4 and mode 5 have obvious advantages over other modes. The common ground of the two modes is the low frequency (35Hz) of reciprocating compressor.

Therefore, the experiment is to find out that the efficiency of a over-frequency (55Hz) is not efficient, and the energy consumption is higher than that of variable clearance volume in the same working condition. Low frequency (35Hz) operation has good energy saving effect, reduced unit consumption by about 3%.

3.2. Energy saving effect

The experiment started in the first half of 2016, and the effect of the frequency-saving energy was significant, and the unit consumption was reduced by nearly 3%. In the course of the experiment, a total of 1.33 million kilowatt-hours of electricity was saved, and the electricity price was 0.65 RMB/kilowatt hour at that time, total savings of 860,000 RMB. The production of the test is steadily rising, from 7 mmcf/d³ to 8.7 mmcf/d³, and the compressor is stable.

In addition, the variable frequency regulation control reduces the workload of the staff to adjust the clearance of the compressors frequently, so as to ensure that the pressure of the pumping drainage system is stable, and reduce the influence of inlet and outlet pressure fluctuation on production.

4. Conclusion

Theoretical analysis and practical results show that it is feasible to use high-voltage inverter to achieve speed control. By controlling the power frequency motor of the reciprocating compressor, it can effectively increase the efficiency of the compressor unit, and effectively reduce the unit consumption in a reasonable frequency range.

- The controllable frequency range of the power frequency motor for reciprocating compressor is 34 Hz to 55 Hz. Over the frequency range runs, the compressor unit will be affected by the vibration alarm and the temperature of the motor coil, which will affect the normal operation of the equipment.
- The resonant frequency of compressor and motor is 51.5 Hz, and the frequency point should be skipped when the frequency converter is set.
- Over-frequency (55Hz) has no energy saving effect, and the energy consumption is higher than that of variable clearance volume in the same working condition.
- Low-frequency (35Hz) operation has good energy saving effect, reduced unit consumption by about 3%.

- When the frequency reaches up to 45 Hz and above, the unit consumption is basically the same as the variable clearance volume adjusting mode, and the power saving effect disappears. Therefore, the effective energy-saving frequency regulation range is 34Hz- 45Hz.

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