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Energy saving design of screw compressor unit

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--***ABSTRACT***--

Energy conservation and environmental protection has become the most important and eternal theme in the world.Compressor industry as the pillar industry of national economic life, its response to the slogan of energy saving is even more urgent.In this study, the retrofit design of screw compressor unit, such as adding frequency converter and optimizing pipeline, is analyzed by numerical calculation, and the performance of some aspects of screw compressor unit after retrofit design is preliminarily estimated.The results of this study will provide direction and theoretical basis for the subsequent energy-saving renovation design of screw compressor unit.

Key word: *Screw compressor unit；Transformation design；Piping design*

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I. INTRODUCTION

Screw compressor unit includes: screw compressor, gas system, oil system and control system.These equipment (except the starting cabinet) are installed on the same common base to form the unit.It has the advantages of high reliability, convenient operation and maintenance, good power balance, strong adaptability and multiphase mixed transmission. For the screw compressor, the motor which provides power is particularly important, and its high efficiency, energy saving and long life is the future research direction of screw compressor. Based on the analysis of the flow characteristics and noise source of screw compressor, the best exhaust port and the best pipeline, as well as the best noise reduction orifice and diameter are designed. Based on this, this work puts forward a variety of energy-saving transformation design schemes and carries out calculation and analysis, which provides a better basis for the energy-saving transformation design of screw compressor unit.

II. ENERGY SAVING TEST

In this paper, the ES22-8 screw compressor unit is taken as the research object for three hours,and the test data is shown in Table 1.

Table 1 Test data of ES22-8 screw compressor unit

Power frequency pressure（Mpa）	Voltage (V)	Electric current (A)	Power (kW)	Temperature before nozzle (T)	Pressure water column difference (mm）
0.5	376.4	39.3	23.4	24.8	259
0.6	373.6	41.7	25.0	24.6	241
0.7	376.3	44.3	26.7	24.5	226
0.8	380.3	46.2	28.2	24.2	207

Table 2 shows some parameters of test run of ES22-8 screw compressor unit.

Table 2 Some parameters of ES22-8 screw compressor

Product model	Nozzle diameter (mm)	Nozzle coefficient（C）	Head air inlet temperature（T)	Working pressure（Mpa）
ES22	34.9	0.981	9	0.7

According to the test data in the above table, calculate the volume flow of es22-8 screw compressor unit.

$$Q = 1129 \times 10^{-8} \times K^2 \times d^2 \times (t_{inhale} + 273) \times \sqrt{\frac{p}{1.032 \times (T+273)}} \quad (1)$$

The calculated volume flow is 3.289 m^3/min.

Under the same condition of other environmental factors and working conditions, ESV22-8 screw compressor was tested for two hours， and the test results are shown in Table 3.

Table 3 Test data of ESV22-8 screw compressor unit

Variable frequency pressure（Mpa)	Voltage (V)	Electric current (A)	Power (kW)	Temperature before nozzle (T)	Pressure water column difference (mm）
0.7	415	43	25.72	26.1	224

Table 4 shows some parameters of ESV22-8 screw compressor unit in test.

Table 4 Some parameters of ESV22-8 screw compressor

Product model	Nozzle diameter (mm)	Nozzle coefficient（C）	Head air inlet temperature（T)	Working pressure（Mpa）
ESV22	34.9	0.981	9	0.7

$Q = 1129 \times 10^{-8} \times K^2 \times d^2 \times (t_{inhale} + 273) \times \sqrt{\frac{p}{1.032 \times (T+273)}}$（2）The calculated volume flow is $3.279m^3/min$

The power consumption of ES22-8 screw compressor unit is calculated as follows：The power consumption of the whole screw compressor is equal to the input power of the whole screw compressor, so the power consumption per unit time of es22-8 screw compressor is 26.7kw under power frequency. However,ESV22-8 may be in variable frequency operation or intermittent operation. If the no-load rate is 33% per day, there is a big gap between them.

22kW power frequency：

$\mathrm{Q} = \mathrm{W} \times 24\mathrm{h} \times 360$（3）The calculated annual consumption rate is $230688kW.h$

22kW frequency conversion：

$Q = W \times 24h \times 33.3\% \times 360$（4）The calculated annual consumption rate is $148221kW.h$

The specific power saving is shown in Table 5 below.

Table 5 System comparison of es22-8 and esv22-8 power consumption

Model \ Column	Input power（kW.h）	One working day	Annual	Electricity saving rate（%）
ES22-8	26.7	640.8	230688	
ESV22-8	25.72	413.6	148221	35.7

III. PIPELINE OPTIMIZATION DESIGN

Pipeline calculation mainly includes the determination of pipe diameter, calculation of pipe wall thickness, calculation of pipe resistance loss, etc.

1）Fixed pipe diameter

The pipe diameter mainly depends on the flow property and flow rate. Generally, the flow rate of liquid medium shall not exceed3m/s,and that of gas medium shall not exceed 100 m/s.For short length and small pipe diameter, the pipe diameter can be calculated from the common flow rate, and then adjusted to the actual inner diameter according to the nominal pipe diameter series specified in the engineering design.

$$\mathrm{d} = 1.13\sqrt{\frac{\omega}{\upsilon}} \quad (5)$$

The calculated pipe diameter is $0.08m$.

2）Determine pipe wall thickness

When the calculated thickness of the straight pipe is less than 1 / 6 of the outer diameter of the pipe, the calculated thickness of the straight pipe shall not be less than the thickness in formula（6）, and the thickness calculation shall be conducted according to formula（7）.

The hard exhaust pipe of the machine head is welded steel pipe, and the material is No. 20 steel.At the design temperature of 120 ℃,allowable stress of material $[\sigma]^t = 128\,MPa$ .When the nominal diameter $DN_1 = 9mm$,the outer diameter of the pipe $D_{01} = 29mm$ 。From

$$t_s = \frac{pD_0}{2([\sigma]^t E_j + PY)} \quad (6)$$

the calculated thickness of pipeline $t_{s_1} = 0.0988m$

The design thickness of the pipe

$$t_{sd} = t_s + C \quad (7)$$

among

$$C = C_1 + C_2 \quad (8)$$

Take the additional amount of thickness reduction $C_1 = 0.4mm$ and corrosion $C_2 = 1.0mm$,then the sum of the additional amount of thickness $C = 1.4mm$.
After calculation, the design thickness of the pipeline $t_{sd_1} = 11.4mm$.The final pipe wall thickness is $10mm$.
（3）Calculation of pipeline resistance loss

For gas pipeline,because of the small gas density ρ ,Static pressure resistance loss of riser ΔP_H and acceleration resistance loss ΔP_υ negligible. Resistance loss along the way：The resistance loss of straight pipe section is caused by internal friction, and its calculation formula is as follows：

$$\Delta h_f = \lambda \frac{\overline{V}^2}{2g} \frac{L}{d} \times 10^3 \quad (9)$$

$$\Delta P_f = \lambda \frac{\gamma \upsilon^2}{2g} \frac{L}{100d} \quad (10)$$

The friction coefficient λ depends on the Reynolds number R_e , and the Reynolds number is calculated as follows：

$$R_e = \frac{d\upsilon p}{\mu} \quad (11)$$

When the medium is in laminar flow state in the pipe, i.e. $\mathrm{R_e} \leq 2100$, the wear coefficient is independent of the surface property of the inner wall of the pipe, and the calculation formula of the friction coefficient is as follows:

$$\lambda = \frac{64}{R_e} \quad (12)$$

When the medium is turbulent in the pipe, the friction coefficient is related to the surface property of the inner wall of the pipe, which can be considered in the following two cases and calculated：
1）For smooth pipe inner wall
When $2100 \langle R_e \langle 10^5$,

$$\lambda = 0.3164 R_e^{-0.25} \quad (13)$$

When $10^5 \langle R_e \langle 10^R$,

$$\lambda = 0.0032 + 0.221 R_e^{-0.237} \quad (14)$$

2）For the inner wall of the unsmooth tube,the friction coefficient λ depends on the Reynolds number $\mathrm{R_e}$ and the characteristic of the tube wall $d/_K$。The equivalent roughness K of various pipes is as follows:

$$\mu = 1.79 \times 10^{-5} Pa.S$$

Known date: $\rho = 1.23 kg/m^3$，$D = 9mm$，$\bar{v} = 11m/s$.
After calculation, the Reynolds number $R_e = 6.8 \times 10^4$.
Therefore, the air flow in the pipe belongs to laminar flow.
Then $\lambda = 0.0110$ and $f = 9.41 \times 10^{-4}$ can be obtained.
The laminar pressure drop is:

$$\Delta P = f \frac{l}{D} \frac{1}{2} \rho \overline{V}^2 = 9.41 \times 10^{-4} \times \frac{71.5}{9} \times \frac{1}{2} \times 1.23 \times 11^2 = 5.563 Pa \quad (15)$$

Therefore, laminar pressure loss $\Delta h_f = 5.389 \times 10^3 m$
Local resistance loss：
Local resistance loss refers to resistance loss caused by obstruction when medium passes through pipe fittings, valves, flow meters, etc，the calculation formula is as follows：

$$\Delta h_k = K\frac{\upsilon^2}{2g}\times 10^3 \quad (16)$$

$$\Delta P_K = K\frac{\upsilon^2}{2g}\frac{\gamma}{100} \quad (17)$$

The equivalent length method is also commonly used in engineering, that is, to convert all kinds of local resistance loss into resistance loss equivalent to the length of straight pipe, and calculate it with the formula of resistance loss along the way.

$$\Delta P_K = \lambda\frac{\gamma\upsilon^2}{2g}\frac{LK}{100d} \quad (18)$$

$$K = \zeta = k_e\left(\frac{S_2}{S_1}-1\right)^2 \quad (19)$$

Can get $K_e = 0.16$

$$\frac{S_2}{S_1} = \frac{\pi R_2{}^2}{\pi R_1{}^2} = \frac{11^2}{9^2} = 1.494 \quad (20)$$

$K = \zeta = 0.16\times(1.494-1)^2 = 0.039$ (21) After calculation, $\Delta h_k = 240m$

Total resistance loss of pipeline:

The calculation formula of total resistance loss of pipeline is as follows:

$\Delta P \approx 1.15\left(\Delta P_f + \Delta P_k + \Delta P_\upsilon + \Delta P_H\right)$ (22) The calculated total resistance loss of the pipeline is $6473.35m$

IV. OTHER ENERGY SAVING METHODS

(1)Theoretical energy saving measures of intercooler

The performance of three-dimensional intercooler also plays an important role in the optimization and energy saving of the whole machine. It plays a cooling role for compressed gas and oil.

The optimization of intercooler is the evaluation of cooling effect. The temperature after cooling plays an important role in the normal operation of the compressor head. If the cooling temperature is too high, the power consumption of the compressed air will increase, and then the power consumption and loss of the motor will increase, and the wear of the head rotor will increase, which will affect the life of the rotor. If the temperature is too low, it will affect the working environment of the oil, resulting in liquid hammer, increase the viscosity of the oil, increase the friction of oil film lubrication, increase the power consumption of the bearing, and then generate the vibration of the machine. Therefore, the optimization of the cooler needs to ensure that its cooling effect reaches the best condition.

(2)Optimization design of oil drum

For the optimization design of oil drum, two aspects are mainly considered：1）reduce the pressure loss of gas entering the oil-gas separator as much as possible.2）The separation effect of the oil-gas separator is improved as much as possible, so as to reduce the separation burden of the oil separation core and improve the service life. At the same time, the two improvement directions are mutually restricted. Improving the separation effect will increase the pressure loss of the oil drum, and reducing the pressure loss will affect the separation effect.Finally, the best design scheme can be selected according to the actual economy and timeliness.

(3)Optimization of three filters and one oil

Three filters and one oil is the place to check the gas and oil circuits of ES22-8 screw compressor unit.The performance of its products is particularly important.For the whole unit, the air filter, oil filter and oil core are all important positions.There is no denying that their performance directly affects the performance of the unit, and it is irreversible.Once something happens, it will cause huge loss to the whole gas circuit and oil circuit, and even lead to the unavailability of the whole machine.

V. CONCLUSION

(1) After adding frequency converter, the measured power saving rate is 35.7%；(2) After the optimal design of the pipeline, the total resistance loss of the pipeline will be reduced；(3) Through the optimization of cooler, oil drum, air filter, oil filter and oil core, the performance of the unit will be improved.

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