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STUDY ON ACTUAL PROFILE SURFACE AND ENGAGING CLEARANCE OF SCREW COMPRESSOR ROTORS

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ABSTRACT

A simple and effective method of obtaining the mathematical description of actual profile surface of screw rotors is put forward in this paper by assuming that the actual surface is composed of a theoretical surface and a surface difference. The surface difference is obtained through mathematical processing by computer to the screw line error, profile line error and graduation error determined by a special measurement apparatus. According to the engaging principle, we can calculate the actual engaging clearance between two mating screw rotors.

NOMENCLATURE

A	centre distance between male rotor and female rotor
ΔA	centre distance error
i	transmission ratio
p	characteristic parameter of screw line
Δp	characteristic parameter error
T	screw line leader
ΔT	screw line leader error
t	profile line parameter
τ	screw line parameter
τ_z	wraple angle of rotor
X, Y, Z	profile line or surface coordinates

ΔX, ΔY, ΔZ profile coordinate differences

φ turning angle

δ engaging clearance

$\Delta\alpha$ graduation error

Subscripts:

1 male rotor

2 female rotor

a actual profile line

as actual profile surface

s profile surface

INTRODUCTION

Some especial advantages, such as light weight and good stability, make the screw compressors be widely applied in industry. It is important for the machines to work high efficiently since the high cost energy. The gas leakage through sealing lines of a machine is generally thought one of the main factors affectting the volumetric efficiency and adiabatic efficiency. The leakage clearances, therefore, should be designed as small as possible on the condition of the machine operating safely.

The rotor tip-housing clearance and lobe end-housing clearance can easily be determined. But the engaging clearance between male rotor and female rotor (engaging clearance) is difficult to be obtained; and it plays an important role in the performance of the machines. Increasing engaging clearance by 0.01 mm, e.g. , would cause a decrease of about one percent volumetric efficiency. Since the engaging clearance depends on actual profile surface and centre distance difference, etc., it is necessary to study the surface.

There are rarely analysis materials in publication about the actual profile surface and engaging clearance between mating rotors. A special dynamic measurement apparatus of screw rotor precision was introduced at last ICEC in 1984. We used it to determine the screw line error, graduation error and profile line error of screw rotor. The achieved information is used in this paper to obtain surface difference, i.e., the actual profile surface through mathematical processing, the later consisting of theoretical profile surface and the surface difference. Manufacturers can apply the calculat

-ed and analized results of actual engaging clearance to manufacture high efficient machines by adjusting the engaging clearance of two mating rotors at certain technology level.

EQUATION OF ACTUAL PROFILE SURFACE

In order to simplify the problem, the following assumptions are made: The profile lines are same of lobes at two arbitrary section surfaces. The actual profile surfaces of male rotor and female rotor, therefore, are also screw ones which are formed by actual profiles spirally moving in actual helical characteristic parameter.

The actual profile lines can be written by

$$X_a(t)=X(t)+\Delta X(t)$$
$$Y_a(t)=Y(t)+\Delta Y(t) \qquad (1)$$

and the actual profile surfaces

$$X_{as}=X_a(t)\cdot COS(\tau)-Y_a(t)\cdot SIN(\tau)$$
$$Y_{as}=X_a(t)\cdot SIN(\tau)+Y_a(t)\cdot COS(\tau) \qquad (2)$$
$$Z_{as}=-(p+\Delta p)\cdot\tau$$

Utilizing eq.(1), we can change eq.(2) into

$$X_{as}=X_s+\Delta X_s$$
$$Y_{as}=Y_s+\Delta Y_s \qquad (2a)$$
$$Z_{as}=Z_s+\Delta Z_s$$

where,

$$\Delta X_s=\Delta X(t)\cdot COS(\tau)-\Delta Y(t)\cdot SIN(\tau)$$
$$\Delta Y_s=\Delta X(t)\cdot SIN(\tau)+\Delta Y(t)\cdot COS(\tau) \qquad (3)$$
$$\Delta Z_s=-\Delta p\cdot\tau$$

It is the so-called profile surface difference.

ACTUAL ENGAGING CLEARANCE

According to the engaging principle, the engaging clearance between male rotor and female rotor actually is the distance between one rotor surface and the conjugate surface of another rotor at mating point. For its distinguishing featur , screw conjugate surface can be obtained in the following steps:

Firstly, obtaining the conjugate line of rotor profile; Secondly, solving the screw surface which is formed by the conjugate line moving in spiral direction.

At first, the appointments below are made out: The line of X_{21a}, Y_{21a} expresses the conjugate line of X_{1a}, Y_{1a}; and parameters of female and male rotor profiles are same, i.e., $t_1=t_2=t$. So, we have

$$\begin{aligned} X_{21a} &= -X_{1a}(t).\cos(k\varphi_1)+Y_{1a}(t).\sin(k\varphi_1)+(A+\Delta A).\cos(i\varphi_1) \\ Y_{21a} &= X_{1a}(t).\sin(k\varphi_1)+Y_{1a}(t).\cos(k\varphi_1)-(A+\Delta A).\sin(i\varphi_1) \\ & X_1(t).\dot{X}_1(t)+Y_1(t).\dot{Y}_1(t)-r_{1t}[\dot{X}_1(t).\cos(\varphi_1)-\dot{Y}_1(t).\sin(\varphi_1)]=0 \end{aligned} \tag{4}$$

Considering the relation of two conjugate lines, we can change the equation above into:

$$\begin{aligned} X_{21a} &= X_2(t)+\Delta X_{21}(t,\varphi_1) \\ Y_{21a} &= Y_2(t)+\Delta Y_{21}(t,\varphi_1) \\ & X_1(t).\dot{X}_1(t)+Y_1(t).\dot{Y}_1(t)-r_{1t}[\dot{X}_1(t).\cos(\varphi_1)-\dot{Y}_1(t).\sin(\varphi_1)]=0 \end{aligned} \tag{4a}$$

where,

$$\begin{aligned} \Delta X_{21}(t,\varphi_1) &= -\Delta X_1(t).\cos(k\varphi_1)+\Delta Y_1(t).\sin(k\varphi_1)+\Delta A.\cos(i\varphi_1) \\ \Delta Y_{21}(t,\varphi_1) &= \Delta X_1(t).\sin(k\varphi_1)+\Delta Y_1(t).\cos(k\varphi_1)-\Delta A.\sin(i\varphi_1) \end{aligned} \tag{5}$$

Therefore, using the conjugate surface formed by the conjugate line above

$$\begin{aligned} X_{21as} &= X_{2s}+\Delta X_{21s} \\ Y_{21as} &= Y_{2s}+\Delta Y_{21s} \\ Z_{21as} &= Z_{2s}+\Delta Z_{21s} \end{aligned} \tag{6}$$

where,

$$\begin{aligned} \Delta X_{21s} &= \Delta X_{21}(t,\varphi_1).\cos(\tau_2)-\Delta Y_{21}(t,\varphi_1).\sin(\tau_2) \\ \Delta Y_{21s} &= \Delta X_{21}(t,\varphi_1).\sin(\tau_2)+\Delta Y_{21}(t,\varphi_1).\cos(\tau_2) \\ \Delta Z_{21s} &= -\Delta p_1 \cdot \tau_2 \cdot p_2/p_1 \end{aligned} \tag{7}$$

and female rotor groove surface,

$$\begin{aligned} X_{2as} &= X_{2s}+\Delta X_{2s} \\ Y_{2as} &= Y_{2s}+\Delta Y_{2s} \\ Z_{2as} &= Z_{2s}+\Delta Z_{2s} \end{aligned}$$

we can express the engaging clearance at meshing point as

$$\delta = \pm\sqrt{(\Delta X_{21s}-\Delta X_{2s})^2+(\Delta Y_{21s}-\Delta Y_{2s})^2+(\Delta Z_{21s}-\Delta Z_{2s})^2} \qquad (8)$$

Whether δ is positive or negative deponds on the practice.

EFFECT OF WORKING ERRORS ON ENGAGING CLEARANCE

Position Differences

1. Graduation Error

The graduation error is assumed $\Delta\alpha$, which is positive when it is consistent with "right-hand rule" and is negative when not. The profile line difference here is

$$\Delta X(t)=X(t).[\cos(\Delta\alpha)-1]-Y(t).\sin(\Delta\alpha)$$
$$\Delta Y(t)=X(t).\sin(\Delta\alpha)+Y(t).[\cos(\Delta\alpha)-1]$$

As an example, graduation error $\Delta\alpha$ is assumed existing only in one of female rotor lobes. On this hypothesis, the "engaging clearance" is deduced from eq.(6) through eq.(8):

$$\delta = \pm\, 2.\left|\sin\left(\frac{\Delta\alpha}{2}\right)\right|.r(t)$$

The negative δ identifies that the conjugate surface of male rotor would inlay with the female rotor. An engaging clearanc must be designed at least as much as $|\delta|$ to avoid the phenomina to take place.

2. Leader Error

It is easy to obtain the engaging clearance designed from eq.(4a) through eq.(8) only when a leader error of ΔT_2 exists in the female rotor:

$$\delta = |\Delta T_2|.\tau_{2z}/(2\pi)$$

If there exist leader errors in both meshing lobes of male and female rotors, the minimum clearance needed becomes

$$\delta = |\Delta T_1.\tau_{1z}+\Delta T_2.\tau_{2z}|/(2\pi)$$

The formula above expresses that the clearance needed would be greater or smaller than that on the condition of leader error only exiating in one rotor lobe.

3. Centre Distance Error

Only a centre distance difference between male rotor and female rotor is assumed existing in a screw compressor. From eq.(4a) through eq.(8), the engaging clearance can easily be obtained

$$\delta = \Delta A$$

Negative ΔA means that the actual centre distance is smaller than the theoretical. The cutting tool must be designed with a clearance ($-\Delta A$) at least to prevent the two rotors from snapping at each other.

Shape Difference

According to the simplified assumptions given in former part, the lobe surface shape difference is caused by the end section profile difference. Because of the complexity of theoretical profile and profile difference, the effects of profile difference on engaging clearance can not be expressed in such a simple formula as the three situations above. However, having obtained the profile difference, we can solve out the engaging clearance from the general expreessions in eq.(4a) through eq.(8). The method of obtaining profile difference description is explained in the following section.

All the errors existed in screw compressor, together with the deformation of forces and heat on or in rotors, must be considered to adjust the engaging clearance and to manufacture high efficient machines.

ACTUAL ANALYSIS RESULTS

A special measurement apparatus of conjugate workpieces can be used directly to measure screw line error and graduation error, and discontineously to measure profile line error. According to numerical approximation principle, the fit relation of profile difference with parameter is obtained by the numerical data measured, which can also make up the shortcoming now existed in the apparatus. A measurement was done in one pair of rotors with nominal diameter D_0=200 mm. The validity of obtaining actual engaging clearance method presented in this paper is verified by the adjusting of engaging clearance in one of manufacturers in our country.

CONCLUSIONS

The method presented in this paper is simple and effective to study the actual profile surface and engaging clearance of screw compressor rotors. By means of the descriptions of the surface and the clearance, we can find out the main working errors affectting the clearance, i.e., gas-leakage, which may help us solve the urgent problem to manufacture high efficient machines.

REFERENCES

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A STUDY OF THE SINGLE SCREW COMPRESSOR PROFILE

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ABSTRACT

Stable hydrodynamic lubrication film is needed between the tooth profiles for smooth running and long life of a single-screw compressor. This lubrication film is easily established with "straight line enveloping screw pair" rotors, but this kind of engagement pair is very difficult to machine. In this paper it is suggested that " a conical surface two-envelope engagement pair " be used as the single-screw compressor profile. The mathematical model, the working-surface characters, the structural characteristics and the machining method of this kind of engagement pair are elaborated. It has beem proven by practice and experiment that this kind of engagement pair can be machined conveniently either in small or large quantities.

SYMBOLS

u axial position variable of conical surface, cm

θ angle variable of conical surface, rad

$a, d_2, d_1 a', E, B, H$ const, cm

α, β const, rad

$\varphi_1, \varphi_2, \theta_1, \theta_2$ rotation angles, rad

i_{12} transmission ratio

θ_v slide angle, rad

σ^{I}, σ^{II} relatively-sliding factor