The Dynamic Measurement and Mating Design of a Screw Compressor Rotor Pair

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MEASURING NETWORK node measurement according to the coupled matrix are not uniform, the noise, thus affecting the economy of the compressor to a great extent.

The paper describes the dynamic measurement in connection with the working process of the compressor, and the inspection and analysis of the whole rotor profile and the engaged clearance. The results of the research on the relationship between the inspection data, the mating design, the technology and the performance are also mentioned.

INTRODUCTION

Recently, Screw compressors are advancing rapidly, because of their small size, light weight, freedom from wear. Besides, they have not pulsating and operate steadily. The rotor's profile design and the curved surface errors in processing have a great influence on the leakage and volumetric efficiency. The gas will go through a sealed line from high pressure to low one (For non-symmetrical profile rotor pairs, the length of the sealed line of the rotor pairs Φ 200ms is 971mm). There must be an engaged gap in order to prevent the rotor or the whole compressor from destruction in case they are not well coordinated. If the gap paths are not uniform, the noise will increase. The amount of the gas discharged is also affected by the errors of the curved surface of the rotor.

The occurrence of the sealed volume in the form of crescent will result in the interflow of two different pressure volumes so as to bring about inner leakage which causes the increase in power.

The article given here describes how to take the network measurement according to the coupled matrix of rotor pair, so as to obtain spatial data for an actual curved surface of the rotor. Meanwhile measured matrix and tolerance matrix are compared in order to evaluate the quality. Through the inspection and analysis of the dualistic function for forming curved surface, the separation on the error and data processing can be done to find out the relationship between relevant parameters and characteristic index. In this way, we can associate the design and performance with its processing.

MEASURING PRINCIPLE

The dynamic measurement apparatus (in brief later referred to as apparatus) researched and manufactured by us has made the network measurements of the profile parameter τ and the screw parameter Θ; imitating the rotor's moving state, the apparatus measured the engaged clearance of the corresponding points of engagement, and this kind of measurement is that of working precision realized on the basis of the principle of the actual distance to the centre. The result is that the optimum engaged clearance can be obtained under the present processing conditions. The three-dimensional parameters are measured in accordance with the node of τ and Θ (see Fig. 1), so it is possible to get an error matrix of the node, and then make a synthetic appraisal of quality by means of the comparison line.

This kind of measurement is intended to measure and then to record and dispose the profile error which may appear first in the course of processing and then when the rotors are being used; and also to inquire how it is related with the rotor's operational performance. The control of the apparatus and its data processing are completed with the help of a micro-processor. In order to simplify the apparatus mechanism, raise the accuracy and speed of measurement, a series of measures are taken to replace part of the mechanism with calculations.

The apparatus was used in non-contact and contact measuring in turn, and the largest non-coincidence of the curve measured was 2μ.

1—network node of female

2—network node of male

1.2 — network node of corresponding engagement

Fig 1. network node measurement of rotor pairs

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COUPLED DESIGN

The rotor pairs of a screw compressor are mating works. Its engaged curved surface consists of several parts. FR1 and FR2 represent the corresponding engaged curved surface of female rotor and male rotor respectively, then they are functions of profile parameter t and screw parameter τ. Although FR1 and FR2 are nonlinear function of t and τ, they are linear function of trigonometrical function of t and τ they can be become linear functions of t and τ by processing the data. In this case, there is a design matrix between vector and design parameter.

\[
\begin{bmatrix}
FR_1 \\
FR_2
\end{bmatrix} =
\begin{bmatrix}
a_{11} & a_{12} \\
a_{21} & a_{22}
\end{bmatrix}
\begin{bmatrix}
t \\
τ
\end{bmatrix}
\]

(1)

where \(a_{ij}\) are all nonzero coefficient. Therefore, it is a coupled matrix. It is indicated in Fig 2 how to use function space describing physical (including geometry) space.

Fig 2  coupled design

According to equation (1), the change of FR2 (the curved surface of male rotor) can be caused by change of either t or τ both, and FR1 (the curved of female rotor) will also be changed correspondingly.

Since the profile design of the screw rotor belongs in the designing of coupling, its conditions of mating are as follows:
1. The profile on the cross section are mated.
2. The rotor ratio lead equals the drive ratio.

THE COUPLED ERROR

According to the aforesaid principle of coupled design this apparatus can be used to measure the value t and τ of two screws respectively, the error line which is formed by the corresponding engagement points of the screw pair, then the coupled error can be found, as so called, which is the measuring of working precision, and not geometric precision. Every instantaneous engaging clearance of the screw pair is shown in Figure(3), which is the error of value that is measured and recorded respectively according to the same time range. Of course the absolute value of the engagement clearance shown in Figure (3) is gotten by two times of demarcation, we take the dispersed values from the record, and use the miniature electronic computer to calculate these values,

then we can get that average of the clearance value is 56.3 that is the average engagement-clearance value of 60 pairs of corresponding engagement points taken from three cycles of the positive screw and two cycle of the negative screw, which can be considered as the average of a pair of screws, the maximum clearance value is 79.2 , and the minimum 56.4 . This wave range of the clearance is caused by the machining errors.

Fig 3 measuring engaged clearance on corresponding engaged points

According to the aforesaid engagement-clearance value which is measured and calculated practically, we can decrease the engagement-clearance value which has selected blindly. If we select the optimum engagement-clearance value during the design, the volume efficiency of the machine can be increased efficiently. If we decrease the larger period errors or select and couple a pair of screws, the noise can be become lower.

when the engagement-clearance value is larger than the maximum value or smaller than minimum value, the equipment that is controled by the miniature electronic computer well give an alarm. This means a larger amount of leakage or that the screw pair well bite each other.

ERROR SEPARATION

It is very important to separate the curved surface error which is yielded by the function of a single error, so as to raise the compressor performance. The error of engagement gap obtained by the apparatus consists of shope error, lead error and index plate error.

1. Lead Error

The screw error (Fig 4) measured can be dealt with by employing the principle of correlative analysis of statistics. In order to gain the lead error, it is necessary to define the constant A and B of the equation \(Y = A + Bx\).

In order to find out the lead error it is necessary to make the index plate error become zero.

The horizontal coordinates is plotted as observation time (t), the normal is plotted as amplitude (A) in Fig 4.
Let the value $Y$ which is on the straight line versus $X$ be $Y^*$ and the measured value be $Y$, then the error:

$$\delta_i = Y_i - Y^*_i = Y_i - (A + BX_i)$$

which is composed of the measured value $\delta_i$ is $\Sigma \delta_i$.

2. Profile Error

The curved surface is determined by profile $t$ and $\tau$. It is clear that profile and its error are the important eigen-parameters in engaged condition. With new profile coming up one by one, great success has been achieved in narrowing the leakage triangular and reducing the length of contact line. However, the profile error obtained in practice is between 25 $\mu$ and 35 $\mu$ because of many factors. It is mainly caused by tool, which accompanied with the machine tool-tone-gauge-workpiece system that cause screw error compose the complete concept of curved surface error.

In the course of measuring profiles the essential work is comparing the actual profile with the standard one. The definition of initial point is very important.

3. The Correlation of Rotor Pairs

Making use of the curve of the corresponding engaged point error (Fig 6), we can work out its correlation function to judge the engagement quality of a rotor pair and perfectly of gas path between the two rotors and thereby to find optimum match for either of the rotors with the purpose of reducing noise and raise volumetric efficiency. The correlation function of the two rotors marked as $R_{xy}(\tau)$, the error curve of male rotor as $X(t)$, the error curve of female rotor as $Y(t)$,

$$R_{xy}(\tau) = \frac{1}{\tau \rightarrow \infty} \frac{1}{T} \int_0^T x(t) y(t+\tau) \, dt \leq 1$$

As is given above, the sample of measuring signal and the calculation of program have been completed by the microcomputer attached to the apparatus.

Fig 4 measuring screw error

![Fig 4 measuring screw error](image)

Fig 5 lead error gained by statistics

![Fig 5 lead error gained by statistics](image)

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \quad \bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i$$

$$R = \frac{\sum_{i=1}^{n} (y_i - \bar{y})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

As is given above, the sample of measuring signal and the calculation of program have been completed by the microcomputer attached to the apparatus.

![Fig 6 relativity of rotor pairs](image)
Therefore the value of function $R_{xy}(\tau)$ is the index for perfection of the two rotors' engagement.

4. Spectral Analysis

According to Fourier's judgement any synthetic curve is a number of sine curves superposed upon each other. So it can be disintegrated into several sine curves. And the comprehensive error curve in process accords with this principle. Then we can use Fast Fourier Transform (for short FFT) to pick out the main frequencies which form the rotors' synthetic error and then use exciting-vibration method to find out the main causes which bring about errors in machine-tools system.

![Frequency Analysis Diagrams](image)

Fig 7 Frequency analysis of rotor pairs

Parameters $\tau$ and $\xi$ lead to the changes of surface (FR changes), varied zones for bettering the coupling design can be gained in the isogram, which are useful in judging if the coupling design is good or bad. There are surface changes caused by force or thermal deformation and the error of parameters $\tau$ and $\xi$, the localization and value of the exceeding of the coupling range created by such changes can be worked out through the fixed-parameter method (or first through simulation test and then calculate), thus we can avoid detours in the early period of designing and make the connection between designing, manufacturing and measuring more theorized.

The screw curved surface obtained through network measurement can be made into smooth curved surface, the solid figure of which can be shown on the screen. It may be applied to rotor pairs of different specifications if the boundary conditions are changed.

In the practical measuring work in users-factories the apparatus has given outstanding results—the best engaged clearance has been achieved. Experiments have proved that every 0.01 mm decrease of engaged clearance of the screw compressor rotors raises the volumetric efficiency by 1% or so. Under the working condition of $-10^\circ/30^\circ$ (vaporization temperature $\circ{C}$ / condensation temperature $\circ{C}$), and Refrigerating Capacity being 520,000 Kcal/hr, every compressor reduce energy distribution by 30,000 kwh annually.

The principle and practice described in this article can be applied to mating rotors of various profiles.

The measuring apparatus used is researched and made by Xi'an Jiaotong University, Han Jiang Machine Tool Works and Huhan Refrigeration Equipment Plant.
NOTATION

\( t \) Profile parameter
\( \tau \) Screw parameter
\( F_{R1} \) Curved surface of male
\( F_{R2} \) Curved surface of female which is corresponding engaged cured surface of \( F_{R2} \)
\( a_{H1}, a_{H2}, a_{H2}, a_{H2} \) Nonzero coefficient of coupled design
\( A, B \) (Fig 5) Constant value in lead error
\( Y^* \) (Fig 5) The value \( Y \) which is on the straight line versus \( X_i \) be \( Y^* \)
\( Q \) Adds up all the square of error for expressing the total error
\( X(t) \) (Fig 6) Error curve of male rotor
\( Y(t) \) (Fig 6) Error curve of female rotor
\( R_{xy} \) (t) Correlation function of the two rotors

**Table 1** Engaged clearance influence on the value \( K_e \) and volumetric efficiency

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Refrigerating capacity ( Q ) (Kcal/h)</th>
<th>Axle power (Kw)</th>
<th>Volumetric efficiency ( (%) )</th>
<th>Synthetic index ( Kc )</th>
<th>Volumetric efficiency ( (%) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10° C</td>
<td>535880</td>
<td>161.1</td>
<td>0.843</td>
<td>3359</td>
<td>3503</td>
</tr>
<tr>
<td>+30° C</td>
<td>580000</td>
<td>165.54</td>
<td>0.890</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15° C</td>
<td>463780</td>
<td>154.3</td>
<td>0.831</td>
<td>2998</td>
<td></td>
</tr>
<tr>
<td>+30° C</td>
<td>490000</td>
<td>158</td>
<td>0.880</td>
<td>3100</td>
<td></td>
</tr>
<tr>
<td>-20° C</td>
<td>379060</td>
<td>146.7</td>
<td>0.807</td>
<td>2513</td>
<td></td>
</tr>
<tr>
<td>+30° C</td>
<td>383000</td>
<td>146</td>
<td>0.835</td>
<td>2623</td>
<td></td>
</tr>
<tr>
<td>-25° C</td>
<td>274190</td>
<td>139.8</td>
<td>0.722</td>
<td>1976</td>
<td></td>
</tr>
<tr>
<td>+30° C</td>
<td>289000</td>
<td>140.6</td>
<td>0.828</td>
<td>2048</td>
<td></td>
</tr>
<tr>
<td>-30° C</td>
<td>218000</td>
<td>128.4</td>
<td>0.794</td>
<td>1711</td>
<td></td>
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<tr>
<td>+30° C</td>
<td>231000</td>
<td>133</td>
<td>0.832</td>
<td>1736</td>
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<tr>
<td>-35° C</td>
<td>169000</td>
<td>122.7</td>
<td>0.684</td>
<td>1374</td>
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<tr>
<td>+30° C</td>
<td>188500</td>
<td>127.5</td>
<td>0.782</td>
<td>1478</td>
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<tr>
<td>-40° C</td>
<td>131900</td>
<td>119.7</td>
<td>0.639</td>
<td>1059</td>
<td></td>
</tr>
<tr>
<td>+30° C</td>
<td>150000</td>
<td>122.3</td>
<td>0.77</td>
<td>1226</td>
<td></td>
</tr>
</tbody>
</table>

![Graph](image)

the engaged clearance:
- rotor pairs A: 0.18 mm
- rotor pairs B: 0.13 mm

**Table 11** Engaged clearance influence on the discharge capacity

<table>
<thead>
<tr>
<th>Machine index</th>
<th>Discharge pressure Kg/cm²</th>
<th>Suction head temperature °C</th>
<th>Water head (mm)</th>
<th>Engaged clearance (mm)</th>
<th>Discharge capacity (m³/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 #</td>
<td>4</td>
<td>24</td>
<td>485</td>
<td>0.13</td>
<td>16.31</td>
</tr>
<tr>
<td>8 #</td>
<td>4</td>
<td>29</td>
<td>433</td>
<td>0.18</td>
<td>15.11</td>
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</tbody>
</table>

**Table 111** Measured profile errors

<table>
<thead>
<tr>
<th>Measured coordinates (mm)</th>
<th>-23.584</th>
<th>-10.278</th>
<th>-4.257</th>
<th>-0.156</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profile error ( A )</td>
<td>type A</td>
<td>0.101</td>
<td>-0.150</td>
<td>-0.078</td>
</tr>
<tr>
<td></td>
<td>type B</td>
<td>-0.070</td>
<td>-0.051</td>
<td>-0.045</td>
</tr>
<tr>
<td></td>
<td>type C</td>
<td>0.290</td>
<td>0.284</td>
<td>0.264</td>
</tr>
<tr>
<td></td>
<td>-0.156</td>
<td>0</td>
<td>1.309</td>
<td>2.496</td>
</tr>
<tr>
<td></td>
<td>-0.029</td>
<td>0.040</td>
<td>0.1200</td>
<td>0.027</td>
</tr>
<tr>
<td></td>
<td>0.079</td>
<td>0.100</td>
<td>0.158</td>
<td>0.2370</td>
</tr>
<tr>
<td></td>
<td>-0.612</td>
<td>-0.658</td>
<td>-0.528</td>
<td>-1.31</td>
</tr>
</tbody>
</table>

Type A -Caused by fit angle error in tool mainly
Type B -Baside A, caused by non-symmetrical between tool and rotor
Type C -Caused by distance errore to the centre

**REFERENCE**

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