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USE THE METHOD OF MAGNETIC SCORE TO MEASURE THE DYNAMIC PARAMETERS OF THE SCREW COMPRESSOR

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ABSTRACT

The dynamic measurement in connection with the working process of the screw compressor and the inspection of the whole rotor profile and engaged clearance have a great effect on improving the volumetric efficiency and saving energy, however this dynamic measurement was not a measurement under the assembling condition. The method of magnetic score can measure the dynamic parameters of the screw compressor in the assembling condition. The results measured by the method of magnetic score can reflect the performance of the whole set truly. The paper presents the principle of the method of magnetic score and the measuring process. The compensation for measuring error and the selection of parameter are discussed.

SYMBOLS

λ	sine magnetic wave length
Z	tooth number
N	railing stripe number
$\bar{\omega}$	rotational speed
ω	angular speed
V	linear speed
f	frequence
R	rotational radium
l	railing stripe distance

u voltage

$\Delta\xi$ graduation error

φ angle between center lines

INTRODUCTION

In "The dynamic measurement and mating design of a screw compressor rotor pair"[1] , the apparatus used to measure screw rotor pair had been introduced. It can measure the rotor's curved surbace errors, engaged clearance and it's alteration. So it has a great effect on improving the volumetric efficiency and energy saving. However, the influence of assemble error, bearing shift, the rotor's graduating error and profile error, the machine's speed, the shape's change by heat and force to the working process of screw compressor or screw refrigerator assembled together is an open question. But the whole set's performance can only be reflected most noturaly and directly in the real situation. As the engaged clearance and it's alteration are affected by many factor and changing quickly we used magneto-railing to treat fixed machine's dyminac measurement, and obtained a lot of useful information.

The dynamic errors can be measured by magneto-railing when the compressor is working. The results reflect the working situction of object very well. The effect of circumstances to the result is very little because the measurement is carried out so quickly. So using mayneto-railing measuring the whole screw machine not only overcomed the disadvantage of ordinary methods, but also soluted the problem that have no answer in this area before. However there are many important know-how in processing the measurment which include electing of the pitch compensating of the magneto-railing graduating error; determining and eliminating of the maynetic disk's assemble error; controlling of the frequency and phase change for receiving signals; A special set fixed in the main axle system to measure the whole set's error and the object measured in step with the automatic recorder operate; the magnetic shielding is used to obtain the single factor's effect; and so on.

MEASUREMENT PRINCIPLE

Fig.1 is a sketch map of the apparatus.

Two magnetic disk fixed individually to the female and male rotor's axle. The rotor and the disks have a same axle line. a integer number of sine maynetic waves which have a same wave length are recorded in the disk by a magnetic head. The cir magneto-railing is formed as the out circle of disk is divided uniformly. Every sine wave on the out circle of disk represents a magneto-stripe of the mayneto-railing. The wave length represents the distance between two stripes.The distance represents the measuring unit of magneto-railing anyle (or length). The sum of the angle (or length) corresponding to these measuring unit can show the dimension of the angle (or length) measured.

The distance between two stripes λ , the rotor's linear velocity V and the frequency of recording magnetic current f have the following relation:

$$\lambda = \frac{V}{f} \qquad (1-1)$$

According to equation (1-1), the different measurement range from narrow (λ is small) to wide (λ is large) can be obtained when varying V or f to control the dimension of the magnetic railing with a same precision. That is, the precision have no relationship with the measurement range when using the magneto-railing as the base of circle graduating.

When a non-conducting magnetism disk is electroplated, the magnetic material should have good mechanical performance, maynetism frequeney characteristic, uniformity and stability. We elected a magnetism-conducting alloy steel which include 30-36% Co, 11% V and 53-59% Fe. The alloy steel with 50% Co, 11% V, 37% Fe Can also be used. After heat treatment the remainder magnetism is 11 x 10^3 gauss, the coercive force is 200 oersteds. The coercive force can be 300 - 400 oersteds and the reminder magnetism can be 10^4 gauss. If the certain alloy steel undergo a special heat treatment and appropriate mechanical process.More than good magnetic performance can be obtained when adding some Ag, Au and Pt into chromium alloy. But all the materials introduced above is expensive. In fact, using PNiCo alloy as the electroplate material of the disk not only have good magnetic performance, but also is very economical.

According to fig.1. The ratio of the railing stripe number is

$$K = \frac{N_2}{N_1} \geqslant 1 \qquad \text{(integer)}$$

The ratio of the tooth number for femal and male rotors is

$$\frac{Z_2}{Z_1} = \frac{\omega_1}{\omega_2}$$

(Z_1 , Z_2 are integers more than 1)

$$f_0 = \frac{1}{Z_2} N_1 \omega_1 \qquad (1-2)$$

and

$$f'_0 = \frac{1}{Z_1} (N_2 \omega_2 / K) \qquad (1-3)$$

because

$$N_1 = N_2 / K$$

$$1/Z_2 = \omega_2 / (Z_1 \omega_1)$$

so

$$i_0 = i_0' \qquad (1-4)$$

According to (1-4) the apparetus's principle is correct and the number of rotor tooth is not linited. Because the femals rotor is drived by the male rotor, the speed of male rotor can be varied to oblain the error respond of different frequency when the speed ratio between female rotor and male rotor is constant. When the rotors is measured the male rotor is drived by a motor. The speed of male rotor is 200 rpm, 400 rpm, 600rpm, 800 rpm,1000rpm and 1200 rpm individually. The linear velocity is $2\pi(50) \times 200/60 \sim 2\pi(50) \times 1000/60$ for the rotor with a diameter of 200 mm.

The various error can be shown separately by dividing frequency comparing phase, recording and analysing the recorded singal's spectum.

Because the largest value of frequecy respond in our recording machine is about hundreds to 1000Hz, the oscillograph can't record in a long time. The two comparing phase puls singals are recorded to the magnetic tape recorder first, then released slowly. Our apparatus has this function:

MEASUREMENT

An angle self-adjustor which can issue signal is fixed in the apparatus main axsis system. An angle self-adjustor which can receive signal is fixed in the automatic recorder. The two angle self-adjustors are connected together to make the rotor in step with automatic recorder operating. So the rotor's whole errors can be measured. This new methods not only shows the synthetical quality when the female rotor is in step with the mal rotor rotating, but also gives a lot of information about the single error he single error can be obtained by analysing the spectrum and the method of proper parameter

1. the measurement of female rotor and male rotor' synchronism.

The male rotor are rotated with the angle velocity of by a motor and a driver. The disk rotated around the same axle line with the male rotor. The female rotor and the disk fixed on it are rotated by the male rotor and the drive ratio is i . Because i is very small generally two divider is needed at least to satisfy the demand of measurement . A frequency multiplier is added into the signals channel of the magnet-railing at driven end. So the circuit is complicated generally.

The measuring results of the famale rotor and the male rotor synchronism is shown in Fig 2.

The synchronism measurement reflects synthetically the engayed precsion of the female rotor and the male rotor. It gives the working precsion of mating rotors. If the mating rotors synchronism is well, the courve of Fig 2 will be a straight line even if the two rotors all have error individually. Of cause this only an idea situation. In fact they can't be synchronous. The errors shown in Fig.2 includes the graduating error of female rotor and the male rotor's profile error, the error of the distance between two axes, the error of bearing shift, the error of the curved surface shaped and the error of the shape changed by heat and force, and so on.

The ratio of tooths numbers for the rotor pair used most widely in our country is 4:6. Take this for example, the 4 x 6=24 engaged precsion curve pairs are obtained by measurement

The average engaged precsion, the largest and the smallest value of engaged precsion can be obtained from the engaged precsion curve. The value of engaged precsion reflect the working precsion of mating rotors directly and entirely. This parameter influences the volumetric efficiency and the noise level in a great deal.

2. The rotation uniformity measurement of female rotor and male rotor

The curve shown in Fig2. synthesized the errors of the female rotor and the male rotor. In order to obtain the single errors of the fernals rotor and the male rotor to improve the engaged precsion, we designed a measurement system shown in Fig 3.

First, turn Switch A to position "2" to start the rotary body, then transfer the signals from two magneto-heads which have a phase-difference π , to have a dynamic correction, until a line appeares on the autorecorder. Second, turn switch A to position " 3 ", and begin to measure. A signal of one magneto-head and a signal form the highly steady and adjustable signal genarator must be sent to the oscilloscope and the phaser respectivily.
After this, regulate the frequency of the signal source until a steady Lisaru ellipse appeares on the screen of the Oscilloscope. This denotes that the frequency of megnote-railing signal is equal to the signal source.

The angular speed ω, rotational-speed $\overline{\omega}$ and linear velocity v of the rotary body are:

$$\overline{\omega} = \frac{2 f \pi}{N} \quad (p.s) \qquad (1-5)$$

$$\omega = f/N \quad (r.p.s) \qquad (1-6)$$

$$v = \overline{R}\overline{\omega}/N \quad (m.p.s) \qquad (1-7)$$

R - radius of the rotery body;

Fig 4. shows the angle-error of rotors. The measured angle-error of male and female rotors is still the overall reflection of the factors which influence the angle. These factors include the bearing clearance, the eccentricity of profile corresponding to assembly datum point, the graduation error and profile error, etc.

The angle error of female rotor also include the transfered error of the male rotor's angle.

3. Analysis of errors

The error of first harmonic is obtained by the spectrum analysis.

The errors are chiefly coused by the deviation between the rotors tooth shape and the assemble center of the rotor. (see Fig.4)

As the error caused by bearing clearance is random, the proper parameter method is used, eg. comparing the measured error curves with bearing clearance and without bearing clearance.

The graduation error has a great difference from the profile error in the freuquence. So they can be easily distinguished. (See Fig.5.)

The profile error of the male rotor adds to that of the female rotor. The error of the male rotor has been measured. So this error can be eliminated from total error curve.

COMPENSATION FOR MEASURING ERROR AND SELECTION OF PARAMETERS

1. Compensation error analysis of two magneto-heads with a interval $\pi/2^{n-1}$.

To connect in series two magneto-heads with a interval $\pi/2^{n-1}$ (n = 1, 2, 3 .....) to compensate the error of harmonic of magnetic railings. is an effective method of improving the magneto-railing precision. (Fig.5) The distance between magneto-head 1 and 2 . is Δx. The angle between the center lines of the two heads $\varphi = \Delta x / R$. When the heads rotate around the assembly center the signal voltage of head 1 is

$$U_1 = U_{m1} \operatorname{Sin}(\omega t + (X)), \qquad (1\text{-}8)$$

Transfering all the parameters from time field to space field, we can obtain

$$t = 2\pi x / l \qquad (1\text{-}9)$$

then

$$U_1 = U_{m1} \operatorname{Sin}(2\pi(X + f(X))/l) \qquad (1\text{-}10)$$

where

$$\varphi(x)=\frac{2\pi}{l}f(x)$$

U -the amplitude of signal of head 1.

l - the pitch of railing stripes of the magneto-railings;

x - the position of the magneto-head outside circle of the magneto-railings.

f(x)- the fuction of graduation error.

If by adjusting, the distance between head 1 and 2 is $\Delta x = nl$, the signal voltage of head 2 U_2 is

$$U_2=U_{m2}\sin\frac{2\pi}{l}(x+f(x+\Delta x)) \qquad (1\text{-}11)$$

the series voltage of u , u is

$$U_o = U_1 + U_2 = U_{mo}\sin\frac{2\pi}{l}(x+\Delta\xi) \qquad (1\text{-}12)$$

From the Fig.6, the amplitude of u is:

$$U_{mo}=\sqrt{U_{m1}^2+U_{m2}^2+2U_{m1}U_{m2}\cos}$$

$$\theta=\pi-\frac{2\pi}{l}(f(x+\Delta x)-f(x))$$

So

$$U_{mo}=\sqrt{U_{m1}^2+U_{m2}^2+2U_{m1}U_{m2}\cos\frac{2\pi}{l}(f(x+\Delta x)-f(x))}$$

(1-13)

$\Delta\xi$ is the total graduation error in the total voltage of u and u . It is clear, that by eliminating every harmonic error, the graduation precision of magneto-vailings can be improved greatly. Fig.7 shows the total voltage projections on the vertical and horizontal coordinates.

$$\Delta\xi=\frac{\lambda}{2\pi}\operatorname{arctg}\frac{U_{m1}\sin\frac{2\pi}{l}f(x)+U_{m2}\sin\frac{2\pi}{l}f(x+\Delta x)}{U_{m1}\cos\frac{2\pi}{l}f(x)+U_{m2}\cos\frac{2\pi}{l}f(x+\Delta x)} \qquad (1\text{-}14)$$

For the same reason, if we want to compensate any order of harmonics, we must make the voltage amplitudes of all the heads equal,

$$\Delta\xi=\frac{f(x+\Delta x)+f(x)}{2} \qquad (1\text{-}14')$$

f(x +Δx) denotes the signal error of heads which have an interval Δx; φ_n is the phase difference of the error harmonic of nth order in the two head signals.

The amplitude of resulting vector of the corresponding order of harmonic is

$$\left|\vec{B}\right| = B_n\sqrt{2(1+\cos\varphi_n)} \qquad (1-15)$$

From equations (1-14) and (1-15), an error compensation table of any order of harmonic with different values of Δx can be obtained.

2. The contral of initial phase

The phase error $\Delta\varphi(\theta t)$ changes repeatly with the error frenquance $F(\theta = 2\pi f)$. If the initial phase φ_0 is not appropriate, the phase difference may surpass the limit of 2π to convert the trigger of phase identifier and can't be measured so the φ_0 must at least satify

$$\Delta\varphi(\theta t)_{max} < \frac{1}{2}(2\pi - \varphi_0)$$

In oder to improve the linerity, we use the relation:

$$\left|\Delta\varphi(\theta t)\right|_{max} < \frac{1}{2}(2\pi - \varphi_0)$$

3. The correction of the magneto-railing center

Fig.8 Shows the dynamic correcting method of the magneto-railings center.

If in any case, the needle of phase can't be made steady. We recorde the error curve of the magneto-railings with the auto-recorder and determine its amount or connect in series the two magneto-heads and adjust the signals to make their amplitudes equal, then the error, which is caused by the assemble eccentricity, can be eliminated as a first order harmonic.

Canclusion

It is proved by experiments that if the engaging clearance was reduced by 0.03mm, the volume efficiency can be increased by 2-4%, and the noise can be decreased. By measurements and analyses, the error of rotational angle uniformity of the female and male rotors, the effect of the random error of the bearing clearance and the effect of the assembly eccentric can be measured.

Since the megneto-railings measurement is highly sensitive, quick, precisive and stable, it can entirely describe the error of the whole machine under the assembly condition, so it has solved the problem, which had never been solved in this field before.

REFERENCES

1 Xiong Zenan., "The dynamic measurement and mating design of a screw compressor rotor pair", Proceedings of 1984 International Compressor Engineering Conference.

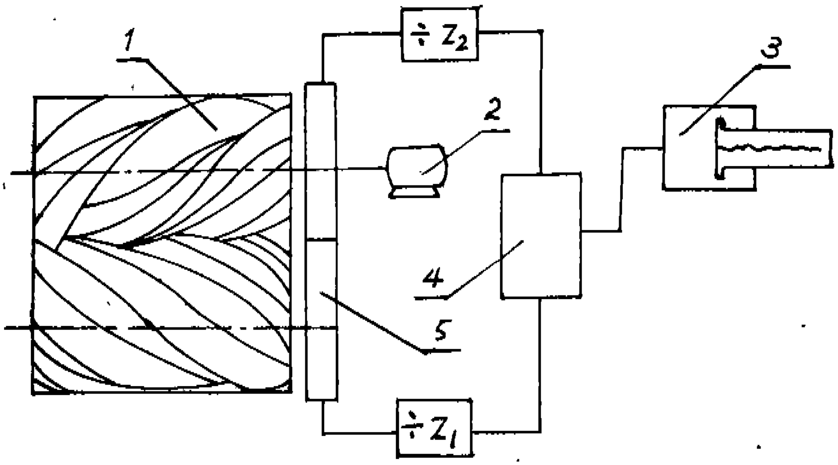

Fig. 1 Sketch Map of Dynamic Measuring Apparatus for Whole set

1-rotor
2-motor
3-auto-recorder
4-phase-identifier
5-disk

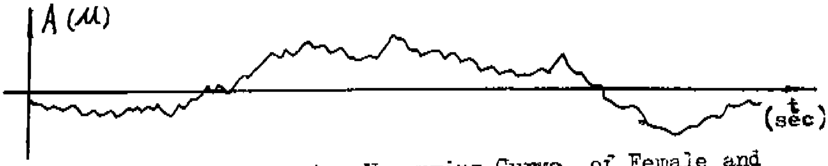

Fig. 2 Synchronism Measuring Curve of Female and Male Rotors

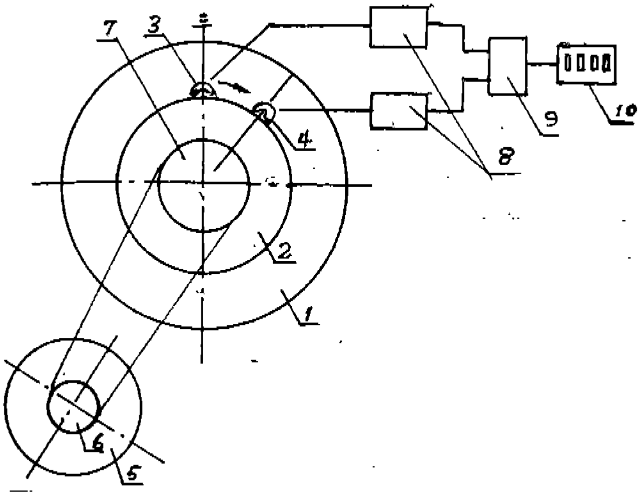

Fig. 3 Uniformity Measured Apparatus of Female and Male Rotors

1-rotatory body 2-cirmagneto-railing
3-inactive head 4-active head
5-motor 6,7-pulley
8-amplifier 9-phase identifier
10-counter

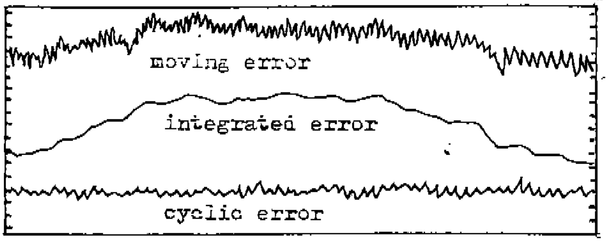

Fig. 4 Curve of Angle-error Measured at the female and male rotors

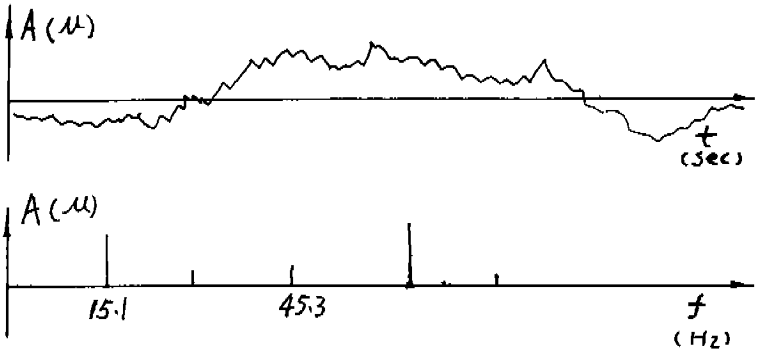

Fig. 5 Spectrum analysis of Synchronous Curve
for the Female and Male Rotors

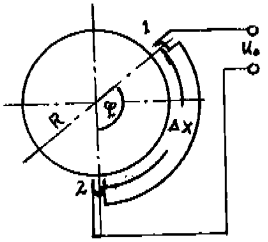

Fig. 6 Compensation Error of Series
Binary Magneto-heads

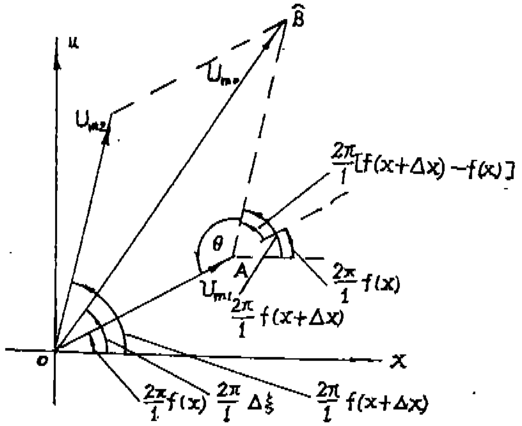

Fig. 7 Vectograph of U_0,U_1 and $\bar{U}_2$

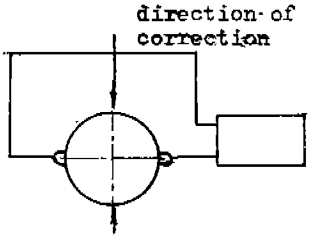

Fig. 8 Dynamic Correction in Center of the Magneto-railing

1-magneto-railing 2-magneto-head1

3-magneto-head2 4-phasor

COMPUTER SIMULATION OF THE HYDRODYNAMIC LUBRICATION IN A SINGLE SCREW COMPRESSOR.

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ABSTRACT.

The hydrodynamic lubrication of the teeth of the gaterotor in a single screw compressor differs from the well-known lubrication of bearings. This difference can be related to the constrained fluid film geometry and the conditions of the lubrication. Under these circumstances the convective fluid inertia will affect the performance of the lubrication.
During meshing, variations of the filmgeometry and the conditions of lubrication result in variations of the distribution of the clearances. A simulation model, based on the theory of lubrication including inertial effects, has been developed to determine the periodical variations of the distribution of clearances. Changes in design can be studied and parametric analyses can be made with this model, resulting in an optimum design.

SYMBOLS.

a	Center distance.
b	Tooth-width.
e	Off center distance.
$\underline{g}$	Acceleration of gravity.
h	Filmthickness.
i	Speed ratio.
$\bar{p}(\bar{x})$	Dimensionless pressure distribution.