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Application of ANSYS on Screw Type Air Compressor Structure System in Dynamic Optimization

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Abstract
The mechanical structure modal analysis and dynamic optimization design method for many years has been a hot issue for scholars at home and abroad, it is for improving the reliability and dynamic system of the mechanical system response characteristics are of great significance. The 3D model of the shell and the rotor of screw type air compressor is established by Pro/E. Finite element analysis software ANSYS is used for the actual operation of the computer simulation, the deformation in the actual working state, provides an important reference for the design and machining of the parts. At the end of the system parameters on the sensitivity of torsional natural frequency has been analyzed. Analysis of effects of various parameters of system parameters on the system torsional inherent frequency provides an important basis for determining the direction of improvement structure. This method provides the basis for further optimization of the mechanical system, provides a new method for the analysis of mechanical structure system.

Key words: ANSYS, Mechanical Structure, Dynamic Optimization

1. INTRODUCTION
The internal combustion engine is currently the most efficient heat engine is widely used in various fields of national defense and national economy. The development of diesel engine development towards high power and light weight, which decreases its stiffness, thus exacerbating the structure vibration and noise of the diesel engine, the vibration will directly affect the engine life(Gomes, 2011). The diesel engine and its components must be dynamic design and analysis, the dynamic performance as an important design goal. Pressure is an important symbol of the development of internal combustion engine, turbocharger technology makes the engine power, economy and emission characteristics were improved, has become the basic model of internal combustion engine. The basic mechanical booster power output directly from the internal combustion engine, driven by the gear box (Miguel, Miguel, 2012). The screw type supercharger has the advantages of compact structure, high efficiency, low noise, high compression ratio, engine acceleration response performance and transient speed, so it has more application (Povilionis, Bargelis, 2015). Screw type air compressor belongs to the power components in internal combustion engine, its performance directly affects the performance and reliability of diesel engine. Oil free screw compressor as turbocharger diesel engine use, has advantages of fast response, high gas, load characteristic, obviously to improve the diesel engine power, its reliability has an important influence on the whole diesel engine. Screw type air compressor is complicated in structure, more components, the transmission connection relations are very complex (Zhao, Choi, Lee, 2011).

To reflect its true face, including not only the parameters calculation, design also includes the important parts, and the relationship between structures of power matching. Screw pump shell, rotor, Male Female rotor synchronous gear and bearing components is the main component of screw compressor, the performance of screw pump, should start from these main parts. Screw pump screw pump shell is the skeleton, all moving parts of the supporting screw pump, so that they remain relatively accurate position at work. The shell and cooling fins, and other parts of the structure and installation of the intake and exhaust window, the shell structure is quite complex (Deaton, Grandhi, 2014). In addition, the housing in the work load is very complex, which makes the simulation of screw pump shell has great difficulty analysis. Female and male are the main rotor moving parts at work, both through the meshing movement and the housing together form a closed volume of compressed air, the pump pressure. In line with the state of their respective processing precision and between directly determines the performance of the pump rotor, not only complex shape, and the comprehensive effect of torque, axial force, work under gas pressure and temperature load, stress condition is complex, is a key and difficult analysis of pump performance(Kang, Zhang, Jiang, et al., 2012). In order to make the screw work has enough stiffness and strength, and the various parts of minimum deformation and vibration, the minimum noise minimum, we must study its dynamic characteristics, through optimizing the structure to suppress the vibration of the screw pump and improve the dynamic stiffness and dynamic strength.
2. STATE OF THE ART

2.1 The definition of modal identification method

Modal identification methods can be divided into two kinds of frequency domain and time domain. The frequency domain identification method developed earlier, at present in the engineering application of modal analysis are widely used in the. Frequency domain modal parameters identification method has been developed to a mature stage, a parameter identification method is integrated with many special spectrum analyzer. The frequency domain method will be testing signal transform in time domain and frequency domain, will be produced by the data transform (FFT) caused by the truncation error. The parameter identification method of time domain modal is without these drawbacks, so as to improve the accuracy of parameter estimation, especially to estimate the modal damping. In addition, the time domain method for direct response signals from the identification of modal parameters to create conditions. Time domain frequency domain method is developed late, but in recent years, with the development of methods(Gholizadeh, Barzegar, 2013). But modal identification is still in the continuous development and perfection.

2.2 The application of modal identification

The modal analysis technology began to research on the dynamic mechanical structure of the system since birth. The mechanical structure of the system is a complex system, in which the dynamic performance of mechanical structure system of parts of large joints such as damping and stiffness dynamic characteristic parameters of the mechanism is still not very clear. Mechanical vibration problems in the analysis and research in engineering, the general method is using a combination of theoretical and experimental(Cauhnye A M, Nie X, Pokharel S., 2012). Design improvement on the dynamic performance of the mechanical structure system includes: dynamic testing, modal analysis, to determine the weak links etc.. According to the actual situation to take corresponding measures to improve the design, is the process of theoretical analysis and dynamic experiment closely. The dynamic characteristics of mechanical structure system played a major role in the few low order modes, as long as you can accurately test and calculate the modal parameters, it can accurately reflect the dynamic characteristics of mechanical structure. The experimental modal analysis technique by dynamic test of structure, modal parameter identification, a modal model, graphical display of structural vibration form, according to the actual use of the structure, find out the weak link, to provide reliable information for structure modification.

3. METHODOLOGY

3.1 Dynamic response analysis of single screw pump

Single screw pump drive system is shown in Figure 2 is shown (Marano G C, Quaranta G, Monti G., 2011).

Figure 1. Screw type air compressor

Figure 2. Analysis of dynamic response of single screw pump calculation diagram
In Figure 2: $J_{tl}$ is the moment of inertia of elastic coupling; $J_{y}$ is the moment of inertia of the driving gear; $J_{9}$ is the moment of inertia of the driven gear. $J_{w}$ is the moment of inertia of the male rotor, $J_{mc}$ is the transformation of the female rotor inertia moment of inertia; $J_{99}$ is combined with the driving gear and the driven gear conversion mechanism; $k_{18}$ is transformation between elastic coupling and gear stiffness; $k_{8}$ is transformed into Male rotor shaft stiffness; $k_{y}$ is transformation mechanism of bardo rotor shaft stiffness; $N_{y}$ is in the original system of bardo rotor shaft speed; $N_{9}$ is male rotor shaft speed in the original system.

$$k_{y} = k_{8} \left( \frac{N_{9}}{N_{y}} \right)^{2} = \frac{8}{9} k_{9}$$  \hspace{1cm} (1)

$$J_{w} = J_{y} \left( \frac{N_{9}}{N_{y}} \right)^{2} = \frac{4}{9} J_{w}$$  \hspace{1cm} (2)

$$J_{99} = J_{8} + J_{9} \left( \frac{N_{9}}{N_{y}} \right)^{2} = J_{8} + \frac{4}{9} J_{9}$$  \hspace{1cm} (3)

The stiffness matrix of single screw pump system is:

$$[K] = \begin{bmatrix} k_{18} & -k_{18} & k_{18} \\ -k_{18} & k_{8} + k_{9} & -k_{8} & k_{9} \\ -k_{8} & k_{9} & k_{9} \end{bmatrix}$$  \hspace{1cm} (4)

The single screw pump system inertia matrix

$$[J] = \begin{bmatrix} J_{w} & J_{99} \\ J_{9} & J_{mc} \end{bmatrix}$$  \hspace{1cm} (5)

Let $[C]$ be a single screw pump system damping matrix, then describes the characteristic equation of transmission system of single screw pump can be expressed as:

$$[J] \{ \ddot{\theta}(t) \} + [C] \{ \dot{\theta}(t) \} + [K] \{ \theta(t) \} = [M] \{ t(t) \}$$  \hspace{1cm} (6)

Where,

$$M = \begin{bmatrix} M_{w} & M_{99} & M_{w9} & M_{mc} \end{bmatrix}$$

$$\ddot{\theta}(t) = \begin{bmatrix} \ddot{\theta}_{w}(t) \\ \ddot{\theta}_{9}(t) \\ \ddot{\theta}_{w9}(t) \\ \ddot{\theta}_{mc}(t) \end{bmatrix}$$

$$\dot{\theta}(t) = \begin{bmatrix} \dot{\theta}_{w}(t) \\ \dot{\theta}_{9}(t) \\ \dot{\theta}_{w9}(t) \\ \dot{\theta}_{mc}(t) \end{bmatrix}$$

$$\theta(t) = \begin{bmatrix} \theta_{w}(t) \\ \theta_{9}(t) \\ \theta_{w9}(t) \\ \theta_{mc}(t) \end{bmatrix}$$
Subscript meaning: tl is an elastic joint; yA is the male rotor; yi is female rotor; 89 is the driving gear and the driven gear conversion to calculate transformation structure of concentrated mass disc; \(M_{yA}(t)\) transformation calculation of resistance moment on quality set by the driving gear and the driven gear on the transformation to the structure. From the working state of the pump, \(M_{yA}(t) = 0\); resistance moment male rotor shaft by the torque is \(M_{yA}(t)\); resistance moment female rotor shaft by the torque is \(M_{yi}(t)\); \(M_{yi}(t)\) is an elastic joint torque of the screw pump function, it and screw pump torque on the elastic coupling effect of the interaction torque and reaction torque that belongs to the transmission system between the moment.

3.2 The dynamic response system

The screw pump and the transmission chain work conditions were rated and variable conditions in two cases, dynamic response analysis of transmission chain system under rated condition and under variable conditions, which assume the transmission chain system has no mechanical loss, the input power system is equal to the output power of three screw pump and. Because the working conditions of the three screw pump size, structure, are the same, so are the input torque of each screw pump are equal, and are equal to the output torque of the output shaft of the reducer is 1/3(Gentil, Parente, Martins, et al., 2011).

Screw work transmission system by torque analysis. Screw pump at work, the force is very complex, but the torsional vibration of transmission system, the greatest impact is the moment, while the other force on the torsional vibration of transmission system has little effect(Han, Fan, Wang, 2011). So the only torque of shafing by analyzing influence, while ignoring the other force. It is worth noting that some gas female rotor profile in the moment is negative, and fluctuate with time, because the working condition of the compressor changes, it is possible to make the total torque on the female rotor in the direction of the ongoing changes in the running process of the compressor, resulting in the impact between the synchronous gear and the rotor, resulting in abnormal the noise and wear.

The system response under rated condition: shaft torque is very complex, many influence factors, it is difficult to accurately calculate, and there is a great fluctuation. So the only possible in a certain period of time the average about make estimates, and only at the rated operating stability, this is of practical significance to estimate. For this type of compressor rotary machine, each kind of load regardless of how complex is in the drive torque changes periodically under the action of the change in accordance with the cycle (generally in accordance with the sine law changes with time). It can be in a stable condition of system harmonic response analysis to determine the displacement, strain and stress changes with time(Mehrabian, Yousefi-Koma, 2011).

In the system response under the condition of variable condition: refers to the transmission system composed of the screw pump and the gear reducer from the shutdown starting and accelerating process, until the normal condition, the working process or the brake until the parking from normal working condition(Valdebenito, Schüller, 2011). Under thermal load, fluid pressure load, friction, mechanical load and other complex loads at work, the transmission system change working conditions more severe shock(Jansen PW, Perez RE., 2011).

4. RESULT ANALYSIS AND DISCUSSION

Finite element analysis of the main parts of shell, screw pump rotor, the male and female rotor, to identify them in the work of the actual deformation. This will have a great effect on the performance of a screw pump. Because if the deformation of the real work of the screw pump has an accurate simulation, it can provide a reliable reference for the design and processing, ensure the reliable work in the best working condition.

4.1 Screw pump casing reliability calculation

Screw pump screw pump shell is the skeleton, all moving parts of the supporting screw pump, so that they maintain a relative position accurately when working on the shell and cooling fins and other parts of the structure and installation of the intake and exhaust window, the shell structure is quite complex. In addition, the housing in the work load is very complex, which makes the simulation of screw pump shell has great difficulty analysis.

Including the thermal deformation and force deformation of the screw pump, wherein the heat deformation plays a major role. For dry screw pump, usually the exhaust temperature is lower than 100 DEG C, the rotor and the shell does not need to heat the air would be enough. The shell geometry does not change obviously, but when the exhaust temperature is higher, because the screw compressor is double cylinder shape, the entire surface of the expansion is not uniform. The thermal expansion coefficient and thermal conductivity of aluminum is relatively large, larger than the steel member general deformation heat pump

The deformation calculation of screw pumps shell heat. The first use of pro/e, construction of the casing and the rotor, the three dimensional model, and then carries on the finite element analysis with Ansys, the shell deformation calculation. The calculation results of this section should be greater than the deformation of the
pump. Because in the actual work to housing restrictions and constraints of other connected parts and other parts of the shell boundary conditions also influence.

The following calculation is divided into normal and abnormal operating condition, under normal condition of host selection conditions when the power is 2400 horsepower, non-normal conditions to select the highest exhaust temperature conditions when the operating point of the basic data, shown in table 1.

**Table 1. Shell heat deformation calculation condition**

<table>
<thead>
<tr>
<th>Project</th>
<th>Inspiratory pressure (bar)</th>
<th>The suction temperature (°C)</th>
<th>Exhaust pressure (bar)</th>
<th>Exhaust temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal working conditions</td>
<td>0.949</td>
<td>35</td>
<td>1.609</td>
<td>95.6</td>
</tr>
<tr>
<td>Non-normal working conditions</td>
<td>0.51</td>
<td>35</td>
<td>2.57</td>
<td>259.1</td>
</tr>
</tbody>
</table>

The shell material is ZL - 101, T5 heat treatment, Richard linear thermal expansion coefficient, thermal conductivity of $2.15 \times 10^{-5} \text{ K}^{-1}$, thermal conductivity of 167W/(m K).

Mesh: shell 3D model with Ansys into pro/e in the first generation, and then into hexahedral elements with 8 nodes of the grid, see Figure 3.

Selection of boundary conditions of temperature field: the key thermal boundary conditions are given a reasonable finite element method. Because the screw pump shell model is very complex, and a lot of heating surface, the transient temperature cannot be determined, so here from the steady temperature field of. According to the experimental and computational experience of the past, the main surface of the shell with third kinds of boundary conditions of internal force, several heating surfaces are applied to air forced convection and natural convection air load, applied load on the contact surface and the environment.

Thermal deformation analysis: normal deformation conditions: under this condition two shell inner cylindrical hole center distance: in the end inspiratory 0.273mm in the exhaust end 0.510mm; shell axial elongation of 1.320mm. non normal conditions: deformation under this condition shell two inner cylindrical hole center distance: in the end inspiratory 0.676mm. In the end the exhaust 1.340mm shell; the total axial elongation was 3.310mm.

**Figure 3. Shell mesh map**

### 4.2 The calculation of deformation of screw pump rotor

Female and male are the main rotor moving parts at work, both through the meshing movement and the housing together form a closed volume of compressed air, the pump pressure. In line with the state of their respective processing precision and between directly determines the performance of the pump rotor, not only complex shape, and the comprehensive effect of torque, axial force, work under gas pressure and temperature load, stress condition is complex, is a key and difficult analysis of pump performance, so the actual conditions for accurate simulation has a very important significance. Based on the analysis of screw pump working process, 3D modeling first rotors using pro/e software, and then the thermal deformation of the finite element analysis with Ansys, combined with a comprehensive analysis of the calculation results on the part of the. The test shows that the temperature difference of the rotor during normal operation with respect to the suction and exhaust temperature is small, the rotor temperature gradient is relatively small. By the structure of the rotor suction side gap is relatively large. The thermal deformations of the rotor were analyzed as follows: the simplified rotor in a linear temperature at both ends of the suction and exhaust, and axial freedom constraints on the exhaust end.

The calculation is divided into normal and abnormal operating condition, normal working condition of diesel engine power is selected when the 2400ps condition, the non-normal conditions to choose the highest temperature exhaust conditions, operating point of basic data see table 2.
The rotor material is DL101, Richard linear thermal expansion coefficient of $2.55 \times 10^{-5} \text{ K}^{-1}$, 155 W/(m K thermal conductivity).

**Table 2.** Calculation conditions of rotor thermal deformation

<table>
<thead>
<tr>
<th>Project</th>
<th>Inspiratory pressure (bar)</th>
<th>The suction temperature (°C)</th>
<th>Exhaust pressure (bar)</th>
<th>Exhaust temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal working conditions</td>
<td>0.949</td>
<td>35</td>
<td>1.609</td>
<td>95.6</td>
</tr>
<tr>
<td>Non-normal working conditions</td>
<td>0.51</td>
<td>35</td>
<td>2.57</td>
<td>259.1</td>
</tr>
</tbody>
</table>

Mesh: curved hexahedron using 3D 8 node mesh of the screw rotor, as shown in Figure 4, shown figure 5.

Selection of boundary conditions of temperature field: according to the simplified internal work and screw pump, the rotor suction side and the exhaust end adopts third kinds of boundary conditions, namely loading convection air temperature and corresponding convection heat transfer coefficient.

Thermal deformation analysis: normal operating conditions: the Female and Male of the radial and axial thermal deformation is shown in table 3.

**Table 3.** Deformations under normal condition of male and female rotor heat

<table>
<thead>
<tr>
<th>Project</th>
<th>The female rotor</th>
<th>The male rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>The axial thermal deformation (mm)</td>
<td>0.920</td>
<td>0.922</td>
</tr>
<tr>
<td>The radial thermal deformation (mm)</td>
<td>0.283</td>
<td>0.288</td>
</tr>
</tbody>
</table>

**Figure 4.** Male rotor meshes

**Figure 5.** female rotor mesh

The non-normal conditions: the condition of female and male of the radial and axial thermal deformation is shown in table 4.

**Table 4.** Deformation of the non-normal conditions of female and male heat

<table>
<thead>
<tr>
<th>Project</th>
<th>The female rotor</th>
<th>The male rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>The axial thermal deformation (mm)</td>
<td>2.415</td>
<td>2.414</td>
</tr>
<tr>
<td>The radial thermal deformation (mm)</td>
<td>0.747</td>
<td>0.757</td>
</tr>
</tbody>
</table>

**Table 5.** Deformation analysis table

<table>
<thead>
<tr>
<th>Project</th>
<th>Normal working conditions</th>
<th>Special working conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Axis</td>
<td>Radial (radius)</td>
</tr>
<tr>
<td>The upper shell thermal deformation (mm)</td>
<td>1.320</td>
<td>0.273(suction) 0.510(row)</td>
</tr>
<tr>
<td>The female rotor thermal deformation (mm)</td>
<td>0.920</td>
<td>0.283</td>
</tr>
<tr>
<td>The male rotor thermal deformation (mm)</td>
<td>0.922</td>
<td>0.288</td>
</tr>
<tr>
<td>The difference (mm)</td>
<td>0.398</td>
<td>-0.298(suction) -0.061(row)</td>
</tr>
<tr>
<td>Design gap</td>
<td>0.3<del>0.4(suction) 0.1</del>0.15(row)</td>
<td>0.23~0.35</td>
</tr>
</tbody>
</table>

Note: in the table on the casing radial deformation data center distance deformation; parentheses "suction" refers to the suction side, "row" refers to the exhaust end
The calculation results show that the deformation of screw pump rotor: under normal conditions, the rotor of the screw pump can work safely and reliably. But in non-normal working conditions, the screw pump operation pressure ratio increases rapidly, power consumption will reach normal operating conditions, power consumption of more than 2 times, the exhaust temperature is nearly 260 DEG C. The rotor and the upper shell and the Female and Male of the rotor thermal deformation calculation shows that, in this case, the rotor thermal expansion will be submerged meshing clearance between rotors, and the centrifugal force of the rotor structure interaction, is likely to cause the rotor stuck, causing damage to the screw pump.

Will the Female and Male of the rotor thermal deformation analysis results are listed in table 5. From table 5, as in the assumption that the screw pump casing and rotor free deformation analysis showed that under normal condition of screw pump deformation result will increase the axial clearance of it, while the Female and Male of the radial gap will decrease, but still in the design gap range; non normal conditions, axial shell the axial deformation was significantly greater than the rotor deformation, so that the axial gap is further increased. The comprehensive results of the radial deformation are the radial deformation on the suction side of female and Male of the rotor has been far greater than the shell deformation, the difference seriously exceeded the design gap. Considering the structure of screw pump, exhaust cover is relatively thick, and is heated gas as shell part of strong, the upper shell and the other parts are end plate connection, they will be subject to constraints, so in fact the suction side is relatively large degree of freedom; at the same time, the diameter of screw pump to the suction port opening is larger. Deep, so hot on the suction side deformation results will first affect the two rotors.

In conclusion, the screw pump is normal in normal working condition, the non-normal conditions before the air suction end of the rotor will kill each other, and nearly 100 meters / circumferential speed of the pump rotor seconds, and serious damage in this case it is likely to cause the screw pump.

5. CONCLUSIONS

The characteristics is of great significance in the design of mechanical structure and engineering practice of vibration modal analysis and dynamic response of mechanical structure system, has been one of the hot issues of domestic and international engineering technology research. Using Pro/E to establish three-dimensional entity model of the main components of screw type air compressor, and the finite element analysis was carried out using the large finite element analysis software ANSYS. They work in the actual condition simulation process, the relative deformation at room temperature when processing heat size, get the temperature distribution of shell, rotor, and rotor of the Female Male, and provides an important reference for the design and manufacture of screw type air compressor. The dynamic response analysis of the working process of screw type air compressor, the sensitivity of natural frequency of torsional vibration of transmission system is analyzed, and found some factors affecting the natural frequency of the system, pointed out the direction to improve the system dynamic performance. This study provides a basis for the further improvement of conclusion the mechanical structure of the system, promote the development of mechanical structure system.

REFERENCE