Design and research of a center adjustment mechanism based on missile ground test stand

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Abstract: For a missile ground test stand that requires a lot of core installation, such as the inner and outer labyrinth centering installation. There are some problems in the installation process, such as complex installation process, difficult adjustment, long installation time, poor positioning accuracy and so on. This paper takes the inner and outer labyrinth centering installation as an example, through non-standard structure selection and processing, designed a set of centering adjustment mechanism, through the field installation comparison, it is concluded that the new centering adjustment mechanism has the advantages of high positioning accuracy, simple operation, greatly saving working time, quick and simple adjustment, etc. The new centripetal adjustment mechanism is also simple, efficient and cost saving for other tasks that need centripetal adjustment on missile ground test bed. Its design and research have high engineering practical significance.

1. Introduction

The missile ground test bed is a high-precision test system which simulates the real state of the high air after the missile engine burns at high temperature and high pressure, and thus obtains a series of parameters and data. Because of the particularity of missile, labyrinth seal is widely used in missile ground test bed. Labyrinth seal has the advantages of simple structure, reliable operation and convenient operation, etc., and it is a reliable sealing element commonly used in missile ground test bed \cite{1}. Labyrinth sealing is achieved by the throttling process in the throttling gap and the kinetic energy dissipation process in the sealed cavity \cite{2-3}. Therefore, there is a cavity gap between the inner sleeve and the outer sleeve of the labyrinth, and there is no direct contact, so it is very suitable for the use of high temperature and high pressure in the missile ground test rig, which is the main reason why the labyrinth seal is widely used in the missile ground test rig.

Centering accuracy is an important index to measure the quality of labyrinth sealing. The concentric result of the installation of labyrinth inner sleeve and labyrinth jacket is related to the leakage quantity of labyrinth seal under the same pressure difference. The smaller the leakage, the better the sealing effect and the higher the performance of labyrinth seal. In recent decades, scholars from all over the world have done a lot of research on labyrinth sealing and put forward many calculation methods of labyrinth leakage, such as Martin formula, Egli, Kearton, Vermes, Stodala calculation method, etc. \cite{4-6}. The concentricity of the installation of the labyrinth inner sleeve and labyrinth jacket can directly affect the velocity and pressure distribution of the gas in the sealed cavity,
and the size of the centripetal accuracy has a great influence on the leakage of the labyrinth seal. The higher the centripetal accuracy of the labyrinth inner sleeve and labyrinth jacket, the gas leakage of the sealing structure can be effectively reduced. The overall performance of labyrinth seal can be greatly improved by studying its centering accuracy.

In the process of installation of traditional labyrinth inner sleeve and labyrinth jacket, it generally depends on the installation experience of workers and a little bit of centering positioning and adjustment with the plug gauge, which consumes a lot of manpower and material resources, but only in order to meet the requirements of coaxiality of designers, it often takes half a day or even a whole day to adjust once. If the test status changes and other types of missile engines need to be replaced, then the previous work of centering will be wasted, and the inner sleeve and labyrinth jacket need to be re-centered and installed. The installation steps of traditional centering positioning are complicated, difficult to adjust, low efficiency, low fault tolerance and prone to empirical mistakes [7-8]. If the inner sleeve and the labyrinth jacket are not installed in place, the gas leakage in the sealing structure will increase, which will fundamentally weaken the use effect of the labyrinth seal. In serious cases, the required experimental data can not even be obtained, resulting in the failure of the whole experiment. This paper presents a new design scheme of centering adjustment mechanism, which can effectively improve the accuracy and efficiency of centering installation in missile ground test rig, and has a high application prospect.

2. The structure and composition of the contraligning mechanism
This design and development of centering adjustment mechanism, including clamping mechanism, fixing mechanism, screw adjusting bolt, dovetail groove guide rod, observation window, hanging lug. The structure and composition of the centering adjustment mechanism is shown in Figure 1.

![FIG. 1 Structure and composition of the centering adjusting mechanism](image)

1. Clamping mechanism 2. Fixing mechanism 3. Setting screw 4. Dovetail groove guide rod 5. Observation window 6. Lifting lug

2.1 Clamping mechanism
The clamping mechanism is divided into upper and lower parts, which are respectively connected with the inner sleeve and the labyrinth jacket. The clamping mechanism plays a role of fixed support and axial positioning, using a split structure, through both sides of the ear through the hole, with bolt connection. The partition structure is simple and convenient. After the installation and positioning is completed, it can be directly and quickly disassembled to reduce the interference with the surrounding components. During the installation process, the labyrinth jacket is placed vertically first, and the lower part of the clamping mechanism is covered and fixed circumferentially, and the inner sleeve of the labyrinth is clamped with the upper part of the clamping mechanism, and then the initial installation of the inner sleeve and the labyrinth jacket is carried out with the help of dovetail groove guide rod. The working status of the clamping mechanism is shown in Figure 2 below:
2.2 Setting screw
In this design and development of the central regulating mechanism in the circumferential setting of six screw adjusting bolts. Its function is that after the initial installation of the inner sleeve and the labyrinth jacket with the clamping mechanism, the feeler gauge is used to measure the circumferential clearance. If the coaxiality requirements of the designers are not met, the six screw adjusting bolts can be used to adjust. Six top silk adjusting bolt uniform circumferential layout, good versatility and interchangeability, solves the asymmetry, coat the adjustment process of stress in the maze, difficult to adjust in place of the problem, decrease the difficulty of the coat in the maze, adjustment to eliminate the operators use the phenomenon of empirical blind adjustment, greatly shortened the time installation and adjustment.

2.3 Dovetail groove guide rod
The clamping mechanism is provided with dovetail groove, dovetail groove guide rod is placed in dovetail groove, dovetail groove and dovetail groove guide rod are used together to guide and support. Dovetail groove guide rod can not only improve the motion accuracy, but also protect the fragile labyrinth teeth from impact and collision damage during the installation process when the inner sleeve and the labyrinth jacket move relative to each other mechanically. Because of its specific shape, dovetail groove guide rod can be closely attached to the dovetail groove, which not only has good guidance and little friction, but also can be accurately positioned under any installation conditions. After the inner sleeve and labyrinth coat were initially installed in place, the two sections of dovetail groove guide rod were locked with screws, which also played a role in fixing and supporting.

2.4 Observation window
The observation window can be used to clearly and intuitively judge whether the inner sleeve and labyrinth jacket are installed properly, which is convenient for operators to install. The observation window is usually rectangular, square, circular and other forms, the design of the observation window in addition to considering its practicality, but also considering its industrial beauty, so there are two pentacle observation Windows on both sides of the clamping mechanism. The five-pointed star observation window can not only directly observe the combination of the inner sleeve and the outer sleeve of the labyrinth, but also improve the industrial aesthetics of the whole contralateral adjustment mechanism.

2.5 Lifting lug
A new type of lifting lug is designed, which can be installed vertically and conveniently horizontally. It has good bearing capacity and stability, and can improve the safety factor of lifting safety load. Central regulating mechanism in the process of use, need many times in the horizontal and vertical transformation between 90 °, these problems cause great trouble at the scene, so the design of the lug
fully considering the vertical and horizontal lifting, in order to facilitate rapid lifting and realize position state transitions, the vertical hole for hoist and separately from the level and the hole for hoist design. Schematic diagram of lifting lug is shown in Figure 3.

![Figure 3: Schematic diagram of lifting lug](image)

### 3. Finite element analysis of contralateral regulating mechanism

#### 3.1 Geometric model of centering adjusting mechanism

Finite element analysis is carried out on the contralining mechanism developed and designed in this paper, and its structure is shown in FIG. 4. The model is modeled by the mainstream 3D design software, and the established digital model is transformed into X-T format and re-imported into the finite element analysis software ANSYS, and then the digital model geometry is simplified and repaired to facilitate the finite element simulation analysis and calculation.

![Figure 4: Geometric model of centering adjustment mechanism](image)

#### 3.2 Meshing

The simulation analysis of the central regulating mechanism as an integral component is carried out, because its components are irregular in shape, almost all of them are curved surface design, so the use of unstructured grid for discrete processing, the grid thinning processing method can be efficient processing and calculation. The centering adjustment mechanism adopts the static reference frame as a whole, and the final grid magnitude is 6.9x10^5. The meshing results are shown in Figure 5 below:
3.3 The theoretical calculation

ANSYS 15.0 Workbench simulation software is used to simulate the structure mechanics of the contralcenter regulating mechanism. The analysis method is the balance equation, geometric equation and physical equation in elasticity. The calculation and analysis equations are as follows:

1) Equilibrium equation

The equilibrium equation of any point in the domain $V$ of the elastomer along the $x, y$ and $z$ directions is:

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + f_x = 0$$
$$\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + f_y = 0$$
$$\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \sigma_z}{\partial z} + f_z = 0$$

$f_x, f_y, f_z$ is the force per unit volume in $x, y, z$ component of direction.

And there are $\tau_{xy} = \tau_{yx}, \tau_{yz} = \tau_{zy}, \tau_{xz} = \tau_{xz}$.

The matrix form of the equilibrium equation is:

$$A\sigma + \vec{f} = 0 \quad \text{(In } V \text{)}$$

Where $A$ is the differential operator

$$A = \begin{bmatrix}
\frac{\partial}{\partial x} & 0 & 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial z} \\
0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial x} & \frac{\partial}{\partial z} & 0 \\
0 & 0 & \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial y} & \frac{\partial}{\partial x}
\end{bmatrix}$$

$\vec{f}$ is a volume force vector, $\vec{f} = [f_x, f_y, f_z]^T$.

2) Geometric equation -- strain-displacement relation

In the case of small displacement and deformation, the higher power of displacement derivative is omitted, then the geometric relation between strain vector and displacement vector is:

$$\varepsilon = \gamma \varepsilon$$

The matrix form of the geometric equation is

$$\varepsilon = L u \quad \text{(In } V \text{)}$$

FIG. 5 Meshing of contralining mechanism
Where L is the differential operator

\[
L = \begin{bmatrix}
\frac{\partial}{\partial x} & 0 & 0 \\
0 & \frac{\partial}{\partial y} & 0 \\
0 & 0 & \frac{\partial}{\partial z} \\
\frac{\partial}{\partial y} & \frac{\partial}{\partial x} & 0 \\
0 & \frac{\partial}{\partial z} & \frac{\partial}{\partial y} \\
\frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial x}
\end{bmatrix}
\]

3) Physical equation -- stress-strain relationship

The stress-strain transformation relationship in elasticity is also called the elastic relationship. For isotropic materials, the stress can be expressed as:

\[
\sigma = D\varepsilon
\]

\[
D = \frac{E(1-\mu)}{(1+\mu)(1-2\mu)}
\begin{bmatrix}
1 & \frac{\mu}{1-\mu} & 0 & 0 & 0 \\
1 & \frac{\mu}{1-\mu} & 0 & 0 & 0 \\
1 & 0 & \frac{1-2\mu}{2(1-\mu)} & 0 & 0 \\
1 & 0 & \frac{1-2\mu}{2(1-\mu)} & 0 & 0 \\
1 & \frac{1-2\mu}{2(1-\mu)} & 0 & \frac{1-2\mu}{2(1-\mu)} & 0 \\
1 & \frac{1-2\mu}{2(1-\mu)} & 0 & \frac{1-2\mu}{2(1-\mu)} & 0
\end{bmatrix}
\]

D is called the elastic matrix, which completely depends on the elastic modulus E and Poisson's ratio V of the elastic material \([12]\).

Lame constants G and λ can also be used to represent the elasticity of an elastic body. Their relationship with E and v is as follows \([13-14]\):

\[
G = \frac{E}{2(1+\mu)}, \quad \lambda = \frac{E\mu}{(1+\mu)(1-2\mu)}
\]

G is also called shear elastic modulus

\[
\lambda + 2G = \frac{E(1-v)}{(1+v)(1-2v)}
\]

The elastic matrix D in the physical equation can also be expressed as:

\[
D = \begin{bmatrix}
\lambda + 2G & \lambda & 0 & 0 & 0 \\
\lambda + 2G & \lambda & 0 & 0 & 0 \\
\lambda + 2G & \lambda & 0 & 0 & 0 \\
\lambda + 2G & \lambda & 0 & 0 & 0 \\
\lambda + 2G & \lambda & 0 & 0 & 0 \\
\end{bmatrix}
\]

3.4 Finite element analysis of contralateral regulating mechanism

The finite element simulation of the contraligning mechanism was realized by the commercial
software ANSYS 15.0 Workbench, and the implicit solution algorithm was used to simulate the structure mechanics of the contralining mechanism. Through the analysis of the finite element simulation results, it is found that the dovetail groove guide rod is the most stressed and weakest place in the whole contralateral adjustment mechanism, and the most easily deformed position is the upper part of the clamping mechanism branch ear.

Through finite element analysis, material upgrading and optimization are carried out on the part of the contralining mechanism. Carbon steel Q235 is adopted as a whole for the centering adjustment mechanism, and the dovetail groove guide rod is made of 304 (06 Cr19Ni10) or 316 (06 Cr17 Ni12 Mo2) material to improve the maximum yield strength of dovetail groove guide rod and the safety of the centering adjustment mechanism. On the other hand, the upper part of the clamping mechanism is thickened to increase the overall stiffness of the lug here and reduce the strain here.
4. Installation and adjustment process

In the missile ground test rig, the coaxiality requirement is very high. After the equipment is installed, the coaxiality is generally required to be within 5–10 wires [9-11]. In order to ensure that the missile ground test rig can accurately obtain accurate experimental data, the contralining mechanism is often very useful.

In the maze, coat installation, for example, in the centering adjustment mechanism, the clamping mechanism is a divided design, so you can use the lower part of the clamping mechanism to completely cover and fix the maze coat, and then put the maze coat vertically. In the same way, attach the upper part of the clamping mechanism to the inner sleeve of the labyrinth. Then, using hoisting tools such as crane and electric hoist, and using dovetail groove guide rail, the inner sleeve of the labyrinth slowly moved into the inner cavity of the labyrinth jacket. The advantage of this vertical installation is that it will protect the labyrinth teeth inside the labyrinth jacket from bumping.

Through the five-pointed star observation window, confirm the maze, coat installed in place, screw the dovetail trough guide rod with bolts to fix. Use theodolite, level and other tools to install the fixing bracket in place, and then use the new lifting lug to lift the whole labyrinth and coat horizontally onto the fixing bracket. Using the fixed mechanism in the centering adjustment mechanism, the maze coat is fixed.

According to the designer's coaxiality requirements, the feeler gauge is used to measure whether the circumferential clearance of the inner and outer sleeve of the labyrinth is qualified. If the requirements are not met, the six top wire adjusting bolts in the circumferential direction can be used to adjust one by one until the coaxiality in the maze and coat meets the experimental requirements.

In the maze, after the coaxiality of the coat meets the requirements, loosen the bolts of the fixing mechanism, and disassemble the clamping mechanism separately, and finally achieve the purpose of installation and adjustment of the centering adjustment mechanism.

5. Conclusion

From the practical results, the centering adjustment mechanism developed in this paper can fully meet the requirements of the installation of coaxiality in the maze and the jacket. Through the use of the auxiliary equipment of the central adjustment mechanism, the maze and jacket can be quickly installed in place, which saves time, is convenient and quick, and saves a lot of labor costs. Its structure is simple and easy to operate, which can greatly reduce the difficulty of coaxiality installation and improve the accuracy and reliability of coaxiality. In the missile ground test bed, in order to obtain accurate experimental data, a large number of coaxial cylinder diameter devices are used to connect, so the installation of coaxiality is large and difficult. This invention can accurately install the labyrinth structure, and is also applicable to other equipment with coaxiality requirements. It has great practical engineering guiding significance and economic benefits.

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References

[1] Jia Shengyu, CHENG Yuantao, Zou Xitao, XU Jinbin, Shang Lingyun. Automobile Practical Technology, 2019(07): 191-193.
[2] Tian Peng, TANG Yangshan, Xia Daohua. Electronic World, 2015(19): 111-113.
[3] Wang Shiqi, Lu Yunfeng. Design and Application of Assembly Motor Turnover Fixture [J]. Mechanical Engineer, 2012(02): 120.
[4] Yang Jing-yuan, JIANG Min-zheng, SHI Jin-feng. Center to Chinese Pipe Tool Positioning Device for High Space Restricted Occasions [J]. Mechanical Engineer, 2008(10): 117-118.
[5] Xiao Fang, WANG Yazhou, Diao Anna, Liu Changfeng. Optimization of labyrinth seal structure based on FLUENT technology [J]. Fluid machinery, 2013, 41(09): 29-32.
[6] Wen Yongmei, Wang Li, Gao Fei, Sun Sen, Dong Yuxi. Nuclear technology, 2016, 39(04): 5-10.
[7] Wang Wen. Design of adjustable pad assembly for disk parts positioning [J]. Machinery, 2015, 42(09): 38-40.
[8] Xie Jinjiao, Kong Xuying. Structural Design and Optimization of Robot Centering Device Based on Positioning System Test [J]. Mechanical Engineer, 2018(02): 31-32.
[9] Huang Jianfeng. Parametric Design and Finite Element Analysis of Labyrinth Seal Structure [D]. Shenyang University of Science and Technology, 2015.
[10] Wenxin Ma, Hongjie Yu, Yunyun Liu, et al. Numerical simulation and parameter sensitivity analysis for the cooling of rolling rubber. 2020, 1549(4).
[11] Relational Database Management Systems: The Business Explosion [J]. Burton. Grad. IEEE Annals of the History of Computing. 2013 (2)