Design and Research of a New Kind Balance Adjusting System of Centrifuge

Li Xinyao, Hong Jianzhong, Wu Wenkai

Abstract—In order to make environmental test centrifuge balance automatically and accurately, reduce unbalance centrifugal force, balance adjusting system of centrifuge is designed. The new balance adjusting system comprises motor-reducer, timing belt, screw pair, slider-guideway and four rocker force sensors. According to information obtained by the four rocker force sensors, unbalanced value at both ends of the big arm is computed and heavy block is moved to achieve balance adjusting. In this paper, motor power and torque to move the heavy block is calculated. In full load running progress of centrifuge, the stress-strain of screw pair composed by adjusting nut and big arm are analyzed. A successful application of the balance adjusting system is also put forwarded. The results show that the balance adjusting system can satisfy balance require of environmental test centrifuge.

Keywords—balance adjusting system, centrifuge, screw pair, timing belt

I. INTRODUCTION

ENVIRONMENTAL test centrifuge is a kind of rotating equipment with big arm, can simulate acceleration, vibration, temperature and other composite environment withstand by specimens. It is widely used for researching on structural and electrical stability of specimen under high g value. The Balance adjusting system is an important part of environmental test centrifuge. In the running process, balance adjusting system can work effective or not would directly impact on the stability and security of centrifuge. People in general to limit the maximum allowable unbalanced force or unbalanced weight to ensure the safe running of the centrifuge. 5% of the maximum mass of specimen is usually allowed the maximum unbalanced value [1].

At present, the form of balance adjusting system of centrifuge contain two types: increase or decrease the heavy block and move the heavy block [1]. The type of move the heavy body can be divided into hydraulically drive, screw-nut drive and worm drive, etc. Because of some existing problems such as: the leak of fluid at high g value, processing difficulties and the assembly accuracy requirements, the structure of balance adjusting system continues improving and optimizing. In this paper, trapezoidal timing belt is adopt to move the heavy block synchronously at rest of centrifuge and screw pairs are adopt to achieve self-lock of the heavy block in running process of centrifuge. The new kind balance adjusting system of environmental test centrifuge is a useful attempt.

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II. CENTRIFUGE BALANCE PRINCIPLE

The common structures of environmental test centrifuges are the long arm on one side and the short arm on the other side. The specimen installs at the end of the long arm. The balance adjusting system installs on the short arm side. When the torque of specimen to rotating center is equal to the torque of the heavy block to rotating center, the centrifuge is balance. As Fig. 1, m_1 -weight of specimen (variable); r_1 -distance between the centroid of specimen and rotating center (value); m_2 -weight of the heavy block (value); r_2 -distance between the heavy body and rotating center (variable).
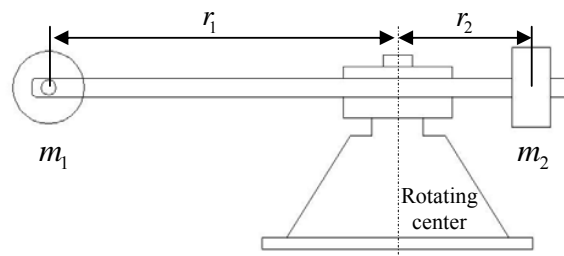

Fig. 1 Schematic diagram of centrifuge balance

At rest of centrifuge, the balance equation as follows:

$$m_1 g r_1 = m_2 g r_2 \qquad (1)$$

When the specimen is installed, the value of m_1 is determined in equation (1), by adjusting r_2 to ensure the equation is equal.

In running process of centrifuge, the balance equation as follows [2]:

$$m_1 g r_1 \omega^2 = m_2 g r_2 \omega^2 \qquad (2)$$

ω -the angle-velocity of centrifuge.

From the formula (1) and (2), the balance equations are equivalent. Therefore, in order to ensure running safe of centrifuge, achieving balance is an important step at rest.

III. BALANCE ADJUSTING SYSTEM STRUCTURE

According to one large environmental test centrifuge needs, trapezoidal timing belt is used to achieve balance adjustment. The structure of balance adjusting system shows in Fig. 2. The system composed by the motor-reducer, small pulley, trapezoidal timing belt, large pulley, screw pairs, slider-guideway, the heavy block and four rocker force sensors and so on.
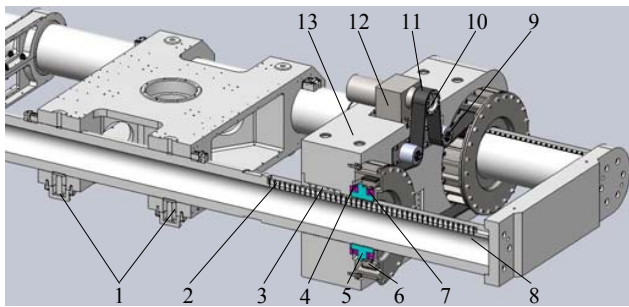
1-rocker force sensors, 2-guideway, 3-slider,
4-cylindrical roller thrust bearings, 5-adjusting nut, 6-large pulley,
7-thrust ball bearings, 8-the big arm, 9-Tensioner, 10-small pulley,
11-Trapezoidal timing belt, 12-motor-reducer, 13-the heavy block
Fig. 2 Structure of balance adjusting system

When the specimen is installed completely at the end of the long arm, according to the information obtained by four rocker force sensors, unbalance force is computed. If the unbalance force meets the requirement of balance accuracy, the heavy block does not need move. If the unbalance force does not meet the requirement of balance accuracy, the motor-reducer drive small pulley to rotate, using the trapezoidal timing belt the small pulley drive the large pulley, then the adjusting nut which joined with the large pulley by bolt rotates, and thus the heavy block is moved on the slider along the guideway. The adjustment would continue until the unbalance force meets the requirement of balance accuracy.

IV. DESIGN CALCULATIONS

A. Motor Power

The calculation of motor power includes two aspects: one is P_a, which need overcome friction between the adjusting nut and the big arm, make the adjusting nut rotate; the other is P_b, which need overcome friction between the slider and guideway, make the heavy block move.

$$P \cdot \eta = P_a + P_b \tag{3}$$

η -power transfer efficiency.

Power P_a,

$$P_a = F_a \cdot \upsilon_a \tag{4}$$

F_a -friction between adjusting nut and big arm, υ_a -rotating speed of adjusting nut.

The 45 ° zigzag thread of the water system is adopt by adjusting nut. The adjusting nut joined with large pulley, weight 1000kg. When the adjusting nut rotates instantly, take the friction coefficient =0.25 [3]. So,

$$F_a =1000 \times \cos45° \times 9.8 \times 0.25 = 1733 \text{ N}$$

The screw pair composed by adjusting nut and big arm, the nominal diameter is 0.520m, the pitch is 0.020m. therefore, the moving speed of heavy block is 0.080m/min that is 4r/min .

$$\upsilon_a =0.26 \times 8 \pi /60 = 0.11 \text{ m/s}$$

So,

$$P_a =1733 \times 0.11 = 190.6 \text{ W}$$

Power P_b,

$$P_b = F_b \cdot \upsilon_b \tag{5}$$

F_b -friction between slider and guideway, υ_b -moving speed of the heavy block.

The heavy body weighs about 30,000kg, when the slider moves instantly, according to the manual of THK, take the friction coefficient =0.005 [4].

$$F_b =30000 \times 9.8 \times 0.005 = 1470 \text{ N}$$

So,

$$P_b =1470 \times 80 \times 10^{-3}/60 = 1.96 \text{ W}$$

According to the equation (3), take the transfer efficiency $\eta = 0.9$, the motor power calculates as:

$$P =215.6+1.96 \text{) }/0.9 = 242 \text{ W}$$

B. Motor Torque

Motor torque is mainly used to overcome frictional torque produced in the rotating process of timing belt, adjusting nut, etc.

The force transmission diagram of balance adjusting system shown in Fig. 3, M_1 -small pulley input torque (motor torque), M_2 -frictional torque.
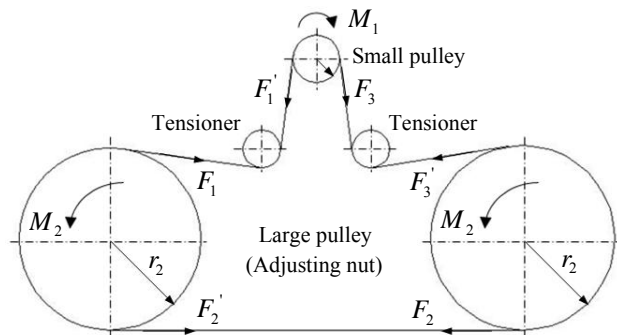

Fig. 3 Force transmission diagram of balance adjusting system

In the course of Balance adjustment, the relationship between M_1 and M_2 is shown as (6):

$$\begin{cases} F_1 \cdot r_2 = F_2' \cdot r_2 + M_2 \\ F_2 \cdot r_2 = F_3' \cdot r_2 + M_2 \\ F_1' \cdot r_1 = F_3 \cdot r_1 + M_2 \end{cases} \tag{6}$$

In which: $F_1 = F_1'$, $F_2 = F_2'$, $F_3 = F_3'$. So,

$$M_1 = \frac{r_1}{r_2} \cdot 2M_2 \tag{7}$$

The frictional torque brought by adjusting nuts and large pulleys is:

$$M_2'=1733 \times 0.26 = 450.6 \text{ N·m}$$

The frictional torque brought by the trapezoidal timing belt tension [3]:

$$M_2''=3203 \times 0.26 = 832.8 \text{ N·m}$$

In structure of balance adjusting system, r_1 =124.805, r_2 =483.58. So the motor torque:

$$M_1 = \frac{124.805 \times 10^{-3}}{483.58 \times 10^{-3}} \times 2 \times (509.6 + 832.8) = 693 \text{ N·m}$$

According to the motor power and torque calculations, a reasonable choice for motor-reducer can effectively move heavy block to achieve the function of balance adjusting system.

V. KEY COMPONENT MECHANICS ANALYSIS

The screw pair composed by adjusting nut and big arm is key component of balance adjusting system. On the one hand, it passes movement in the course of adjustment. On the other hand, it withstands the centrifugal force generated by balance adjusting system in the running process of centrifuge. The force diagram of a single adjusting nut shows as Fig. 4. When the centrifuge run at the maximum of 100g, a single adjusting nut need to bear the load about 900t which is even distributedΦ0.63 m~Φ0.745m.
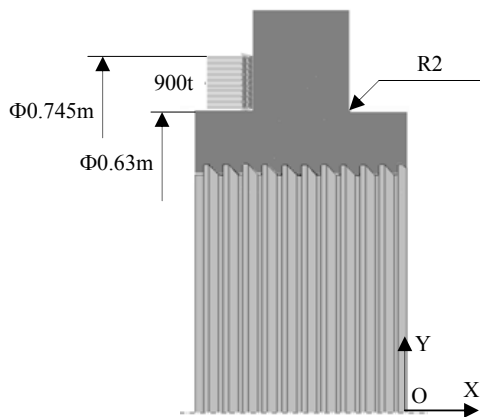


Fig. 4 Force diagram of a single adjusting nut

According to the structure character of screw pair, axisymmetric model is adopted in MSC. The X-axis is the axis of symmetry. Based on the situation of adjusting nut which withstands centrifugal force, the chamfer of screw pair and contact, constrain the displacement in the X direction, mesh the model with SOLID45, obtain 39334 units and 40175 nodes [5],[6]. Stress distribution of adjusting nut and big arm show as Fig. 5. Strain distribution of adjusting nut and big arm show as Fig. 6.

The maximum equivalent stress of adjusting nut is 367.8MPa, occurred in the first thread root on left. The maximum equivalent stress of big arm is 287.1MPa, occurred in the first thread root on left. The maximum synthetic displacement of adjusting nut is 0.36mm. the maximum synthetic displacement of big arm is 0.11mm.

Reference to mechanical properties of materials, select appropriate materials can satisfy the requirement of adjusting nut and big arm.
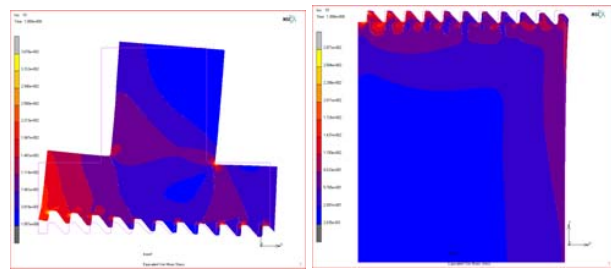
(a) adjusting nut   (b) big arm
Fig. 5 Stress distribution of adjusting nut and big arm
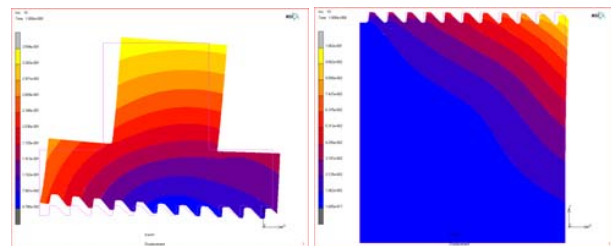
(a) adjusting nut   (b) big arm
Fig. 6 Strain distribution of adjusting nut and big arm

VI. APPLICATION

Balance adjustment system successfully applied in one large environmental test centrifuge. When the centrifuge is at rest, relative to the rotating center, the balance adjusting system can move within 1.8m~3.3m to balance the specimen from 2t to 6t. When the centrifuge is running, the balance adjustment system can achieve self-lock to ensure safe running.

VII. CONCLUSION

In this paper, a new kind of balance adjusting system is designed. The system uses motor drive could avoid leakage caused by hydraulic drive at high g value; uses trapezoidal timing belt could avoid process and install difficulties, such as screw-nut drive and worm drive, etc. The cost of balance adjusting system is reduced. The applicability of balance adjusting system in high g value is improved. The system also achieve integrative design about move at rest and self-lock in running. The application indicates that the system is compact, mechanical interface simple, running smooth, reliable, and can be applied to other centrifuge design.

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