Mechatronics and Automation Technology
J. Xu (Ed.)

doi:10.3233/ATDE241260

A New Type of Ball Screw Design and Loaded Experimental Research

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Abstract. Aiming at the traditional ball screws with insufficient number of payload balls which are easily deformed by the load, a conservative design scheme of inner and outer double-turn large-capacity loaded ball screws is proposed.Separately on the large-capacity ball screw axial and radial load and equivalent strain analysis,the analysis results show that:when the screw is subjected to radial load, the deformation area of the screw is concentrated in the nut and the support position at both ends. Finally, it is concluded that in the case of unchanged screw diameter or nut conditions, increasing the payload ball can also increase the stiffness of the ballscrew, thus reducing the impact of the deformation of the screw due to the load. At the same time, the feed speed of the screw becomes faster and the required driving torque is reduced.

Keywords. CNC, ball screw, load experiment, tension stiffness, load ball.

1. Introduction

Ball screw is an important transmission device, it has a high load capacity, high precision and other advantages, is widely used in various types of machinery and equipment, such as CNC machine tools[1], precision tooling machines[2], industrial robots[3], electronic machinery[4], conveyor machinery[5], aerospace industry and other fields[6] . The main working principle of ball screw is to use the load ball rolling in the ball groove on the surface of the screw to drive the nut on the screw to move along the direction of the screw, and then convert the rotary motion into linear motion. However, the screw is susceptible to deformation when subjected to excessive loads[7] , which affects the precision of the screw drive. Therefore, a double-turn inner and outer cyclic load ball screw is designefid to increase the load capacity of the ball screw sub-screw.

2. High Capacity Load Ball Screw Design

As shown in figure 1, this is due to the large capacity and the standard amount of ball screws in the axial and radial direction of the existence of the load on the number of ball, each ball can withstand from the axial and radial aspects of the load, so more than the standard amount of ball screws by the axial or radial load is less affected.

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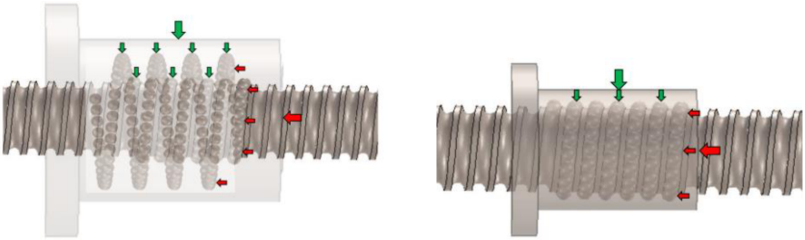


Figure 1. Comparison of Large Capacity and Standard Volume Ball Screw Loads

As shown in figure 2, The nut has a double row of ball circulation, the first row of balls (left side) from the 1st route to start the line through the 2nd route, then through the 3rd route, and finally through the 4th route, forming a cycle. Similarly, the second row of balls (right side) starts from route No. 1 via route No. 2, then via route No. 3, and finally via route No. 4, forming another cycle.

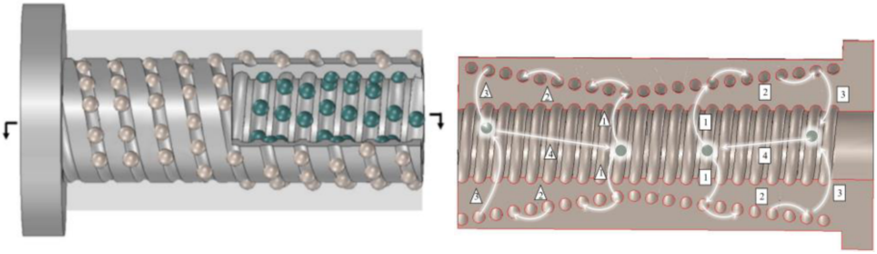


Figure 2. Nut ball movement principle

3. Analysis of Deformation of Ballscrews under Load with Large Capacity Loads

Compared with the radial load, the main load of ball screw is the axial load along the axial direction of the screw in the working process. The axial load mainly comes from the screw to overcome the ball friction generated by the work[8], at this time if the axial stiffness of the screw is not enough, the screw will produce axial deformation, which has a greater impact on the axial positioning accuracy of the screw. Therefore, the axial stiffness of the screw is crucial for the axial transmission accuracy of the screw.

According to JB/T 9893-1999 ‘ball screw vice ball nut mounting connection size’ [9] and JB/T 3162 [10] recommended. The selected ball screw type is shown in table 1.

Table 1. Main Technical Parameters of Ball Screws

Parametric	Parameter Value
Nominal Diameter/Mm	40
Lead/Mm	10
Bottom Diameter/Mm	32.9
Support Distance At Both Ends/Mm	820
Ball Diameter/Mm	5.953
Nut Length/Mm	94

Nut Diameter/Mm	85
Flange Diameter/Mm	127

Selection of machining centre feed ball screws as the object of study, the working condition is to drive the table workpiece moving positioning and processing. Ball screw in driving the workpiece for machining conditions shown in table 2.

Table 2. Ball Screw Working Condition Parameters

Parametric	Parameter Value
Rotation Speed/R· Min^{-1}	80
Feed Rate/M· Min^{-1}	0.8
Axial Cutting Force/N	1000
Radial Cutting Force/N	500
Axial Load/N	1850
Prestressing/N	1000
Kinetic Friction Factor/M	0.1
Table And Workpiece Fixture Weight/N	8000
Operating Temperature/°C	23

Combined with table2 and table 3, when the machining centre cuts the workpiece axially, the ball screw drives the table to complete the corresponding feed movement, at this time the axial load on the ball screw causes axial deformation, as shown in figure 4. When the nut is in the weakest position of the screw (middle position), the ballscrew is fixed at both ends and fixed travelling two types of mounting respectively under the axial load and axial deformation.

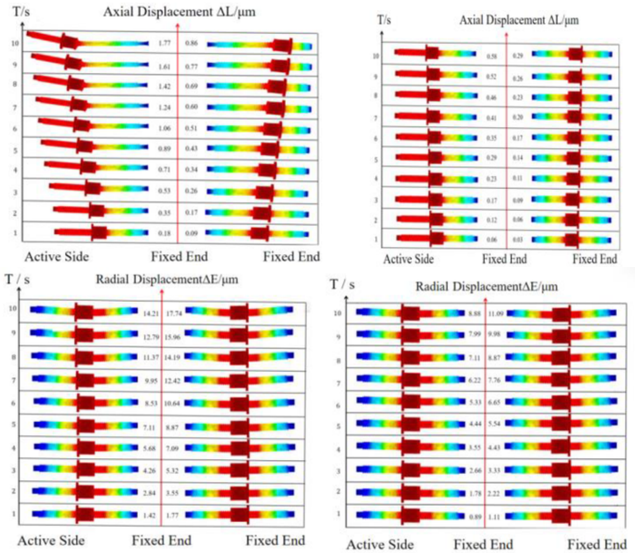


Figure 3. Axial load deflection of standard and high capacity ballscrews

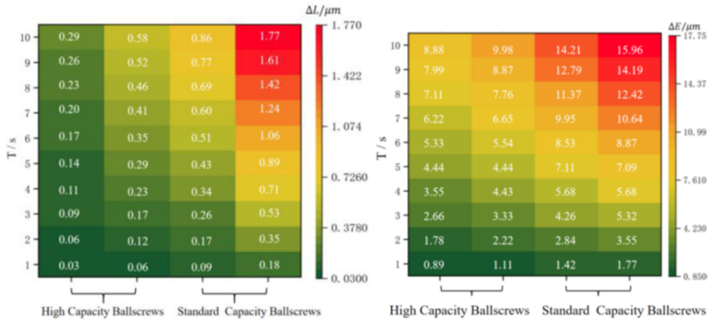
As can be seen in figure 3, the ball screw is fixed at both ends of the installation mode than the use of fixed travelling installation mode under the axial stiffness effect is nearly twice as good, the average axial load deformation to be reduced by half. This is due to the process of fixing the two ends of the screw, one end is equipped with disc springs and adjusting nuts. When the nut is adjusted, the tightening torque under the action of the screw will produce a certain preload along the direction of the screw axis. For ball screws mounted in a fixed travelling way, the travelling end is subjected to radial force only and is able to do a small amount of axial floating. This is to avoid bending caused by the weight of the Screw and elongation of the Screw to one end due to thermal deformation. However, the axial stiffness of the screw is also reduced accordingly. Therefore, under the same working condition, Ball Screws with fixed mounting at both ends have much greater axial stiffness than Ball Screws with fixed travelling mounting, and can withstand more axial loads, so the axial load deformation is relatively small.

The axial deformation of large-capacity Ball Screws under the same working conditions is much smaller than that of standard-capacity Ball Screws. As the large-capacity Ball Screws have internal and external double-layer loaded balls, so the axial stiffness is much larger than the standard amount of Ball Screws. Therefore, the axial load deformation is much smaller than standard ball screws.

When the machining center on the workpiece for radial cutting, this time the radial load on the ball screw, coupled with the table and fixtures and workpieces and other self-weight caused by the radial deformation of the screw, as shown in figure 3. When the nut is in the weakest position of the screw, i.e., the middle position, the ball screw was fixed at both ends and fixed swimming two types of installation under the radial load deformation.

As shown in figure 3, the radial load deflection of a standard-quantity ballscrew with fixed mounting at both ends is larger than that with fixed travel mounting. This is due to the fact that in the process of radial load on the screw with fixed travelling mounting, the travelling end of the screw can cushion part of the radial displacement, so the radial displacement of the screw is smaller than that of the screw with two fixed ends.

As shown in figure 3, the use of large-capacity ball screws in the same working conditions under radial load deformation than the standard amount of ball screws is smaller. As the large-capacity Ball Screw nut contains both internal and external double-layer loaded balls, the number of balls in the ball system increases, and the loaded area increases accordingly, allowing the Screw to withstand more loads from the radial direction.



(a)Screws subjected to axial loads (b)Screws subjected to radial loads

Figure 4. Correlation between the amount of balls and the amount of axially loaded shapes of screws

(a)Screws subjected to axial loads (b)Screws subjected to radial loads

Figure 5. Displacement change rule of screw in different load conditions

As shown in figure 4(a), the large-capacity ballscrews are correlated with the standard-volume ballscrews in terms of axial loaded deformation. The axial load stability of large-capacity ballscrews is much better than that of standard-volume ballscrews. As the loading time increases, the axial load deflection of the high capacity Ball Screws is in a stable state, while the axial load deflection of the standard Ball Screws varies more drastically. However, this is very important for the dimensional stability of workpiece axial feed machining.

As shown in figure 4(b), the ball volume correlates with the amount of radial loaded deformation of the screw. As the time of the screw subjected to radial load increases, the radial displacement of the high-capacity ball screw changes less relative to the standard-volume ball screw. It shows a more stable change trend. The radial displacement of the screws with fixed ends is larger than that of the screws with fixed travel mounting.

As shown in figure 5, the large-capacity Ball Screw, whether it is a fixed travel or fixed installation at both ends, has the advantages of stable deformation under load, slow change and smooth operation, whether it is subjected to axial load or radial load.

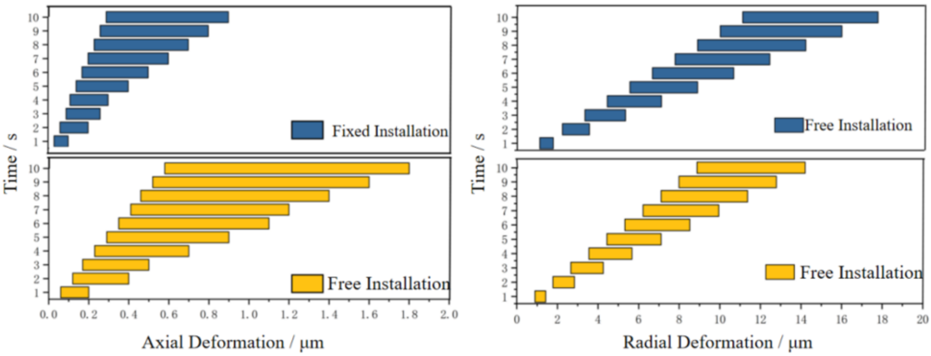


Figure. 6 Comparison of Load Deflection of Large Capacity and Standard Ball Screws

As shown in figure 6, the loaded deformation of high capacity ballscrews under different mounting methods is compared. In terms of axial load, the axial displacement of Ball Screws with fixed mounting at both ends is much better than that of Ball Screws with fixed travel mounting. The large capacity Ball Screws have a combined reduction of 66.9% in axial displacement compared to the standard capacity Ball Screws. In terms of radial load, the radial displacement of Ball Screws with fixed travel mounting is basically the same as that of Ball Screws with fixed mounting at both ends. Large capacity Ball Screws have a 37.5% reduction in radial displacement compared to standard capacity Ball Screws.

4. Conclusion

In this paper, ball screw with large capacity is designed to improve the stiffness and dynamic load capacity of ball screw. By applying axial and radial loads to the weakest part of the ball screw and the standard ball screw, the load capacity and deformation relativity as well as the stiffness and equivalent strain of the whole ball screw are analyzed. The conclusions are as follows:

(1) the transmission quality of ball screw can be improved by increasing the number of ball bearing effective load.

(2) Compared with the traditional method of increasing the diameter of the lead screw to increase the stiffness of the lead screw is more conservative and effective. The utility model has the advantages of small torque needed for driving the lead screw and quick feed speed response.

Acknowledgements

This project is sponsored by Guangxi Science & Technology Normal University, school-level scientific research team “precision ball screw thermal expansion mechanism and precision maintenance of key technology research”, Project No.: GXKS2024QNTD20.

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