Kinetic and friction analyses of a preloaded double nut ball-screw

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ABSTRACT – High speed transmission table is wildly used in industry and its demand is increased. Preloaded ball-screw device is a major component in a transmission system. In order to bear applied load, preload and inertia force, double-nut ball-screw is necessary. Each nut has two ball cycles, the kinematic behavior and friction of ball and raceway are more complex than double-cycles ball-screw. A new calculating concept is used to simplified complex calculation. Contact and friction were found out at each cycle and they are varied with operating conditions, such as applied axial load and rotational speed. The study is helpful in realizing contact and friction behavior in a preloaded double-nut ball-screw.

1. INTRODUCTION

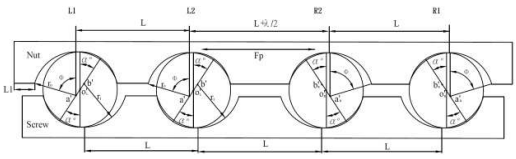
The increasing demands in precision engineering applications for positioning systems have instigated the investigation into ball screws. The reciprocating ball screw mechanism is a force and motion transfer device. The high transmission speed ball screw is a major component in rapid processing devices, and must be designed with a high degree of positioning accuracy and stiffness by applying a higher preload.

Lin et al. [1,2] presented a theoretical study on the kinematics of the ball screw mechanism where a function was developed to understand the motion of the balls and their contact patterns with the contact elements. However, the friction coefficients, normal forces and contact angles created at the ball-screw and ball-nut contact areas were assumed to be equal. Also, the drag force produced by a ball moving in an oil lubricant was not considered in the force balance.

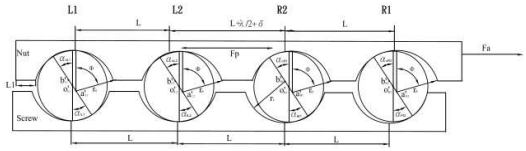
Kinematic analysis of the ball screw mechanism that considered variable contact angles and elastic deformations was studied by Wei and Lin [3]. Their theoretical analysis was developed for a ball screw with a single nut and a single cycle of balls. Therefore, no preload effect on the mechanical efficiency was discussed in the study. An analytical method developed by Takafumi et al. [4] was used to determine the motion of the ball and the ball load distribution, including the effect of the motion for a given ball screw geometry and its operating conditions. Wei et al. [5] presented an analytical model for a preloaded ball screw system with lubrication, and the numerical results confirmed the mechanical efficiency of their experimental data. Contact and friction analyses of double-cycle ball-screw mechanism are already well established [5]. Four-cycle ball-screw mechanism is more complex than double-cycles and wieldy used in industry. The study presents a well analyzing process and finds out contact and friction behavior at ball and raceway contact areas of a four cycles preloaded ball-screw.

2. THEORETICAL MODEL

Four-cycle ball-screw mechanism is shown in Fig.1. Non-external load is applied in the ball-screw, as shown in Fig.1(a), right hand side contact behavior is opposite to the left hand side due to the preload which is exerted between the left and right hand sides. When an enough load, Fa, which is greater than the preload, is applied on the nut, contact geometry is changed as shown in Fig.1(b). The difficult of the analysis is how to arrange load bearing on each contact side. Each contact side has one pair balls, and these two contact side can also be considered as two balls. Fist, assume load is average bearing on two balls of each contact side, respectively. Then calculating contact geometry and kinematic behavior of each contact side, as shown in Fig.2. The analyzing model is based on the single-nut double cycle ball-screw numerical calculating. Detail analyzing equations are referred to the paper published at 2009 [5]. Analyzing coefficients of ball-screw are listed in the Tab.1.



(a)



(b)

Figure 1 Sketch of four-cycle ball-screw, (a) without external load, (b) with external load.

Contact loads at contact area between ball and raceway are varied with axial load, as shown in Fig.3. Contact force of right contact side is greater than the left side, and they have the same tendency varying with the increase of applied load at the same contact side. The variance of contact load affecting by the preload and axial load is similar to the double-cycles ball-screw [5].

Table 1 Parameters of the testing ball-screw [From catalogue of Hiwin Corp.]

Type	R32-16k2-FDC-598-776-0.018	
Parameter	Value	Unit
Helix angle	8.67	Degree
Cycles of each nut	2	
Lead	16	mm
Curvature of raceway	3.429	mm
Ball diameter	6.35	mm
Effect ball number	66	
Preload	120	kgf

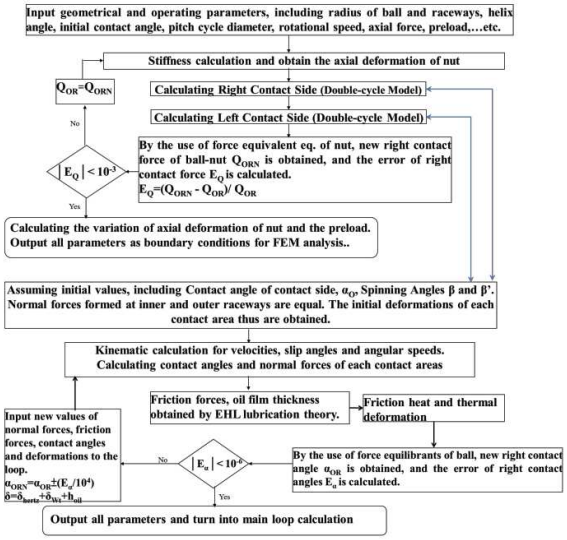


Figure 2 Flowchart of calculating process.

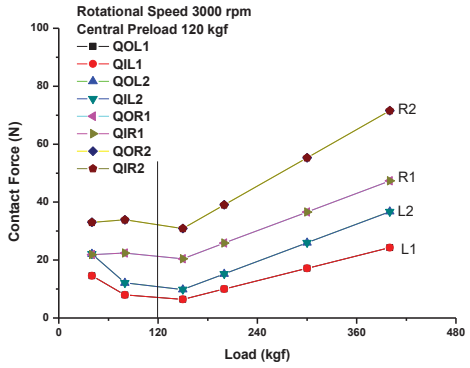


Figure 3 Contact forces VS axial load.

Friction forces are slightly increasing with the increase of contact forces as shown in Fig.4. The difference of friction force at outer and inner contact area of each cycle is few. But friction force is increased with rotational speeds proportionally, as shown in Fig.5. Average friction forces of right contact side are larger than the left side. Owing to the contact geometry is different at these two contact side, friction forces are not increased with the increase of contact forces. They are affected by contact angles and sliding speeds of contact areas.

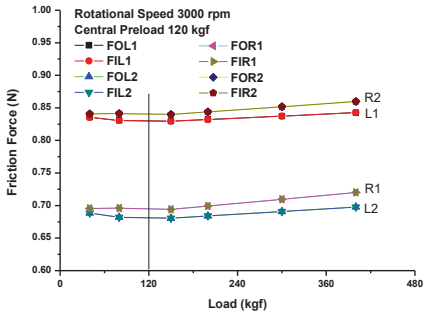


Figure 4 Friction forces VS axial load.

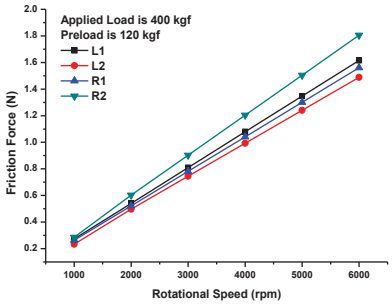


Figure 5 Friction forces VS rotational speed.

3. SUMMARY

The study has built an analyzing model for a vertical motion preloaded double nut ball-screw device. Vertical motion lets the applied axial load is extremely existed at the nut. Contact force existed at R2 ball cycle, which is nearby the applied preload and axial load, is greater than the other cycles. Contact force of left contact side is decreased with the increase of applied axial loads initially. After the axial load is greater than the preload, contact forces of both contact side are gradually raised with the increase of applied axial load. Friction forces are dominated with the increase of rotational speed and only slightly increase with the rising of applied axial load. The study can help in understanding the contact and friction behaviors in a vertical motion ball-screw system.

4. REFERENCES

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