Research on the Motion Threaded Mechanism

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Abstract

This short article includes introduction to different designs of screws for linear motion, their advantages, disadvantages and problems. Ball screws and cheaper lead screws are the most common in the industry. An innovative screw mechanism is described in the next part of the article – motion threaded mechanism which solves problems with balls inside the nut of a ball screw, for example circulation of balls (it is complicated for the nut with a multiple thread) and greater threaded pitch. The next two parts feature the production of a motion threaded mechanism and future measuring of qualities and then a comparison between a motion threaded mechanism and a ball screw. The last part of the chapter motion threaded mechanism describes the stiffness measurement of the nut in brief.

Keywords: motion threaded mechanism; sheaves; nut; ball screw; stiffness

1. Introduction

The basic function of lead screws and ball screws is the transformation of rotating motion to linear motion. Their basic parameters are stroke, speed, acceleration, indispensable force, accuracy of positioning and efficiency. The shaft of the lead screw is in direct touch with the nut. Thanks to this friction, lead screws have a lesser efficiency. The friction also produces heat energy and causes thermal expansion of material. It is the reason why friction has to be decreased, for example by application of new materials or higher accuracy of production.

The solution of the friction is to use a lead screw with roller elements – usually ball screws. Balls are inside the nut and transmit the load by rolling (Fig. 1 shows section through the nut with the ball circulation). Passive resistance is reduced to rolling resistance only. The advantages of ball screws are high efficiency, long lifetime, possibility of creating preload (for higher stiffness and accuracy), prevention of jerky movements and possibility of transformation of linear motion to rotating motion. On the other hand, the nut of a ball screw is more complicated and expensive because it is necessary to ensure a circulation of balls. The transmission of balls inside the nut can be a reason for formation of vibrations and noise. Important parameters for ball screws are the following: nominal diameter, screw pitch, speed, load capacity, static and dynamic stiffness, efficiency, lifetime, passive resistance, thread profile groove, ball diameter, load force and preload. [1], [2]

For lower friction, there are special types of screws such as a planetary roller screw which uses threaded rollers instead of balls. Qualities are better than those of a ball screw but the price is higher. Another variant is a lead screw with a hydrostatic nut. A liquid is pressed between threaded shaft and nut by hydraulic pump.

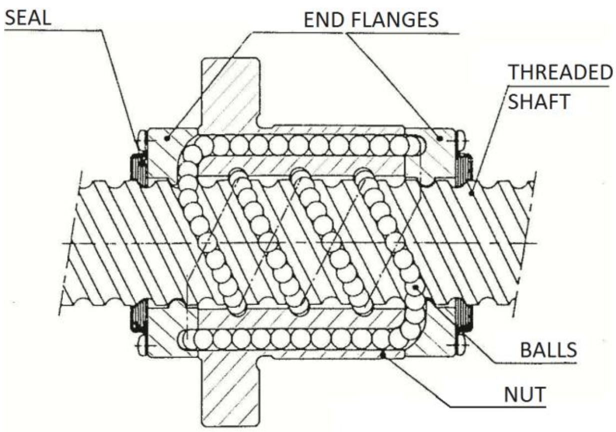

Fig. 1. *Section through the ball nut. [2]*

A motion threaded mechanism is one of the unconventional designs of the screw for linear motion. Its design and production are described in the following chapters. The screw was invented by doc. Ing. Vladimír Andrlík, CSc. and won a competition Best Cooperation of the Year 2014 and a competition Innovative Idea in the year 2014. [3], [4]

2. Motion Threaded Mechanism

2.1. Design of Motion Threaded Mechanism

The shaft of the motion threaded mechanism has the same circular thread profile groove as a ball screw shaft. The nut consists of four rings with sheaves and two end

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flanges (Fig. 2). Constituent rings and end flanges are fitted with seals and all parts are clipped by bolted rods. Modular conformation of the nut has advantage in universal production for different loads.

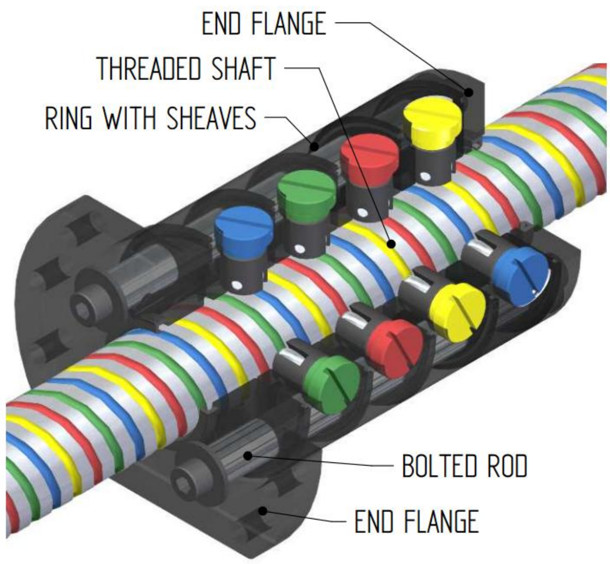

Fig. 2. *Section of the motion threaded mechanism.*

Radially supported sheaves replace balls which circulate inside the nut. It is a completely new solution of the disposition. A sheave assembly contains four parts, sheave with the pintle is put inside the cylindrical bushing (Fig. 3). The bushing is pressed on the shaft of the screw by the threaded bushing. Sheave assemblies are four in one ring and each of them copies one groove of the four-threaded screw. The nut is also equipped with lubricator and seals. The advantage of this solution is silence and smoothness during the motion. [3], [4]

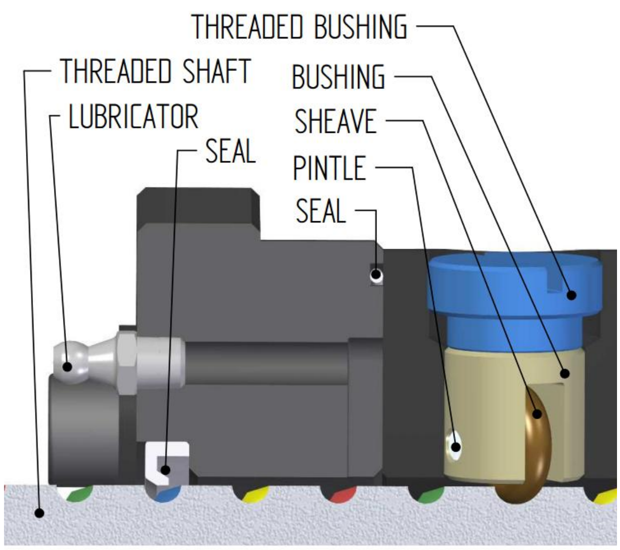

Fig. 3. *Detailed view of the modular nut (end flange and ring) with sheave assembly.*

2.2. Production of Motion Threaded Mechanism

The nut of motion threaded mechanism (Fig. 4) and the threaded shaft were made according to technical drawings. The production was simple in comparison with ball nut and usual production technologies are sufficient.

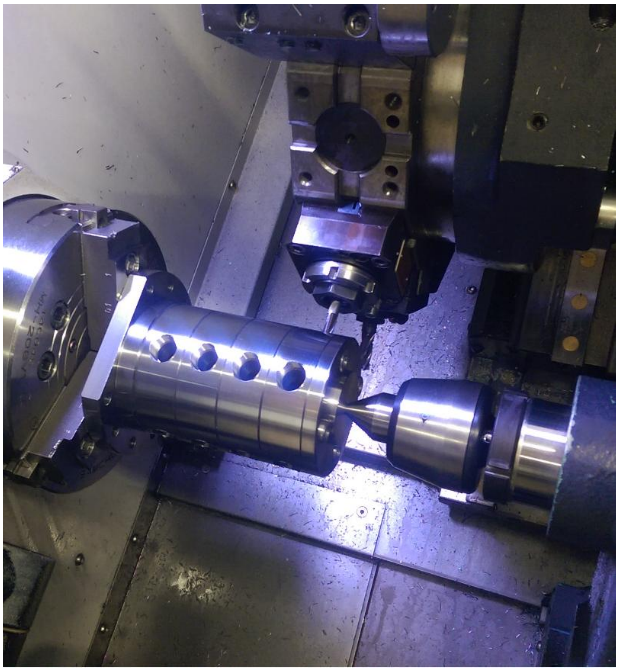

Fig. 4. *Modular nut cutting by a CNC machining centre.*

2.3. Future Experimental Research of Difference between Motion Threaded Mechanism and Ball Screw

Because the motion threaded mechanism is a completely unique mechanism for transforming rotary movement to linear movement, it is necessary to perform experimental research to identify the behaviour during the process, such as a vibration, noise, smoothness during running, stiffness etc. At present a real test bed is being prepared (Fig. 5), together with a threaded shaft, a sheave nut with three rings and a ball nut. The results of the nut of the motion threaded mechanism and the ball nut will be evaluated and compared with each other.

The measurement consists of the following parts:

- static stiffness
- dynamic stiffness
  - modal analysis
  - smoothness during running
- noise
- load capacity
  - static load capacity
  - dynamic load capacity
  - lifetime
  - maximal running speed
- efficiency

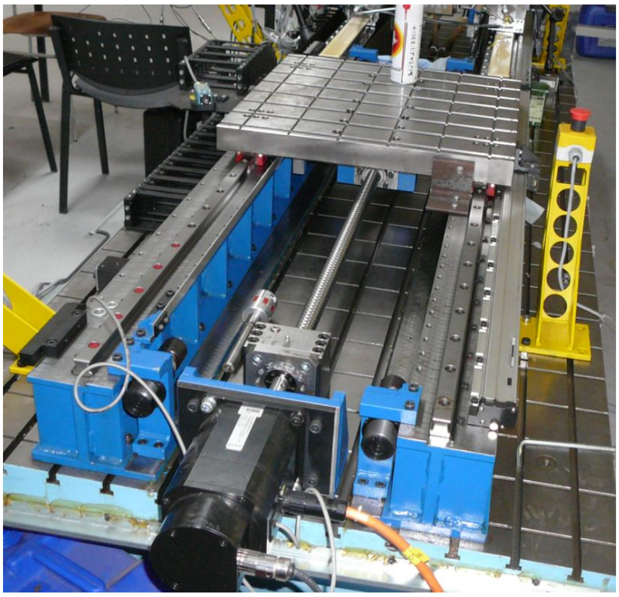

Fig. 5. Test bed for measuring of qualities.

2.3. Preparation for the Measurement of the Static Stiffness

As the first measurement, the static stiffness of all mechanism will be tested on the test bed. The table of this test bed is stopped against the fixed body and the motor is operating (the table is creating pressure on the fixed body). Sensors are used for sensing of the angle and path difference in three positions (Fig. 6). Sensor number 1 is hidden inside the motor and measures running speed (spin). Sensor 2 is located on the nut, coaxially to the threaded shaft and checks the angle difference. The last sensor number 3 controls linear position of the body deformation.

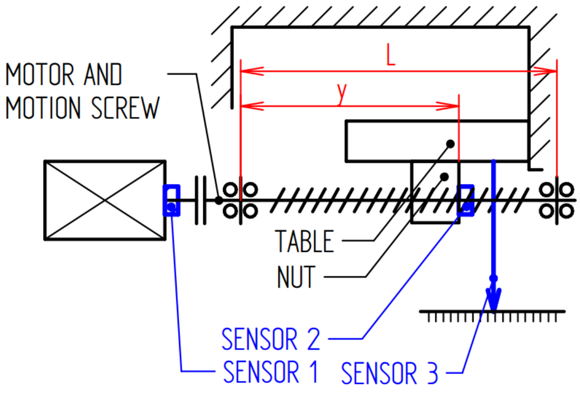

Fig. 6. Schematic picture of the test bed and measurement of the stiffness.

The measurement should be supported by the calculation. The stiffness of the screw is expressed in its inverted value, compliance (the linear compliance c_L, the rotational compliance c_R and their sum c_C) due to easier count. The threaded shaft is converted into a smooth-surfaced shaft with diameter D and length L because of the simplification of the calculation. An active length y means the distance between bearing and nut, Δy is displacement of the active length, $\Delta\varphi$ is displacement of the lead angle and the last needed dimension is the lead of the thread h. Threaded shaft torque M_s produces the force F_s on the distance h. Letters G and E are moduli of elasticity - G for shear and E for tensile. Next three equations (1-3) describe simplified theoretical calculation of compliance. [2]

$$c = \frac{1}{k} \qquad \Delta\varphi = \frac{32 M_s y}{\pi G D^4} = \frac{\Delta y}{h} = \frac{32 F_s h y}{\pi G D^4} \tag{1}$$

$$c_R = \frac{\Delta y}{F} = \frac{32 h^2 y}{\pi G D^4} \qquad c_L = \frac{4(Ly - y^2)}{\pi E D^2 L} \tag{2}$$

$$c_C = c_R + c_L = \frac{32 h^2 y}{\pi G D^4} + \frac{4(Ly - y^2)}{\pi E D^2 L} \tag{3}$$

Higher lead of the thread badly affects the rotational compliance because it decreases with quadrate (h^2). The worst position of the nut for stiffness is determined by the derivation of the compliance c_C (next equation). This position is over the half of the shaft. [2]

$$\frac{\partial c_C}{\partial y} = 0 \;\rightarrow\; y_{maxC} = \frac{L}{2} + \frac{4ELh^2}{GD^2} \tag{4}$$

Calculation of the stiffness of the nut is more complicated. Balls are deformed by the load force inside the ball screw nut body and the theoretic displacement is possible to calculate by using Hertzian contact stress theory. During the development and many experimental researches, Hertzian relation was corrected and has special form for example for axial bearings or angular contact bearings. Then, if the normal displacement of balls inside the ball screw nut isn't determined in a catalogue, it is possible to take the middle of values for axial bearings or angular contact bearings as Hertzian relation. But the determination of the value for sheaves inside the groove is hard because nobody has tested it before.

3. Conclusions

For the linear motion, an innovative motion threaded mechanism was designed which uses tightly supported sheaves in the threaded groove instead of balls. This solved problems with balls inside the nut of a ball screw, for example circulation and greater threaded pitch. Because of the completely unique mechanism, it is necessary to perform experimental research on qualities of this motion threaded mechanism such as vibration, noise, smoothness during running, stiffness etc. Now, measuring of these parameters is being prepared and then the motion threaded mechanism will be compared with a usual ball screw.

In the future, a new idea of the motion mechanism will be prepared for the production – regulating motion mechanism. The linear nut speed could be changed or reversed with the constant running speed of the screw.

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The threaded shaft was made by the company Kuličkové šrouby Kuřim, a.s.

List of symbols

c	compliance
c_C	sum of the linear and rotational compliance
c_L	linear compliance
c_R	rotational compliance
D	threaded shaft diameter
E	modulus of the tensile elasticity
F_S	threaded shaft force
G	modulus of the shear elasticity
h	lead of the thread
k	stiffness
L	threaded shaft length
M_S	threaded shaft torque
Δy	displacement of the active length
y	active length of the threaded shaft
y_{maxC}	position of the highest compliance
$\Delta\varphi$	displacement of the lead angle

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