Proceedings of the 15th International Conference on Manufacturing Systems – ICMaS
Published by Editura Academiei Române, ISSN 1842-3183

"Politehnica" University of Bucharest, Machine and Manufacturing Systems Department
Bucharest, Romania, 26 – 27 October, 2006

STATE OF ART AND TENDENCIES IN THE USE OF SCREW-NUT TRANSMISSIONS IN THE BUILDING OF MACHINE TOOLS

George DOBRE, Marcel DĂSCALIUC, Radu Florin MIRICĂ

Abstract: *The screw-nut transmissions have today a large application in the building of machine tools, as sort, type and dimensions. The paper performs a survey of the employ of screw-nut transmissions on the types of machine tools. The main technical basic characteristics and the main tendencies of the use of screw-nut transmissions at machine tools are mentioned and discussed. The paper represents a synthesis of scientific and applicative interest for design and research.*

Key words: *machine tools, screw-nut transmissions, basic characteristics.*

1. INTRODUCTION

The main subject of the paper is to evaluate a state of art and tendencies in the use of the screw-nut transmissions in the building of machine tools. The use of the screw-nut transmissions remains indispensable in the building of machine tools, even the new and larger employ of the alternative three-phase motors in the CNC machine tools restrains their area of application.

The state of art is starting by formulation of criteria of classification that tries to cover the main characteristics and applications of screw-nut transmissions in the machine tools building. Then, these criteria are discussed largely. Further tendencies in application of the screw-nut transmissions are presented on this basis. Thus, the paper offers a survey of the use of this type of transmissions, often required in their design and research. After our knowledge, a similar paper task is not approached in this way in the specialty literature (only the papers [1, 2, 3, 4] are cited in the limited paper space). It is based merely on own experience of authors in the field, based on practice and the knowledge of the catalogues and documentations from companies profile.

2. STATE OF ART OF USING SCREW-NUT TRANSMISSIONS AT MACHINE TOOLS

2.1. Classifications

A problem is the establishing the specific criteria of classification of the screw-nut transmissions used at machine tools. The following criteria of classification are proposed:

1. dynamic and static axial load ratings from the point of view of the bearing type and sizes;
2. feed speeds;
3. positioning and repeatability of movable components;
4. rigidity of all components of screw-nut transmissions;
5. preloading system;
6. constructive simplicity.

Classifications are given in a manner of the Tables 1–9, instead of the classical representation by graph schemes, because the mentioning of the several distinctiveness could be better includes in this way.

A large discussion of these classifications is giving in the following sub-chapters, to better point out main individuality of the appliance of the screw-nut transmissions to the machine tools building.

Table 1

Classification and recommendations for ball screw-nut transmissions used at machine tools by the criteria of dynamic and static axial load ratings

$\frac{C_{a0}}{C_a}$	Recommendations	
	Characteristics of machine tool	**Characteristics of screw-nut transmission**
3…7	Heavy masses, large sizes	Circular normal profile
2…5	Medium masses, normal sizes	Circular or ogival (gothic) normal profile
1.1…2.5	Light machines and high speed devices	Ogival (gothic) axial profile

Table 2

Classification and recommendations for planetary roller screw-nut transmissions used at machine tools by the criteria of dynamic and static axial load ratings

$\frac{C_{a0}}{C_a}$	Recommendations	
	Type of machine tool	**Characteristics of screw-nut transmission**
1…1.5	Grinding machines	Planetary roller with 2…4 starts
2…5	Drilling machines	Planetary roller with 1…6 starts

Table 3

Classification and recommendations for screw-nut transmissions used at machine tools by the criteria of speed feed, considering the maximal value of nominal lead

Characteristics of machine tool	**Range of nominal lead values of screw-nut transmission**
High precision machine tools	(0.02…0.10) D_{pw}
Normal precision machine tools	(0.05…0.40) D_{pw}
Machine tools no special precision	(0.10…1.20) D_{pw}

Table 4

Classification and recommendations for screw-nut transmissions used at machine tools by the criteria of feed speed, by the product $n_{max} \times D_{pw}$

Type of machine tool	Parameter $n_{max} \times D_{pw}$ for screw-nut transmission
Lathes, milling machines, drilling machines, honing machines, grinding machines.	≤ 50,000
NC or CNC cutting machines	≤ 70,000
CNC machines for wood, aluminum, machining centers	≤ 100,000
Special purposes (robotics, manipulators, flexible lines)	≤ 160,000

Table 5

Classification and recommendations for screw-nut transmissions used at machine tools by the criteria of positioning and repeatability of movable components

Type of machine tool	Type of screw-nut transmission
Plane and cylindrical grinding machine. Rifle machines. Accuracy screw threading machines.	• Planetary roller screw-nut transmissions • Screw-nut (P type) transmissions with small lead, having a double nut with more than 4 circuits
Cutting machines	• Screw-nut transmissions (P or T type) with circular or ogival normal profile, having a single or double nut with normal number of circuits
CNC machines, measuring machines	• Hollow screw shaft transmission immersed in oil, having a double nut with controlled preloading • **Error! Not a valid link.** • Screw-nut transmission (P type) having a double nut and wit maximal preloading and a controlled nut cooling
Marking machines, textile machines, manipulators, actuators etc.	• Screw-nut transmissions (P type) with large lead, having a single nut with more than 2 starts

2.2. Criterion of dynamic and static axial load capacity

This criterion is very important for all types of machine tools. In the Table 1 it is analyzed by the ratio between the basic axial static and, respectively, dynamic load rating, $\frac{C_{a0}}{C_a}$. For the ball screws nut transmissions, this ratio has the biggest values for the machine tools having heavy masses in movement and low speed, where the static loading is important. This fact is carried out by the following characteristics:

- a normal circular profile, having a larger contact as the ogival profile;
- a large nominal contact angle (45°…60°), because it permits the higher axial loading;
- a high value of conformity ratio of 0.53…0.56.

The small ratio values require lower axial loads and higher speeds, where the large importance is to provide a high accuracy. For this, the characteristics of the screw-nut transmissions are: ogival profile having smaller contact area; a contact angle under 45°; a conformity ratio of 0.51…0.53.

The medium ratio values are dedicated for medium size machine tools. The characteristics of the screw-nut transmissions are supplementary: the profile could be ogival; the contact angle could be 40°…45°; a conformity around 0,53.

For planetary roller transmission, the conformity ratio is superfluous. The multiple of contacts points of the threaded rollers offers larger axial loading capacities comparatively with the ball screw nut transmissions. The large ratio (Table 2) is intended for grinding machines tools because of: small elastic deflection; higher stability and control of masses in movement by the ratio of transmission; higher accuracy and positioning.

Table 6

Classification and recommendations for screw-nut transmissions used at machine tools to ensure a high precision of the positioning and repeatability

Type of machine tool	Type of screw-nut transmission
CNC machining centers	• Ogival (gothic) normal profile • Medium preloading • Controlled oil temperature • Working stroke < 3500 mm • Working feed ≤ (80…120) m/min • Normal leads
CNC grinding machines	• Ogival (gothic) normal profile • High preloading • Controlled oil temperature • Working stroke < 1500 mm • Small leads
Conventional/DRO, NC machines: • Boring and milling • Plano–miller • Heavy floor lathe • Deep drilling	• Ogival (gothic) or circular normal profile • Medium to high preloading • Fix or rotational nut system • Double flanged or single • Working stroke 6000…19000 mm; • Multi-joining shaft • Supplementary shaft supports

Table 7

Classification and recommendations for ball screw-nut transmissions used at machine tools by the criteria of the component's rigidity

Rigidity		Part from total rigidity, R_{tot}
Symbol	Denomination	
R_S	Rigidity of the ball screw shaft of 1 m length	$(1.5…2.5)R_{tot}$
$R_{nu,ar}$	Rigidity of the ball screw shaft within in the loaded ball nuts area	$(5…9)R_{tot}$
R_{bs}	Rigidity of the bearing system	$(3…5)\ R_{tot}$
R_{ns}	Rigidity of the nut bracket and support bearing system	$(10…20)R_{tot}$

2.3. Criterion of feed speeds

This criterion is discussed using two types of classification:

- by the maximal value of nominal lead (Table 3);
- by the product $n_{max} \times D_{pw}$ (Table 4).

Table 8

Classification and recommendations for screw-nut transmissions used at machine tools by the criteria of preloading

Axial preloading force	Nut type	Type of machine tool	
		Designation	Applications
$(0…0.01)C_a$	Single nut	Lower axial load, normal or high speed, long life, normal precision	Robots, handling systems, actuators, valves
$(0.01…0,04)C_a$			Semiconductor industry
$(0.035...0.075)C_a$	Double or single nut	Medium or high axial load, normal speed, long life, normal and high precision	General purpose machines
$0,10C_a$			CNC machine tools
$(0.10…0.30)C_a$	Double nut	Lower and medium load, lower and normal speed, very good rigidity, reduced life, normal and high precision	Heavy machine tools, drilling gun machines, Rotary table
$\geq 0.30C_a$	Double or single nut	Lower axial load, no speed interdictions, extreme high rigidity, very short life, very high precision	Special appli-cations

Table 9

Classification and recommendations for screw-nut transmissions used at machine tools by the criteria of constructive simplicity

Type of machine tool	Characteristics of screw-nut transmissions
General cutting machine tools	• Normal lead • Double symmetrical or single nut • Mono-block shaft • Internal deflector
High speed machine tools	• Large lead, multiple starts • Single preloading nut • Mono-block shaft • Tube recirculation
Heavy machine tools	• Large lead, large diameters • Double symmetrical or single nut • Joined shaft • End-cape recirculation
CNC measuring machine tools	• Small lead, medium diameters • Zero-backslash single nut • Hollow shaft • End-cape recirculation

From the point of view of the first classification – very important technologically and constructively –, there are some rations between the lead and diameter, which are strongly influenced by the balls diameter. The small leads are used preferentially at high precision machine tools; meanwhile the large ones are generally designated to the low precision machine tools. Actually, the modern machine tools are not related to the precision by the quality of the large or small leads, because of very accurate linear or angular encoders from these machines.

The second classification criteria is pointed out by the product between the maximal value of shaft speed and pitch circle diameter. Frequently, the small values of this parameter (< 50.000) are used for all types of conventional machine tools. The highest values of this product are limited by the following parameters: the vibrations and noise generated; uncontrolled centrifugal phenomena of the rolling corps; the heating generated by the friction phenomena; the frequency of the impacts between the rolling corps and deflectors.

For example, the THK company has presented an innovation consisting of disk spacer cage between balls, to improve all influencing parameters mentioned above.

2.4. Criterion of positioning and repeatability of movable components

For each working axis, it must select between the two types of ball screws: P (positioning) and T (transport) (ISO 3408, Part 1 [3]). Several aspects in field are shown in the Table 5. The P type is applied for precision positioning which enables indirect measurement of axial travel from the angle of rotation (rotary encoder) and the lead. The T type is used for directly measurement of the axial travel by a separate measuring system (linear encoder), independent of angle of rotation and the lead. Positioning accuracy and the repeatability are direct related to the lead error of the treaded shafts besides other parameters. Some recommendations are presented in Table 6 regarding these aspects.

The optimum solution will be also decided by criterion of the costs ensuring the desired repeatability in the system.

2.5. Criterion of rigidity of all components of screw-nut transmissions

The rigidity is defined generally as deflection under loads. The elastic deflections are to be considered in such approach and hence the influence of each component of the screws drives transmissions.

The total rigidity of the screw-nut transmission is generally accepted by the following equation:

$$\frac{1}{R_{tot}} = \frac{1}{R_s} + \frac{1}{R_{nu,ar}} + \frac{1}{R_{bs}} + \frac{1}{R_{ns}}, \quad (1)$$

where the denominations of different rigidity types and influence of different factors (Table 7). Table 7 gives also the each partial rigidity contribution over the total rigidity, in dependence of dimensions of the screw-nut transmission.

2.6. Criterion of preloading system of the assembly screw-nut transmission

An important influence on the ball screw-nut transmission lifetime has the amount of preloading. The admitted

Table 10

Simplicity aspects for screw-nut transmissions

Simplicity grade	Screw-nut	Parameters influenced by the constructive solution
Low simplicity	Screw shaft with two end bearings, fixed nut and rotary shaft	• Increasing quantity of lubricant • Preloading of shaft • Bearing alignment • Great overall sizes of bearings • Great number of components
High simplicity	Screw shaft with one end bearing, rotary nut and fixed screw shaft	• Decreasing quantity of lubricant • Preloading of shaft • Bearing alignment • Lower overall sizes of bearings • Lower number of components • Bearings for rotary nut support

values are recommended in the Table 8. From this point of view, each screw-nut producer offers bigger or lower values which enable the end-user to select the adequate transmission for the proper needs.

2.7. Criterion of constructive simplicity of the assembly screw-nut transmission

Some constructive characteristics are given in the Table 9 and the simplicity differs mainly from followings:

- a reduced number of components;
- the shape of the shaft (hollow, mono-block or joined);
- the shape of the deflector (internal, tube, end cape);
- the nuts types (single, double, fixed, rotating);
- the preloading methods.

In that respect the Table 10 gives two examples of constructive simplicity for screw-nut transmissions. One would see that the second solution is simpler, principally because of the low number of components.

3. FURTHER TENDENCIES

An overall view regarding the modern further tendencies in machine tools screw-nut transmissions are in our opinion:

- over 7 circuits for one ball nut body;
- hollow ball screw shaft;
- generalized thermostatic control system for the modern screw-nut transmissions;
- recirculation system by ball cage or special shape recirculation pipe;
- special coating screw shaft;
- nut contact seal systems;
- rigid bearing arrangements;
- safety locking nuts.

A modern solution (including further tendencies) that could be applied in machine tool construction for rotary nut and fixed shaft is given in the Fig. 1. It has modern innovative aspects from different points of view:

- identical parts (nut 1, washers 2);
- multi-functionally components (washer-cylinder housing 3, locknut-cylinder corps 4);

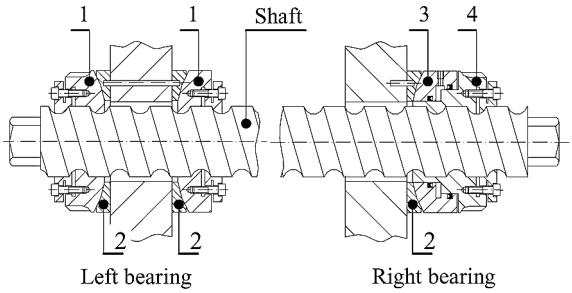

Fig. 1. Modern solution of screw-nut transmission including further tendencies in field.

- very rigid assembly having the shaft with constant cross-section on full length on shaft;
- two ends "spherical knee" system for a better and easy alignment;
- hydraulic preloading system giving an adjustable preloading and continuous thermal displacement compensation;
- safety locking nuts 1 and 4.

4. CONCLUSIONS

Screw-nut transmissions remain a large type used today and further in machine tools' building.

A state of art in the application of the screw-nut transmissions for machine tools is developed by the formulation of classifications based on specific criteria and the characterization of these classifications.

Modern tendencies are manifesting in further development in field.

REFERENCES

[1] Spotts, M. F., Shoup, T. E., Lee, E., Hornberger, L. E. (2005). *Design of Machine Elements*, 8th Edition, Prentice Hall, ISBN 0130489891.

[2] Oberg, E., Jones, F. D., Horton, H. L., Ryffel, H. H. (2004). *Machinery's Handbook*, 27th Edition, Industrial Press Inc., New York.

[3] *** ISO 3408. *Ball screws*, Part 1 (1991), *Vocabulary and designations*, Part 2 (1991), *Nominal diameters and nominal leads – Metric series*; Part 3 (1992), *Acceptance conditions and acceptance tests*; Part 4 (1994), *Axial rigidity*, Part 5 (1994), *Static and dynamic axial load rating and operational lifetime*.

[4] *** Technical documentation from the companies, FAG-Kugelfischer AG, Germany, www.fag.com; INA- Scaeffler KG, Germany, www.ina.com; Korta SA, Spain, www.korta-sa.com; NSK, LTD, Japan, www.us.nsk.com; THK CO., LTD, Japan, www.thk.com.

Authors:

Ph.D. Eng. George DOBRE, Prof., Department of Machine Elements and Tribology, E-mail: geo@meca.omtr.pub.ro
Dipl. Eng. Marcel DĂSCALIUC, WPC of Bucharest,
E-mail: marceldascaliuc@yahoo.com
Ph.D. Eng. Radu Florin MIRICĂ, Assoc. Prof., Department of Machine Elements and Tribology,
E-mail: geo@meca.omtr.pub.ro