Chapter

Simulating the Effect of Friction on Drive Screw Using System-of-System Modeling with Predetermined Torque

Fatima Isiaka, Awwal M. Adamu, Salihu A. Abdulkarim and Abdullahi Salihu

Abstract

In most mechanical systems, screw threads serve three main basic purposes: (i) to transmit power, (ii) to provide a clamping force, and finally (iii) to restrict or control motion. This chapter demonstrates the effects of friction and behavior which can occur in a bolted fastening (screw thread) for advanced design purposes. To model this behavior, other control components are attached to the bolted screw. The bolt preload is applied with a predetermined torque. For this case the preload depends on the friction under the head and in the thread. The friction prevents the loosing of the bolted fastening. This effect is termed as self-locking effect. We designed an algorithm that reproduces an exemplary simulation scenario, which determines friction and its effect on thread angle based on the strength of the coefficient of friction at a specific tension or clamp load value using the system-of-system approach. The result shows specific behavior on both the motion in threads and drive screw with predetermined torque. The chapter is limited to creating a simple simulation environment to demonstrate the effects.

Keywords: predetermined torque, bolted fastener, tension, runout turn, drive screw

1. Introduction

A drive screw usually consists of head radius, shank, runout, and threads (as shown in **Figure 1**). The chapter defines the behavior of a thread fastener on drive screw by focusing more on the thread behavior and on the fasteners [1]. The mating parts introduced in this chapter consist of the worm drive, which meshes with the worm gear connected to the drive screw and the hypoid, to maintain high-speed reduction using a pair of hypoid gears. They are used to control friction by reducing rotational speed and transmit higher torque. Usually, when a bolt is tightened by applying a torque to the bolt head, the bolt gets stretched out causing the clamping plates to be compressed together. Fastener coatings are being required to comply with corrosion specifications and also fulfill specified tightening characteristical requirements. Some of these requirements mostly include test for torque tension and sometimes a coefficient of friction test. The torque-tension test usually consists of an acceptance input

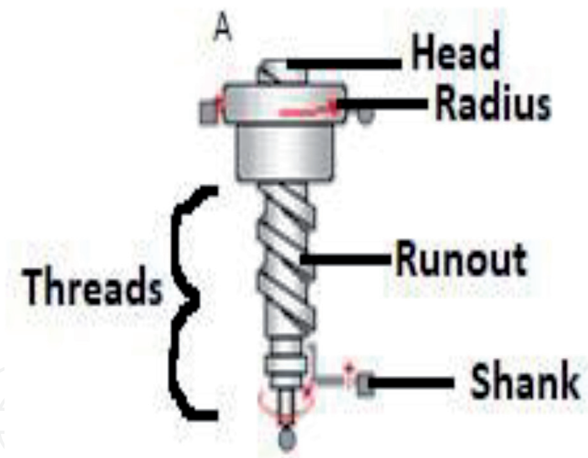

Figure 1.
A typical drive screw with its characteristic component.

torque which is often known as the predetermined torque at a specific tension clamp load value, while the coefficient of friction tests requires an acceptance coefficient of reference friction with a specified tension or a clamp value [2, 3].

Threaded faster assembles take some process, most especially for critical bolted joints, which takes some stages into account; this involves controlling both the input torque and the angle of tension that turns to achieve the desired output of proper preload of the bolted assembly [4, 5]. An accurate clear understanding of the role of friction is needed for both the underhead and threaded contact zones to giving a definition to the relationship between the angle of tension, the predetermined torque, and tension control; there are a lot of factors that affect the tension created in a bolt when tightening behavior occurs in the torque control. All the bolted joints consist of the main torque-angle signature. Additionally, by combining the torque-angle curves with a precise computation and a basic understanding of the logic mechanisms of the threaded fasteners, we can obtain the practical information required to evaluate the characteristics of the individual fastener tightening processes. The torque-angle curves can provide the necessary parametric data to properly qualify the capability of tightening tools to tighten a given fastener [6–8].

Figure 2 shows the energy transfer process that occurs when tightening threaded fasteners. The area under the torque-angle curve is basically proportional to the energy required to tighten the fastener. To model this process, achieving proper control of the tightening process is possible if we get a comprehensive understanding of the relationship between the torque and turn in the development of the tension [9, 10]. It is necessary to be familiar with what happens when a typical fastener is tightened. The concept behind tightening a fastener involves turning in advance the lead screw and torque at turning moment so that the preload tension happens at the fastener. The predicted output is a clamping force that holds the components together. Modeling the torque turn signature for the fastener tightening process has four characteristic zones (**Figure 3**). The first is the rundown or prevailing zone, which occurs before the fastener head or nut contacts with the bearing surface. Basically, the alignment zone is the second part of the tightener; in this zone, the fastener and the joint mating surfaces are drawn into alignment to obtain a possible snug condition. The elastic clamping is the third zone, where the slope of the torque-angle curve is alternatively constant [11, 12]. The last zone, which is the post-yield zone, begins with an inflection point at the end of the elastic range. Constantly, this fourth zone can be due to yielding in the joint or gasket or due to the yield of the threads in the nut or clamped components or nut rather than

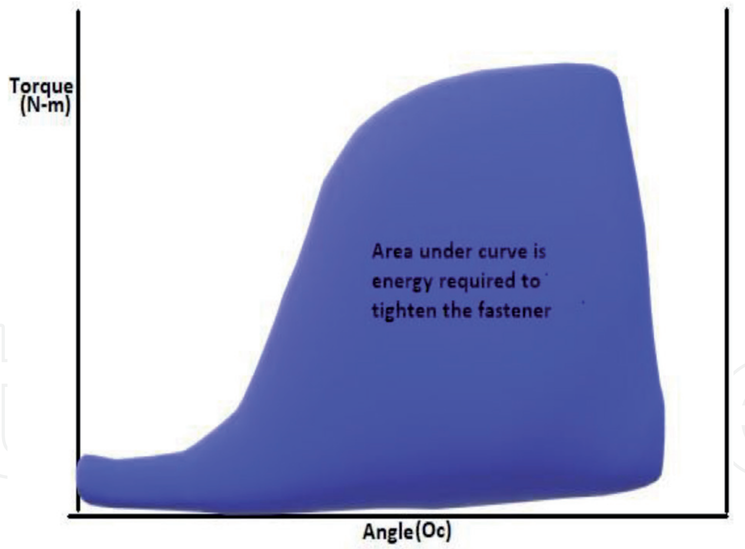

Figure 2.
Total energy area required to tighten the bolt fastener.

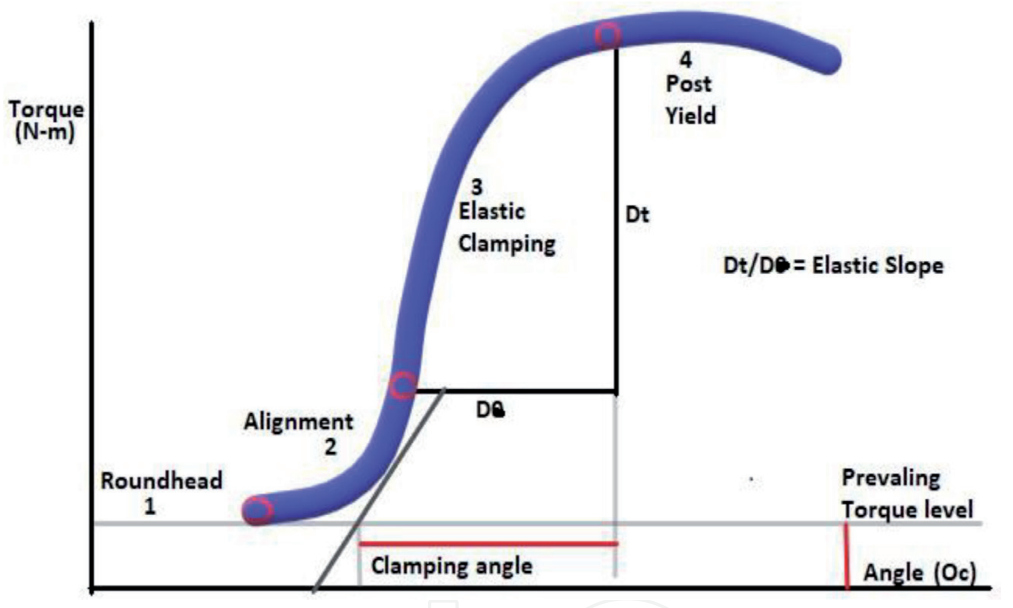

Figure 3.
A basic narrative of the four zones in a threaded screw.

to the yield of the fastener. This chapter is mostly focused on what occurs with the threads, when all zones are combined in the tightening process [13, 14].

2. The system-of-system approach

Drive screws is mostly a subject area less discussed in mechanical system methodology. Most of its process optimization, especially on fastener tightening, is purely theoretical and not deployed dynamically, which is mostly controversial because of its limited area of application. The application of system of systems (SOS) is a new approach to addressing this particular area, by connecting its basic components to different controls to optimize its process flow. The controls or process blocks are obtained from the visual library of simulation X, which enables the set of tools for deployment and development processes. This approach or method requires various blocks, which seeks to optimize each individual controls or

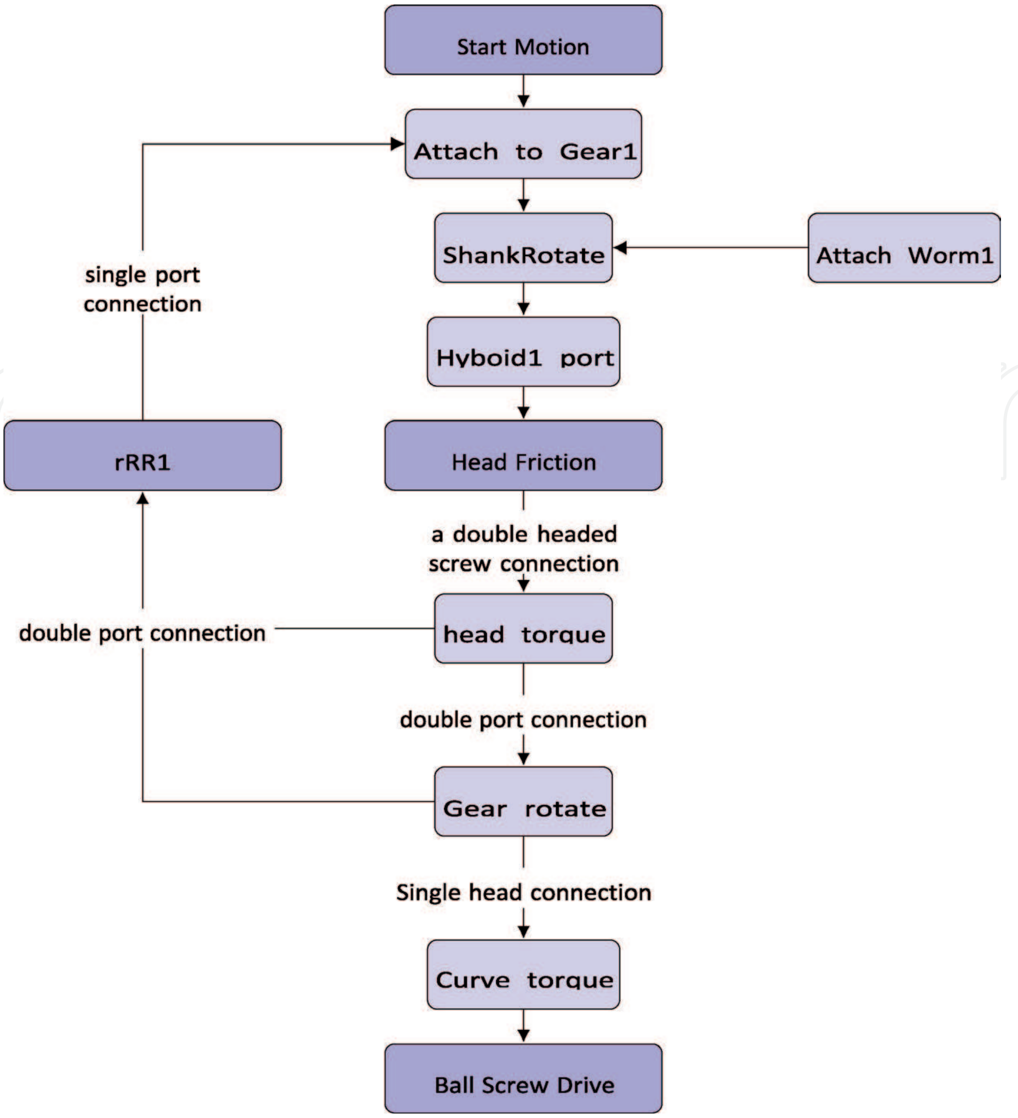

Figure 4.
Algorithm to determine the logic flow for a drive screw.

process flow. The tension of fasteners and torque effect are two different aspects of this system which are discussed in Sections 3.1 and 3.2. The process starts with the double gear which represents the gear, and it is controlled by the shank rotate and hypoid port; these serve as the first system (**Figure 4**). The second system which is the head friction loop is connected by a double-headed screw to the head torque gear rotate and the curve torque that controls the ball drive screw; this serve has the third system with a double-port connection to the rRR1. It initializes the process all over again with a single-port connection to the double-headed gears. This loop is continued till the mated parts are tightly connected. This process is better visualized on the virtual environment created in simulation X.

3. Method

The method applied in this chapter is based on applying a simple algorithm using the system-of-system approach, which helps in determining the effections of tension on the torque, friction on the drive screw, which is described in the proceeding sections. To achieve this, more controls are attached to the threaded screw to understand is mechanics. The torque applied to a fastener is absorbed in different areas, such as the underhead friction, which absorbs almost 50% of the total torque. The thread friction absorbs close to 40% of the applied torque. The remaining 10% of the applied torque represents the clamping force that holds the components together. An increase in friction of say 5% reduces the tension that equals half power. The area under the curve on the torque angle represents the total energy required to tighten a fastener. Some parts of this area represent the clamping force or energy under the bolt and clamped component in the force deformation process. A starting point for all threaded fastener analysis depends on the basic torque-tension equation which is given as

$$T = K \times D \times F \tag{1}$$

This represents the relative magnitudes of torque and clamp force or friction. This also defines a linear correlation between the torque and tension on a bolted screw. The design model is given as

$$T = KdF \tag{2}$$

where T, torque (N m); d, nominal diameter (m); F, force (N); and D, nut factor.

Geometrically, the deformation (δ) of the fastener and angle of turn are related by the following:

$$P_{thread} = \delta \times \frac{360}{\alpha} \tag{3}$$

where δ, deformation (m); α, angle (O^c); and P_{thread} pitch thread (in).

3.1 Tension on fasteners

When the fastener is tightened on a joint infinite stiffness, the relationship correlates directly with the stress induced by the strain in the fastener. The tension produced is totally proportional to the angle of turn from the elastic origin when extensive testing is conducted on the tension product. By projecting the tangent line, the elastic origin can be located near the elastic portion of the torque-angle curve towards the zero-torque zone. The basic correlation of the stress on strain in the elastic region is given as

$$S_{stress} = S_{strain} \times \xi \tag{4}$$

where S_{stress}, stress (in/in); S_{strain}(M/m), strain; and ξ young modulus (N/m^2).

The stretch ∇ or friction of the bolt loaded in tension is computed as

$$\nabla = \delta \times \frac{360}{\alpha} \tag{5}$$

Based on the above given equations, the process for determining the friction on the threaded screw is illustrated in the algorithm (**Figure 4**). This is used to define and describe the mechanics of the given model in **Figure 5**.

The input torque can be thought of as the amount of work (or energy) which is applied to a threaded fastener that causes the bolt to turn in an "α" amount of degrees and in turn stretching the bolt to produce a clamp load. The input torque is added in two ways on the thread and headed torque. The first is the reaction to the input torque and the amount of the torque it takes to keep the nut from turning when an input torque is applied to the bolt head, while the second is the amount of the input torque it carries to overcome friction in the bearing surface of the part of the fastener being turned. To obtain a friction effect M_a, there is a need to combine the force of gravity M_g and Kenal effect M_K. Therefore the input torque is given as

$$M_a = M_g + M_K \tag{6}$$

3.2 The torque effect

The thread torque is a combination of two factors which are thread friction torque and the pitch torque. The frictional portion of the thread torque describing the amount of torque it takes to overcome the friction in the engaged threads and the geometrical faction for the thread torque describing the amount of torque that is used to stretch the bolt.

The graph in **Figure 6** indicates the thread head friction torque which is calculated by subtracting the pitch torque from the thread torque. The graphical representation makes the input torque definition look like an increase in shank transmission on the friction plate. The amount of thread torque and underhead torque presents a shank tightening which can be described using friction coefficients. These are always described in terms of two kinds of material, the shank plating and coatings. It describes the friction between mating threads. The value describing the friction between the bearing materials of the bolt and the first clamping plate and nuts depends on the end of the fasteners which are turned. Also the value describing the overall friction in the joint that combines the aspects of both the bearing surfaces and the threaded head.

Figure 7 indicates the result in friction coefficient based on the plate contact, drive screw, and shank transmission; these are calculated values using the measured input torque, the clamp load, and thread torque alongside some geometric characteristics such as the thread pitch and bearing diameter. A 150 to 100% of the torque input is used to overcome the friction in the threaded and underthreaded regions, with a remainder of the 50 to 0.0% of the input torque left to stretch the bolt producing clamp load. The basic distribution of both the threaded and underthreaded

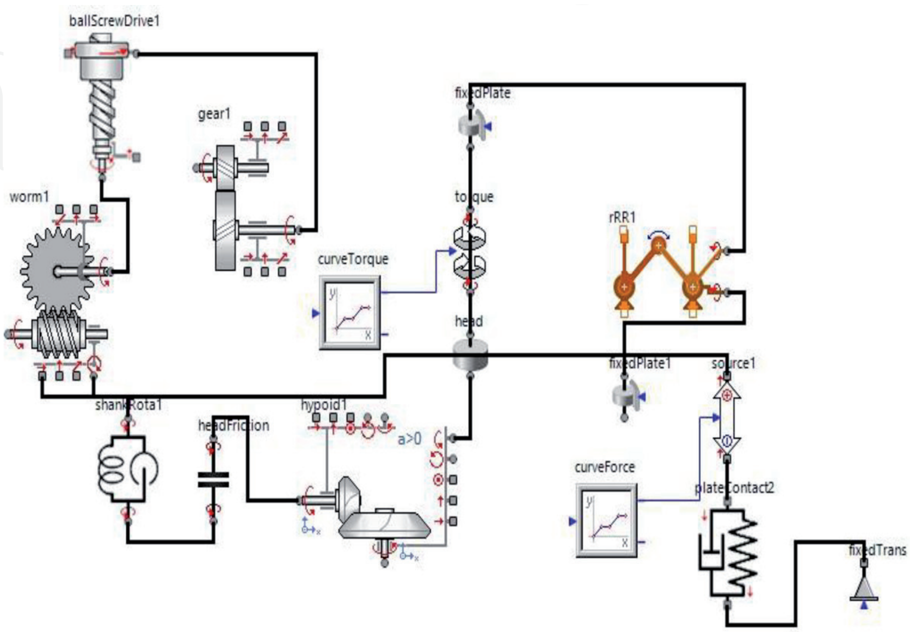

Figure 5.
Determining the friction of the drive screw model with curve torque.

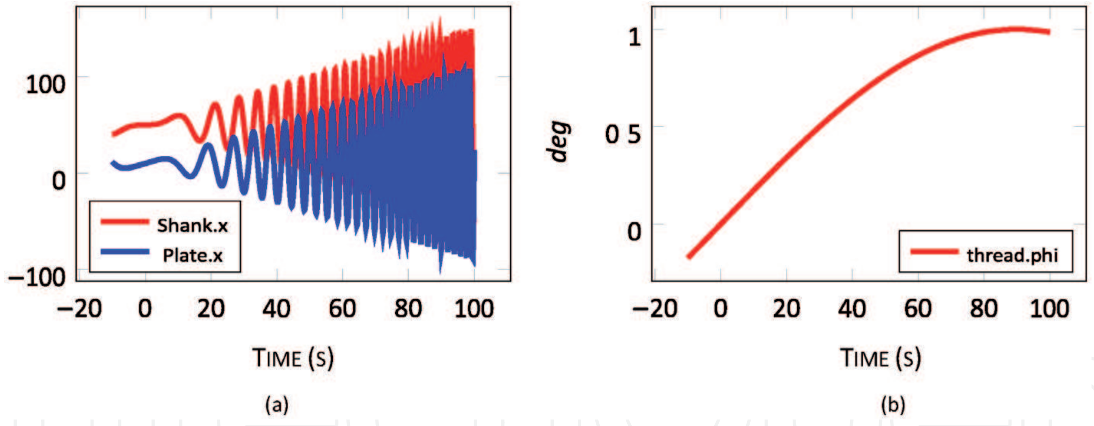

Figure 6.
Rotation angle of the screw and displacement of the screw. (a) Friction behavior on screw drive, (b) Thread displacement on screw.

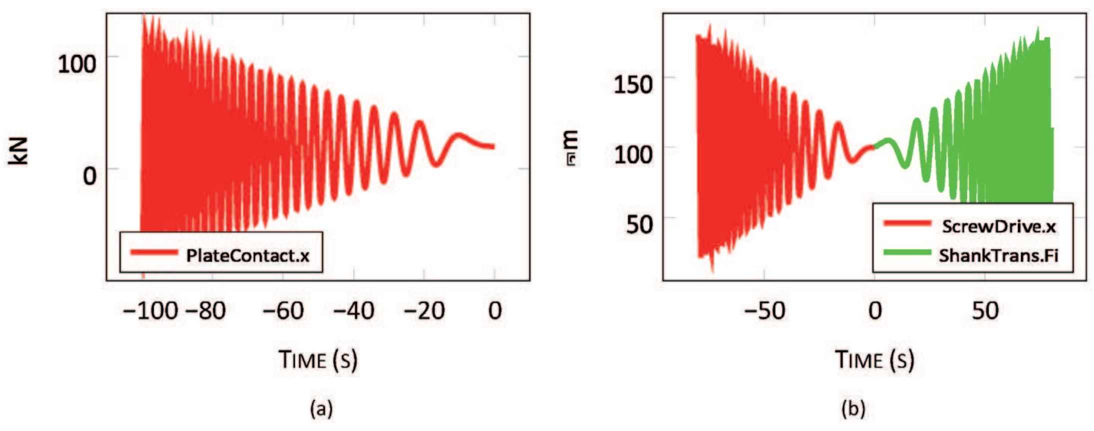

Figure 7.
Forces and deformation of the contacts between screw plate. (a) Force on Plate contact, (b) Deformation on screw drive.

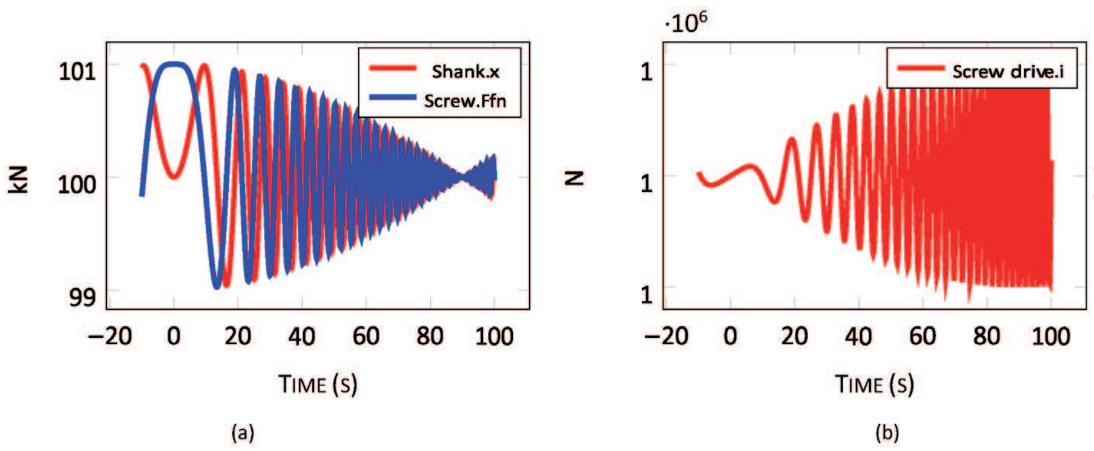

Figure 8.
Friction in the thread and normal force on drive screw. (a) Friction on shank and screw drive, (b) Force on screw drive.

area takes more torque to overcome the friction depending on the bearing surface area along with the friction coefficient between contact surfaces.

Comparing the shank heat transfer and drive screw regarding friction coefficient in **Figure 8**, the wider it takes the friction to get in range, the wider the clamp load range will be at a given torque value for both drive screw and the shank heat. Most tension on drive screw requires tightening a specified bolt/washer

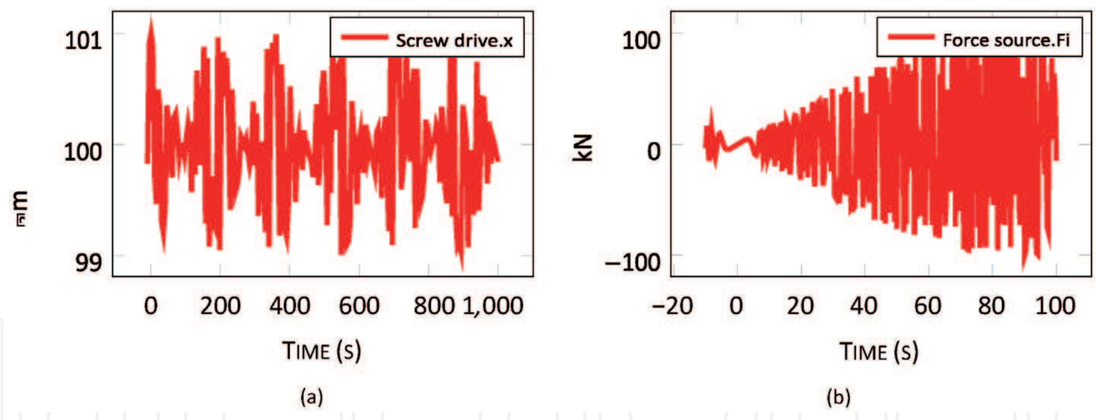

Figure 9.
Motion in the thread and the external force. (a) Force motion on screw drive, (b) Behavior of Force on screw drive

combination to a given clamp load value and returning a torque value. Both the nut and washer have a typical plating and dimensional requirements, and the bolt has requirements for the material and dimensions, which reduces all variances in the joint to the bolt coating for a drive screw.

Figure 9 compares the drive screw and force on bolt; the input values were being tested at a specified tension value. The coefficient of friction values can be calculated using the default values and Eq. 5 described above along with the torque-tension data. The calculated data is plotted and compared with the source of the force on the bolt or drive screw for this case. Friction variances affect the tightening of a bolted joint occurring in the bearing area and the threads. The friction variances are always a function of two materials of the mating parts. These two materials are the hypoid and worm effect on the drive screw, which makes it possible for the torque and tension behavior to be synchronous. The torque is a measure of the models' twisting force which is required to spin the nuts along the thread, while the tension allows the stretch of the bolt that provides the clamping force of the joints. So the plating used have a consistent relationship between the torque and tension.

4. Conclusion

The chapter mostly focused and limited to determining the effect of friction on a drive screw for the optimization on advanced mechanical purposes. The torque value effect are strictly based on the friction obtained, which is present in the bolted joint assembly. The sum of the variances in the friction leads to the variance in the amount of tension attained at the specified input torque value. The friction variation is a function of two materials of the mating parts. Likewise the coefficient of the frictions is obtained for all parameter comparisons, which is not given in terms of the material plating. The simulation effect is used to limit the amount of variance allowed in the friction coefficients against a specified material. It allows for the end user to basically be confident that the plating used has a consistent relationship between both torque and tension.

For future purposes, it is recommended that the torque time print of all the torque and audit simulation be recorded and reviewed before specification of the equipment and settings of numerical limits of the manual simulation. When conducting these basic simulations, it should always include the torque angle and its time print or signature of analysis for the installation steps. This is required prior to any meaningful correction factor that is established in relation to installation and audit recordings.

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