

## CONTROL OF THE PROCESS OF SCREWING IN THE INDUSTRIAL SCREWDRIVERS

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### ABSTRACT

The article presents the results of research on the original screwdriver for industrial applications in the event of the need to obtain the value of tightening torque in narrower tolerances. The operating of the screwdriver is supervised by the control program, which has algorithms implemented for selecting the operating mode. The program also allows archiving operating parameters and visualization of on-line characteristics of screwing. The results allowing to verify the adequacy of the mathematical model of screwdriver operation with actual operating conditions are also presented.

**Keywords:** screwdriver, control program, screwing characteristics.

### INTRODUCTION

In the process of tightening the threaded fastener is tensioned by means of pre-clamping force  $Q_w$ . This force should be sufficient in order to prevent any clearance between the elements being connected after the application of working load  $Q_r$ .

The condition for the creation of these forces is tightening the threaded fastener by means of torque  $M_d$  with a certain value. Torque  $M_d$ , also called total torque  $M_c$ , is the sum of the twisting moment  $M_s$  in the bolt shaft and torque  $M_t$  which takes into account the friction resistance of the screw or screw cap on the surface of the components joined.

In terms of industrial conditions in the automation of assembly processes, tightening of threaded fasteners is conducted using screwdrivers. The screwdrivers allow tightening of threaded fasteners with specified torque value within the tolerances. The most commonly used are screwdrivers with pneumatic drive. They allow to achieve high tightening torque within the tolerance of 20%. Electrical equipment is used less often used due to less developed tightening torques, however, they have the advantage of being able to control the exact value of the tightening torque.

Increasing the efficiency requires the use of mounting devices enabling the development of tightening torque over a wide range with the ability to control its value. This forces the construction of screwdrivers operating in integrated control systems of operating parameters with the ability to change their values [5]. In [7] a control method based on the artificial neuron network is presented. The system has been tested to diagnose the correctness of the mechanical association and damage recognition of threaded fastener. A neural network was trained using computer simulation analysis based on a mathematical model of the process of screwing.

In automated assembly processes it is important to enable smooth adjustment of the value of the tightening torque while maintaining its value of the specified tolerances. Modern designs of electric screwdrivers meeting the above requirements are described in [7, 6].

The original screwdriver being the subject of the article is a device [2] using the kinetic energy of the drive and operating system to do the job of screwing. As a drive the shunt DC motor with a voltage of 30 V was applied and to limit the value of the tightening torque the self-adjusting overload coupling was used. It is intended for install-

ing the bolts with diameters of M6 to M12, so it can develop tightening torque with a maximum value of  $M_d = 50.4 \text{ Nm}$ . The tightening cycle may be implemented according to the two methods. The method of single pulse provides a short time of technological process while maintaining the condition that the screwing torque is equal to tightening torque. During the method of successive individual pulses the bolt is tightened with  $i=1..n$  pulses, of which the  $n$ -th allows the development of the tightening torque. This method in practice is used when tightening the bolts with the dimensions of M8 – M12.

The construction work of the screwdriver was preceded by the development of a mathematical model of the process of screwing and balance of torques acting during each phase of operation was carried out. This allowed the calculation of the value of the kinetic energy of components of the drive and operating system translated into the tightening work. The process of tightening is characterized by the number of screwing pulses, screwing torque values at the end of each pulse and the time of screwing process. Later the algorithm of screwdriver operation control was created. During the process of screwing in a continuous way checking the value of the tightening torque occurs and is compared to the set value.

The results obtained from the mathematical model were used to create a database which is an integral part of the program controlling the screw-

driver operations. Supervision of the parameters of the tightening process is implemented by measurement of the angular speed of the screwdriver bit during each of the tightening pulse and the value of developed screwing torque. These values are compared with the values inherent in the database and assigned to the diameter of the screwed bolt. The control unit allows the cycle of work according to a single screwing pulse (Figure 1) and during subsequent screwing pulses (Figure 2).

### FUNCTIONAL TESTS OF THE SCREWDRIVER

Screwing process parameters and the adequacy of the implemented control algorithms have been checked on the test bench (Figure 3) consisting of the screwdriver and measuring tool [3]. This tool allows the following measurement: axial force in the threaded fastener  $Q$ , the twisting torque in the bolt shaft  $M_s$  and measuring the friction torque under the head of the bolt  $M_f$ .

Program controlling the screwdriver work also has the opportunity to visualize the parameters of its work and to compare them with the courses described using mathematical models. Visualization allows obtaining graphs depending between the process parameters and dependent on the diameter of the screw adapter chaser. Visualization allows to obtain graphical view of the correlation between the process param-

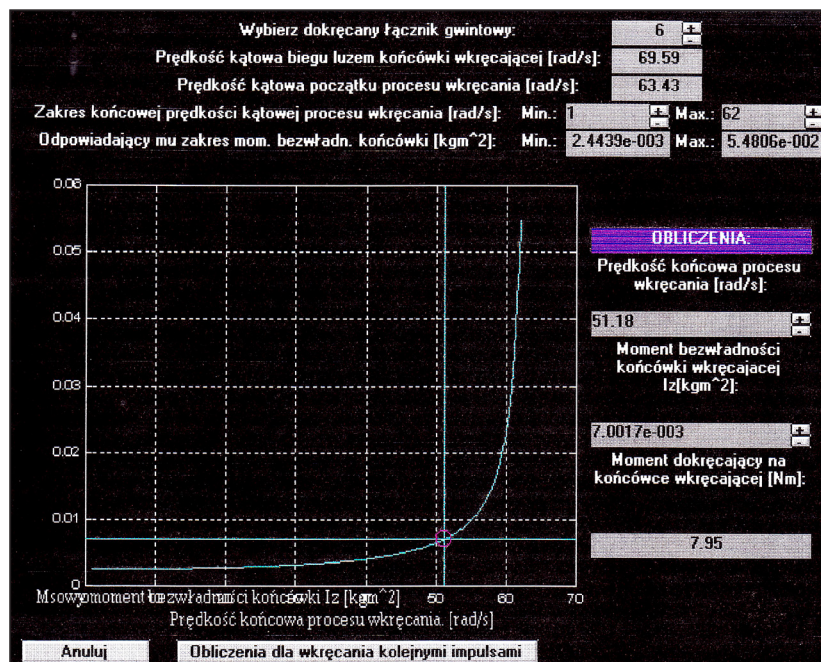


Fig. 1. Interface of the program controlling the screwing process realized during individual screwing pulse

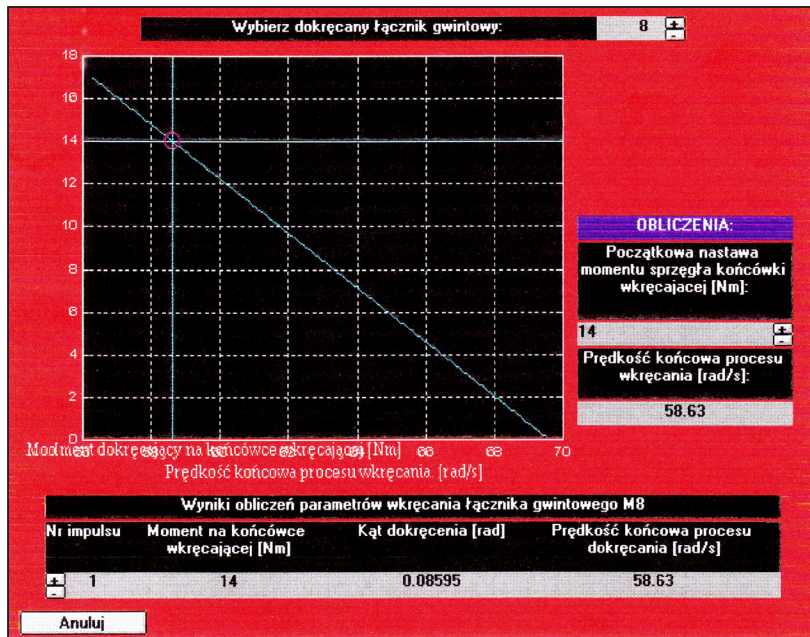


Fig. 2. Interface of the program controlling the screwing process realized during successive screwing pulses

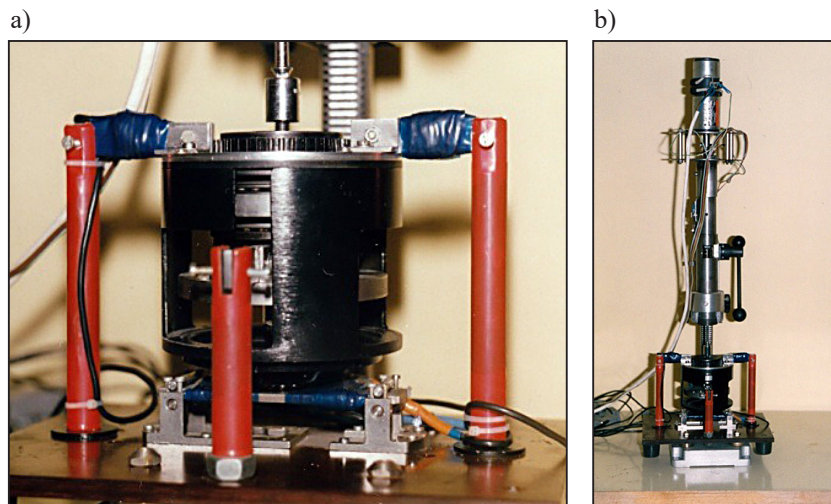


Fig. 3. The test bench to test screwing parameters: a – tool to measure the course of force and torques in the process of screwing, b – screwdriver on the test bench

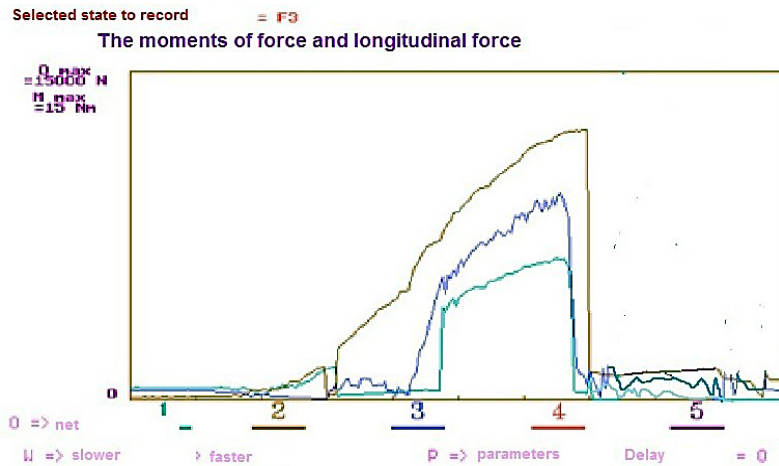
eters of screwing dependent on diameter of the screwed threaded fastener. In Figure 4 is an example of the process of screwing bolt M6 class 6.8 performed in class B.

### THE ADEQUACY OF THE MATHEMATICAL MODEL OF SCREWING PROCESS

The results obtained during the measurements helped to determine the range of variation of tightening torque and axial force in the bolt. Example values for bolt M6 are presented in the Table 1. Registered values of

the twisting torque  $M_s$ , friction torque  $M_t$  and axial force in the bolt were used to quantify the correlation between these variables and to determine the most likely function of the average values of the variables. The non-linear model was applied. Square of the curvilinear coefficient correlation was defined, which indicates what percentage of the spread of results is explained by means of the model based on correlation characterized by the type of function used to plot the curve of regression. Examples of courses of screwing process characteristics obtained for bolt M6 are shown in Figures 5 and 6.

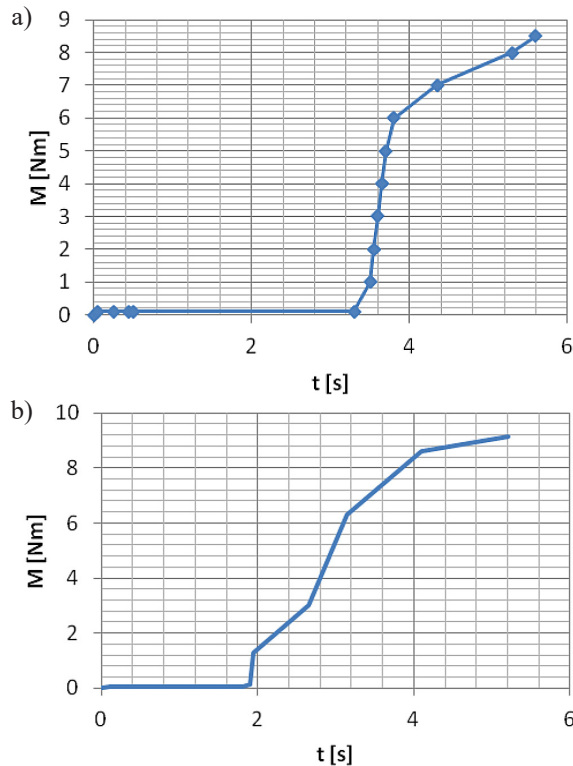




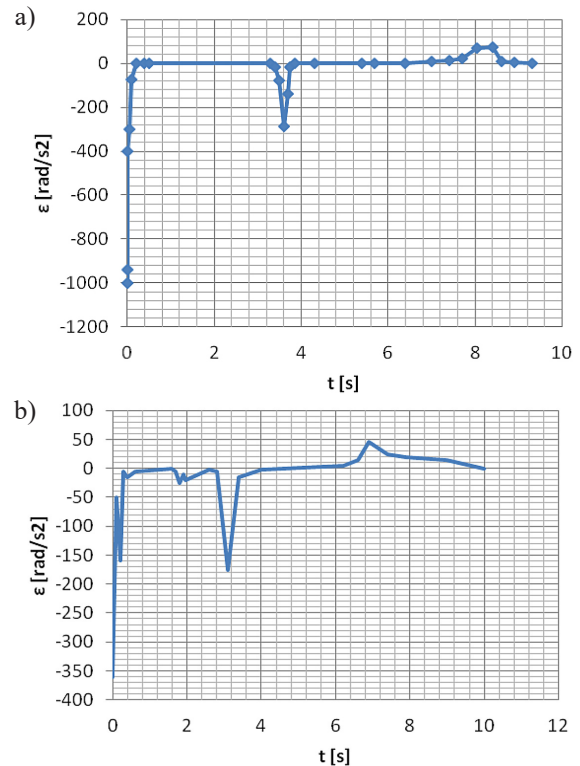
**Fig. 4.** Examples of characteristics of screwing bolt M6 6.8 B obtained on the test bench: 1 – friction torque under the bolt head, 2 – twisting torque on the thread, 3 – axial force in the bolt. The horizontal axis – the angle of rotation of the bolt. One – phase screwing – in by means of a screwdriver [2], in-screwing parameters measurement on the device [3]

**Table 1.** The values of the screwing parameters obtained when screwing bolt M6

Parameter	Tightening torque $M_d$ [Nm]	Twisting torque in the bolt shaft $M_s$ [Nm]	Friction torque under the head of the bolt $M_T$ [Nm]	Axial force $Q$ [N]
Mean value	9.426	5.316	4.11	5887
Minimum value	8.51	4.87	3.64	5386
Maximum value	9.50	5.26	4.24	6031
The average standard deviation	0.164	0.164	0.224	246.66



**Fig. 5.** Dependence of the tightening torque  $M$  on time  $t$  of the screwing process – a threaded fastener M6: a – on the basis of the mathematical model, b – the course of the actual process of screwing



**Fig. 6.** Dependence of angular acceleration of the screwing bit  $\epsilon$  on the process of screwing:  $t$  – a threaded fastener M6: a – on the basis of the mathematical model, b – the course of actual process of screwing

Polynomial functions of torque dependencies: twisting, friction and tightening depending on the axial force in the bolt with a thread M6: The process of tightening bolt M6:

$$M_s = 3.488 - 0.01148Q + 0.000012Q^2 - 3.5239 \cdot 10^{-9} Q^3 \quad r^2 = 0.8344 \quad (1)$$

$$M_t = 3.9613 - 0,01509Q + 0,000021Q^2 - 1.1278 \cdot 10^{-8} Q^3 \quad r^2 = 0.8114 \quad (2)$$

$$M_d = 3.8542 - 0.011825Q + 0.000013Q^2 - 4.06634 \cdot 10^{-9} Q^3 \quad r^2 = 0.7803 \quad (3)$$

The obtained functions allow to calculate the torque values characterizing the process of screwing depending on the value of the force Q necessary to obtain in the threaded fastener. The curvilinear model can be used to determine (with the set tolerance) parameters of screwing in the calculation of precise measures to reduce the safety factor of a threaded fastener.

## CONCLUSIONS

Presented experimental studies have shown compliance of obtained screwing parameters with theoretical assumptions. Operating parameters whose values were in the spread not exceeding 7% in comparison with the results of the calculations using mathematical models were obtained. The constructed screwdriver was used to study the effect of changes in the tightening torque depending on the type of protective covering on the windings of the thread and the presence of a lubricating agent [4].

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