Theoretical and empirical methods of estimating energy and force characteristics of impact wrenches

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Abstract: The Article represents theoretical and empirical methods of estimating the characteristics of impact wrenches when torquing specific threaded connections and in fixed anvil mode. They allow addressing the following issues: indirect determination of single impact energy in production conditions based on the proposed technique of estimating specific characteristics of stiffness and impact threshold of the wrenches, which are used to obtain base of the initial design values of the mathematical model. These methods and the techniques developed based on them allow for determination of single impact energy both in laboratory and production environment, which is important at the stage of tool creation as well as during its operation in order to reasonably develop the size range of impact wrenches, carry out strength analysis of their striking mechanisms and choose a proper tool for a specific range of threaded connections. The correct choice of the tool can make installation procedure much more efficient due to the reduced time for assembly and ability to control torquing tightness of threaded connections. In hydrotechnical construction a significant amount of work falls on assembling threaded connections in the use of metal structures, products, and in used construction equipment.

1 Problem statement

Creation of construction machines requires a great number of operations dealing with the assembly of threaded connections using hand-operated power tools like electric wrenches. Their high performance essentially determines the efficiency of the whole assembly process. In average, a single construction machine involves more than 300 threaded connections, which should be assembled reaching a certain degree of tightness specified for each one of them. It is known that tightness can be determined by measuring either the strain produced in the bolt being a part of a threaded connection, or the tightening torque. For assembling threaded connection such types of power tool like impact wrenches and electric screwdrivers for various kinds of fasteners are used. Most of electric wrenches can operate in impact mode and they are not equipped with a torque-controlling device. Meanwhile, it is torque-controlled tightening which creates design conditions for operation

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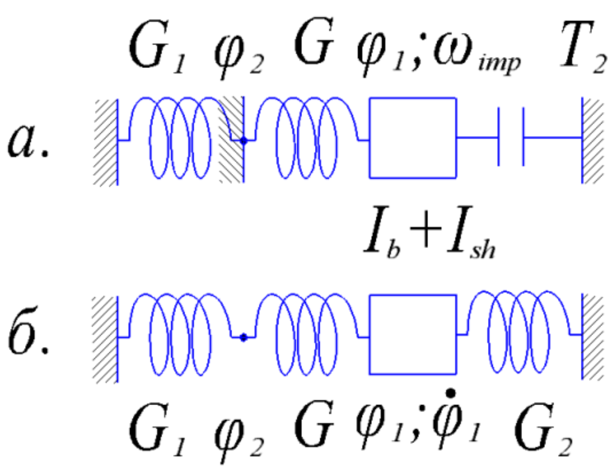
of threaded connections both with regard to their operating performance and service life. [1] For this reason, it is a very urgent issue to know how tightening torque depends on single impact energy of the impact wrench for a specific threaded connection. The single impact energy is a key characteristic of impact wrenches in order to make a correct choice of the tool. Analysis of the existing works covers the development of models of diverse complexity, which describe threaded connections and actuators of impact wrenches. For impact wrenches it is important to make estimations of the single impact energy in production conditions for groups of threaded connections. The established relation between the tightening parameter and the single impact energy allows identifying the region of rational values for threaded connections. Let us solve the problem based on the proposed threaded connection in the form of a simplified single-mass elastic friction model assuming the seamless contact between the adjoining parts and overcoming their minimum deformation. Based on this, we shall reveal the analytic dependence to determine the coordinates of impact wrench spindle and bolt as a function of the single impact energy and the number of impacts. On the practical side of the study, it seems reasonable to find an analytical solution for simplified model of the threaded connection, which allows for quicker resolving the problem of estimating the single impact energy in production environment in order to choose a proper tool.
Based on the simplified single-mass elastic friction model of threaded connection with self-retardation shown in Fig. 1 we can find analytical formula for determination of the coordinates of the wrench's spindle and the bolt's head as a function of energy and number of impacts [2].



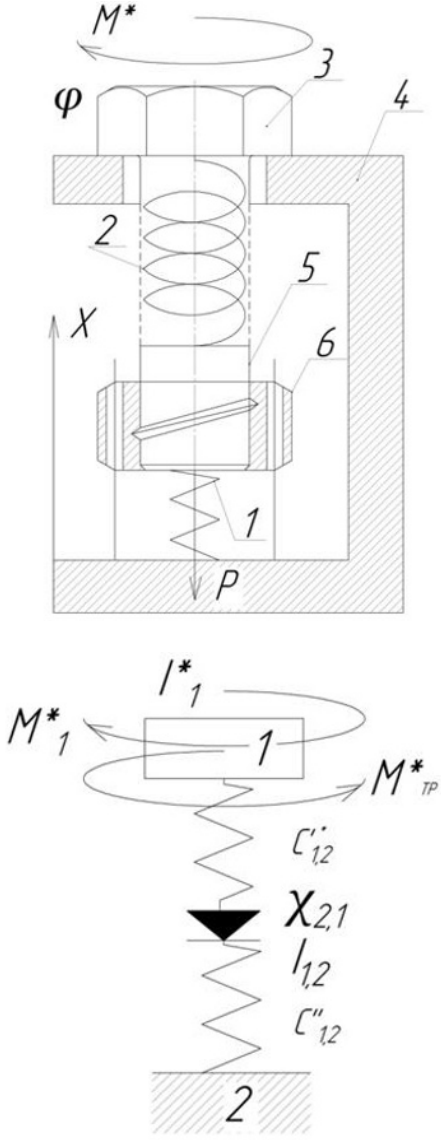


Fig. 1. Dynamic model of threaded connection during impact torquing: a – in spinning mode with fixed thread; б – in pulling mode.

G_1 – torsional stiffness of the spring imitating flexibility of parts; G – torsional stiffness of the bolt; φ_1 – angular coordinate of the bolt; φ_2 – angular coordinate of the self-retardation element (thread); I_{sh} – spindle's moment of inertia; I_b – bolt's moment of inertia; T_2 – friction torque under the bolt's head; ω_{imp} – post-impact rotating speed of the wrench's spindle

2 Results of mathematical model analysis

The mathematical model of the impact torquing for dynamic scheme (Fig. 1) is described by the following type of piecewise linear equation:

- in spinning mode with fixed thread

$$(I_{sh} + I_b)\ddot{\varphi}_1 + T_2 + G(\varphi_1 - \varphi_2) = 0 \quad (1)$$

$$\varphi_2 = const$$

- in pulling mode

$$(I_{sh} + I_b)\ddot{\varphi}_1 + T_2(\varphi_1) + C_1\varphi_1 = 0 \tag{2}$$
$$\varphi_2 = \frac{G}{G_1+G}\varphi_1$$

The mathematical model uses the following dynamic parameters:

$C_1 = \frac{GKr^2\text{tg}\alpha\text{tg}(\rho\prime+\alpha)}{G+Kr^2\text{tg}\alpha\text{tg}(\rho\prime+\alpha)}$ – reduced stiffness of the threaded connection in pulling mode;

$G_1 = Kr^2\text{tg}\alpha\text{tg}(\rho' + \alpha)$ – torsional stiffness of the spring imitating flexibility of parts;

$T_2 = -PRf sign\varphi_1$ – friction torque under the bolt's head;

$P = \frac{GKr\text{tg}\alpha}{G+Kr^2\text{tg}\alpha\text{tg}(\rho\prime+\alpha)}\varphi_1$ – tightening force;

G – torsional stiffness of the bolt; p – pitch of thread; α – angle of thread; r – average radius of thread; $\rho' = \text{arctg}\frac{f}{\cos\frac{\beta}{2}}$ – reduced friction angle in the thread; f – friction coefficient of the friction pair; β – flank angle; R – equivalent friction radius of the bolt's underhead bearing surface; φ_1 – angular coordinate of the bolt; φ_2 – angular coordinate of the self-retardation element (thread); I_{sh} – spindle's moment of inertia; I_b – bolt's moment of inertia; $\rho_{rest}' = \text{arctg}\frac{frest}{\cos\frac{\beta}{2}}$ – reduced static friction angle in the thread; K – equivalent longitudinal stiffness of the bolt or body; $f_{rest} = kf$ – static friction coefficient.

Based on the analysis of energy balance equations within the mathematical model, the following recurrence relation was obtained:

$$\varphi_k = \sqrt{E\omega_{imp}^2 + (E^{rest} - E\sigma^{rest})\varphi_{k-1}{}^2}, \tag{3}$$

Where φ_k – bolt's head coordinate reached at the current impact; φ_{k-1} – bolt's head coordinate after previous impact; E, E^{rest}, σ^{rest} – parameters of a specific threaded connection (according to Table 1); $\omega_{imp} = \sqrt{\frac{2E_{imp}}{I_{sh}+I_b}}$ – post-impact rotating speed of the wrench's spindle; E_{imp} – single impact energy of the impact wrench.

3 Engineering technique of impact energy calculation

Calculation algorithm of the proposed technique include:

1. Determination of the bolt's coordinate at the transition to the impact mode

$$\varphi_0 = \frac{T_{st}}{C_1},$$

where T_{st} – maximum torque in static mode of impact wrench operation (usually not exceeding 5…8 N*m).

2. Determination of post-impact rotating speed ω_{imp} using a given value of wrench impact energy (spindle's moment of inertia assumed to be 2.107 10^{-5} and 9.057 10^{-5} kg*m^2 for the spindles intended for heads ½" and ¾" respectively).[3]

3. Iterative calculation of the coordinate according to equation (3) for the given number of impacts (in this case k is the order number of an impact) and the corresponding torque.

$$T(k) = C_1\varphi_k.$$

4. Determination of maximum torque when tightening of given threaded connection with specific impact wrench according to the formulas

$$\varphi_{\lim} = \sqrt{\frac{E}{1-(E^{rest}-E\sigma^{rest})}}\omega_{imp}, \quad T_{lim} = C_1\varphi_{lim} \tag{4}$$

5. Determination of wrench impact energy with measuring limit torque in production

conditions (at a representative threaded connection) by comparing the measured value with the results of calculation according to para.

4 Conclusions

The proposed experimental-theoretical methods can improve the efficiency of assembly work through the use of rational methods for creating and operating impact wrenches.

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