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DEVELOPMENT OF MODELS AND TECHNIQUES OF PARAMETERS CALCULATION OF THE EQUIPMENT USED FOR IMPROVEMENT OF THE QUALITY OF THREADED CONNECTIONS ASSEMBLY

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Abstract. The questions of assembly of engineering products by screw-driving mechanisms are shown in the paper. The author designs a calculation technique of diagnostic tester parameters for definition of single impact energy of a box wrench. The results of theoretical and experimental researches of this method of control and guideline on its application are presented.

Key words: threaded connection, assembly**,** quality of assembly, energy of single impact, torque tightening, diagnostic tester, number of impacts

1. Introduction

Threaded connections make up approximately 25-35 % of all used kinds of connections [1] and are one of the most widespread means of interfaces and they are met practically in all hardware products of engineering. Thus, the labour input of their assembly specially in conditions of small-serial and serial productions remains high mainly because of a considerable fraction of a manual labour. The main reasons of high labour input are [2, 3] complexity of automation and comparative complexity of maintenance of demanded quality of assembly works. However consumer properties of hardware products and their engineering-and-economical parameters are determined in many respects by quality of assembly operations, as closing stage of production process.

The automation of assembly processes of threaded connections can be effective only at output of production permitting in a sufficient measure to load the equipment [1], that in conditions of isolation of manufacturers and competing on price even for small batch workpieces, calls problems.

An effective direction of quality assurance of output production is technological advancement of assembly [5]. But for now widespread small-batch production the most effective is the approach using of advancement not only of the technology, but also the equipment for assembly of threaded connections and control of a tightening level. Therefore it is necessary at the solution of problems of quality assurance of threaded connections from positions of the technology of their assembly to consider methods, used for it, and means of regulation of tightening efforts. One of the directions of assurance of quality assembly of threaded connections in conditions of small-batch production is usage of impact wrench. They allow receiving considerable efforts of a tightening at small driving power that provides lowering weight and sizes of these means of mechanization [6].

One of factors in assembly quality of threaded connections is the features of technological capabilities of used box wrenches. The poor notice to development of mathematical models for calculation of parameters of the used equipment for assembly of threaded connections, for example, energy of single impact, is one of reserves of an increase in the effectiveness of production, so it promotes reaching of the indispensable qualitative indexes.

Thus, the creation of new equipment and engineering development for effective realization of operations of assembly of threaded connections with development of the mathematical description of their operation and technique of calculation of parameters of the used assembly equipment is the important and indispensable component at a solution of a problem of maintenance of their quality.

2. Main body

Maintenance of reliable operation and qualitative accomplishment of technological process of assembly needs realization of tests of box wrenches by their operation in a shock mode on special diagnostic tester, where the conditions of a loading of box wrenches approximate to operational conditions are as much as possible. It's necessary to pay special attention to definition of energy and power characteristic of shock box wrenches during tests. This provides finding of a range of tightening threads.

The energy of simple shock A_e equal to energy of impacting mass (anvil and added to it of a driving tool with a nut), received at transfer of shock impulse from a flywheel to an anvil is the main normalized parameter for rarely impact wrenches. The introduction of such a parameter in shock box wrench characteristics allows by a calculation way [2] to define the tightening torque M_i of a threaded connection after ***i-th*** box wrench shock, indispensable amount of n box wrench shocks for reaching the demanded tightening torque and other characteristic describing this technological process. Actual goal is the determination of simple shock energy of rarely impact wrench during its operation.

Some methods of theoretical calculation of simple shock energy are known [7].

The most actual for applying in constant practice is the definition of values of shock energy on special diagnostic tester where energy of an anvil is perceived by a loaded element emulating a load on a threaded connection during a tightening.

In one of such diagnostic tester [5] the loaded element is executed as torsion. One of torsion end is hardly fastened in the body of the diagnostic test bench, and other is on coaxial to a spindle of a box wrench. By operation of a box wrench its shock energy is spent for twisting torsion:

$$A_e = \frac{M}{2K}, \tag{1}$$

where: M - moment of twisting;
K - torsional stiffness of torsion.

This energy is defined by potential energy of a torsional deformation by measuring an angle φ its twisting:

$$A_e = \frac{GJ_p}{2l}, \tag{2}$$

G - rigidity modulus;
$J_p = 0{,}1d_t^4$ Polar inertia moment of cylindrical torsion, diameter of section which one - d_t
l - length of torsion.

The applying in the given diagnostic tester of the torsional simulator of a threaded connection has essential defect. The potential energy twisted as a result of shock of torsion again turns at its unloading to kinetic energy of an anvil. Thus the speed of a recoil of a flywheel appears greater than at a tightening of a threaded connection. In outcome the mode of collision of a box wrench parts on the diagnostic tester differs from a mode of collision at a loading of a real threaded connection.

For maintenance of equivalence of collision modes at tests on the diagnostic tester and at work of a box wrench the loaded device should emulate both elastic, and dissipative properties of a threaded connection. This condition runs in the diagnostic tester with the elastic - frictional simulator [6]. Such construction is presented in a figure 1.

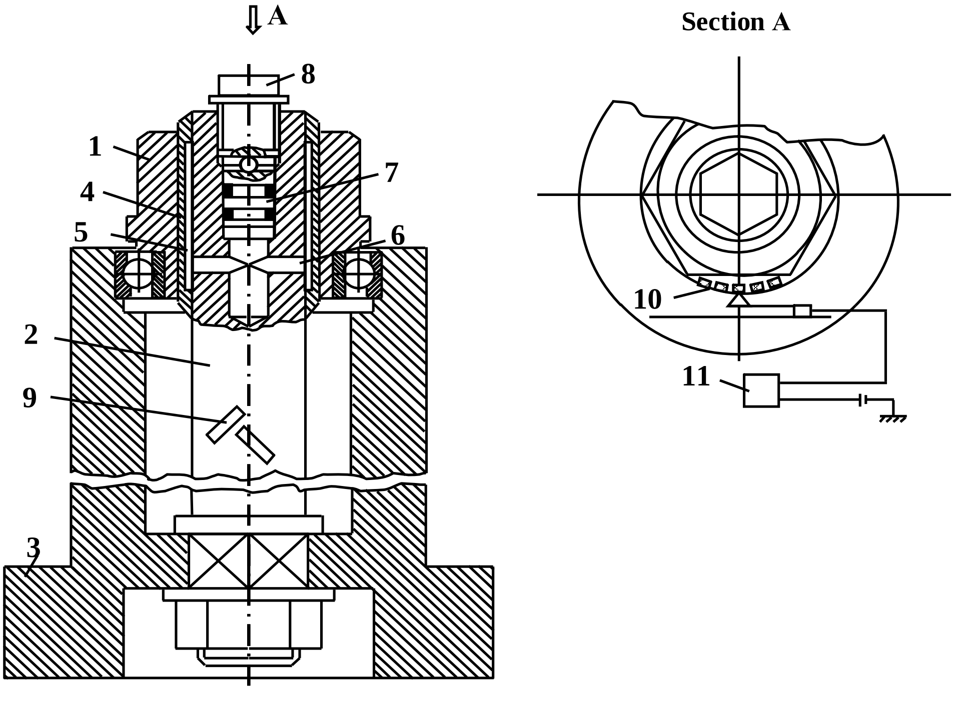

Fig. 1. Stand for measuring of shock energy of a box wrench

The loaded device of the considered diagnostic tester is executed as changeable prism 1 with a smooth axled bore (inertia moment of this prism is equal to inertia moment of a nut) and emulating rod 2. One of rod end is fastened in the body 3 diagnostic tester, and other end by means of the hydraulic clamping device is coupled to an internal cylindrical surface of an axled bore of a prism. The ring-type diaphragm 4 hydraulic clamping device is hardly fastened with a rod and will form the hermetic camera 5, joint with the help of the channel 6 with an axled counter hole of a rod. There the cylinder piston 7 and screw plug 8 are located. The moving of the cylinder piston 7 at rotational displacement of a screw plug 8 creates requisite pressure of hydraulic fluid in the hermetic camera 5 of hydraulic clamping device, ensuring resistance to rotational displacement of a prism at the expense of friction between conjugated surfaces.

By transfer of shock impulse from a box wrench the prism 1 rotates relative to the bodies 3 of diagnostic tester, transmitting on a rod 2 of moment of frictions, which limits its rotational displacement. The value of moment of friction is registered by resistance deformation gauges 9, turned on to a measuring circuit, and the rotation angle of a prism 1 is measured with the help of the step angular sensor 10, containing uniformly alternating current- conducting and isolating sections. The contact of current collector 11, included in a circuit of a pulse counting device 12 slips along these sections at rotational displacement of a prism 1. Thus the energy of simple shock [7] is defined on dependence:

$$A_e = M_r \varphi_1 + \frac{M_r{}^2}{2K_2}, \tag{3}$$

where: M_r - resisting moment to rotational displacement of a prism;

φ_1 - rotation angle of a prism;

K_2 - torsional stiffness of a rod.

Let's consider process of a loading of the system «a box wrench - test stand». The flat model is presented in a figure 2.

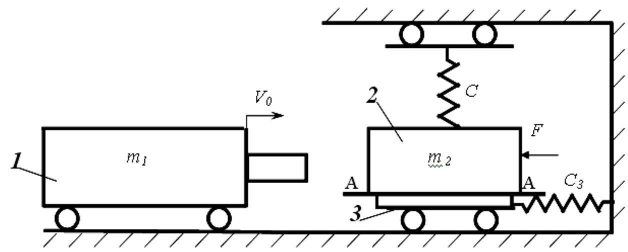

Fig.2 – Model of the system «means for assembly of threaded connections - test stand»

In this model the body of 1 mass m_1 emulates a flywheel with inertia moment J_1, and body of 2 mass m_2 – anvil with affixed to it through a transitional spanner by a prism of the diagnostic tester. Their total inertia moment is J_2. The inertialess element 3 emulates a cylindrical rod 2 diagnostic tester, and elastic element C_3 - its torsional stiffness. The operating fluid pressure in a hermetic cave of the hydraulic clamping device is modelled by an elastic element with a stiffness coefficient C. The stiffness coefficient C on a surface A-A of the model creates resistance force F to relative moving of bodies 2 and 3, applicable to moment of friction M_r:

$$M_r = 0{,}5 p_k \pi d^2 l_k f\ , \tag{4}$$

where: p_k - pressure with one the ring-type diaphragm of the hydraulic clamping device on a changeable prism;

d - diameter of an axled bore of a prism;

l_k - length of a contact surface of the hydraulic clamping device;

f - coefficient of sliding friction.

As a result of collision of a body 1, moved with initial velocity V_0 and fixed before shock of a body 2 them postimpact speed will be as follows.

$$V_1 = V_0 \frac{(1 - R\mu)}{1+\mu} \quad \text{and} \quad V_2 = V_0 \frac{(1+R)}{1+\mu},$$

where: $\mu = \dfrac{m_2}{m_1}$ - inertial parameter of colliding bodies;

R - coefficient of restitution at shock.

In postimpact movement the shock energy is spent for a deformation of an elastic element and overcoming of friction at movement of bodies depicted by the differential equations:

$$m_2 \ddot{x}_3 = -c x_3 \quad \text{when } x_3 \le \frac{F_{tr}}{c} \quad .$$

$$\text{and} \quad \begin{matrix} m_2 \ddot{x}_2 = F_{tr} \\ m_3 \ddot{x}_3 = F_{tr} - c x_3 \end{matrix} \quad \text{when } x_3 \succ \frac{Ftr}{c}$$

The analysis of these differential equations demonstrates that the body 2 at first goes together with a body 3 under the law of oscillations: $x_3 = A \sin kt$, and then in an instant $t = \tau$, when the elastic element will become deformed on value $x_{3\tau} = \dfrac{F_{tr}}{c}$, their separate movement will begin. At a stage of separate movement the body 2, overcoming friction force, slips on a body 3. The body 3 continues to oscillate concerning centre, displaced concerning of the equilibrium position on spacing interval $x_{3\tau}$.

At the first stage of oscillating motion of a body 3 parts of simple shock energy pass in potential energy of an elastic element deformation. The degree of energy, expended on a deformation depends on duration of this stage: if the separation of movement of these bodies will not happen during a quarter of a period of these oscillations, all shock energy will be spent for a deformation of an elastic element, as in the torsional diagnostic tester.

For maintenance of adequate accuracy of measuring of shock energy on the offered diagnostic tester it is recommended to select elastic-inertial characteristic of the diagnostic tester (torsional stiffness of a cylindrical rod, moment of friction) such, that the large part of shock energy (to 90 %) was spent for overcoming of friction between conjugated surfaces of a prism 1 and cylindrical rod 2 of diagnostic tester.

The torsional stiffness of rod is selected on the selected sizes (diameter *d* and length *l*) of cylindrical rod:

$K_2 = 0{,}1\dfrac{Gd4}{l}$, and then value of friction moment $M_т$ through a part of simple shock energy is calculated:

$$M_T = \sqrt{\xi A_e 2K_2} \qquad (5),$$

where ξ - factor describing a part of deformation energy of a rod (at accounts was accepted ξ =0,01).

For creation of demanded moment of friction[8] it is necessary in the hermetic camera of the hydraulic clamping device to create operating pressure of a liquid *P*, providing sufficient effort $P_к$ of forcing down of a ring-type diaphragm of the hydraulic clamping device to the changeable prism defined according to previous dependence:

$$P_k = \frac{2M_T}{\pi d^2 l_k f}.$$

The earlier investigation [8] established that the ring-type diaphragm of the hydraulic clamping device (fig. 3) with the thickness *h* and length *l* under operating of fluid pressure *P* in the hermetic camera is subjected to a local bending in neighborhoods *l** of the fastened butt ends.

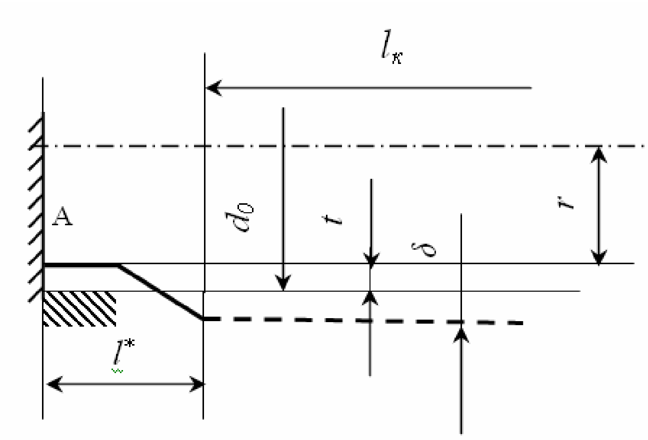

Fig. 3 – A general view deformable diaphragm of a hydraulic clamping device at absence of restriction on the part of the bushing; at presence of restriction on the part of the bushing.

Thus radius *r* of a median membrane at absence of restriction is changed (on distances $l^* = 2{,}35/\beta x$ from butt ends) on value $\delta = \dfrac{Pr^2}{Eh}$, and on other length ($l - 2l^*$) keeps this deviation, changing in limits no more than 3 … 4 % from value δ (fig.3). In real conditions of hydraulic clamping device work, when the diaphragm deformation is limited to a gap $t = 0{,}5(d - h) - r$, last presses on an insert by contact pressure $P_к$, equal to a difference of pressure ensuring diaphragm deformation on size:

$$\delta = \frac{P \cdot r^2}{E \cdot h} \qquad (6)$$

and on size of a backlash:

$$t = \frac{P_t \cdot r^2}{E \cdot h}, \qquad (7)$$

i.e.:

$$P_k = \frac{E \cdot h}{r^2}(\delta - t) \qquad (8)$$

The equation (8) enables to establish that part of working pressure in the hermetic chamber, which is realized for creation of the required moment *M* of friction determined from expression (4).

Thus, the received dependences allow making accounts of constructive parameters of the elastic-frictional diagnostic tester for measuring simple shock energy.

The account of characteristic of the diagnostic tester is recommended to be done in the following order:

1. To select the sizes of a cylindrical rod depending on a nominal diameter *d* of thread, having accepted its diameter $d_2 \approx 0{,}8d$ and length $l_2 \approx 5d$, having rounded off these value to nearest normalized.
2. To calculate value of friction moment, having applied dependence (5).
3. To establish the radial sizes of device. To choose a middle diameter $d_c = 2r$ ring diaphragm of a hydroclip, depending on a nominal diameter *d* of threaded connection. Proceeding from conditions of maintenance of availability to a fixing detail, sufficient durability and necessity of reduction of inertness of the device, it is recommended to accept $d_c = 1{,}5d$ with the subsequent rounding off of this size up to the nearest normalized size.
4. To determine thickness *h* ring diaphragm from a condition of durability by transfer of the twisting moment equal *M* to the tightening torque of threaded connection $\tau = \dfrac{M}{W_p} \le [\tau]$. That polar moment of resistance of a thin-walled ring by thickness *h* and by a

middle diameter d_c (under condition of $h < 0,1\ d_c$) is defined by dependence [10]:

$$W_p = \frac{\pi d_c^2 h}{2}$$, we shall receive:

$$h \geq \frac{2M}{\pi d_c^2 [\tau]},$$

where $[\tau]$ - admitted tangential stress of a material diaphragm.

5. To establish size of a backlash between surfaces of diaphragm of a cylindrical insert in the non-loaded condition, and also required size of deformation diaphragm for creation of the necessary moment of friction between these surfaces. The interface of these details on surfaces with a nominal diameter $d_B = d_c + 2h$ is recommended to be carried out with backlash, appropriate to fit $\frac{H7}{h6}$, and in working order it connection should correspond to interference fit $\frac{H7}{s6}$. Then the maximal backlash between surfaces will be: $t = H7_d + h6_d$, and settlement deformation diaphragm: $\delta = H7_d + s6_u$, where $H7_d$, $h6_d$, $s6_u$ - bottom (d) and top (u) of a deviation from a nominal diameter d_B in the appropriate fit.

6. To establish the minimal specific pressure P_k on the contact surfaces of diaphragm and of a cylindrical insert on dependence (8):

$$P_k = \frac{4E \cdot h}{d_B^{\ 2}}(\delta - t).$$

7. Using the formula (6) to calculate required working pressure P in the hermetic chamber of a hydraulic clip:

$$P = \frac{4Eh\delta}{d_B^2}$$

8. From (4) to determine required length l_k contact surface of diaphragm:

$$l_k = \frac{2M}{\pi d_B^2 P_k f},$$

where f - coefficient of sliding friction.

9. To determine length of diaphragm $l = (l_k + 2l^*)$, previously having calculated parameter of an environment β on dependence $\beta = \frac{1,817}{\sqrt{d_B h}}$ and length of deformable sites $l^* = \frac{2,35}{\beta}$.

On the submitted technique the account of parameters of several standard sizes of the diagnostic tester in range of diameters of threads 36 … 56 mm was carried out. The results of accounts are submitted in the table 1:

Table 1

Parameters	Value of parameters			
d, mm	36	42	48	56
A_e, J	40	63	100	160
M, Nm	1100	1800	2700	4300
K_2, Nm/rad	43200	68600	102400	281000
d_2, mm	30	35	40	45
l_2, mm	180	210	240	280
M_T, Nm	185	294	452	948
d_0, mm	35	40	45	52
h, mm	1,2	1,5	1,8	2,5
$t\ 10^{-3}$, mm	44	44	44	50
δ, 10^{-7} mm	79	79	79	95
P_K, MPa	28,8	27,6	26,1	34,9
P, MPa	65,1	62,3	58,9	71,7
l_K, mm	31,5	38,5	47,8	55,1
l, mm	48,5	59,1	71,2	85,7

Friction coefficient between contacting surfaces of diaphragm and cylindrical insert selected to be equal of 0,1. Calculated value of thickness diaphragm are increased up to the sizes, specified in the table, in view of safety factor.

Knowing single impact energy it is possible to calculate number of impacts of a box wrench indispensable for reaching of calculating tightening torque:

$$n = \frac{\ln\left[1 - \frac{M^2(\xi_i - \xi_{i-1})}{2A_e K}\right]}{\ln(1+\xi_{i-1}) - \ln(1+\xi_i)} \qquad (9)$$

where ξ_i и ξ_{i-i} - structural coefficients describing a ratio of rigidity of system components accordingly in the end and in a start of impact cycle.

Under the introduced formula (6) the number of impacts of a box wrench, indispensable for experimental researches, was determined. In calculations the axial flexibility of subtended details was accepted twice as much as flexibility of a rod of a bolt, and the friction coefficients in a thread and at butt end of a nut were received for a case of uncovered details with a grease equal accordingly 0,095 and 0,078. The torsional stiffness was determined in range of diameters of a thread 30 … 160 mm for a rod of bolts of the indicated sizes and cylindrical spindle of a box wrench with diameter d_{sh} = 1,4d and length l_{sh}=d. At calculation of energy parameters the number of impacts was established from conditions of limitation of value of a relative increment of the moment on a key for the last impact. The calculations have shown that for threaded connections having different diameters of a thread and length of fasteners, i.e., different axial flexibility, value of a relative increment of the moment *δM* at identical quantity of impacts differs unsignificantly.

The standard oscillogram of a tightening process is shown in a figure 4.

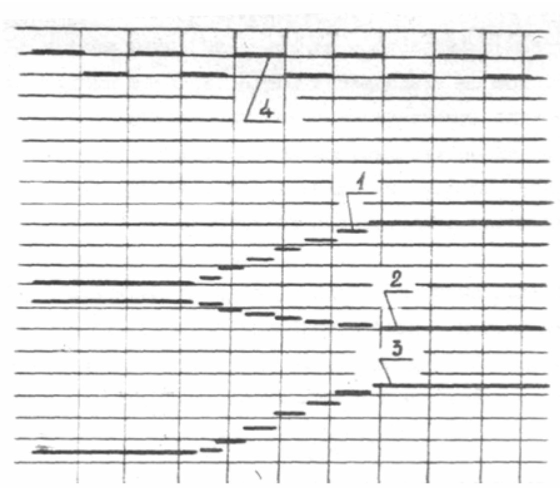

Fig. 4. - Oscillogram of a tightening process of a bolt: 1 **-** lengthening of a bolt during a tightening; 2 **-** moment at butt end of a nut; 3 **-** moment in a thread; 4 **-** time signal

The processing of the obtained experimental data was conducted pursuant to the generally accepted guidelines and with usage of the application package of statistical processing [11]. The researches have demonstrated good enough convergence with theoretical calculations, according to which the tightening should be executed for 7 impacts. The relative error has appeared below generally accepted and equal $\pm$ 8,24 %.

Conclusions

Thus, the introduced model of a system «means for assembly of threaded connections **-** test stand » and technique of calculation of the basic parameters of elastic **-** friction characteristic of simulators of thread connection allow to project some designs of the test bench for enough precise measurement of single impact energy of the rarely impact wrench. The number of shocks of a box wrench for reaching factored moment is calculated on known energy of simple impact. That promotes increase of efficiency and quality of a manufacturing process of thread connections assembly.

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