UDC 667.64:678.026

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DIAGNOSIS OF THREADED JOINTS USING ACOUSTIC WAVES

С.В. Ковалевський, О.С. Ковалевська, Г.А. Євдовська. **Діагностика різьбових з'єднань за допомогою акустичних хвиль.** В роботі розглянуті сучасні методи акустичної діагностики деталей. Використання акустичних хвиль при діагностиці різьбових з'єднань дозволяє проводити контроль вузлів, болтових з'єднань при складанні, а також майже миттєво виявляти дефектні вироби, невірні розміри та інші чинники браку за ознаками акустично частотної характеристики. При великій кількості різноманіття різьбових деталей, значного розкиду за шагом та діаметральним розмірам, застосування акустичних хвиль представляє собою новий інноваційний підхід до неруйнівного контролю вузлів при складанні виробів машинобудування. Мета – розробка алгоритму діагностики різьбових з'єднань при складанні вузлів із застосуванням акустичних хвиль. Для контролю деталей вузлу використовувався акустичний метод зі зняттям частотної характеристики і побудовою нейронної мережі. Для створення нейронної мережі було виміряне всі розміри деталей, проведено акустичну діагностику зі зняттям частотних характеристик і внесено отримані данні в програму NeuroPro. Для отримання частотних характеристик вузлів використовувався пристрій з двома датчиками. Один датчик працює на прийом другий посилає постійний сигнал на частоті білого шуму. Кожен вузол болтів був змінений загвинчуванням болтів до гайки на 10º. Замірювання проводилося з загвинчуванням болтів в позиціях: 0º, 10º, 20º. За допомогою нейронної мережі було проаналізовано ступінь затяжки гвинтів вузла, поділено по категоріям та визначено з них найбільш значущі. Експеримент показав, що достатньо мати 2 фільтра частот, щоб визначати розміри з точністю до 0,03 мм. Побудова нейронної мережі деталей і складеного вузлу дозволить майже миттєво виявляти дефектні вироби, не вірні розміри та інші чинники браку за ознаками акустично частотної характеристики. За даною методикою можливо проводити контроль вузлів, болтових з'єднань при складанні.

Ключові слова: різьбові з'єднання, акустичні хвилі, нейронна мережа, крутний момент

S. Kovalevskyy, O. Kovalevska, H. Yevdovska. **Diagnosis of threaded joints using acoustic waves**. The paper deals with modern methods of acoustic diagnostics of parts. Using of acoustic waves in the diagnosis of threaded connections makes it possible to inspect assemblies, bolted connections during assembly, as well as to almost instantly to identify defective products, incorrect dimensions and other factors of rejection based on the acoustic frequency response. With a large variety of threaded parts, a significant variation in pitch and diametrical dimensions, the use of acoustic waves represents a new innovative approach to non-destructive testing of units in the assembly of mechanical engineering products. Purpose: Development of an algorithm for diagnostics of threaded connections when assembling units using acoustic waves. To control the details of the node, an acoustic method was used to take the frequency response with the construction of a neural network. To create a neural network, all dimensions of the parts were measured, acoustic diagnostics were carried out to remove frequency characteristics, and the obtained data were entered into the NeuroPro program. To obtain the frequency characteristics of the nodes, a device with two sensors was used. One of them worked for reception, the second sent a constant signal at the frequency of white noise. Each bolt assembly was modified by screwing the bolts to the nut 10º. The measurement was carried out with screwing the bolts in the positions: 0º, 10º, 20º. Using a neural network, data on the degree of tightening of the bolts of the node were obtained and divided into categories. The most significant of them have been identified. The experiment showed that it is enough to have 2 frequency filters in order to determine the dimensions with an accuracy of 0.03 mm. Building a neural network of parts and a prefabricated unit will allow to almost instantly identifying defective products, incorrect dimensions and other factors of rejection based on the acoustic frequency response. This technique can be used to control units, bolted connections during assembly.

Keywords: threaded connections, acoustic waves, neural network, torque

Introduction

Nowadays, issues related to the control of threaded connections in mechanical engineering are relevant due to the fact that in many designs threaded connections are the responsible components that determine the reliability, strength and safety of the whole mechanism. In case of insufficient or excessive tightening force, the threaded connection does not meet the requirements for reliability and quality proposed to it, so increased requirements are made to ensure the accuracy of the tightening force [1].

At the stage of tightening there is a power short circuit of the connecting parts, which is accompanied by a change in the stress-strain state of the connection and the micro geometry of the thread, the operational properties of the threaded connections are finally formed [2].

DOI: 10.15276/opu.3.62.2020.03

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

The efficiency of the assembly process depends on many factors, the main of which are static and fatigue strength, pre-tightening force, thread geometry, etc. In case of insufficient or excessive degree of tightening, the assembly does not meet the required characteristics, and plastic deformations of the product, temperature factors and vibrations lead to the loss of locking properties of the connection during operation.

Analysis of recent research and publications

To improve the quality of the assembly process, in [3, 4] it is proposed to use a combination of ultrasonic and shock-pulse method. In the case of application of this approach in combination there are changes in the kinematic conditions of contact of surfaces, friction is reduced, and the nature of the stress state of the metal in the friction zone changes. However, the disadvantage is the inaccuracy of the control of the variable length of the thread profile.

The use of known tool methods to control the parameters of threaded connections is limited by low performance and inability to use during operation of the node.

The disadvantage of magnetic methods [5] is the inability to measure the depth of cracks, the difficulty of controlling the internal thread, as well as limitations in the study of non-ferromagnetic materials and alloys.

Weakening of tightening of a threaded connection can lead to sharp decrease in operational properties of knot or even to its breakage [6].

To increase the reliability and efficiency of threaded joints, the use of solid lubricating coatings, such as polymers and composite materials based on solid lubricants, which increase the uniformity of load distribution on the turns of threaded joints [7].

The main reason for the destruction of threaded parts is the inability to obtain reliable information about the amount of force acting on these parts during installation and operation, as there are no methods for experimental determination of these forces [8].

Non-destructive acoustic method, which involves the use of special ultrasonic equipment, is the most advanced method of monitoring the condition of threaded connections [9]. In order to obtain information about the voltage inside the threaded connection, it is affected by acoustic waves, and then takes them and compared the obtained characteristics with the reference.

The acoustic method allows carried out contactless control of uniformity of tightening of threaded connections in the course of operation without dismantling and stopping of production [10].

The authors [11, 12] show the relevance of the development of acoustic methods for controlling the stress – strain state of threaded joints. Methods and schemes of acoustic measurements are presented. The result of development and introduction into the production process of specialized equipment is described, which provides an increase in the accuracy of determining the mechanical stresses in the threaded connection.

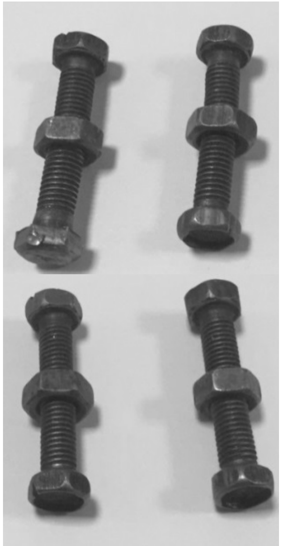

Fig. 1. Bolts are folded

Objective

To develop an algorithm for diagnosing threaded joints when assembling assemblies using acoustic waves.

Presentation of the main material

Control the details of the node leading filling stations one by one and in folded form, it is proposed to use the acoustic method with the removal of the frequency response and the construction of a neural network. To build a neural network, it is necessary to measure all the dimensions of the part, perform acoustic diagnostics with the removal of frequency characteristics and obtain data to enter the program Neuro Pro. In the program the neural network of a detail of the representative is built then training of a neural network begins. The neural network learns to correlate the obtained frequency characteristics with the data of the details of the representative assembled node.

An experiment was performed according to the developed method.

8 M8 bolts were used for the experiment. All sizes of bolts were measured, after measurement bolts were fed on nuts (Fig. 1).

Thus, 4 composite nodes were obtained. A special device with two sensors is used to obtain the frequency characteristics of the nodes, the sensors are connected to a computer (Fig. 2). One sensor operates to receive the other sends a constant signal at a white noise frequency (Fig. 3).

Each bolt assembly was changed by screwing the bolts to the nut by 10º. The measurement was performed by screwing the bolts in the following positions: 0º, 10º, 20º. The obtained data are processed and entered into an Excel spreadsheet.

Audio Sweep Gen is used to create the signal (Fig. 4).

The program is used to remove the frequency response Spectrum Analyser (Fig.5).

Fig. 2. Device for acoustic diagnostics of the clamping force

Fig. 3. Connection of the sensor for signal supply

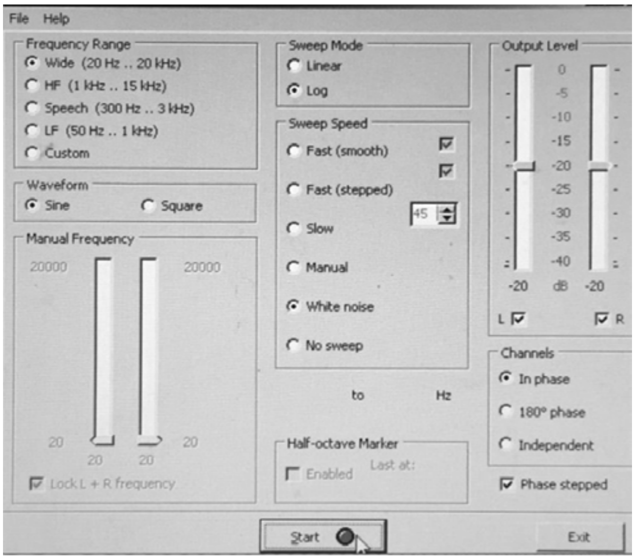

Fig. 4. Program settings Audio Sweep Gen

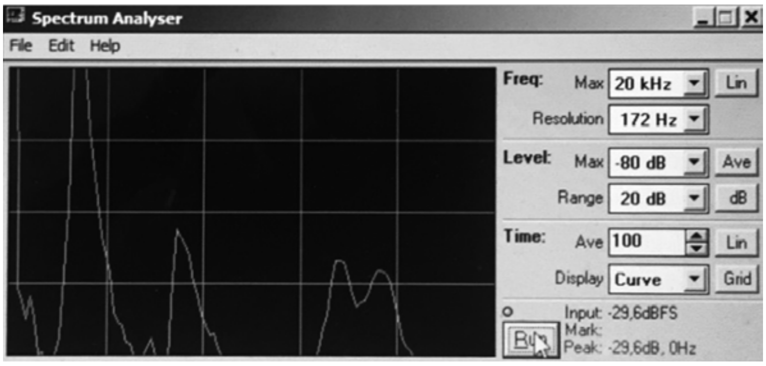

Fig. 5. Removal of the acoustic spectrogram

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

The obtained data of the frequency spectra are entered into the table Fig. 6. After data processing, the file is prepared to work in the program Nero Pro. The transposed files are saved in DBF format (Fig. 7).

1	Hz	s_0	s1-2_н	s3-4_н	s5-6_н	s7-8_н	s1-2_1	s3-4_1	s5-6_1	s7-8_1	s1-2_2	s3-4_2	s5-6_2	s7-8_2
2	0	-29,68	-29,66	-29,65	-29,7	-29,7	-29,66	-29,68	-29,62	-29,65	-29,65	-29,67	-29,65	-29,42
3	172,3	-29,68	-29,66	-29,64	-29,7	-29,7	-29,66	-29,68	-29,62	-29,65	-29,66	-29,67	-29,65	-29,42
4	344,5	-94,22	-93,4	-95,01	-92,32	-91,76	-91,37	-91	-91,44	-94,84	-86,24	-96,54	-91,44	-90,06
5	516,8	-95,04	-96,24	-98,15	-98,03	-96,6	-94,65	-95,14	-95,56	-97,57	-86,76	-97,23	-97,45	-87,15
6	689,1	-97,9	-97,94	-98,3	-100,3	-98,49	-93,73	-95	-97,22	-99,15	-91,47	-99,29	-97,92	-87,05
7	861,3	-99,48	-99,33	-99,93	-99,88	-98,43	-96,57	-93,09	-94,91	-99,35	-94,35	-99,86	-98,77	-92,37
8	1033,6	-98,68	-99,85	-100,57	-99,99	-100,06	-98,81	-95,55	-96,77	-99,3	-95,71	-100,66	-99,36	-99,38
9	1205,9	-98,97	-100,14	-100,11	-100,39	-99,88	-99,79	-99,29	-98,63	-100,22	-95,88	-100,66	-100,52	-96,09
10	1378,1	-100,23	-100,97	-99,72	-99,94	-99,27	-101,06	-100,02	-99,09	-99,92	-98,8	-99,66	-100,09	-98,59
11	1550,4	-100,76	-100,56	-100,26	-101,66	-100,46	-100,04	-101,35	-100,19	-99,97	-99,96	-100,85	-100,3	-94,71
12	1722,7	-100,91	-100,98	-101,12	-100,72	-100,46	-99,9	-100,37	-99,48	-100,52	-100,1	-101,21	-100,98	-91,95
13	1894,9	-101,29	-100,08	-101	-100,61	-100,68	-100,34	-100,31	-99,11	-99,51	-99,91	-100,04	-100,56	-94,75
14	2067,2	-101,77	-98,28	-100,41	-100,07	-100,42	-100,09	-100,75	-97,57	-95,58	-99,71	-93,2	-100,79	-87,6
15	2239,5	-102,16	-93,96	-99,18	-99,73	-98,25	-101,23	-100,14	-91,28	-90,65	-99,83	-88,83	-98,12	-84,04
16	2411,7	-101,59	-88,68	-97	-100,25	-94,54	-100,25	-100,05	-81,92	-90,62	-99,31	-89,2	-93,18	-85,29
17	2584	-102,12	-87,29	-96,63	-99,81	-87,46	-100,48	-98,34	-78,55	-94,34	-99,89	-91,51	-91,39	-88,62
18	2756,3	-101,7	-90,66	-97,82	-98,97	-84,57	-100,53	-96,27	-82,96	-96,93	-98,89	-94,13	-93,55	-89,07
19	2928,5	-102,22	-93,87	-99,54	-99,75	-87,68	-101,66	-93,88	-89,38	-98,4	-98,84	-95,68	-97,51	-90,37
20	3100,8	-102,24	-96,85	-99,3	-99,2	-93,14	-101,74	-86,8	-94,1	-98,66	-99,39	-96,04	-97,45	-91,7
21	3273	-101,21	-97,27	-99,2	-99,34	-95,75	-100,15	-82,13	-95,87	-98,98	-99,72	-94,58	-97,04	-92,96
22	3445,3	-101,77	-96,85	-99,26	-99,85	-98,09	-100,11	-85,77	-96,8	-99,65	-99,07	-93,75	-96,51	-94,19
23	3617,6	-101,9	-95,17	-99,28	-100,02	-98,95	-98,9	-93,59	-98,29	-98,98	-97,66	-93,02	-96,39	-96,5
24	3789,8	-101,59	-95,63	-100,03	-100,44	-97,09	-98,77	-96,95	-99,51	-98,73	-96,75	-92,75	-97,82	-97,33
25	3962,1	-102,04	-96,61	-100,46	-99,56	-96,48	-98,09	-98,51	-99,57	-97,55	-95,87	-92,68	-97,07	-97,05
26	4134,4	-102,41	-95,94	-100,56	-98,41	-96,63	-98,18	-98,55	-99,73	-96,4	-96,02	-92,37	-97,2	-97,83
27	4306,6	-102,8	-94,81	-100,54	-97,67	-98,16	-99,28	-97,78	-100,66	-96,27	-95,73	-92,14	-96,42	-99,11
28	4478,9	-101,74	-93,29	-100,02	-93,46	-98,85	-98,48	-96,87	-100,64	-95,18	-96,17	-91,63	-95,97	-99,56
29	4651,2	-102,45	-93,93	-99,87	-90,96	-99,68	-98,06	-96,86	-101,57	-95,44	-97,67	-91,5	-96,61	-100,45
30	4823,4	-101,87	-97,72	-98,94	-92,4	-99,23	-96,27	-94,29	-100,43	-96,08	-95,74	-91,69	-96,89	-99,1

1	Hz	s_0	s1-2_н	s3-4_н	s5-6_н
2	0	-29,68	-29,66	-29,65	-29,7
3	172,3	-29,68	-29,66	-29,64	-29,7
4	344,5	-94,22	-93,4	-95,01	-92,32
5	516,8	-95,04	-96,24	-98,15	-98,03
6	689,1	-97,9	-97,94	-98,3	-100,3
7	861,3	-99,48	-99,33	-99,93	-99,88
8	1033,6	-98,68	-99,85	-100,57	-99,99
9	1205,9	-98,97	-100,14	-100,11	-100,39
10	1378,1	-100,23	-100,97	-99,72	-99,94
11	1550,4	-100,76	-100,56	-100,26	-101,66
12	1722,7	-100,91	-100,98	-101,12	-100,72
13	1894,9	-101,29	-100,08	-101	-100,61
14	2067,2	-101,77	-98,28	-100,41	-100,07
15	2239,5	-102,16	-93,96	-99,18	-99,73
16	2411,7	-101,59	-88,68	-97	-100,25
17	2584	-102,12	-87,29	-96,63	-99,81
18	2756,3	-101,7	-90,66	-97,82	-98,97
19	2928,5	-102,22	-93,87	-99,54	-99,75
20	3100,8	-102,24	-96,85	-99,3	-99,2
21	3273	-101,21	-97,27	-99,2	-99,34
22	3445,3	-101,77	-96,85	-99,26	-99,85
23	3617,6	-101,9	-95,17	-99,28	-100,02
24	3789,8	-101,59	-95,63	-100,03	-100,44
25	3962,1	-102,04	-96,61	-100,46	-99,56
26	4134,4	-102,41	-95,94	-100,56	-98,41
27	4306,6	-102,8	-94,81	-100,54	-97,67
28	4478,9	-101,74	-93,29	-100,02	-93,46
29	4651,2	-102,45	-93,93	-99,87	-90,96
30	4823,4	-101,87	-97,72	-98,94	-92,4

Fig. 6. Obtained frequency spectrum data

1	x117	x118	x119	x120	x121	x122	x123	x124	x125	x126	x127	x128	P
2	-103,01	-103,31	-103,77	-104,72	-104,92	-105,71	-107,58	-109,48	-111,04	-110,79	-111,97	-120,33	0
3	-103,3	-103,99	-103,51	-103,91	-105,45	-105,28	-106,61	-108,24	-110,13	-111,82	-112,42	-119,82	0
4	-103,31	-103,03	-104,01	-104,83	-105,26	-106,53	-108,79	-109,01	-110,61	-111,44	-112,22	-120,05	0
5	-102,71	-102,93	-102,91	-103,04	-103,39	-103,55	-105,47	-108,5	-109,92	-110,66	-111,96	-120,92	0
6	-102,25	-102,84	-103,38	-104,15	-105,38	-106,08	-107,37	-108,91	-109,13	-110,73	-111,96	-118,69	1
7	-101,13	-102,45	-103,72	-105,09	-106,63	-106,36	-107,68	-108,8	-109,4	-110,89	-112,08	-119,46	1
8	-102,57	-103,64	-103,91	-103,84	-105,47	-106,61	-107,42	-108,5	-109,81	-110,39	-111,38	-120,03	1
9	-103,1	-103,66	-103,53	-104,38	-105,25	-107,02	-107,85	-109,47	-110,13	-111,48	-111,8	-118,68	1
10	-102,64	-103,48	-104,2	-104,68	-105,54	-106,77	-108,7	-109,25	-109,53	-110,65	-111,88	-121,01	2
11	-101,16	-102,77	-104,13	-105,19	-105,44	-106,26	-107,39	-108,85	-110,5	-110,9	-112,11	-119,88	2
12	-102,08	-103,71	-104,43	-103,91	-104,66	-105,78	-107,78	-108,7	-110,76	-110,85	-111,54	-119,54	2
13	-104,02	-105,24	-104,7	-104,23	-105,39	-106,75	-108,01	-108,5	-110,73	-111,08	-112,04	-119,6	2

Fig. 7. Transposed file for building a neural network

The main condition for reliable operation of the threaded connection is to create the necessary effort and tightening torque, which for the responsible threaded connections must be specified in the technical requirements of the assembly drawing of the unit or mechanism. In the General case, the tightening torque (torque applied to the wrench) is equal to the sum of the moments of friction directly in the thread and the time of friction of the bearing surface of the nut or bolt and is determined by the following formula:

$$M = Q\left[\frac{d_2}{2}\,\mathrm{tg}(\beta - p') + \frac{D_\tau}{2} f_T\right];$$

where: d_2 – average thread diameter;

β – thread lift angle;

p' – the angle of friction in the thread, which is equal to: $p' = \mathrm{arctg}\, f_p'$, where f_p', the coefficient of friction in the thread is equal to $f_p' = f_p / \cos\frac{a}{2}$; a – thread profile angle, f_p' – thread friction coefficient;

D_τ – the radius of action of friction forces on the bearing surface of the nut, which is equal to: $D_T = \frac{2}{3} \cdot \frac{D^3 - d_0^3}{D^2 - d_0^2}$, where D and d_0 – outer and inner diameters of the support annular surface of the nut or bolt head;

f_T, coefficient of friction on the bearing surface of the nut or bolt head.

For fasteners with a metric thread that has a profile angle of 60 degrees, the formula for calculating the tightening torque takes the following form:

$$M = Q(0.16P + 0.58 d_2 f_p) + Q\frac{D_T}{2} f_T;$$

where: Q – tightening force;

P – thread pitch.

The coefficient of friction in the threads and on the support surface depends on the type of coating of the fasteners and the presence of oil during assembly. At the same time their size fluctuates:

– for f_p, from $0.64^{+0.12}_{-0.08}$ when oxide coating and assembly with lubrication in the form of machine oil with additive 20% molybdenum disulfide;

– for f_T, from $0.34^{+0.09}_{-0.14}$ at an oxide covering and assembly without greasing, to $0.06^{+0.01}_{-0.02}$ when cadmium plated and assembled with lubrication in the form of machine oil with the addition of 20 % molybdenum disulfide.

In this case, the minimum value of the tightening torque should ensure the tightness of the threaded elements (for example, bolts and nuts, or studs and nuts), and the maximum value should not exceed the strength of the threaded connection. Therefore, when calculating the amount of tightening torque of the threaded connection of the fasteners of the manufactured parts:

– From carbon steels is acceptd $\sigma_{zat} = (0.6 - 0.7)\sigma_{\mathrm{T}}$, where σ_{T} – the yield strength of the bolt or stud material;

– From alloy steels is accepted $\sigma_{zat} = (0.6 - 0.7)\sigma_{\mathrm{T}}$.

When tightening the threaded connection by applying external torque to the bolt rod, due to the influence of two force factors (Q and M), there is a complex load state, which is characterized by the value of normal σ_zat and tangential loads t the ratio between the values of elastic deformation depending on:

$$\frac{\sigma}{\tau} = 2\frac{d_{sr}}{d_1}\mathrm{tg}(\beta - p').$$

The tightening force taking into account the stress state of the bolt is determined by the following formula:

$$Q = \frac{\sigma_{zat} F}{\sqrt{1 + 0.75\left[d_{sr}\frac{F}{W_p}\mathrm{tg}(\beta - p')\right]^2}};$$

where: F – the cross-sectional area of the bolt;

W_p – polar moment of inertia.

Results

After training the neuron, the network shared the input data Fig. 8 of the frequency x52, x58 the main frequency at which the control puff goes at angles: 0º, 10º, 20º (Fig. 9). After learning the neuron, the network clearly divides the tightening of the node screws into categories. It is enough to have 2 frequency filters that would control these two frequencies. Thus, the frequency response can determine the size with an accuracy of 0.03 mm.

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

	BB	BC	BD	BE	BF	BG	BH
1	x52	x53	x54	x55	x56	x57	x58
2	-99,89	-98,07	-95,03	-94,16	-96,15	-98,02	-99,22
3	-98,54	-98,23	-98,88	-99,01	-98,25	-98,13	-98,33
4	-101,68	-101,9	-102,03	-101,18	-100,8	-101,79	-102,01
5	-96,18	-94,96	-93,23	-90,96	-88,91	-87,11	-87,51
6	-97,58	-97,54	-98,1	-98,97	-99,51	-98,33	-97,82
7	-100,2	-100,37	-100,42	-99,62	-99,74	-100,06	-100,65
8	-95,37	-94,59	-94,92	-94,02	-93,31	-94,67	-96,72
9	-102,2	-102,53	-101,57	-102,68	-102,15	-102,25	-101,73
10	-98,27	-98,55	-98,36	-100,1	-101,39	-101,74	-101,65
11	-98,12	-98,25	-99,12	-100,49	-101,21	-101,71	-101,6
12	-100,68	-101,93	-101,25	-100,81	-101,39	-101,65	-101,83
13	-101,36	-102,1	-102,08	-102,8	-102,68	-101,91	-102,16

Fig. 8. Significance of frequency x52, x58

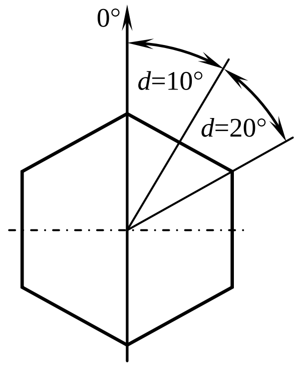

Fig. 9. Scheme of tightening bolts at angles 0º, 10º and 20 º

Verbal description of the site:
Database fields (initial symptoms): X 52
X58
Database fields (end syndromes):
P
Processing of database input fields for network supply:
X52 = (X52—98.785) / 3.414997
X58 = (X58—94.83501) / 7.325001
Functional converters:
Sigmoid 1 (A) = A / (0.1+ | A |)
Level 1 syndrome:
Syndrome 1_1 = Sigmoid 1 (-X52 + 0.7242469 * X58-0.08202159)
Syndrome 1_2 = Sigmoid 1 (X52-0.7271721 * X58 + 0.08119417)
Syndrome 1_3 = Sigmoid 1 (-X52 + 0.7217082 * X58-0.0831995)
Syndrome 1_4 = Sigmoid 1 (0.3791681 * X58)
Syndrome 1_5 = Sigmoid 1 (X52-0.3553772 * X58 + 0.5645317)
Syndrome 1_6 = Sigmoid 1 (-X52 + 0.3767371 * X58-0.541944)
Syndrome 1_7 = Sigmoid 1 (X58 + 1)
Syndrome 1_8 = Sigmoid 1 (-X52-0.2016536 * X58)
Syndrome 1_9 = Sigmoid 1 (-X52)
Syndrome 1_10 = Sigmoid 1 (-0.7135977 * X58-0.6515552)
Syndrome 1_11 = Sigmoid 1 (-X52-X58-0.8611292)
Syndrome 1_12 = Sigmoid 1 (X52-X58 + 0.09941051)
End syndromes:
P = - Syndrome 1_1 + Syndrome 1_2- Syndrome 1_3- Syndrome 1_4- Syndrome 1_5 + Syndrome 1_6- Syndrome 1_7- Syndrome 1_8-0.3120861 * Syndrome 1_9 + Syndrome 1_10 + Syndrome 1_11- Syndrome 1_12 + 1
Post-treatment of end syndromes:
P = ((P * 2) +2) / 2)

Conclusions

The method of assembling threaded joints by applying external torque is simple and versatile, as it allows the use of traditional tools and equipment for manual, mechanized and automated assembly, while providing the necessary process performance. Its main disadvantage is the occurrence in the process of tightening in the bolt torsional stresses, which reduce the bearing capacity of the threaded connection.

Modern methods of acoustic diagnostics of details are considered. The results of the experiment of acoustic diagnostics of composite nodes with the construction of a neural network are shown. The experiment showed that the construction of a neural network of parts and a composite node will almost instantly detect defective products, incorrect dimensions and other factors of failure on the basis of acoustic frequency response. According to this method, it is possible to control the units, bolted joints during assembly.

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Received November 06, 2020

Accepted December 17, 2020