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LOAD CHARACTERISTICS OF A SPUR GEAR TRANSMISSION: CALCULATION OF FORCE AT CONTACT POINT

***Abstract**: The results of a computer calculation of forces at the contact point of a spur gear transmission under conditions of changing the angular speed and loading torque of the shaft are presented in the article. It is noted that the forces at the contact point of the gear transmission operating at low speeds have mostly positive magnitudes. On the other hand, in high-speed gear transmissions, the forces at the contact point are variable.*

Key words*: gear transmission, gear, angular speed, loading torque, force at contact point.*
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1.Introduction

A transmission of torque from shaft to shaft in the gear transmission is carried out by constant engagement of teeth, rotating a gear and a gear wheel. The process of engagement the teeth is carried out between the points of intersection of the line of engagement with the addendum circle of wheels [1-3]. In fact, contact occurs on a certain area of the faces of the teeth over the entire time range of engagement [4-10]. Thus, taking into account the cyclic loading of the tooth faces, the calculation of force changes at the contact point is important for predicting the material fatigue of the gear and the gear wheel. Since gear transmissions are used to change the speed of rotation or movement of the output link, an analysis of the loaded state of the teeth during the engagement of the gear and the gear wheel in various operating modes will determine the effect of certain operating parameters of the mechanism on the load characteristics of the spur gear transmission.

2.Materials and methods

The force calculation at the contact point between the gear and the gear wheel was performed in the COMSOL Multiphysics program. For this purpose, three-dimensional models of the gear with 20 teeth, the gear wheel with 30 teeth, and two shafts with diameters of 20 mm were built. The gear and gear wheel models were created according to the following geometric parameters: pitch diameter – 100 and 150 mm, pressure angle – 25 degrees, addendum to module ratio – 0.85, tooth height to addendum ratio – 2.1, backlash to pitch diameter ratio – 0.001, tip fillet radius to pitch diameter ratio – 0.01, root fillet radius to pitch diameter ratio – 0.01, hole diameter to pitch diameter ratio – 0.2 and 0.13333, gear width to pitch diameter ratio – 0.2 and 0.13333, ring width to gear width ratio – 0.2, ring outer diameter to root diameter ratio – 0.8, ring inner diameter to hole diameter ratio – 1.5, shaft length to pitch diameter ratio – 3 and 2, mesh alignment angle – 0 and 6 degrees, respectively. The engagement of the gear and the gear wheel made it possible to obtain a spur gear transmission with the following parameters: gear ratio – 1.5, center to center distance – 125 mm and backlash – 1 mm. The models were given the following properties of structural steel: density – 7850 kg/m³, Young's modulus – $200 \cdot 10^9$ Pa and Poisson's ratio – 0.3. The experimental plan for changing the mean angular speed and loading torque of the shaft model is presented in the Table 1. The quality range of the finite element grid on the part models was 0.004022-0.4979, which allowed us to obtain acceptable computer simulation results.

Table 1. Variable parameters of operation of the spur gear transmission.

Test number	Mean angular speed, rad/s	Loading torque, N·m
1	5.236	50
2	10.472	50
3	20.944	50
4	36.652	50
5	52.36	50
6	73.303	50
7	104.72	50
8	5.236	100
9	10.472	100
10	20.944	100
11	36.652	100
12	52.36	100
13	73.303	100
14	104.72	100
15	5.236	200
16	10.472	200
17	20.944	200
18	36.652	200
19	52.36	200
20	73.303	200
21	104.72	200
22	5.236	500
23	10.472	500
24	20.944	500
25	36.652	500
26	52.36	500
27	73.303	500
28	104.72	500

3. Results and discussion

The calculation results are shown in the Figs. 1-4.

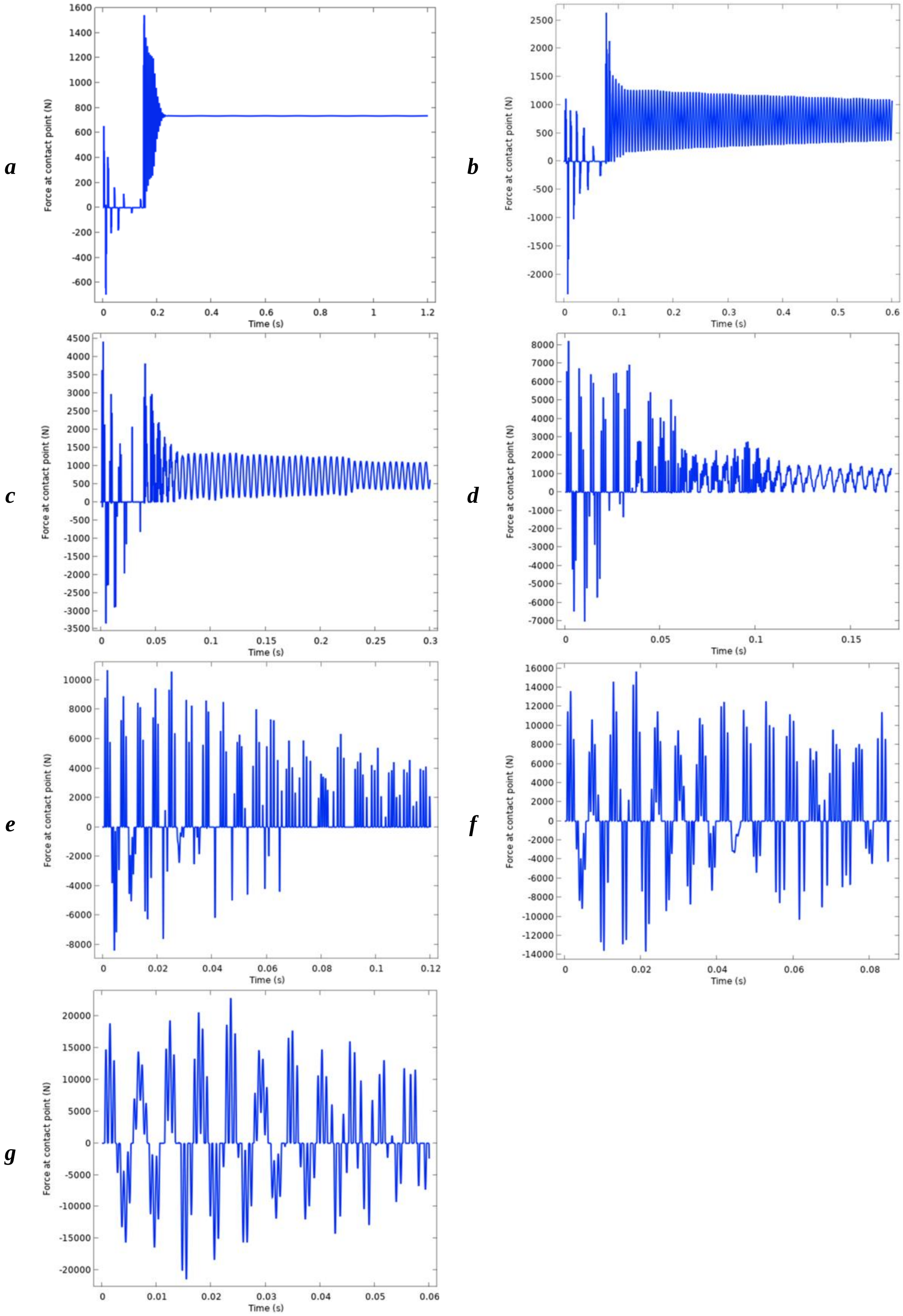

Figure 1. The dependence of force at the contact point of the gear transmission on the variable shaft speed and constant loading torque: *a*) angular speed – 5.236 rad/s and loading torque – 50 N·m; *b*) angular speed – 10.472 rad/s and loading torque – 50 N·m; *c*) angular speed – 20.944 rad/s and loading torque – 50 N·m; *d*) angular speed – 36.652 rad/s and loading torque – 50 N·m; *e*) angular speed – 52.36 rad/s and loading torque – 50 N·m; *f*) angular speed – 73.303 rad/s and loading torque – 50 N·m; *g*) angular speed – 104.72 rad/s and loading torque – 50 N·m.

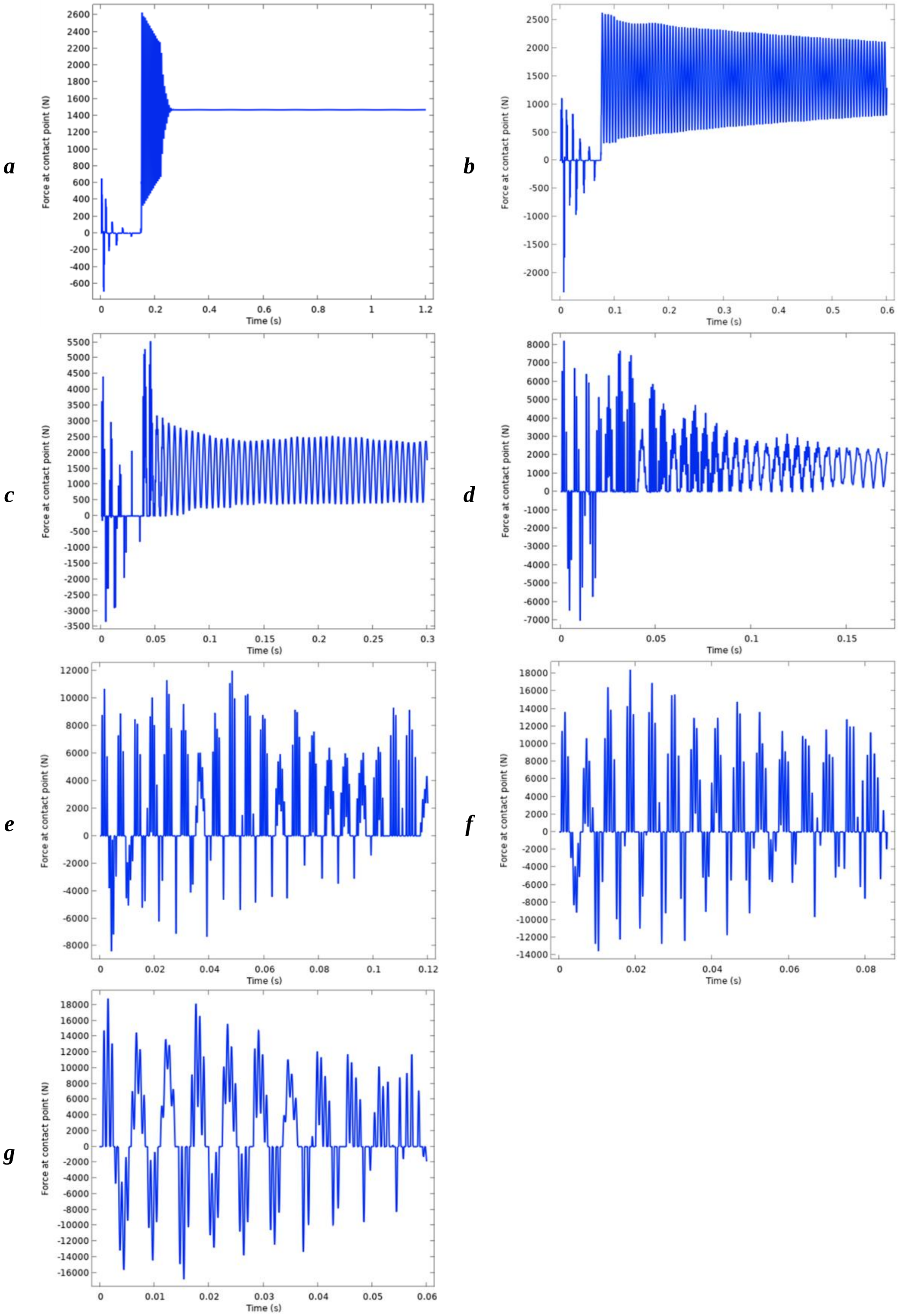

Figure 2. The dependence of force at the contact point of the gear transmission on the variable shaft speed and constant loading torque: *a*) angular speed – 5.236 rad/s and loading torque – 100 N·m; *b*) angular speed – 10.472 rad/s and loading torque – 100 N·m; *c*) angular speed – 20.944 rad/s and loading torque – 100 N·m; *d*) angular speed – 36.652 rad/s and loading torque – 100 N·m; *e*) angular speed – 52.36 rad/s and loading torque – 100 N·m; *f*) angular speed – 73.303 rad/s and loading torque – 100 N·m; *g*) angular speed – 104.72 rad/s and loading torque – 100 N·m.

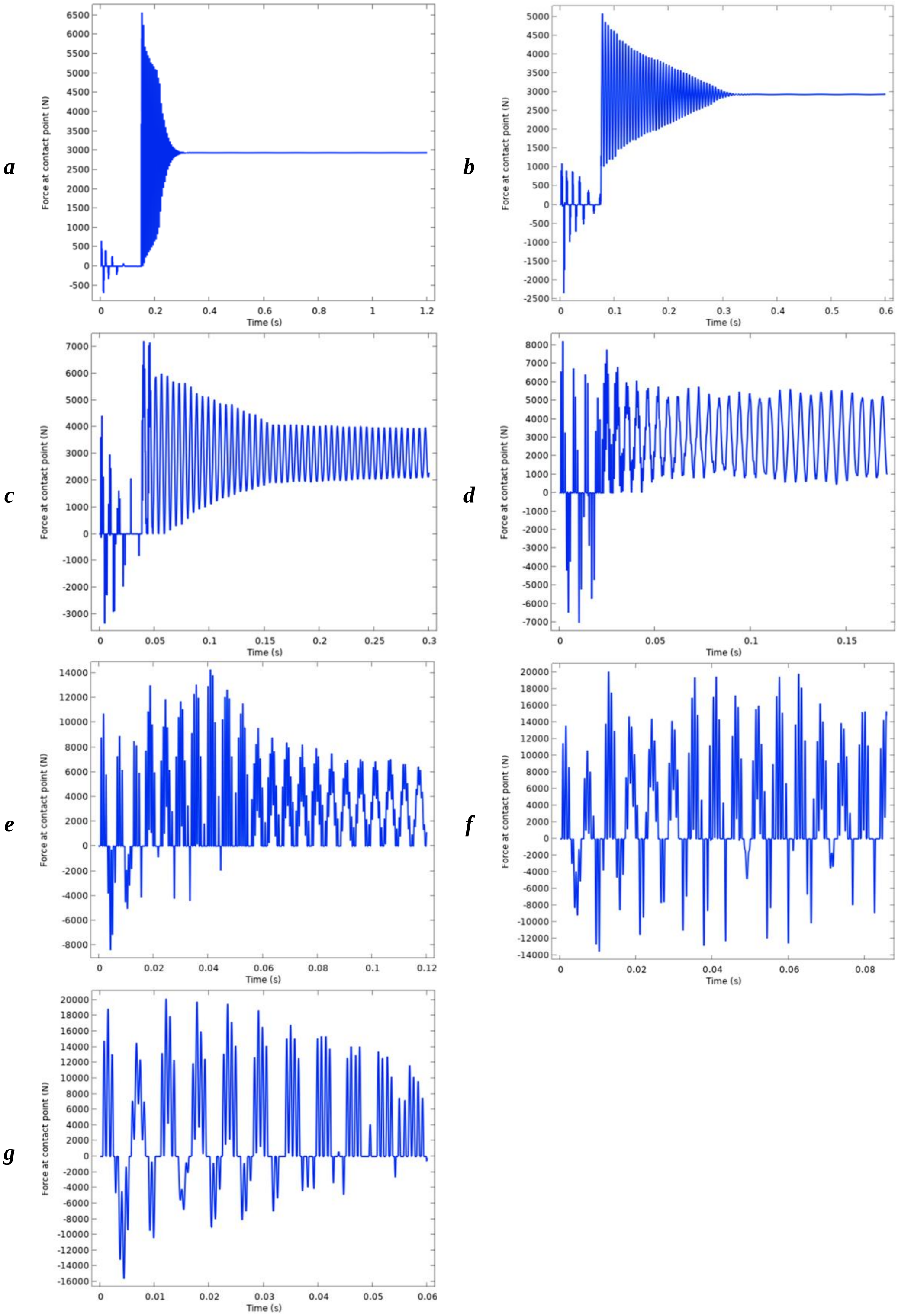

Figure 3. The dependence of force at the contact point of the gear transmission on the variable shaft speed and constant loading torque: *a*) angular speed – 5.236 rad/s and loading torque – 200 N·m; *b*) angular speed – 10.472 rad/s and loading torque – 200 N·m; *c*) angular speed – 20.944 rad/s and loading torque – 200 N·m; *d*) angular speed – 36.652 rad/s and loading torque – 200 N·m; *e*) angular speed – 52.36 rad/s and loading torque – 200 N·m; *f*) angular speed – 73.303 rad/s and loading torque – 200 N·m; *g*) angular speed – 104.72 rad/s and loading torque – 200 N·m.

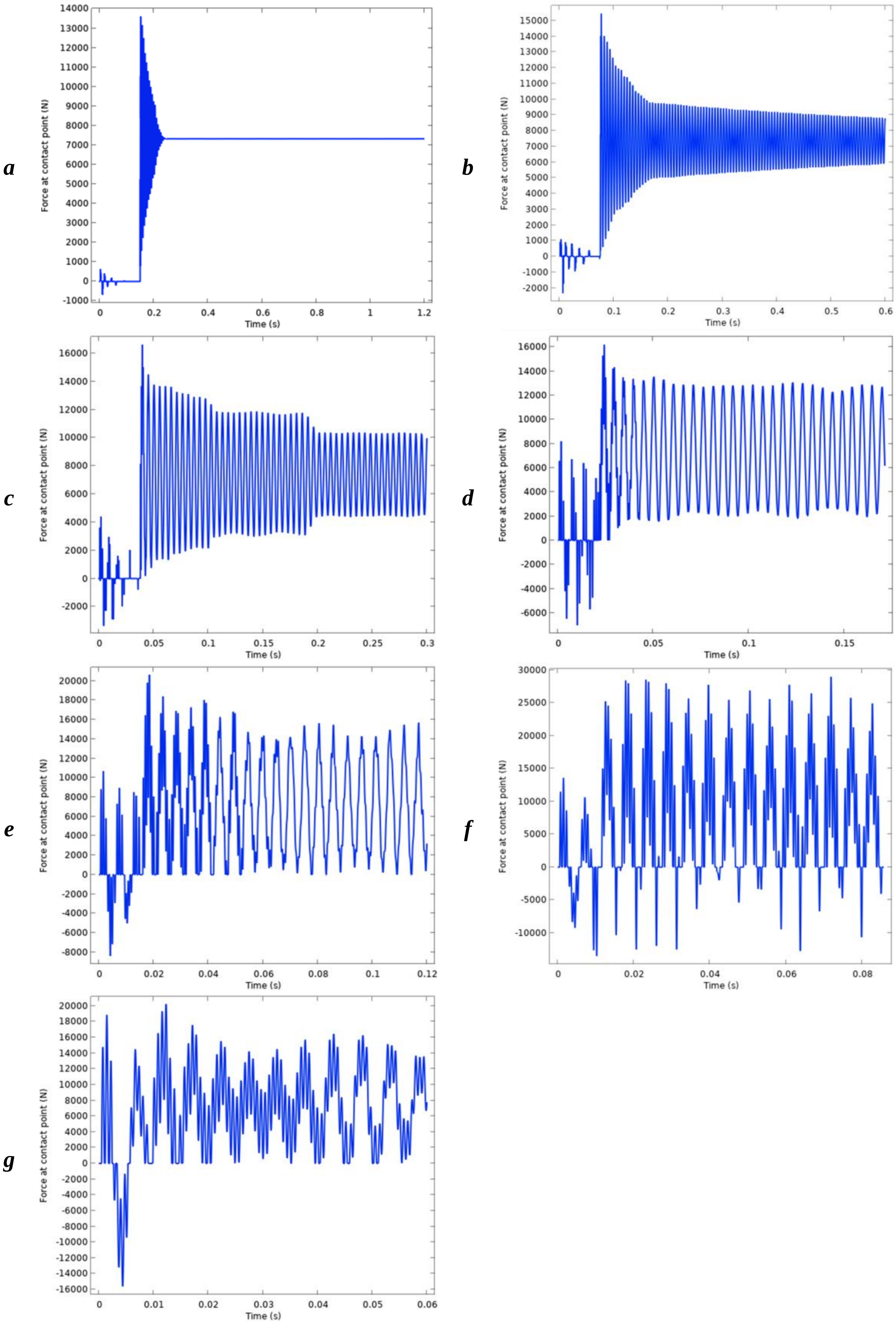

Figure 4. The dependence of force at the contact point of the gear transmission on the variable shaft speed and constant loading torque: *a*) angular speed – 5.236 rad/s and loading torque – 500 N·m; *b*) angular speed – 10.472 rad/s and loading torque – 500 N·m; *c*) angular speed – 20.944 rad/s and loading torque – 500 N·m; *d*) angular speed – 36.652 rad/s and loading torque – 500 N·m; *e*) angular speed – 52.36 rad/s and loading torque – 500 N·m; *f*) angular speed – 73.303 rad/s and loading torque – 500 N·m; *g*) angular speed – 104.72 rad/s and loading torque – 500 N·m.

The time range on all graphs corresponds to one rotation of the shaft around its axis. Accordingly, the graphs show the force magnitudes at several contacts of the teeth of the transmission links.

Let's consider the force changes at the contact point of the teeth during low-speed and high-speed modes of operation of the spur gear transmission. At the moment of the beginning of the gear rotation, the first teeth of the gear and the gear wheel collide, which leads to a sharp fluctuation in the force magnitudes at the contact point (shown in graphs *a*, *b*, *c* and *d* of all figures). Subsequent force magnitudes equalize and decrease. High-speed modes show more stable force readings at the contact point, although the range of forces increases.

The tensile deformation of the tooth material during engagement prevails in absolute magnitude over the compression deformation at high angular speeds of shaft rotation. The range of force magnitudes decreases with increasing loading torque. For example, with the same angular speed of the shaft (104.72 rad/s) and loading torques of 50 N·m and 500 N·m, the contact forces vary in the range of -22500 N/22500 N and -16000 N/20000 N, respectively.

4.Conclusion

Having analyzed the dependences of force at the contact point of the gear teeth and the gear wheel on the change in angular speed and loading torque during one revolution of the shaft around its axis, the following conclusions can be drawn:

1. At high angular speeds of shaft rotation (104.72 rad/s) and loading torques (200-500 N·m), the range of forces at the contact point is the same and has a stable nature.
2. The maximum variable parameters of the loading and the speed of shaft rotation showed the occurrence of deformation of the teeth of the gear and the gear wheel in one direction, which is characteristic of the stretching of material.

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