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LOAD CHARACTERISTICS OF A SPUR GEAR TRANSMISSION: SHAFT CALCULATION

Abstract*: The results of an analysis of the loaded state of shafts of a spur gear transmission are presented in the article. The conducted multifactorial experiment made it possible to determine the magnitude of the bearing force and the bearing moment on the gear transmission shafts when the angular speed and loading torque of the shaft change. The study showed that an increase in the angular speed of the shaft in the range of 5.236-20.944 rad/s for* *all the cases considered does not significantly change the magnitude of the bearing moment and bearing force on the shaft. At the initial moment of engagement at an angular speed of up to 36.652 rad/s, a peak magnitude of the bearing moment and bearing force on the shaft is observed along all coordinate axes. With the time of operation of the gear transmission, the loads decrease, and with high-speed operating modes, the loads increase and their magnitude is almost the same along all coordinate axes.*

Key words: *gear transmission, shaft, angular speed, loading torque, bearing force.*

Language: *English*

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1.Introduction

A gear transmission is a kinematic mechanism consisting of two or more links and oriented shafts on which these links are mounted [1]. The combination of these elements ensures the transmission of torque from one shaft to another.

Spur gear transmissions with external engagement are the simplest types of gear transmissions [2]. These gear transmissions have proven themselves well at low and medium operating speeds. With high-speed operation modes, vibrations appear in these gear transmissions, which reduce the accuracy and reliability of the mechanism and over time can lead to failure of the kinematic links [3-5]. The combination of circumferential and radial forces acting on the tooth of the gear (gear wheel) leads to a corresponding loading of the parallel shafts [6-10]. At the same time, the shafts are subjected to deformations (for example, deflection of the shaft).

In this work, by means of computer simulation of the operation of the spur gear transmission, the dependences of changes in the load characteristics of the shafts under low-, medium- and high-speed operating modes of the mechanism are obtained. These results will allow us to estimate the degree of shaft loading from the magnitude of angular speed and loading torque.

2.Materials and methods

Calculation of the load characteristics of the shafts (on which the gear and gear wheel are mounted) it was performed in the COMSOL Multiphysics program. For this purpose, three-dimensional models of the gear (number of teeth was 20), the gear wheel (number of teeth was 30) 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 the spur gear transmission with the following parameters: gear ratio – 1.5, center to center distance – 125 mm and backlash – 1 mm. Roller bearings having the following dimensions of elements were installed on the shafts: ball diameter – 1.33 mm, pitch diameter – 21.33 mm, inner race radius – 0.7049 mm and outer race radius – 0.7049 mm. All models were assigned the following properties of structural steel: density – 7850 kg/m³, Young's modulus – $200 \cdot 10^9$ Pa and Poisson's ratio – 0.3. A general view of the computer model of the spur gear transmission is shown in the Fig. 1. 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 models of gear transmission parts was 0.004022-0.4979, which allowed us to obtain acceptable computer simulation results.

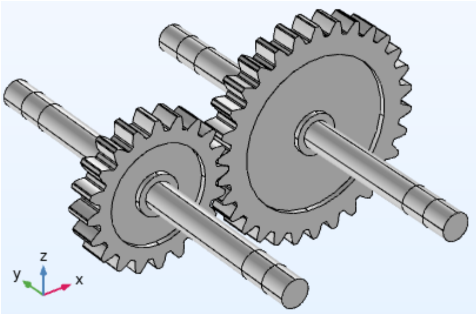


Figure 1. A computer model of the spur gear transmission.

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

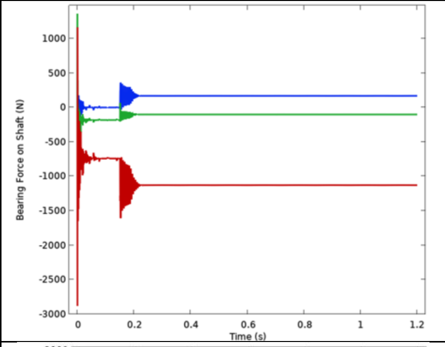
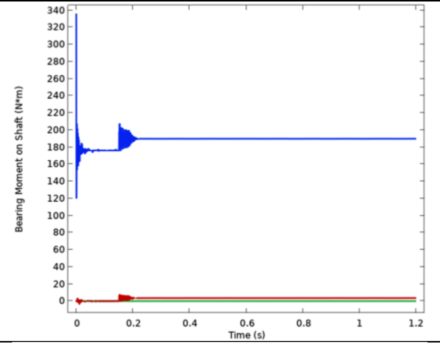
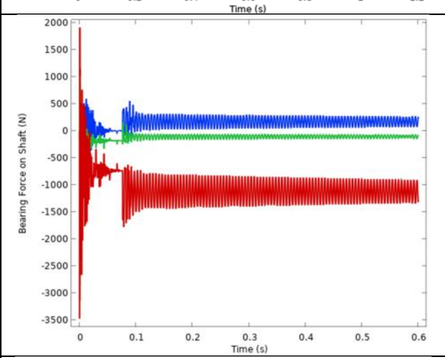
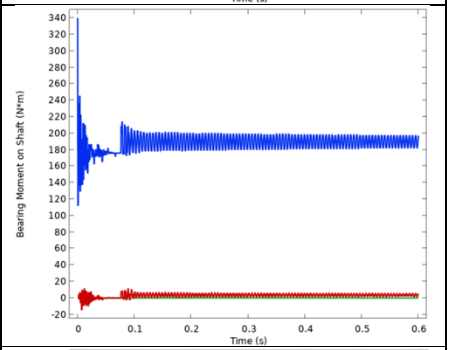
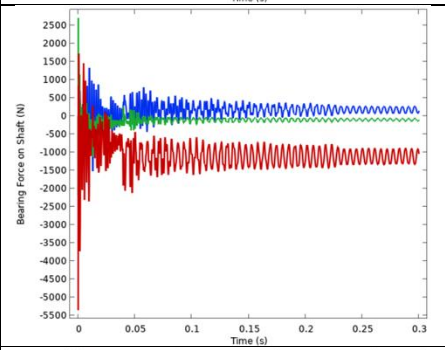
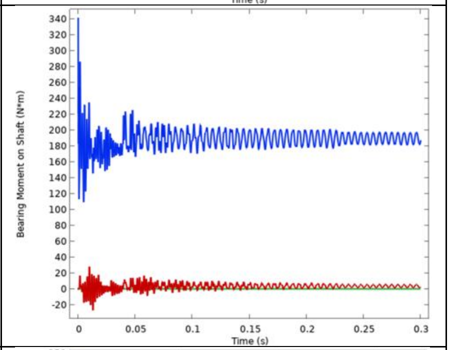
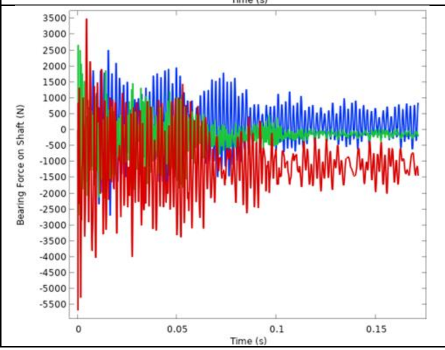
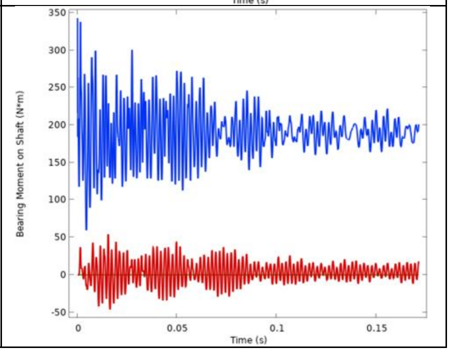
3. Results and discussion

Load characteristics of the shafts were calculated using three coordinate axes (*X*, *Y* and *Z*) of a rectangular coordinate system.

The calculation results are presented in the Tables 2-5 by the dependences of changes in the bearing force and bearing moment on the shafts with changes in the angular speed and loading torque of the shaft. Components of the coordinate system in the graphs are indicated in the appropriate color.

The bearing force changes on the shaft along the three coordinate axes are as follows: at low angular speeds, the readings on the *Y* axis are minimal, but with increasing shaft rotation speed, the range of bearing force magnitudes increases and takes on almost the same magnitudes as on the *X* and *Z* axes. Magnitudes of the bearing force along the *X* and *Z* axes are positive and negative, respectively, at low shaft speeds. The loads on the three components of the axes at high speeds of shaft rotation are characterized by both positive and negative magnitudes of the bearing force.

Table 2. The dependence of the bearing force and the bearing moment on the shafts 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. — *x* component; — *y* component; — *z* component.

a		
b		
c		
d		

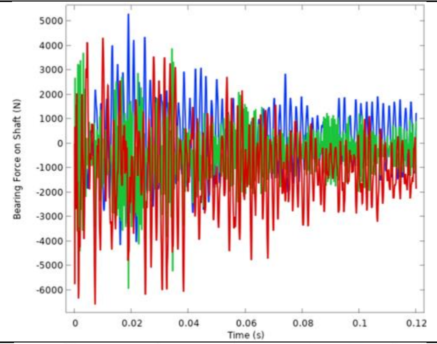
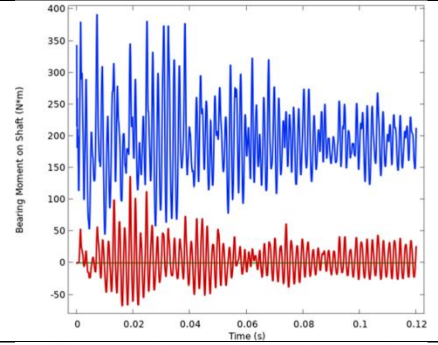
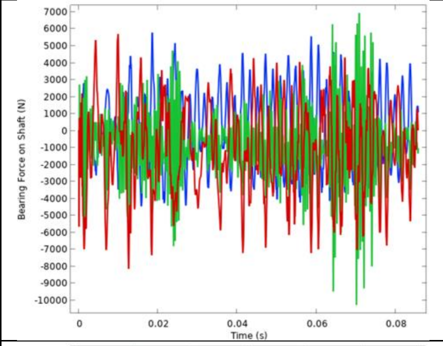
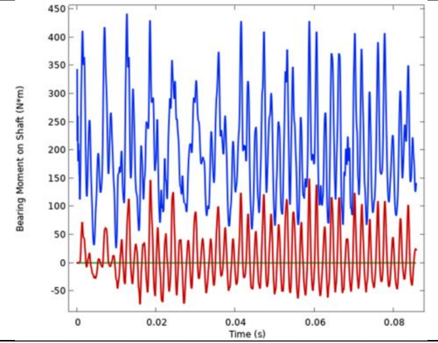
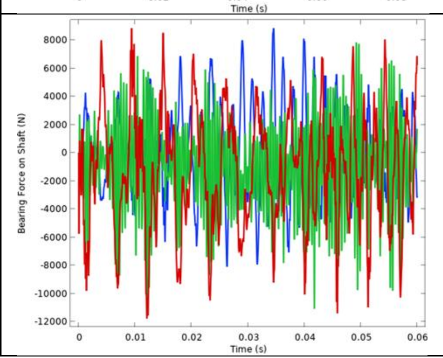
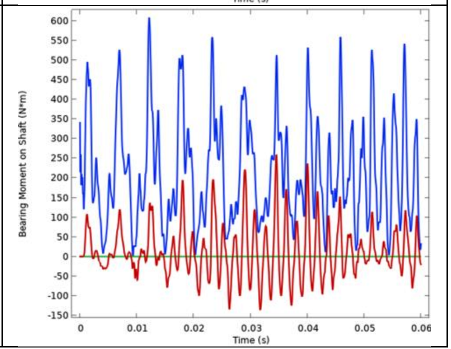
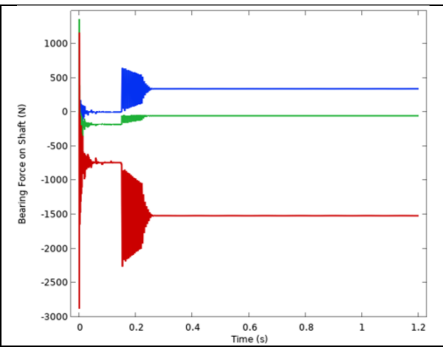
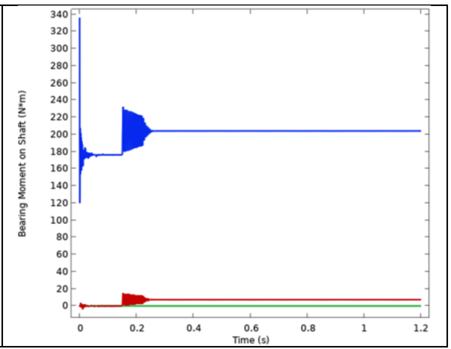
e		
f		
g		

Table 3. The dependence of the bearing force and the bearing moment on the shafts 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. — *x* component; — *y* component; — *z* component.

a		

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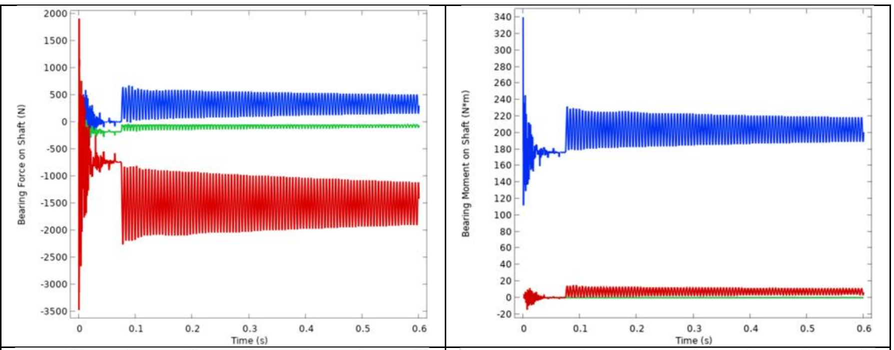

Bearing Force on Shaft (N)
Time (s)
Bearing Moment on Shaft (N*m)
Time (s)

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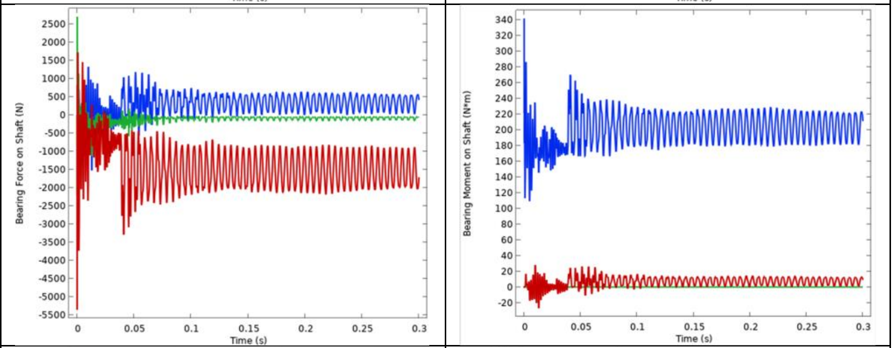

Bearing Force on Shaft (N)
Time (s)
Bearing Moment on Shaft (N*m)
Time (s)

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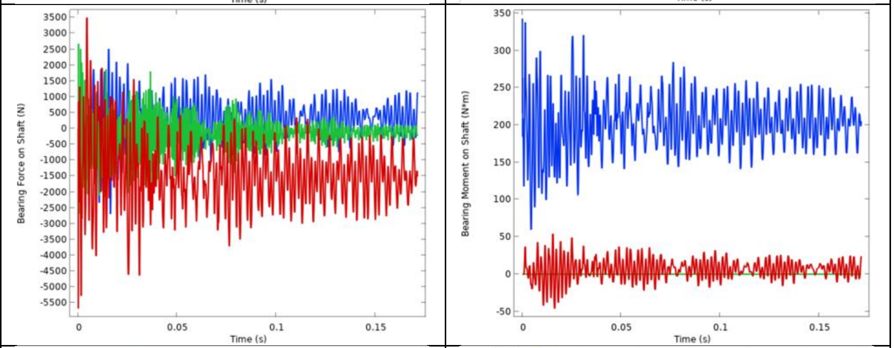
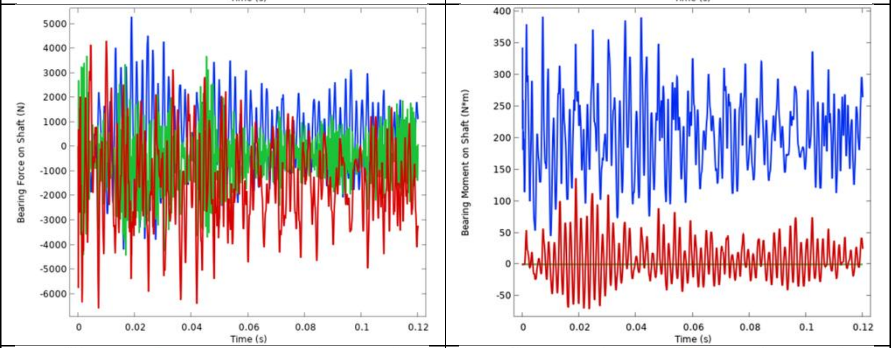


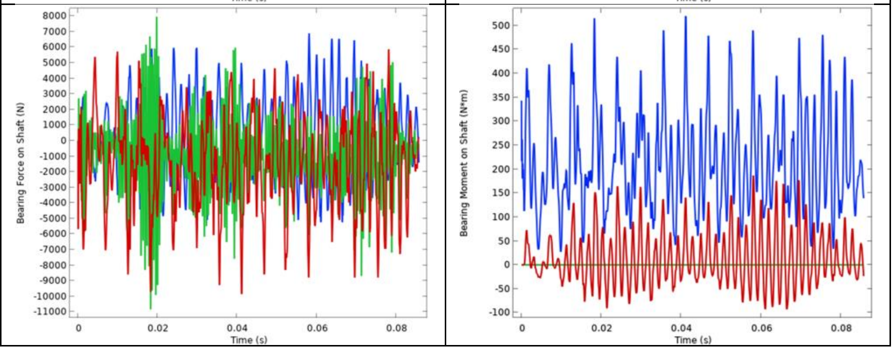
Bearing Force on Shaft (N)
Time (s)
Bearing Moment on Shaft (N*m)
Time (s)

e

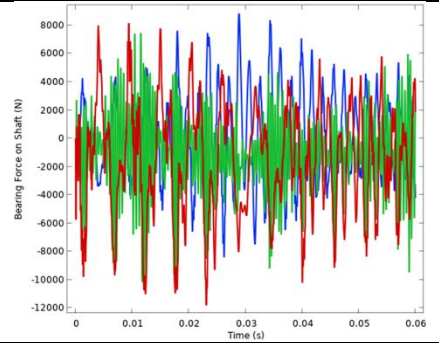
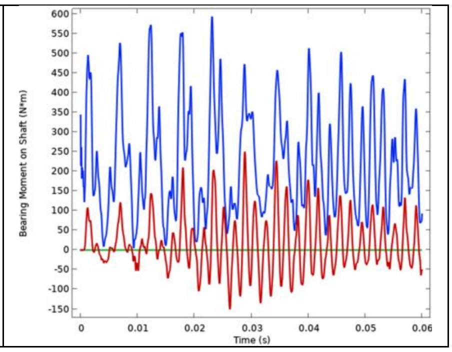


Bearing Force on Shaft (N)
Time (s)
Bearing Moment on Shaft (N*m)
Time (s)

f

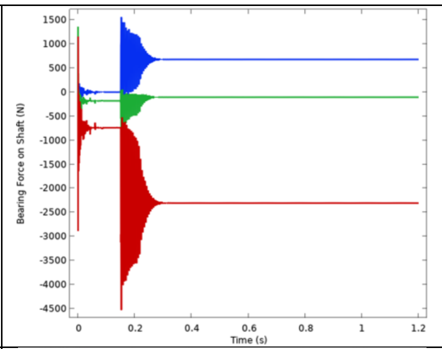
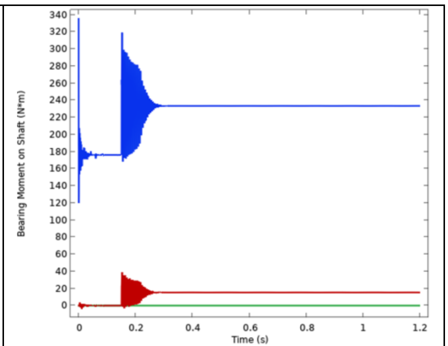
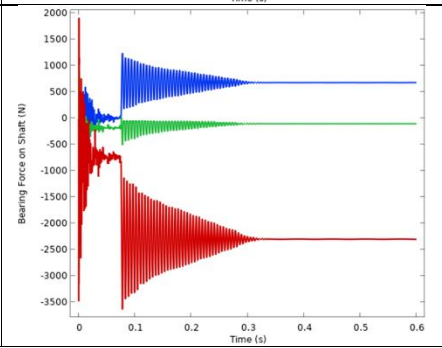
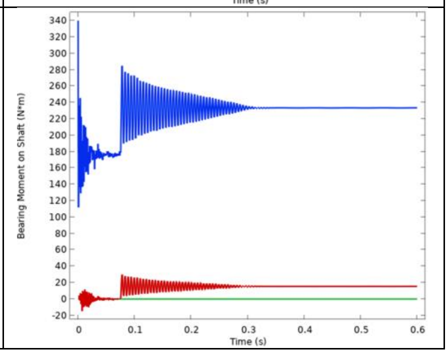


Bearing Force on Shaft (N)
Time (s)
Bearing Moment on Shaft (N*m)
Time (s)

g		

Analyzing the graphs on the right in the tables, it is noted that the magnitude of the bearing moment along the *Y* axis can be neglected (magnitudes do not change over the entire time range of shaft rotation and are practically zero). The largest change in the magnitude of the bearing moment is observed along the *X* axis. At high angular speeds of shaft rotation, there is no decrease in the magnitudes of the bearing moment along the *X* and *Z* axes. At the same time, the magnitude of the bearing moment along the *X* axis is always positive (acting in one direction), and along the *Z* axis, starting from 36.652 rad/s, it has negative magnitudes. The bearing moment on the shaft changes slightly when the loading torque is doubled. With a 4-fold increase in the loading torque, the fluctuations in the bearing moment magnitudes are 15-30%. And only when the loading torque is increased by a factor of 10, the magnitude of the bearing moment can change from 10 to 120%.

Table 4. The dependence of the bearing force and the bearing moment on the shafts 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. — *x* component; — *y* component; — *z* component.

a		
b		

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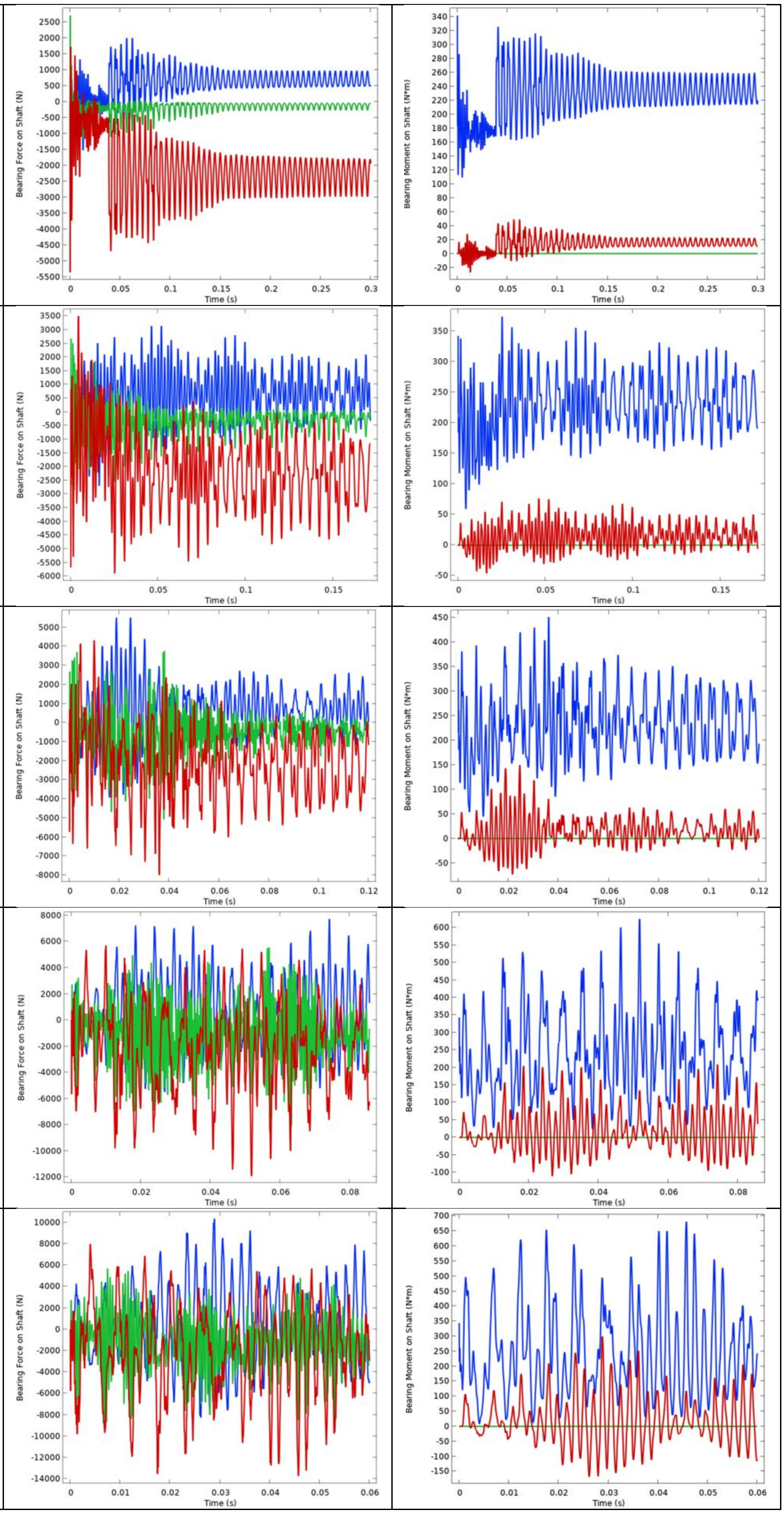
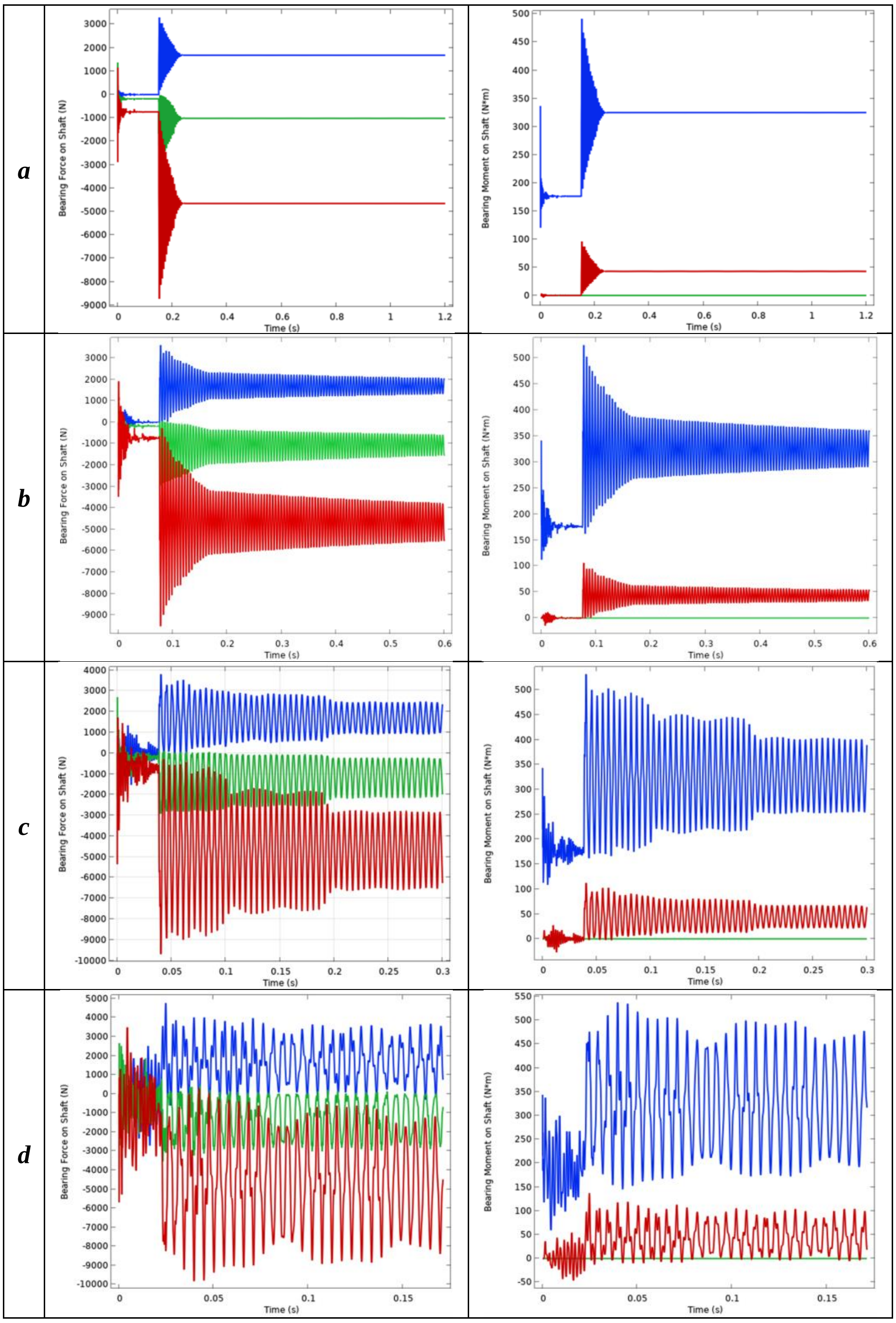
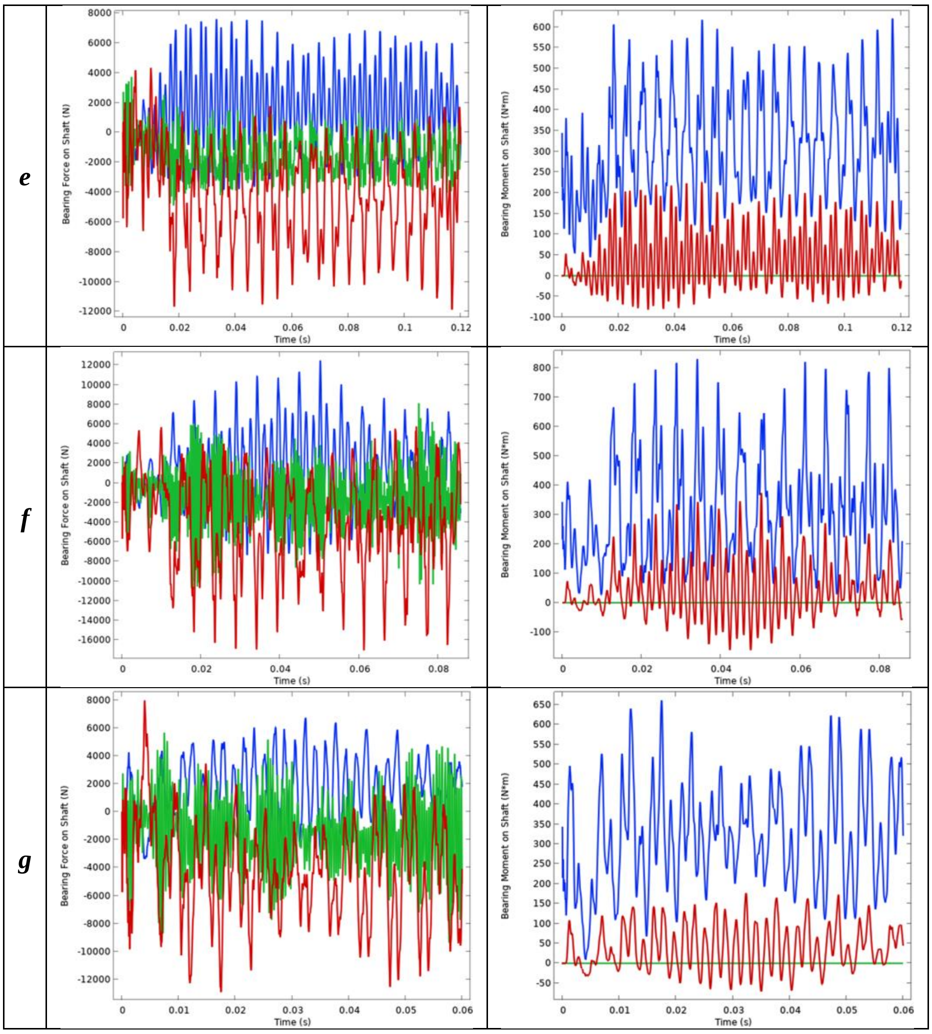


Table 5. The dependence of the bearing force and the bearing moment on the shafts of the gear transmission on the variable shaft speed and constant loading torque: *a*) angular speed – 5.236 rad/s and loading torque – 500 N·m; *b*) angular speed – 10.472 rad/s and loading torque – 500 N·m; *c*) angular 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. — *x* component; — *y* component; — *z* component.





4. Conclusion

Based on the analysis of the research results, the following conclusions can be drawn:

1. Deformations occur to a lesser extent along the shaft length when changing the speed and load modes of operation of the spur gear transmission.

2. Low-speed shaft rotation modes (up to 36.652 rad/s) do not cause significant vibrations of the gear transmission elements, which has a positive effect on the accuracy and reliability of the system.

3. The studied load characteristics of the shaft are significantly affected by the angular speed of shaft rotation.

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